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Designers Lighting Forum

Quantification of Perceived Spatial Brightness: Feu and MRSE

Speakers: Craig Bernecker, An Hsu

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Learning Objectives

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

1. Following the presentation, participants will recognize that illuminance recommendations do not always correlate with the perceived adequacy of light in a space.

2. Following the presentation, participants will be able to identify the parameters that determine the FEU for a given space.

3. Following the presentation, participants will be able to determine the mean room surface exitance (MRSE) for a space.

4. Following the presentation, participants will be able to compare the FEU value and MRSE for a space and evaluate which metric better correlates with the perceived adequacy of light of light.

INTRODUCTION

- Luminance-based metric: Feu
- Spatial Brightness
- Interior Reflectance
- Light Distribution

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IS THIS ROOM WELL-LIT?

WHAT DO WE MEAN BY "WELL-LIT"?

WHAT IS THE PURPOSE OF LIGHTING A ROOM? WHAT IS

THE "RIGHT" LIGHT LEVEL?

- In standard lighting practice, the appropriate lighting level is determined according to the activities carried out in the space, and the light is distributed over the area where those activities are expected to be carried out.
eg. office Eh @ 4' AFF 300 lux

Work out how much light is required for your task, and apply it to your task area...

THIS IS, HOWEVER, NOT ENTIRELY TRUE.

- The goal of standard practice is not lighting for ***task performance***, but lighting for perceived adequacy of illumination (Cuttle, 2010).

In other words, our measurements need to map to ***people's perceptions of how much light is in the space.***

DOES THE ILLUMINATION ON THE HORIZONTAL WORK PLANE DO THIS?

No

(Bean, 1977, 1978; Cuttle, 2010; Duff et al., 2015b, 2015c; Julian, 1987; Longmore, 1969; Lynes, 1970; Waldram, 1969).

To quote Lynes (1970):

*"It is now widely accepted that the traditional arbiter of lighting levels—**the illumination on a horizontal working plane—cannot be relied upon to tell whether one room will look brighter than another or whether one object will seem to be receiving more light than another**."*

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WHICH ROOM LOOKS BRIGHTER?

Space A

Space B

source: panasonic.com

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WHICH ROOM LOOKS BRIGHTER?

Space A

Lux
Average illuminance of floor

120

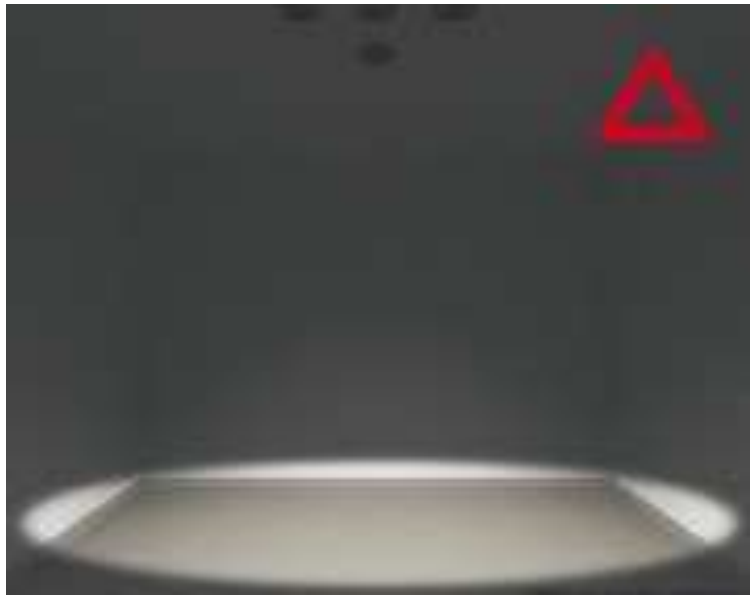
Space B

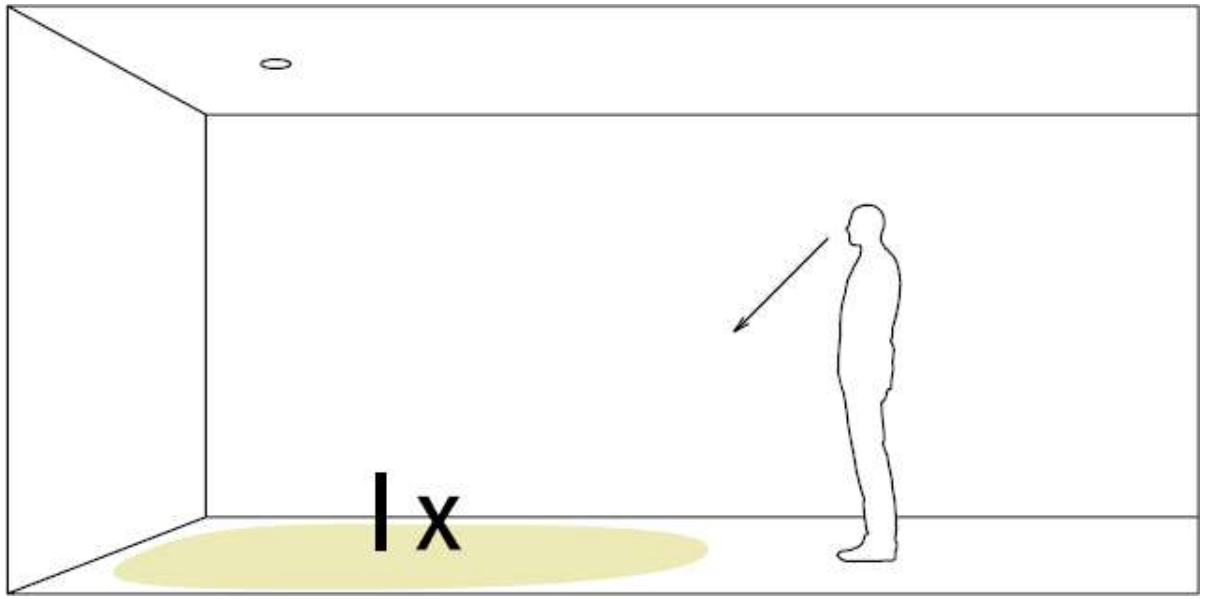
Lux
Average illuminance of floor

190

source: panasonic.com

Horizontal illuminance doesn't accurately convey the way that human eye perceived brightness within a space





When humans look into a space, they naturally perceive not only the floor but also the ceiling, walls, etc.

So, what should we measure instead?
The logical answer is to measure all the light that people see in a space.

LIGHTING FOR TASK PERFORMANCE

+

PERCEIVED SPATIAL BRIGHTNESS

WHAT IS SPATIAL BRIGHTNESS?

- An early attempt to define spatial brightness was given by the IES Visual Effects of Lamp Spectral Distribution Committee as follows:

> *Spatial brightness describes a visual sensation to the magnitude of the ambient lighting within an environment, such as a room or lighted street. Generally, the ambient lighting creates atmosphere and facilitates larger visual tasks such as safe circulation and visual communication. This brightness percept encompasses the overall sensation based on the response of a large part of the visual field extending beyond the fovea. It may be sensed or perceived while immersed within a space, or when a space is observed remotely but fills a large part of the visual field. Spatial brightness does not necessarily relate to the brightness of any individual objects or surfaces in the environment, but may be influenced by the brightness of these individual items. (Fotios and Atli, 2012)*

- A more concise definition is: Spatial brightness relates to ***the perceived quantity of light within a space***, or the light that is ***influencing the appearance of a space*** rather than illuminating the tasks.

LUMINANCE-BASED METRIC

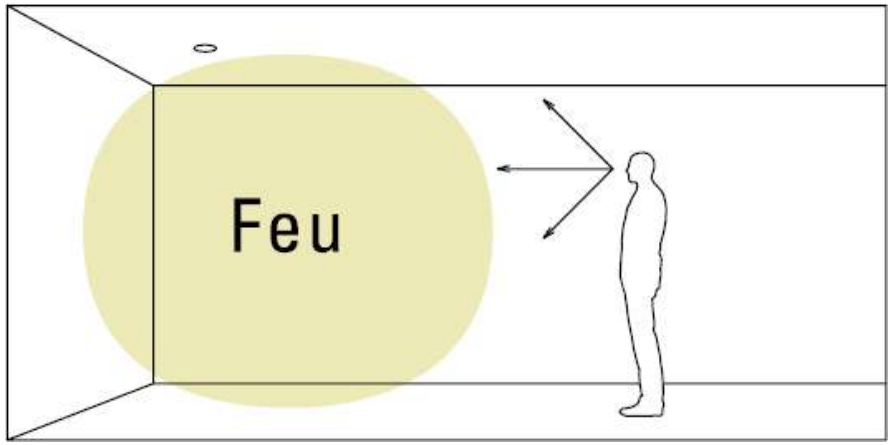
FEU

Feu=1.5 Lg ^ 0.7

Lg: The average luminance of FOV

- Feu is a spatial brightness index that ***quantifies the perceived spatial brightness.***

- Using "Feu," it is possible to execute lighting design more ***objectively*** and ***quantitatively.***



When humans look into a space, they naturally perceive not only the floor but also the ceiling, walls, etc.
"Feu" is the quantifiable space brightness index which includes these effects comprehensively.

source: panasonic.com

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Feu makes it possible to express perceived spatial brightness in numerical terms

Space A

Lux Average illuminance of floor	**120**
Feu	**10**

Space B

Lux Average illuminance of floor	**190**
Feu	**6**

source: panasonic.com

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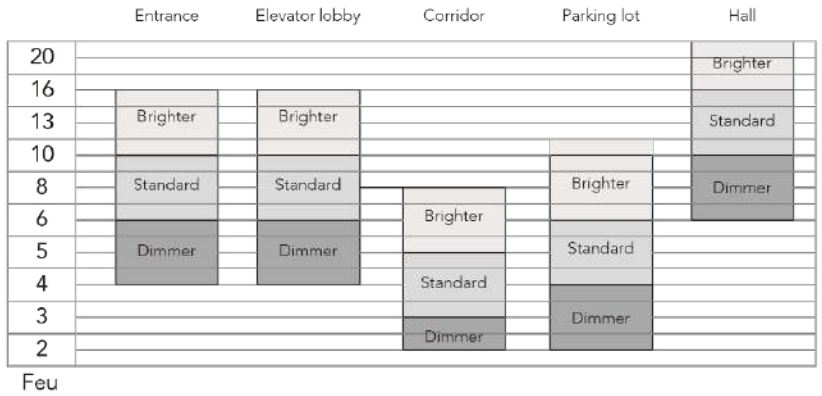
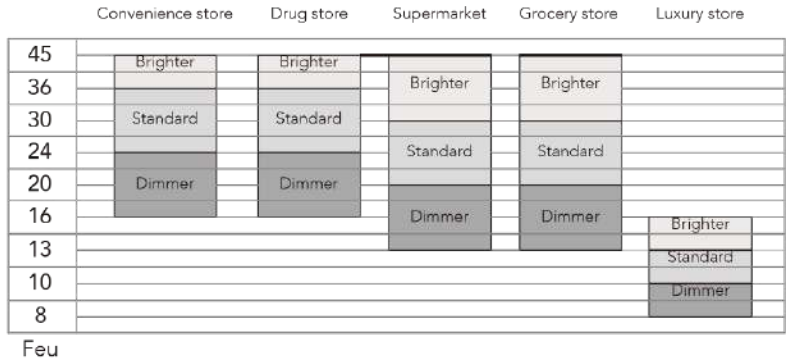
FEU VALUE BENCHMARKS FOR EACH AREA

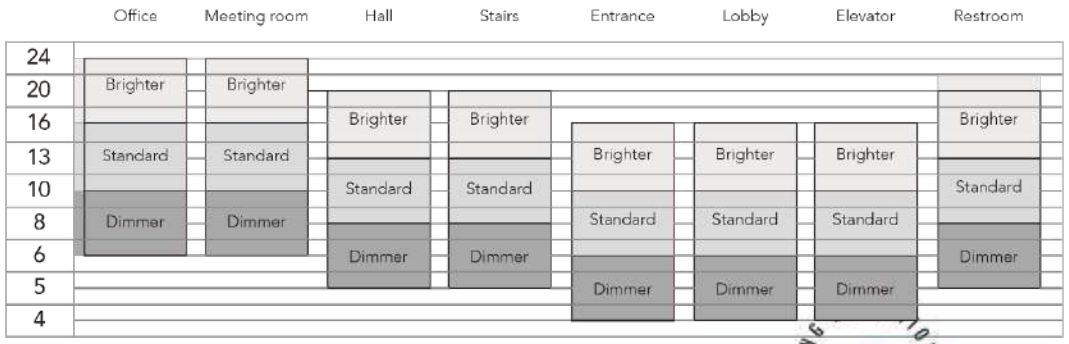
- Residental Building



- Retail Space



- Office Building



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Cuttle: Mean Room Surface Exitance

• In the 21st century when most things that need to be seen have been designed to be seen, the function of general lighting in most spaces should shift from providing an amount of light related to task difficulty to providing an amount of light that meets the expectations of most occupants in appearing **adequately bright or dim**.

• For designers, Cuttle proposes a change in design approach from specifying levels of illuminance for task to providing levels of light that yield predictable assessments of **surrounding brightness** on a scale the runs from distinctly bright on the upper end to very dim on the lower.

