Calculating Lighting Solutions

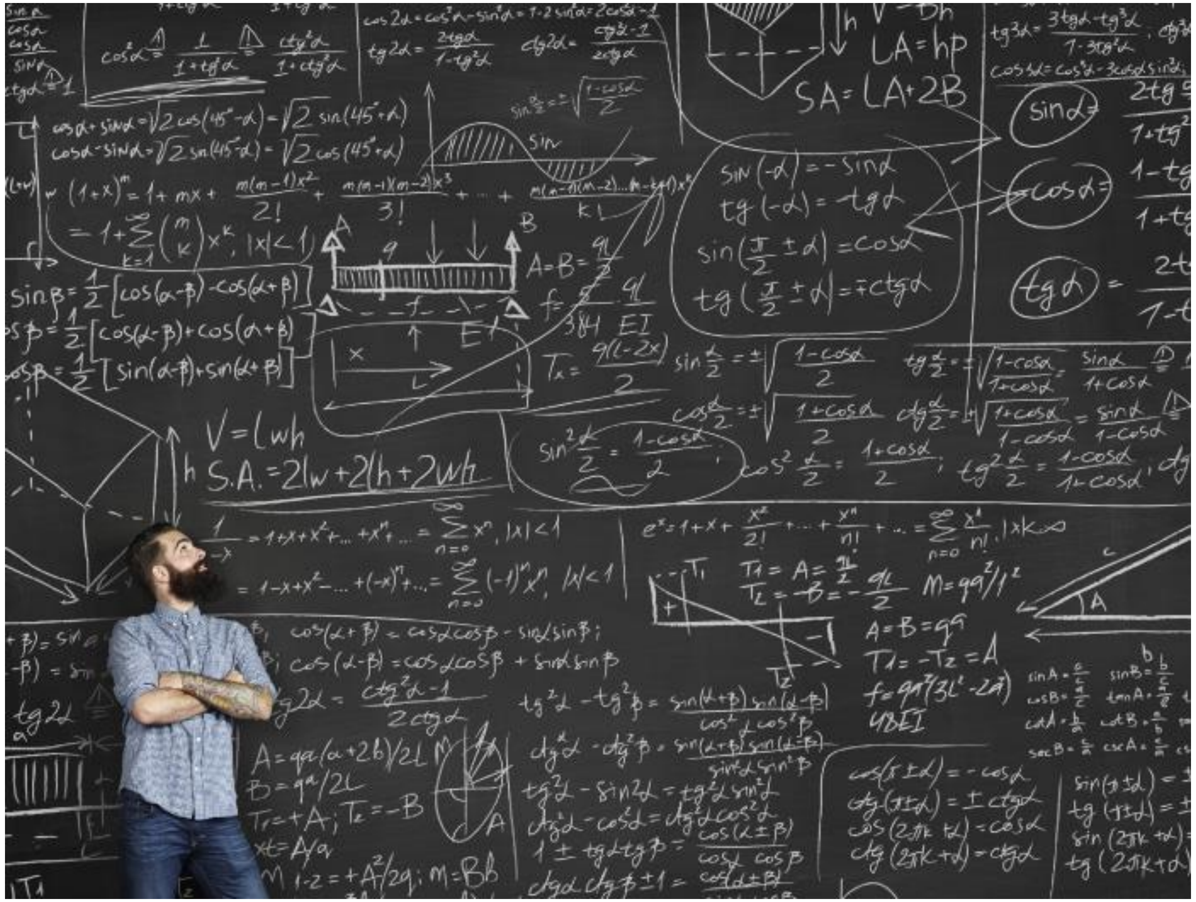
James Donson, PE, LC, BEAP, MIES

April 14, 2020

- No longer paper—online.
- Saves paper, easier to tabulate results.
- Just as important!
- Link emailed to you before noon.
- I'll provide time before final class wrap-up.

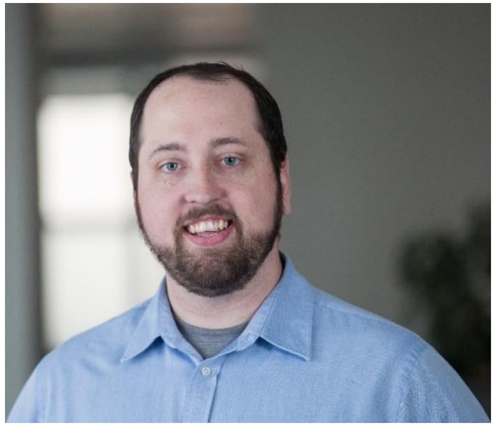
AGENDA

- Welcome & Safety Announcement
- Topics to Cover
  - Point Source Illuminance
  - Lumen Method
  - Computer-Aided Calculations



About your Speaker

James Donson, PE, LC, BEAP



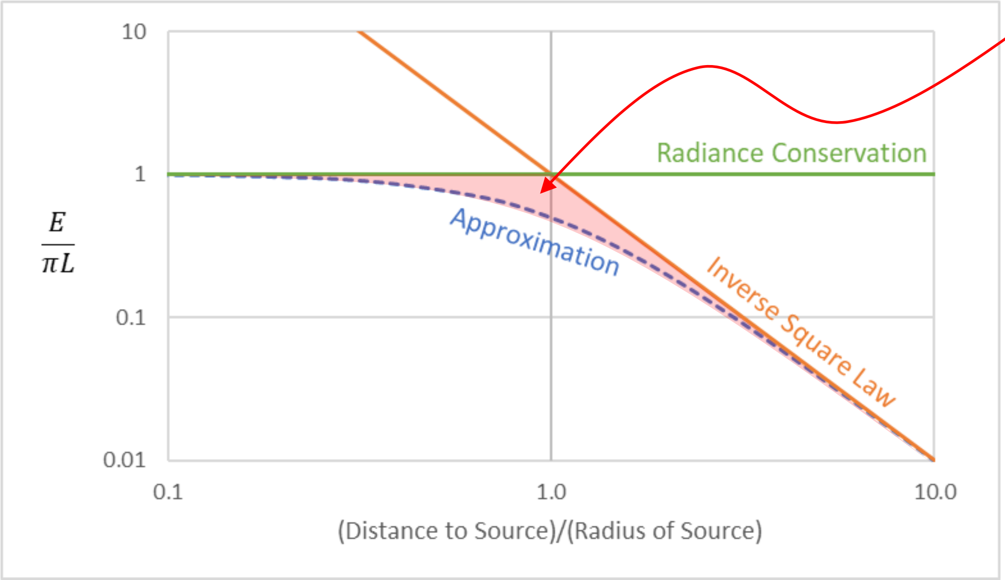
- BSME Cal Poly Pomona, 2008
- MIES & ASHRAE Member
- Board Member of IES San Francisco
- kW's Lighting Expert
- Diverse Project Load
  - Commercial & Industrial Audits/RCx
  - Lighting Research
  - New Construction Lighting/Electrical Cx
  - Lighting Buildouts
- ZNE Retro-fit & Advanced Lighting Tech. & Controls

POINT SOURCE ILLUMINANCE

Point by Point Calculations