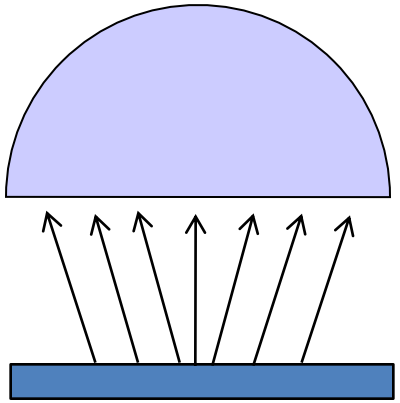
• Perceived Adequacy of Illumination [**PAI**] is a binary judgement of whether or not the illumination is adequately bright or dim for a specific use.

• Mean Room Surface Exitance [**MRSE**], as a measure of the overall density of inter-reflected flux within a space, has been proposed as a reliable indicator of **surrounding brightness** and, for the purposes of design guidelines and standards, that correlates with **PAI**.

Exitance (Luminous Exitance)

"The areal density of luminous flux *leaving* a surface at a point."

Unit = *lumens/ft*^{2} *Symbol* = *M*



- used to describe the quantity (density) of light leaving a surface

- M = luminous flux/area

Brightness

MRSE (lm/m^2)	Perceived Brightness
10	Lowest level for color discrimination
30	Dim appearance
100	Lowest level for 'acceptably bright' apperance
300	Bright appearance
1000	Distinctly bright appearance

Cuttle's proposed range of subjective assessments of lit appearance related to MRSE.

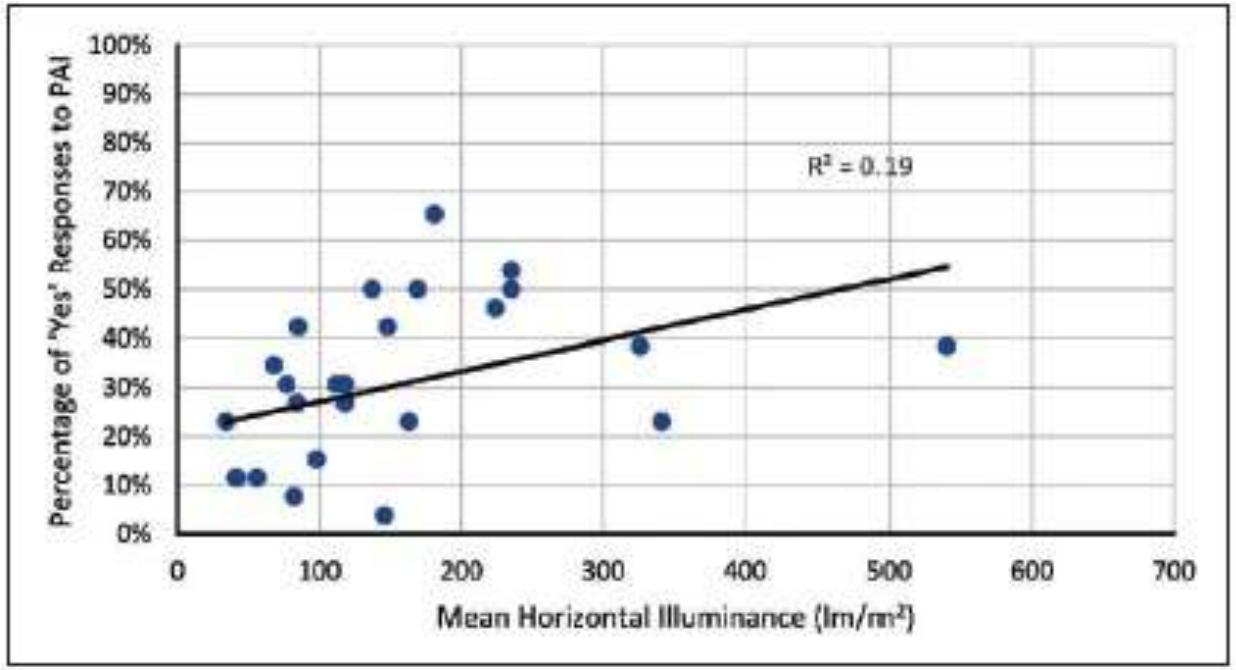


Figure 8 – Yes responses to PAI against Horizontal Illuminance.

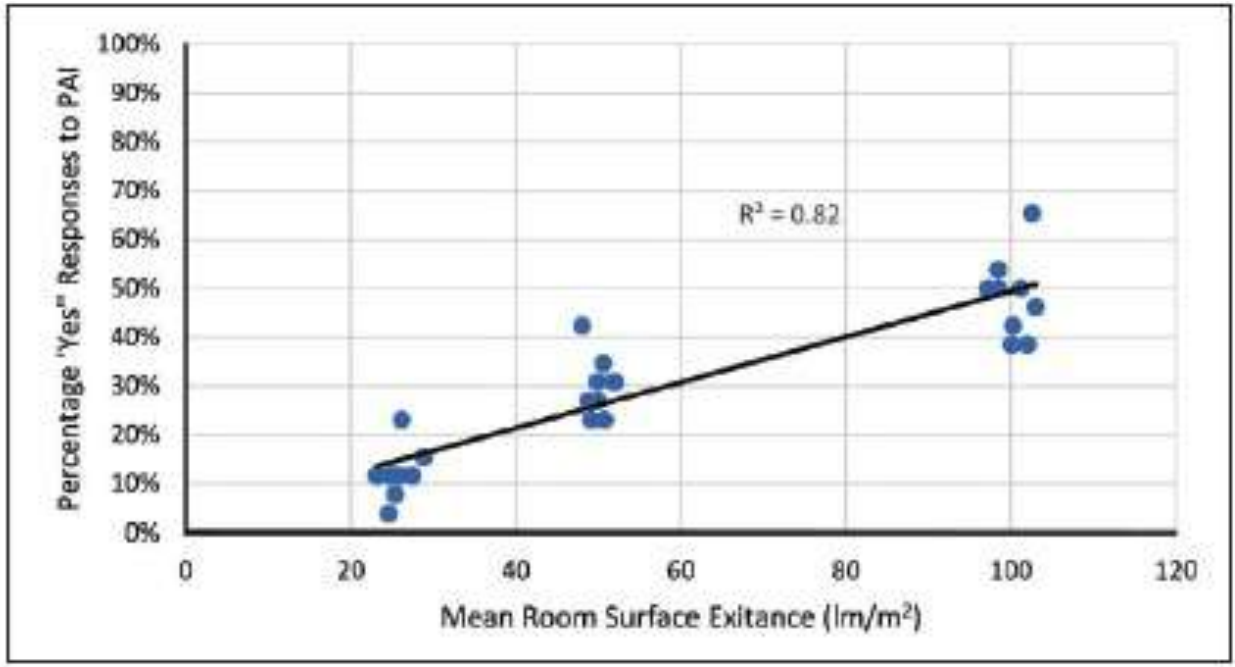
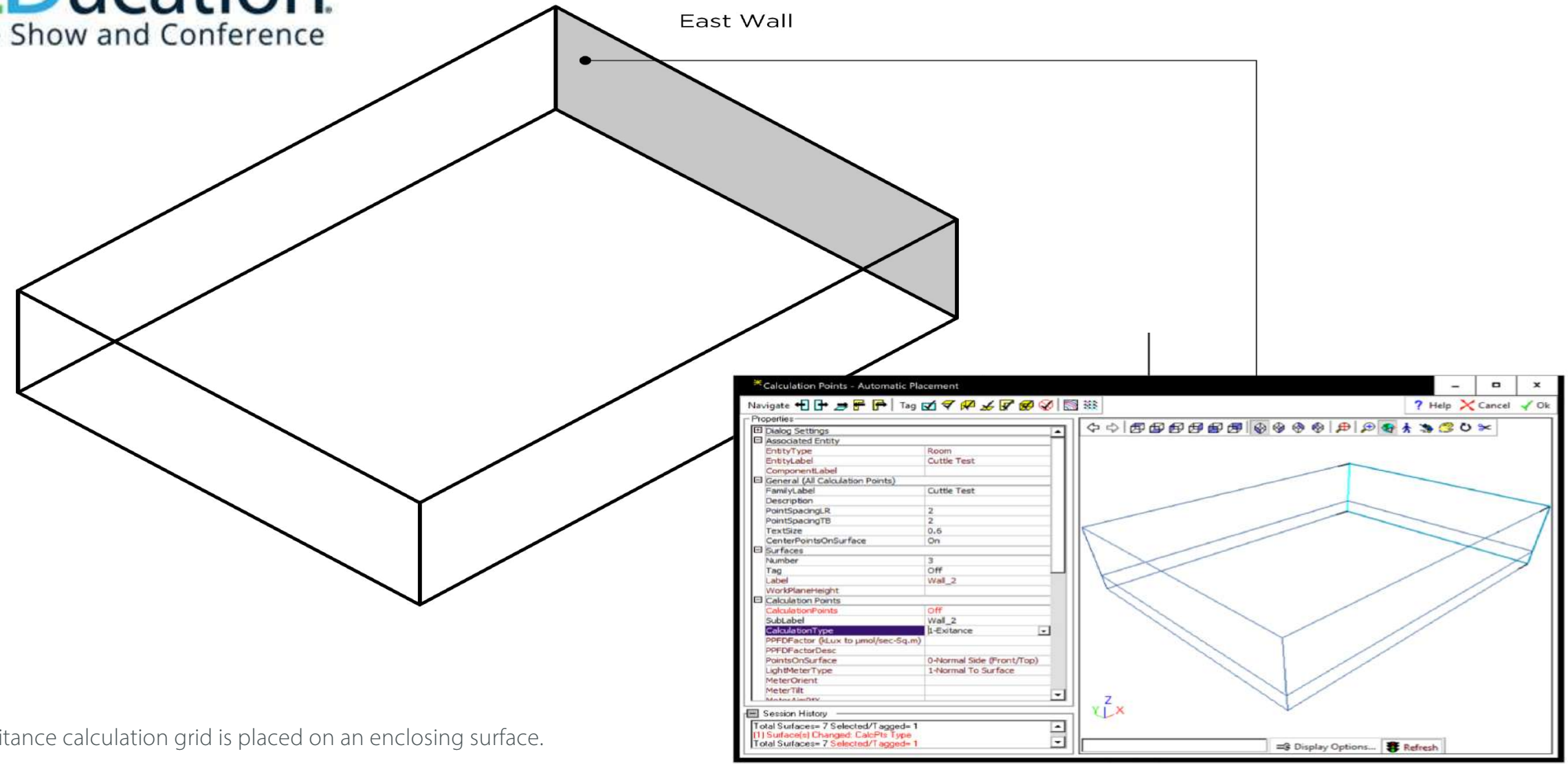


Figure 9 – Yes responses for varying levels of MRSE against PAI.

Duff J, Kelly K, Cuttle C. (2017) Spatial brightness, horizontal illuminance and mean room surface exitance in a lighting booth. Lighting Research and Technology; 49(1): 5-15.



An exitance calculation grid is placed on an enclosing surface.

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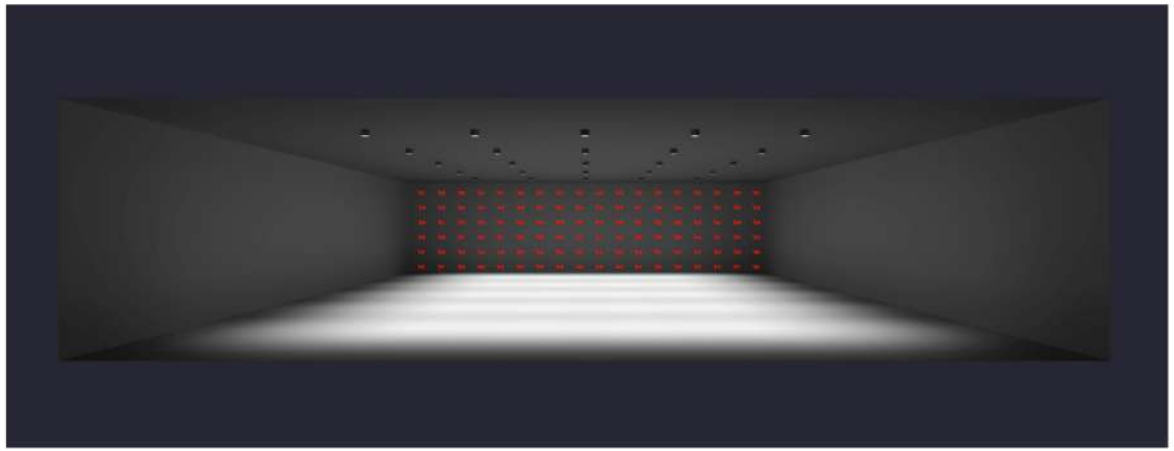

East Wall Exitance (Lms/SqM)
Average = 4.02 Maximum = 6.1 Minimum = 1.2 Avg/Min = 3.35 Max/Min = 5.08

The calculation is run.

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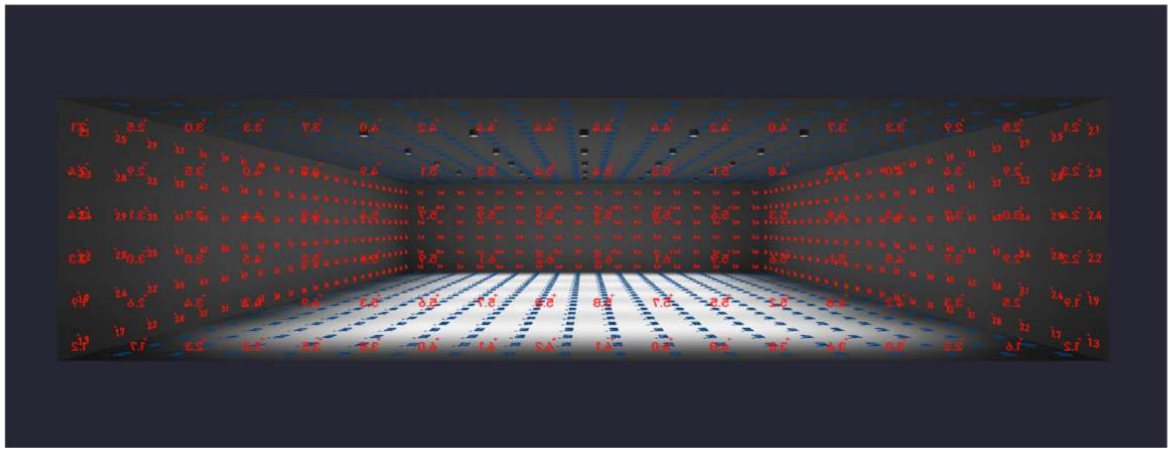

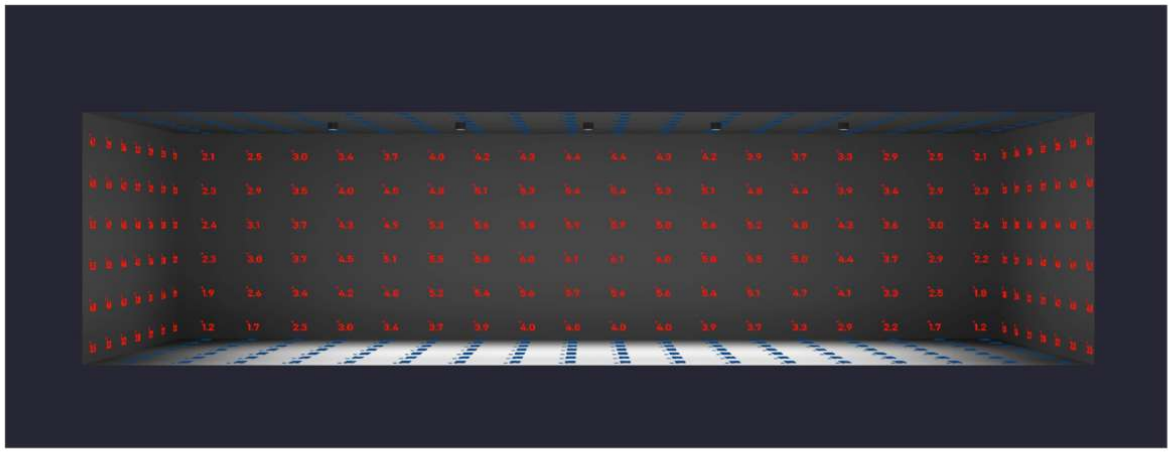

Ceiling Exitance (Lms/SqM)
Average = 4.14 Maximum = 6.7 Minimum = 1.2 Avg/Min = 3.45 Max/Min = 5.58

East Wall Exitance (Lms/SqM)
Average = 4.02 Maximum = 6.1 Minimum = 1.2 Avg/Min = 3.35 Max/Min = 5.08

Floor Exitance (Lms/SqM)
Average = 48.59 Maximum = 91.1 Minimum = 0.5 Avg/Min = 97.18 Max/Min = 182.20

North Wall Exitance (Lms/SqM)
Average = 4.14 Maximum = 5.9 Minimum = 1.3 Avg/Min = 3.18 Max/Min = 4.54

South Wall Exitance (Lms/SqM)
Average = 4.07 Maximum = 5.8 Minimum = 1.3 Avg/Min = 3.13 Max/Min = 4.46

West Wall Exitance (Lms/SqM)
Average = 4.07 Maximum = 6.2 Minimum = 1.2 Avg/Min = 3.39 Max/Min = 5.17

An exitance calculation grid is placed on all enclosing surfaces.

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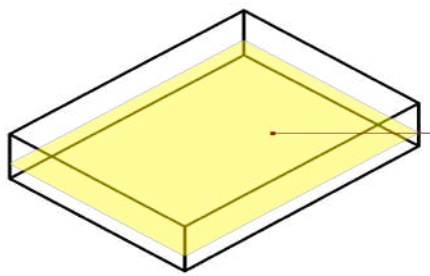
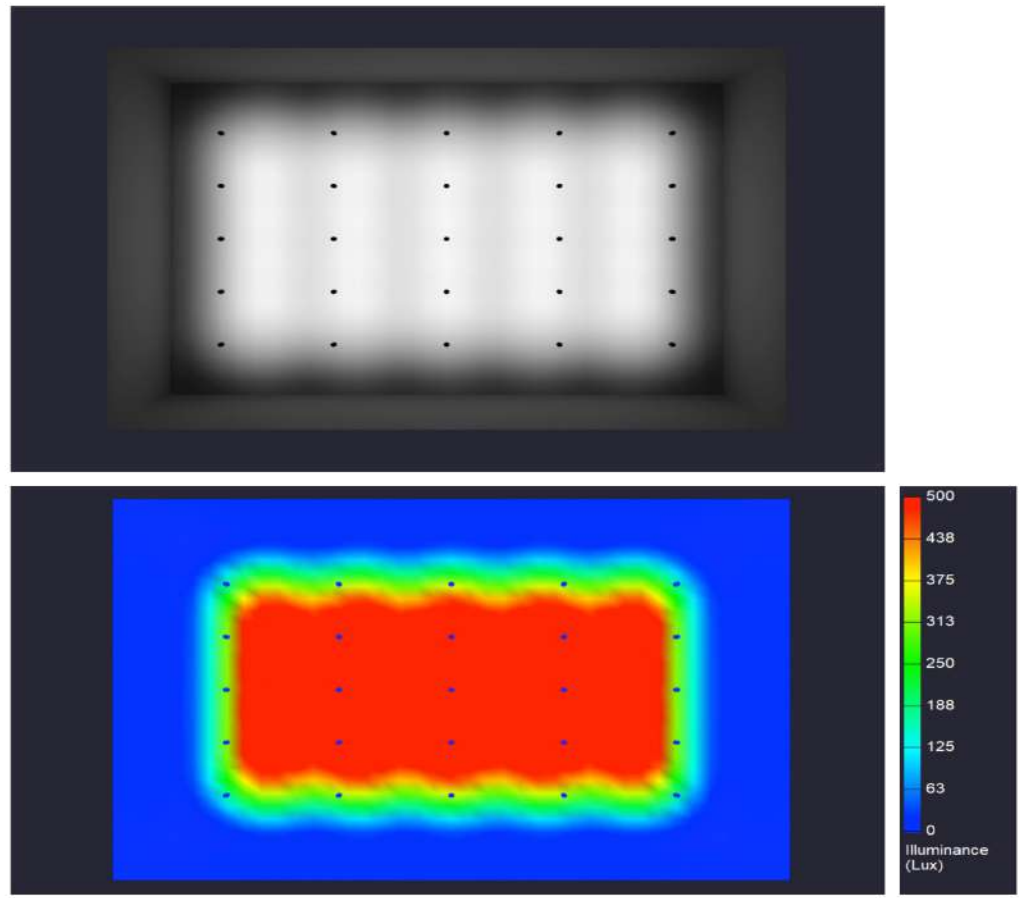
Surface	Avg. Exitance (lm/m^2)	Surface Area (m^2)	Total Surface Lumens
Ceiling	4.14	108	447.12
Floor	48.59	108	5247.72
North Wall	4.14	36	149.04
East Wall	4.02	27	108.54
South Wall	4.07	36	146.52
West Wall	4.07	27	109.89
		Total Surface Area: $342m^2$	Total Spatial Lumens: 6208.83
		Total Surface Lumens/ Total Surface Area	Mean Exitance: **18.15**



Illuminance @ workplane: 327lux



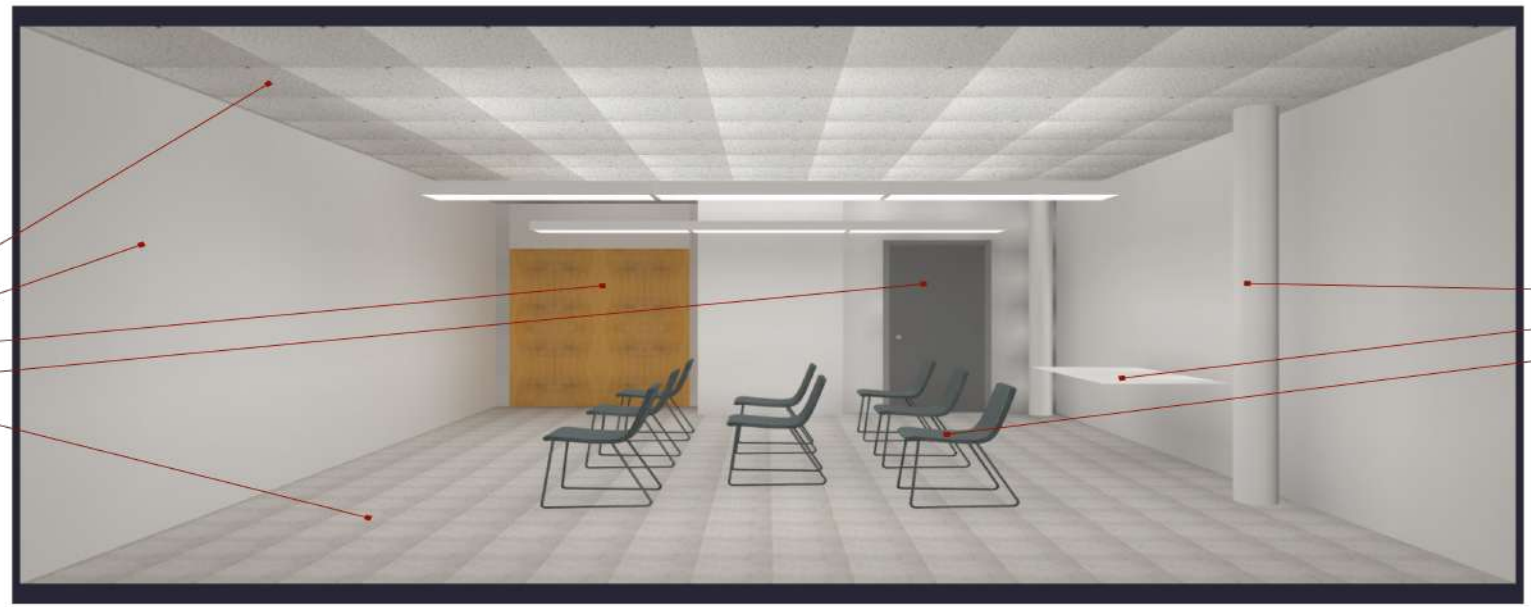
From the mean exitance of a single surfaces to the mean exitance of all enclosing surfaces. Calculating the diffused field of inter-reflected flux within the volume of a space.

MRSE (lm/m^2)	Perceived Brightness
10	Lowest level for color discrimination
30	Dim appearance
100	Lowest level for 'acceptably bright' apperance
300	Bright appearance
1000	Distinctly bright appearance

Cuttle's proposed range of subjective assessments of lit appearance related to MRSE.

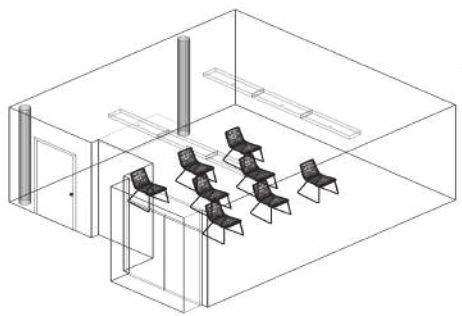
Room Surface Reflectance Values

Ceiling	**0.64**
Wall	**0.93**
Closet Door	**0.44**
Entry Door	**0.22**
Floor	**0.63**



Object Surface Reflectance Values

Column	**0.93**
Table	**0.88**
Chair	**0.15**



Modeling the test site.

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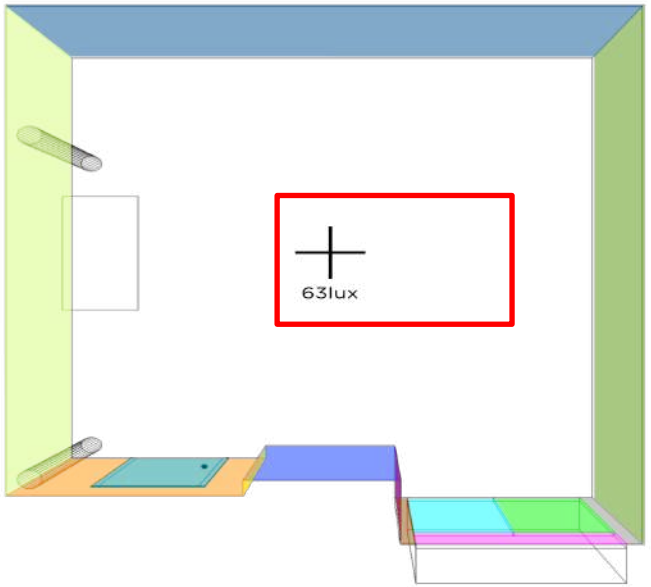
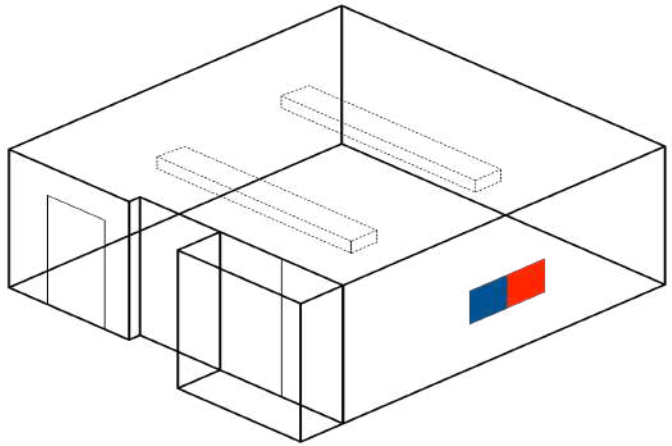
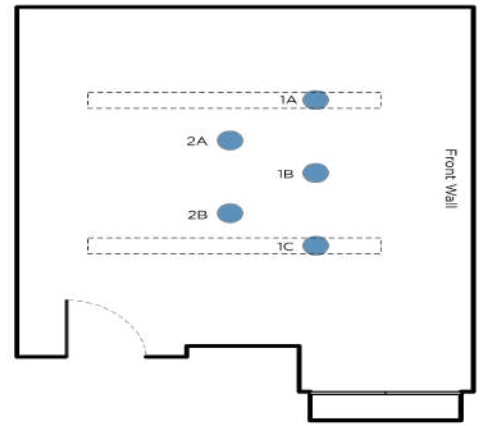


Surface Exitances

Surface	Avg. Exitance (Lm/m²)	Surface Area (m²)	Total Surface Lumens
Bulkhead	24.15	1.115	26.93
Bump Out	25.23	0.488	12.31
Ceiling	33.74	32.189	1086.06
Closet Door East	12.59	1.951	24.56
Closet Door West	12.87	1.951	25.11
East Wall	29.93	17.054	510.43
Entry Door	7.50	1.95	14.63
Entry Door Surround	27.02	3.369	91.03
Floor	28.92	32.189	930.91
North Wall	33.58	15.155	508.90
South East Closet Surround	18.12	0.375	6.80
South Return Wall	19.41	2.021	39.23
South Wall Between Closet and Door	38.73	3.745	145.04
South West Closet Surround	19.97	0.375	7.49
West Wall	30.48	15.521	473.08
		Total: 129.45	**Total Spatial Lumens: 3,467.19**
		Total Spatial Lumens/ Total Surface Size	Mean Exitance: 30.15

Calculating an MRSE and generating a corresponding illuminance vale at a fixed point.





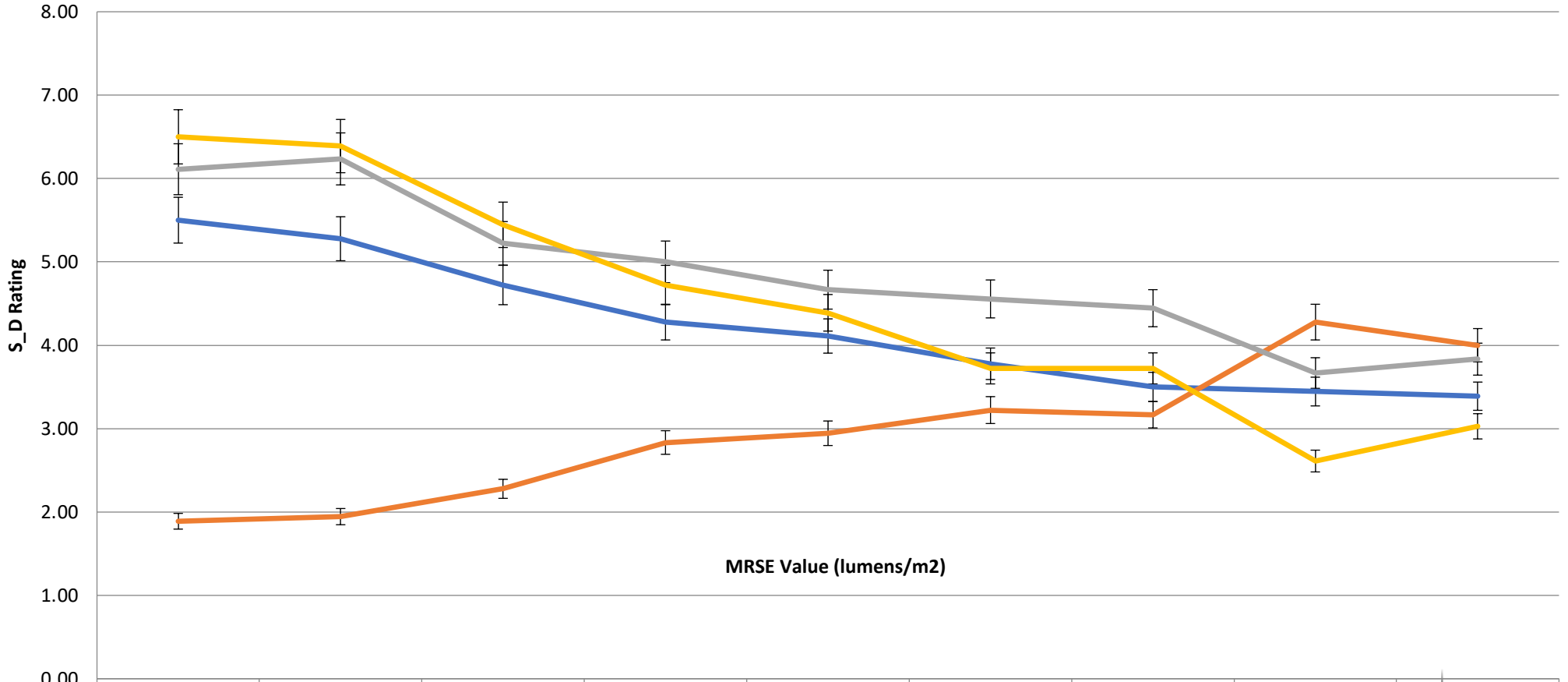
Bright		X					Dim
Colorful							Colorless
Relaxed							Tense
Lively							Subdued
Adequate for reading/writing							Inadequate for reading/writing
Adequate for socializing							Inadequate for socializing
Adequate for contemplation/meditation							Inadequate for contemplation/meditation

The semantic differential scales.

MRSE (lm/m²)	Perceived Brightness
10	Lowest level for color discrimination
30	Dim appearance
100	Lowest level for 'acceptably bright' apperance
300	Bright appearance
1000	Distinctly bright appearance

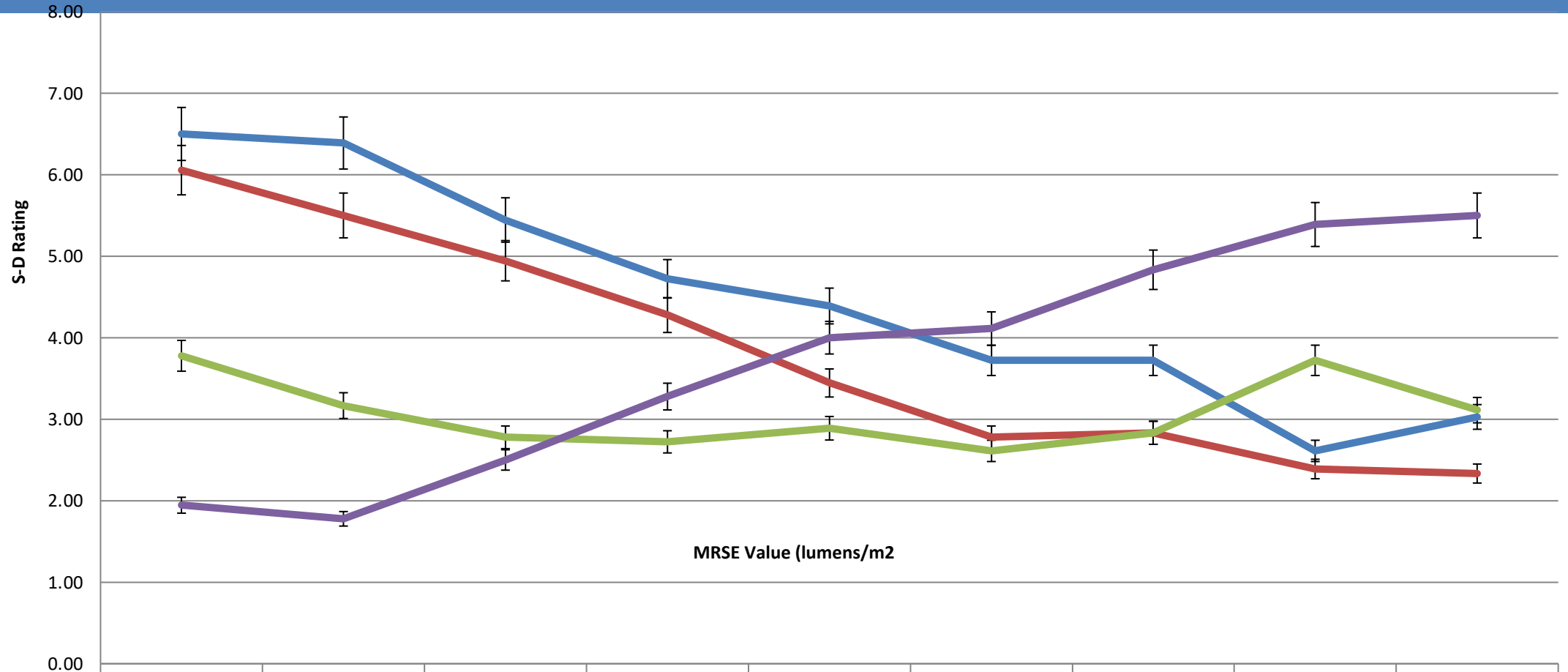
MRSE	Assoc. Illum.	Venue
380.69lm/sqM	75fc (807lux)	Class experiment
	50fc (538lux)	Class experiment
132.99lm/sqM	25fc (269lux)	Class experiment
98lm/sqM	200lux	Individual experiment
88lm/sqM	183lux	Individual experiment
65lm/sqM	136lux	Individual experiment
50lm/sqM	104lux	Individual experiment
42lm/sqM	88lux	Individual experiment
27lm/sqM	56lux	Individual experiment
11.5lm/sqM	24lux	Individual experiment
7.5lm/sqM	16lux	Individual experiment
4lm/sqM	8lux	Individual experiment

Table 1. Semantic-Differential Ratings Relative to Mean Room Surface Exitance for Colorful-Colorless , Relaxed-Tense, Lively-Subdued, and Bright-Dim Rating Scales



	4	7.5	11.5	27	42	50	65	88	98
Colorful-Colorless	5.50	5.28	4.72	4.28	4.11	3.78	3.50	3.44	3.39
Relaxed-Tense	1.89	1.94	2.28	2.83	2.94	3.22	3.17	4.28	4.01
Lively-Subdued	6.11	6.24	5.22	5.00	4.67	4.56	4.44	3.67	3.83
Bright-Dim	6.50	6.39	5.44	4.72	4.39	3.72	3.72	2.61	3.03

Table 2. Semantic-Differential Ratings Relative to Mean Room Surface Exitance for Bright-Dim Rating Scale and Adequate-Inadequate for Reading-Writing, Socializing and Contemplation Scales



	4	7.5	11.5	27	42	50	65	88	98
Bright-Dim	6.50	6.39	5.44	4.72	4.39	3.72	3.72	2.61	3.03
A/I Reading, Writing	6.06	5.50	4.94	4.28	3.44	2.78	2.83	2.39	2.33
A/I Socializing	3.78	3.17	2.78	2.72	2.89	2.61	2.83	3.72	3.11
A/I Contemplation	1.94	1.78	2.50	3.28	4.00	4.11	4.83	5.39	5.50

MRSE (lm/m²)	Perceived Brightness
10	Lowest level for color discrimination
30	Dim appearance
100	Lowest level for 'acceptably bright' apperance
300	Bright appearance
1000	Distinctly bright appearance

MRSE (lm/m²)	Perceived Brightness
5	Lowest level for color discrimination
4-20	Adequate for Contemplation + Meditation
- 30	Subdued Atmosphere
30	Dim appearance
- 65	Relaxed Atmosphere
50+	Adequate for Reading + Writing (Short Duration)
100	Lowest level for 'acceptably bright' apperance

FACTORS THAT AFFECT SPATIAL BRIGHTNESS

1. INTERIOR REFLECTANCE

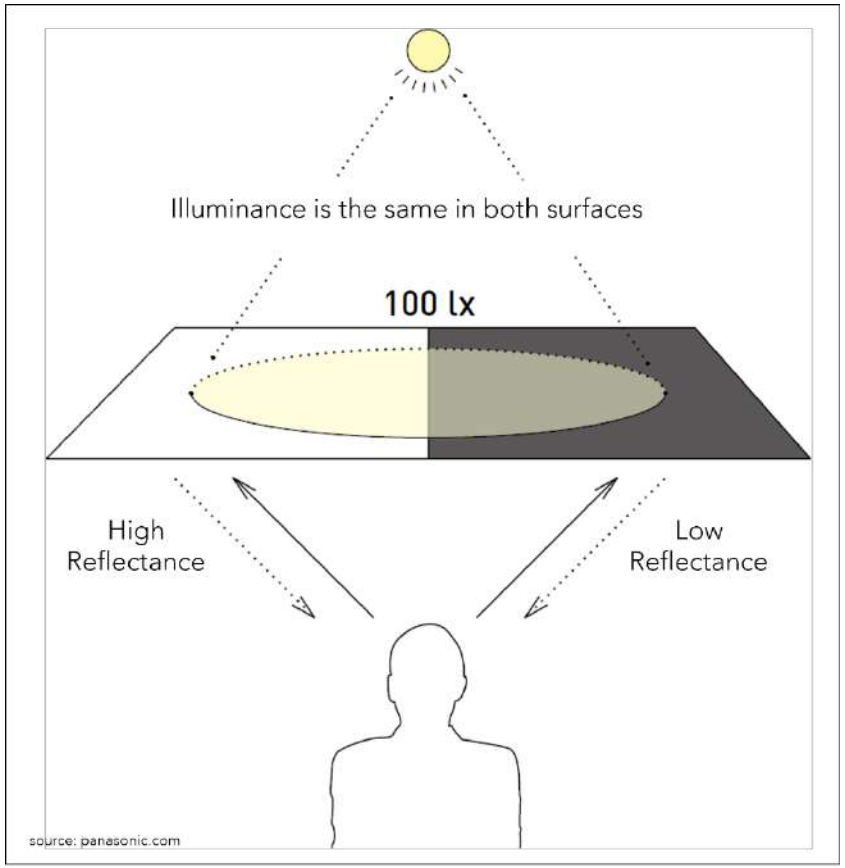
2. LIGHT DISTRIBUTION

Both the interior reflectance, and the light distribution (Kato and Sekiguchi, 2005; Kirsch, 2014; Tiller and Veitch, 1995) are known to affect how bright a space appears.

SPATIAL BRIGHTNESS

INTERIOR REFLECTANCE

- Reflectance properties that make up the interior, ceiling, walls and floor.



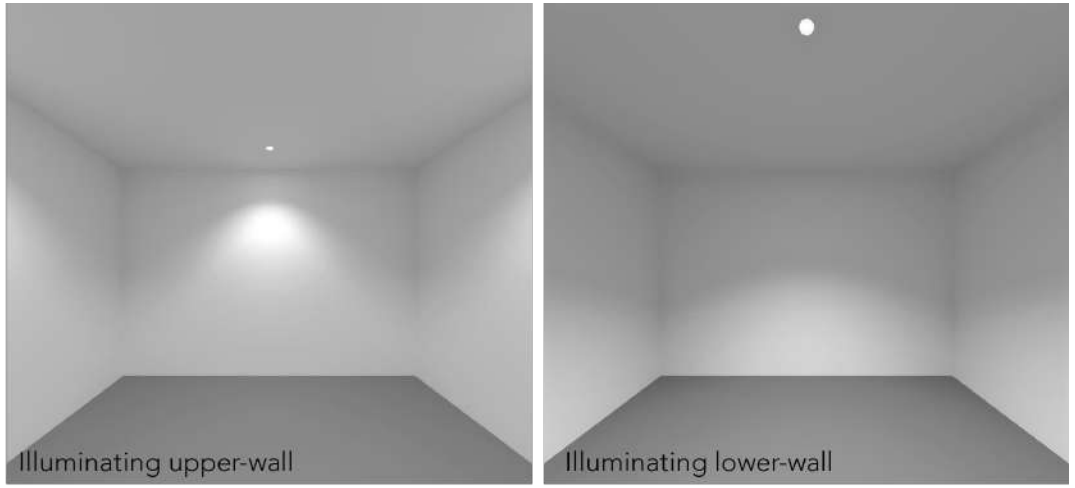
High Reflectance appears brighter to eye

SPATIAL BRIGHTNESS

INTERIOR REFLECTANCE

- Light distribution refers to the general concept of spatial distribution of the light in a space.

- It encompasses all aspects of the distribution of the light, including both magnitude and spatial arrangement.



Same number of fixtures is used in both images,
but the left image appears to be brighter.

WHAT IS THE EFFECT, IN QUANTIFIABLE TERMS,

OF INTERIOR REFLECTANCE AND

LIGHT DISTRIBUTION ON SPATIAL BRIGHTNESS?"

THESIS STATEMENT

By using an alternative luminance-based metric ***"Feu"*** as a spatial brightness indicator, this thesis conducts a set of computer experiments to evaluate how the ***interior reflectance*** and the ***light distribution*** influence the ***perceived spatial brightness.***

Based on the results of the experiments, recommendations for interior reflectance and light distribution are proposed.

SETTINGS

EXPERIMENT

Environment:

- Computer software

Computer parameter settings:

- Controlled variables
- Independent variables
- Number of experiment runs

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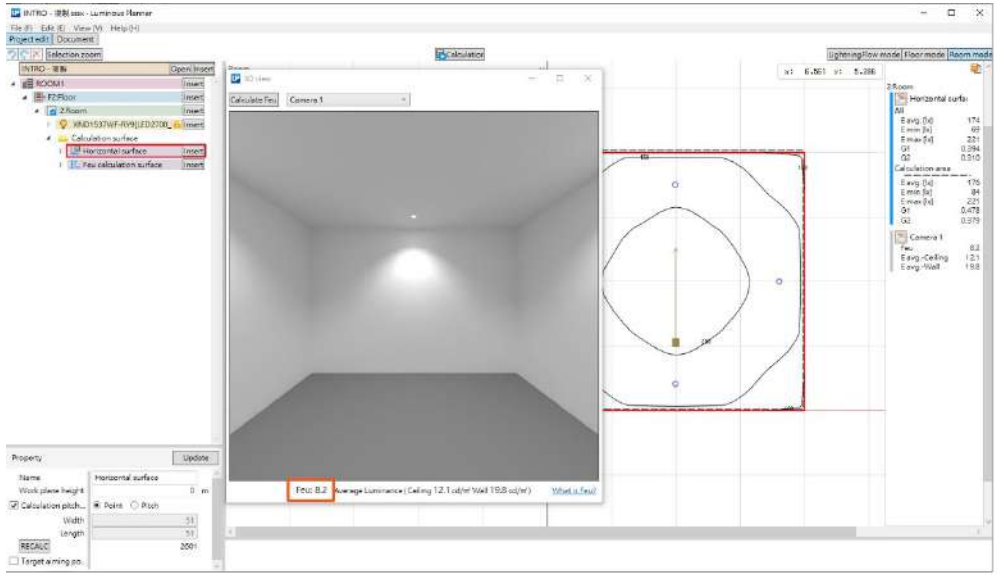
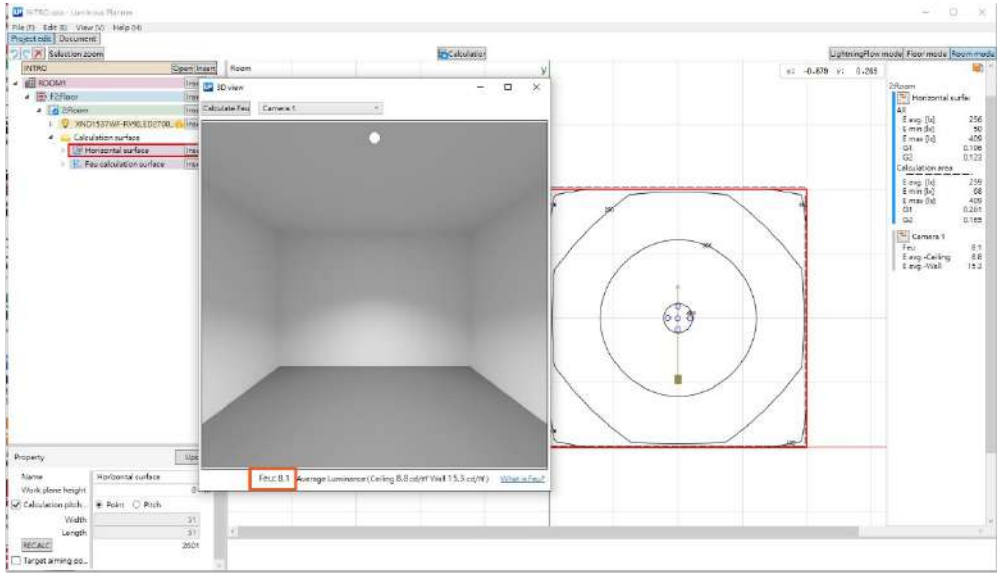
COMPUTER SOFTWARE

ENVIRONMENT

- Luminous Planner launched in 2020



Lux Average illuminance of floor	**174**
Feu	**8.2**



Lux Average illuminance of floor	**256**
Feu	**8.1**

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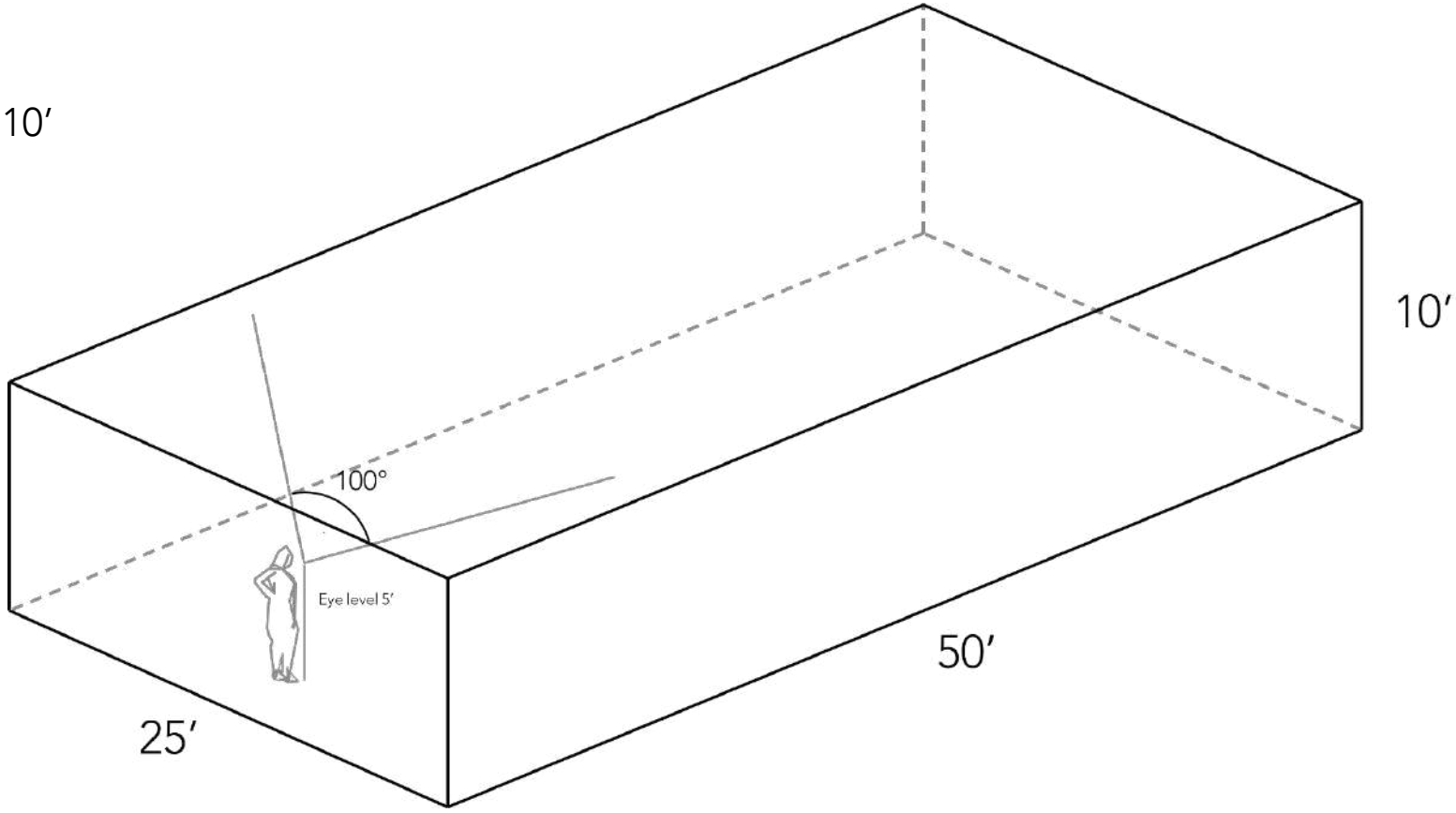
CONTROLLED VARIABLE

SPACE

Dimension of the space: 25’x 50’x 10’

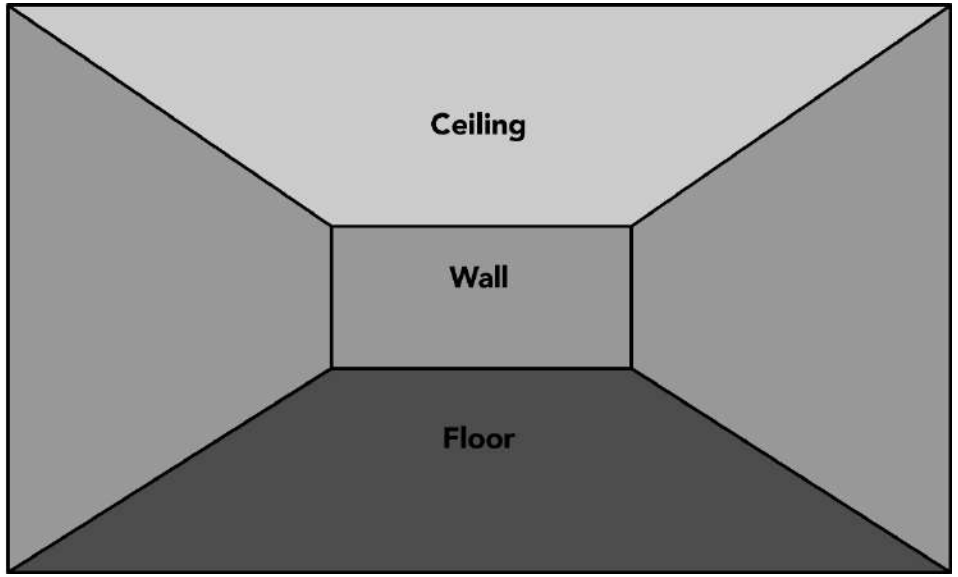
Camera height: 5’



INDEPENDENT VARIABLE

INTERIOR REFLECTANCE

Reflectance (%)		
Ceiling	**Wall**	**Floor**
30	30	30
50	50	50
70	70	70



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INDEPENDENT VARIABLE

INTERIOR REFLECTANCE

Reflectance (%)		
Ceiling	**Wall**	**Floor**
30	30	30
50	50	50
70	70	70

3 x 3 x 3 = 27 combinations

Using ***Orthogonal Table*** to reduce the number of experiment from 27 to 9

L9 (3^3)

Test No.	Reflectance (%)		
	Ceiling	**Wall**	**Floor**
1	30	50	70
2	30	70	50
3	30	30	30
4	50	70	70
5	50	50	30
6	50	30	50
7	70	70	30
8	70	30	70
9	70	50	50

Orthogonal experimental design is the study of multi- factor and level of design method, through the part of the test to find out ***the optimal level combination.***

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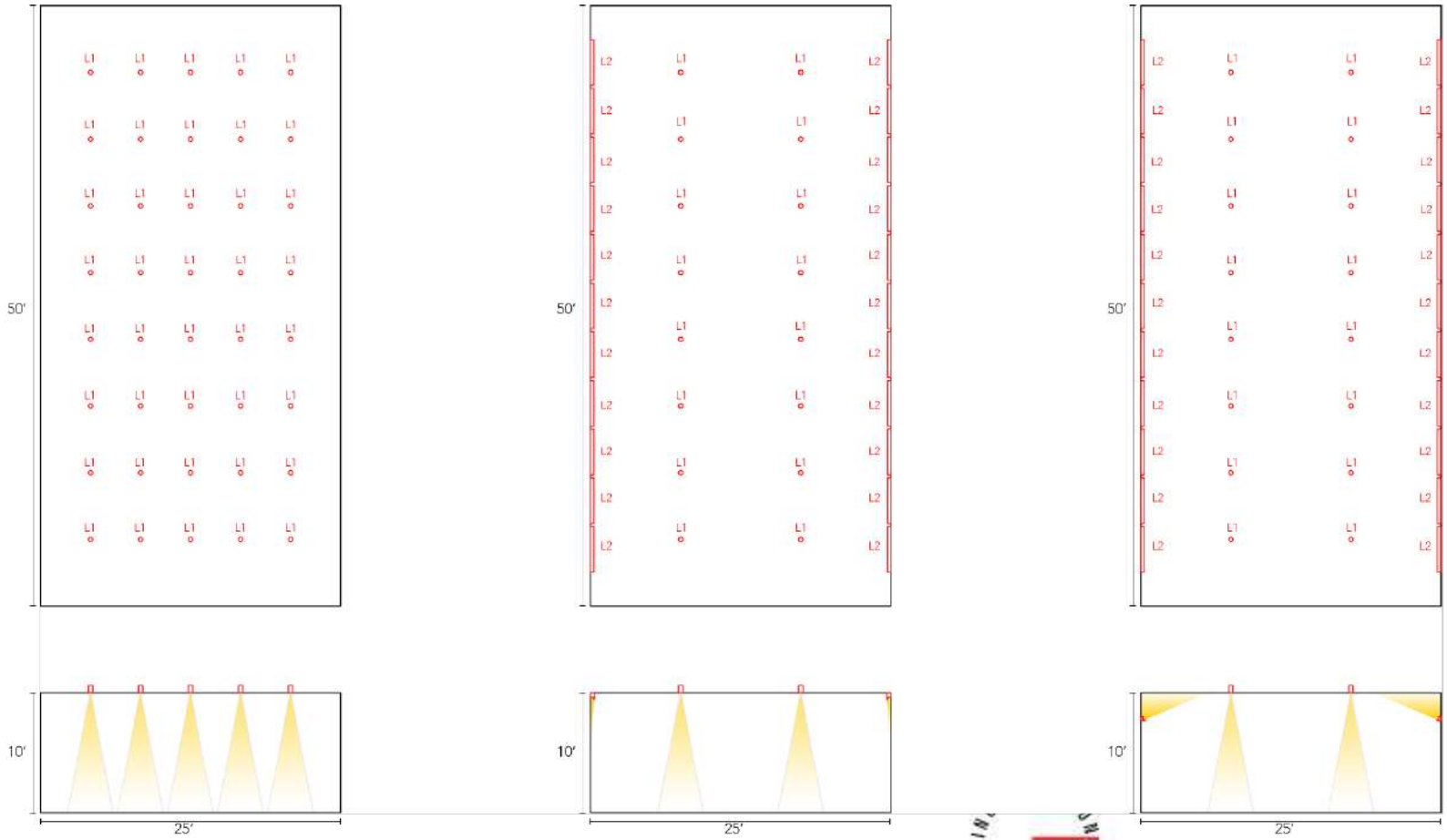
INDEPENDENT VARIABLE

LIGHT DISTRIBUTION

L1: DN Light 5W
L2: Linear Light 4.5W/ ft



1. Direct lighting

2. Illuminating Walls + Direct lighting

3. Illuminating Ceiling + Direct lighting

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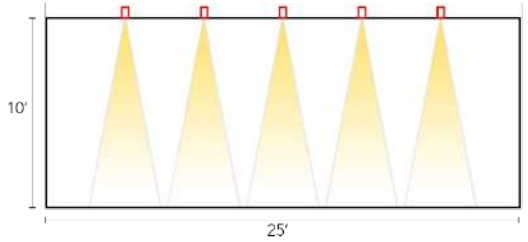
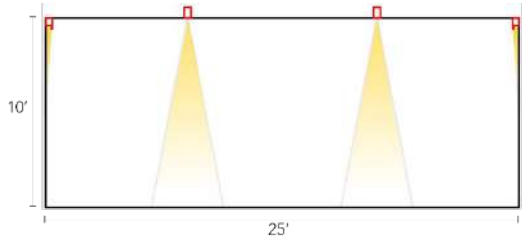
INDEPENDENT VARIABLE

INTEIOR REFLECTANCE + LIGHT DISTRIBUTION



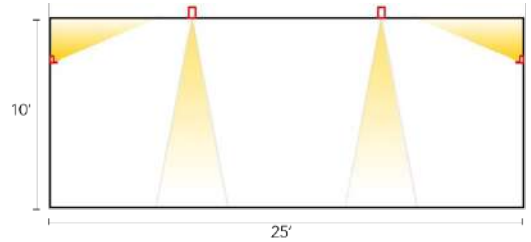
1. Direct lighting

Test No.	Reflectance (%)			Direct Lighting	
	Ceiling	Wall	Floor	Illuminance (Lux)	Feu
1	30	50	70	148	12.1
2	30	70	50	148	10.7
3	30	30	30	110	5.9
4	50	70	70	178	16.4
5	50	50	30	139	7.6
6	50	30	50	142	9.4
7	70	70	30	153	9.5
8	70	30	70	164	13.6
9	70	50	50	160	12.2
Avg.				149	10.8



2. Illuminating Walls + Direct lighting

Test No.	Reflectance (%)			Illuminating Walls + Direct Lighting	
	Ceiling	Wall	Floor	Illuminance (Lux)	Feu
1	30	50	70	135	13.5
2	30	70	50	160	13.8
3	30	30	30	103	6.6
4	50	70	70	198	20.6
5	50	50	30	133	9.8
6	50	30	50	111	9.9
7	70	70	30	187	13.9
8	70	30	70	140	13.8
9	70	50	50	160	14.7
Avg.				147	12.9



3. Illuminating Ceiling + Direct lighting

Test No.	Reflectance (%)			Illuminating Ceiling + Direct Lighting	
	Ceiling	Wall	Floor	Illuminance (Lux)	Feu
1	30	50	70	120	12.5
2	30	70	50	128	11.8
3	30	30	30	101	6.7
4	50	70	70	184	19.9
5	50	50	30	134	10.4
6	50	30	50	130	11.6
7	70	70	30	196	14.9
8	70	30	70	179	17.6
9	70	50	50	189	17.3
Avg.				151	13.6

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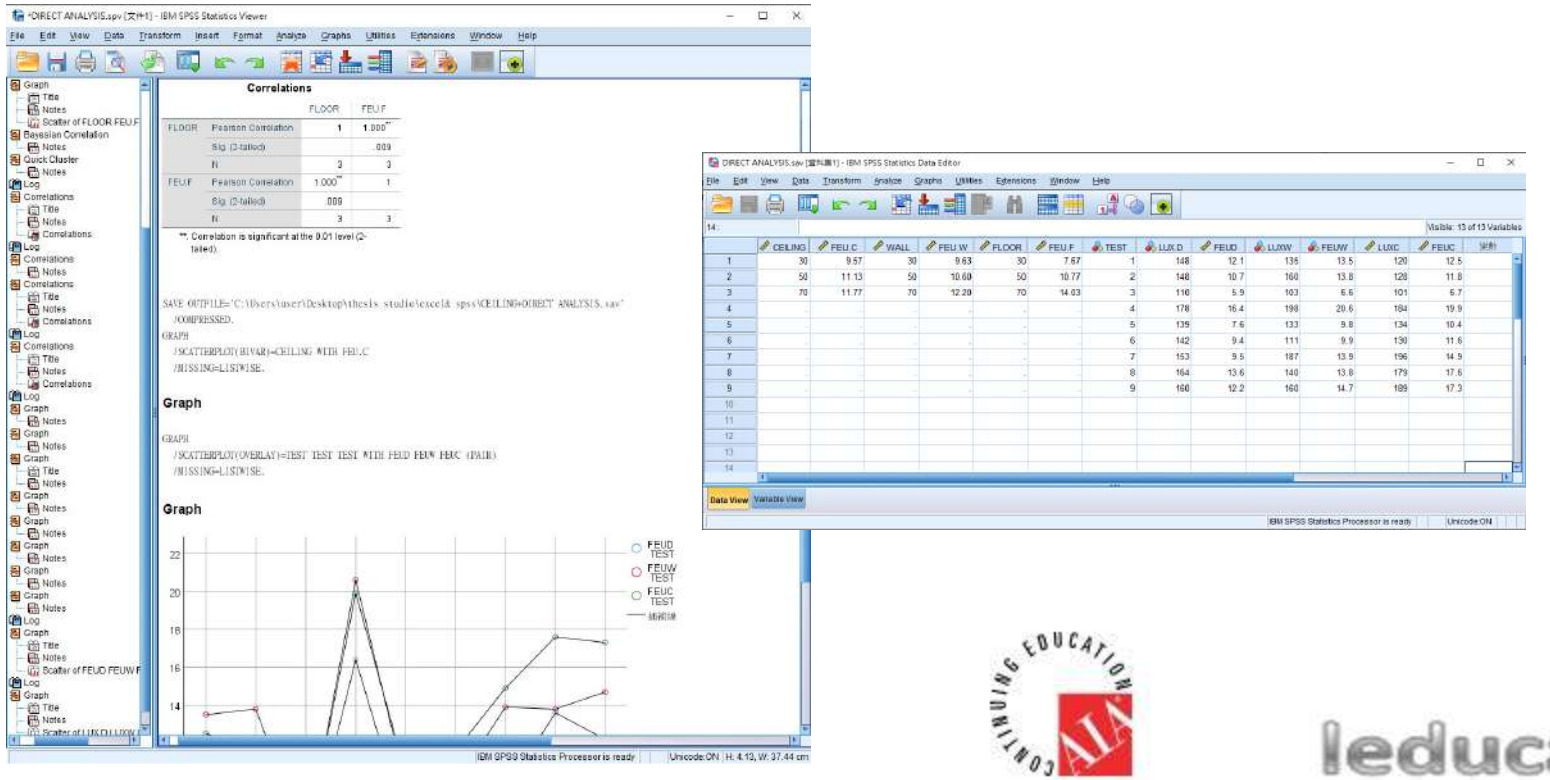
METHOD & SOFTWARE

RESULT & DATA ANALYSIS

- Using parametric statistical tests requires the data to be drawn from a normally distributed sample.

Distribution of data is investigated using statistical and graphical methods available through SPSS.



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INTERIOR REFLECTANCE

RESULT & DATA ANALYSIS

HOW MUCH DOES INTERIOR REFLECTANCE

AFFECT SPATIAL BRIGHTNESS?

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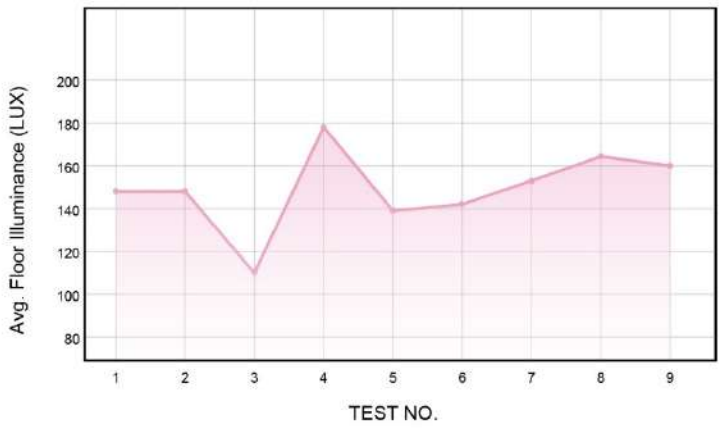
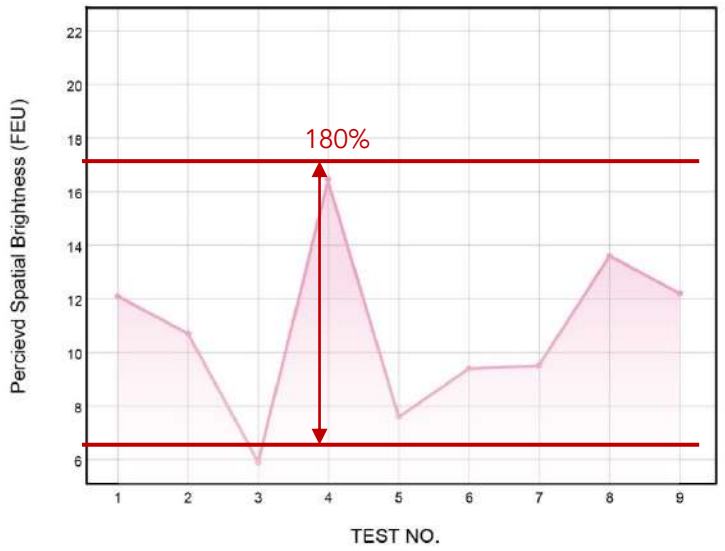
DIRECT LIGHTING

RESULT & DATA ANALYSIS





TEST 1

148 Lux/ Feu: 12.1

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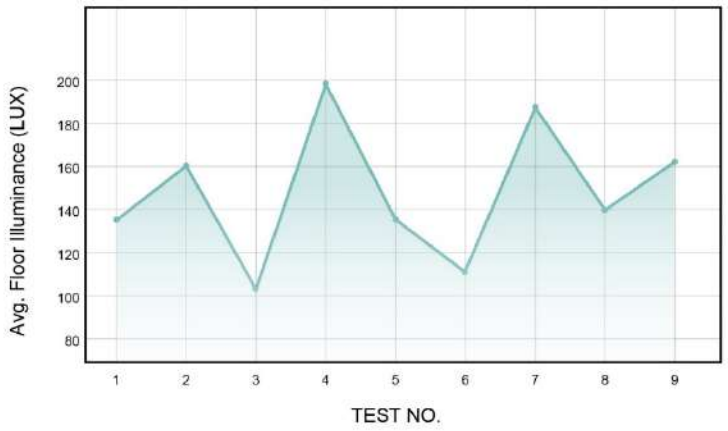
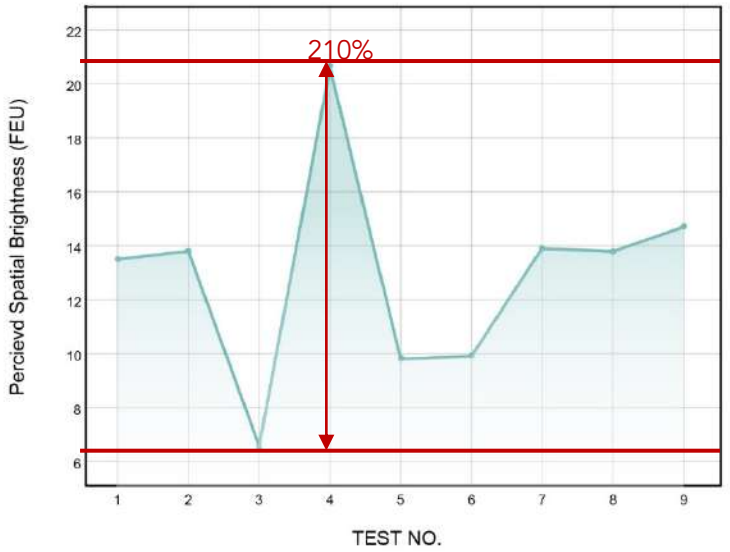
ILLUMINATING WALLS + DIRECT LIGHTING

RESULT & DATA ANALYSIS





TEST 1

135 Lux/ Feu: 13.5

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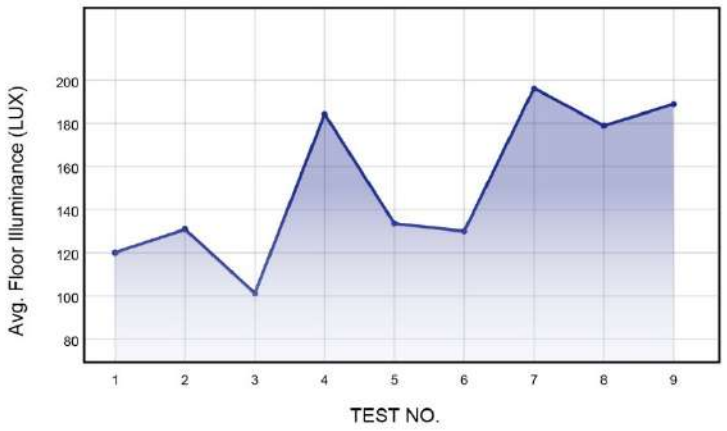
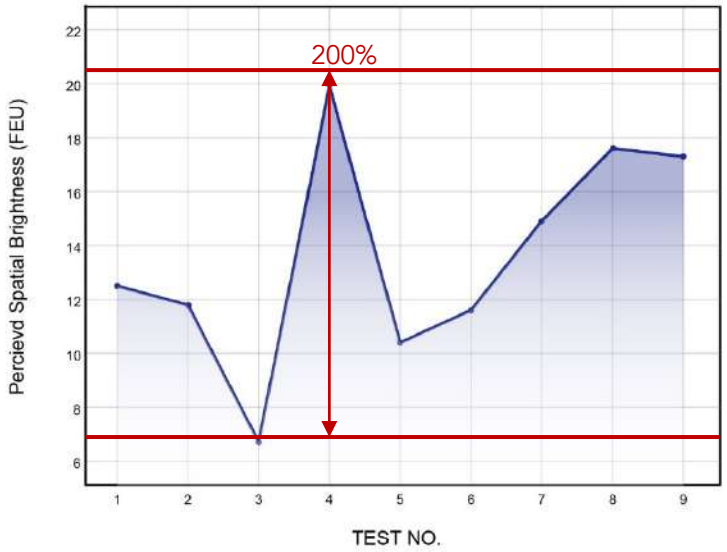
ILLUMINATING CEILINGS+ DIRECT LIGHTING

RESULT & DATA ANALYSIS





TEST 1

120 Lux/ Feu: 12.5

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LIGHT DISTRIBUTION

RESULT & DATA ANALYSIS

HOW MUCH DOES LIGHT DISTRIBUTION

AFFECT SPATIAL BRIGHTNESS?

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Direct Lighting

TEST 1

148 Lux/ Feu: 12.1

Illuminating Walls + Direct Lighting

TEST 1

135 Lux/ Feu: 13.5

Illuminating Ceiling + Direct Lighting

TEST 1

120 Lux/ Feu: 12.5

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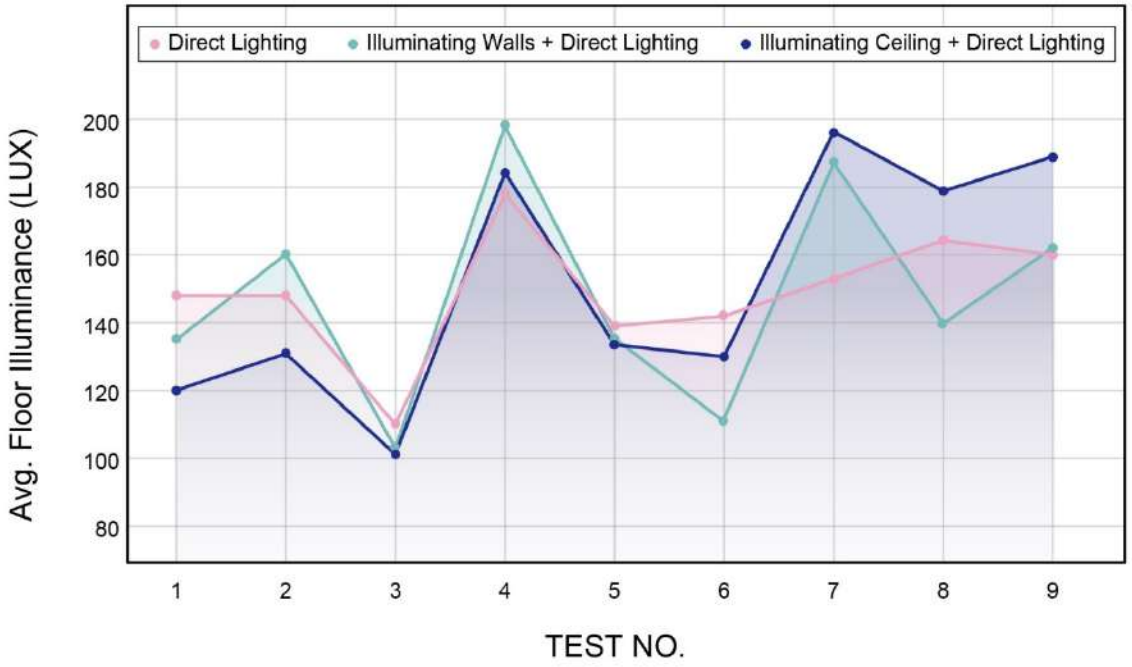
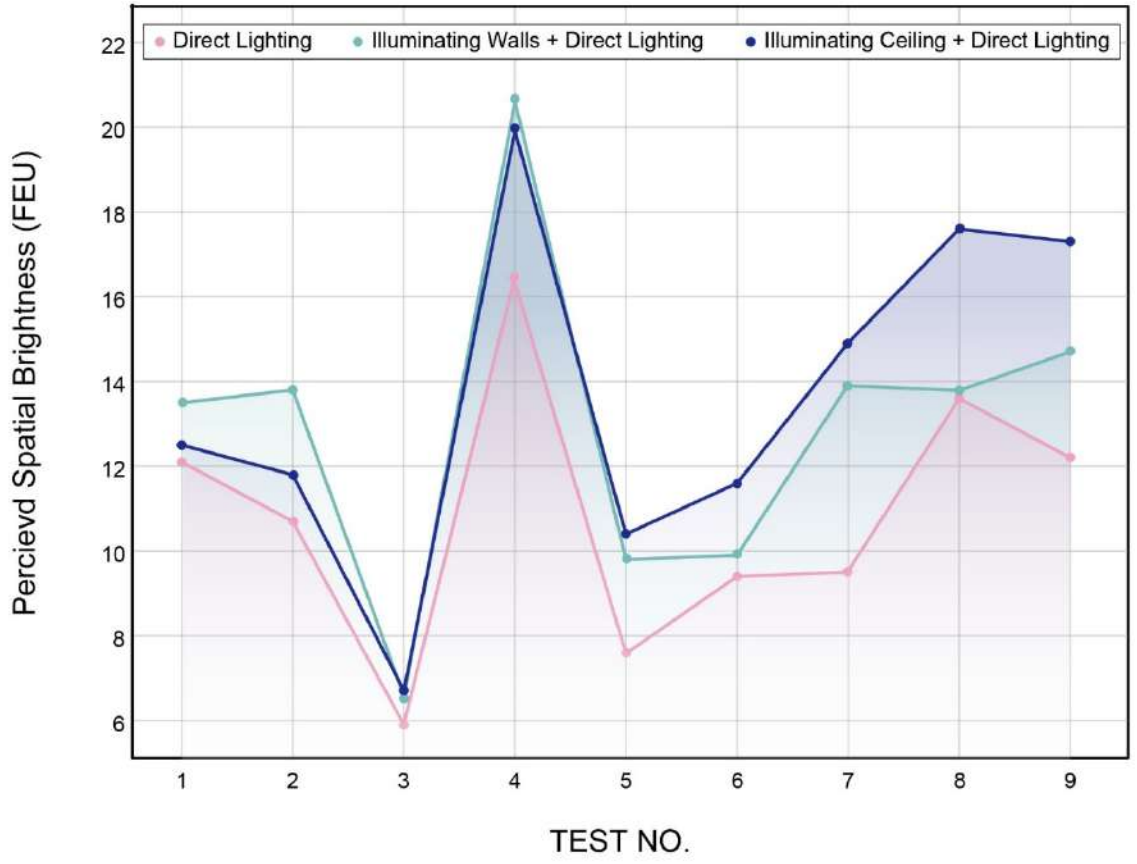
OVERALL

RESULT & DATA ANALYSIS





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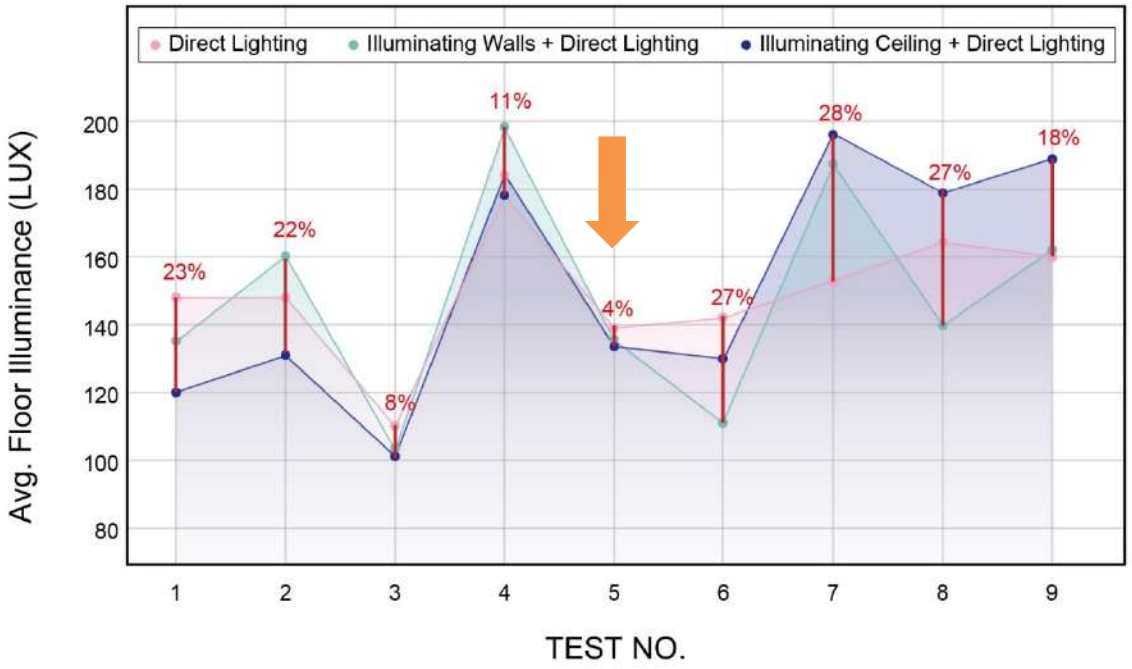
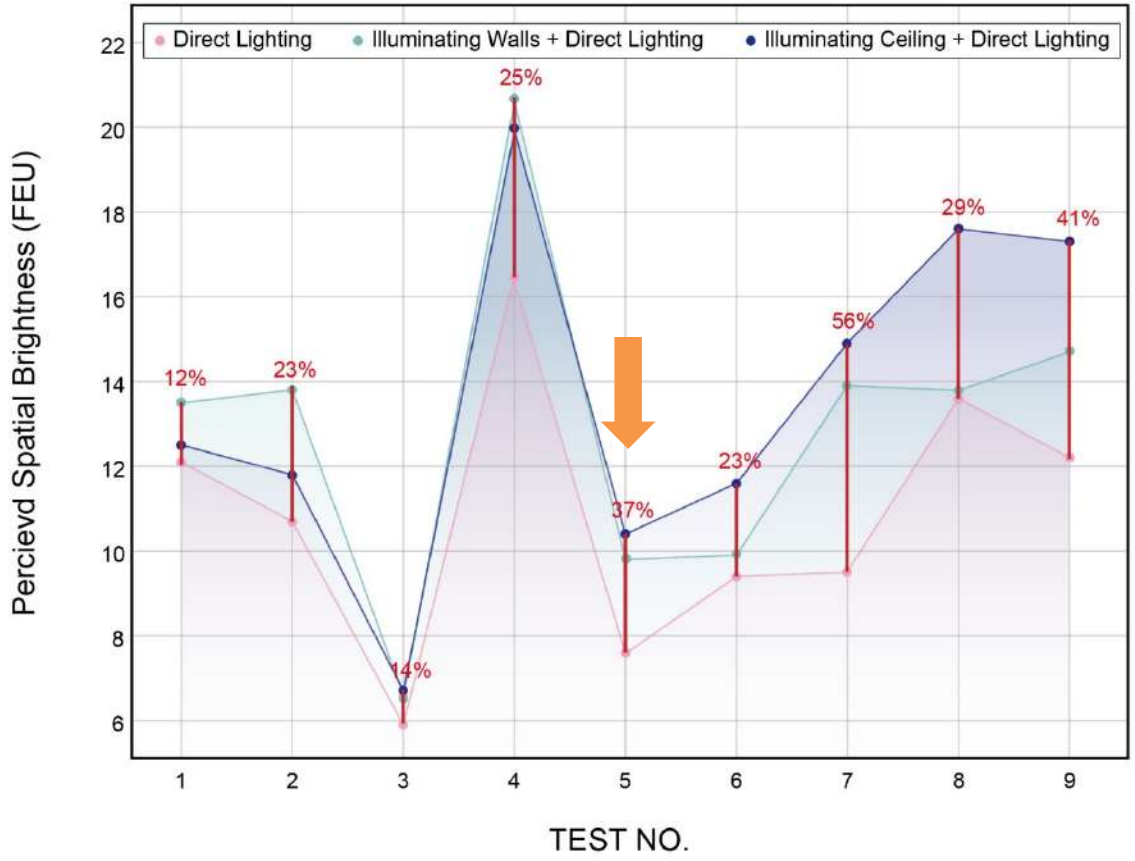
PERCENT VARIANCE

RESULT & DATA ANALYSIS





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INTERIOR REFLECTANCE & LIGHT DISTRIBUTION

RESULT & DATA ANALYSIS

THE RELATIONSHIP BETWEEN

INTERIOR REFLECTANCE & LIGHT DISTRIBUTION

- Interior reflectance has different degree of influence on different light distribution

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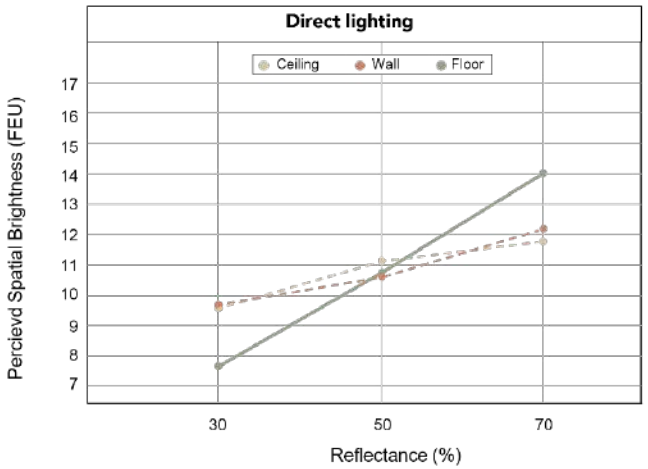
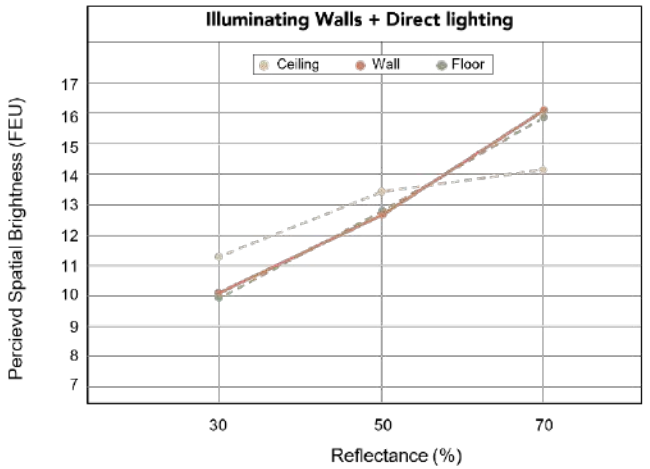
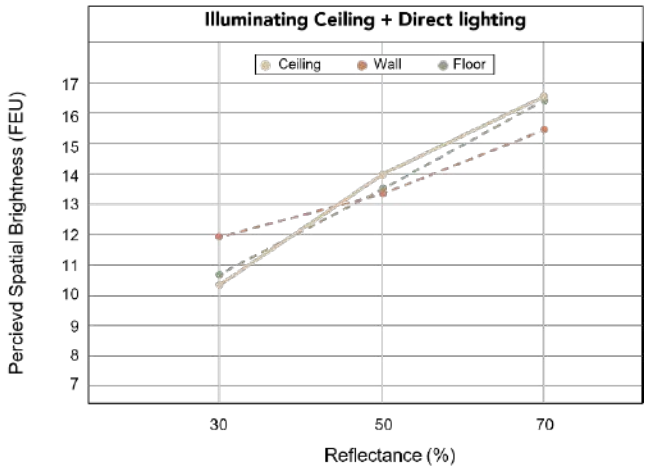
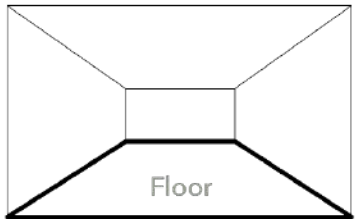
RANGE ANALYSIS

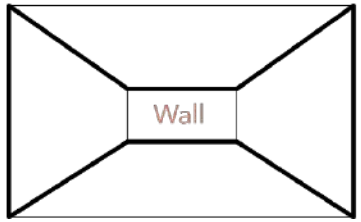
RESULT & DATA ANALYSIS

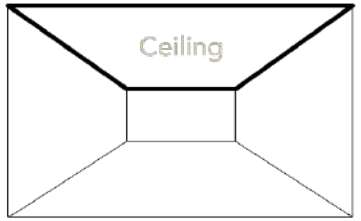






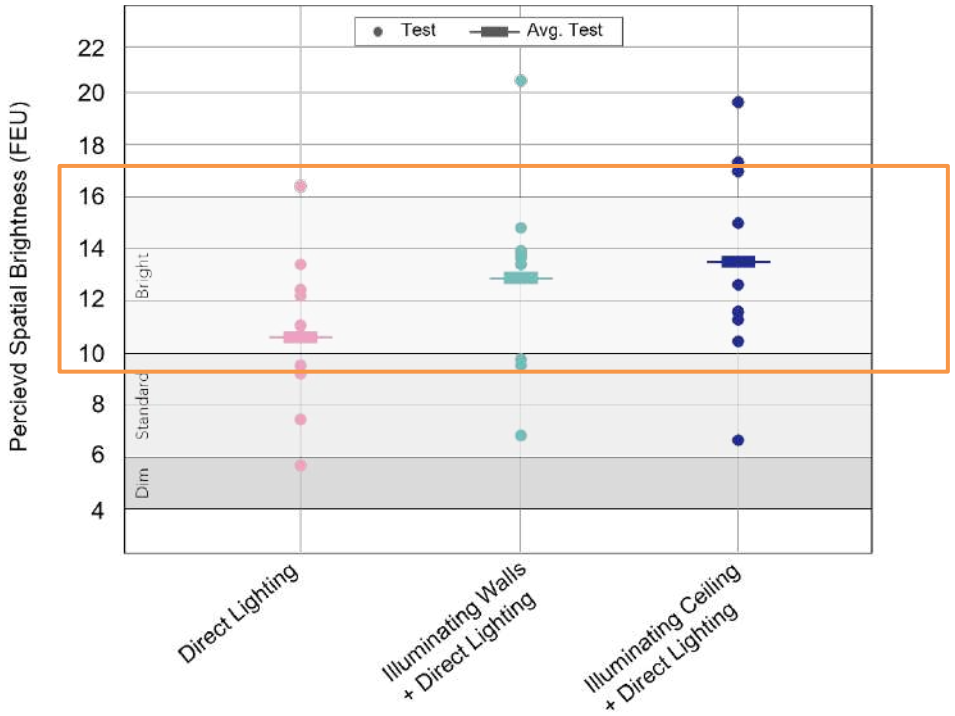


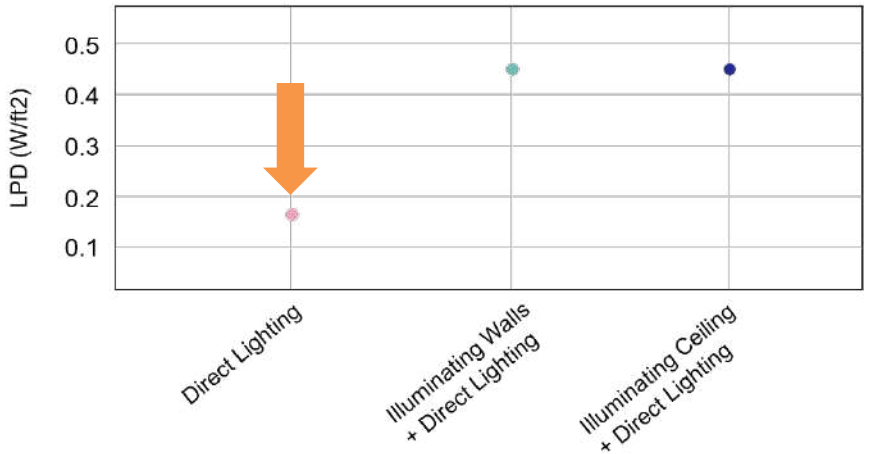




FEU & LPD

RESULT & DATA ANALYSIS





CONCLUSION & DISCUSSION

a) To facilitate the development of better quantitative method of spatial brightness

b) To better describe the practical significance of interior reflectance and light distribution

c) To propose recommendations for interior reflectance and light distribution.

- Spatial brightness can be greatly improved (200%) by either changing interior reflectance or light distribution.

-Interior reflectance has different degrees of influence on different light distributions, and spatial brightness can be improved by increasing the specific interior reflectance (ceiling, walls, or floor.)

FURTHER STEPS

- Testing hybrid solutions that is mixed lighting strategies with vertical and horizontal lighting in combinations
- Testing different dimension of spaces, different room index
- Consider other factors that may also affect spatial brightness, color temperature etc., and investigate how several factors interfere with each other

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WHAT IS THE EFFECT, IN QUANTIFIABLE TERMS,

OF INTERIOR REFLECTANCE AND

LIGHT DISTRIBUTION ON SPATIAL BRIGHTNESS?"

The designer that understands these processes may have significant opportunity to adjust the brightness effect to their needs.

Depending on the balance of light distribution and reflectance, brightness may be increased, decreased, or held constant at a desired level.

~fin~

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This concludes The American Institute of Architects Continuing Education Systems Course

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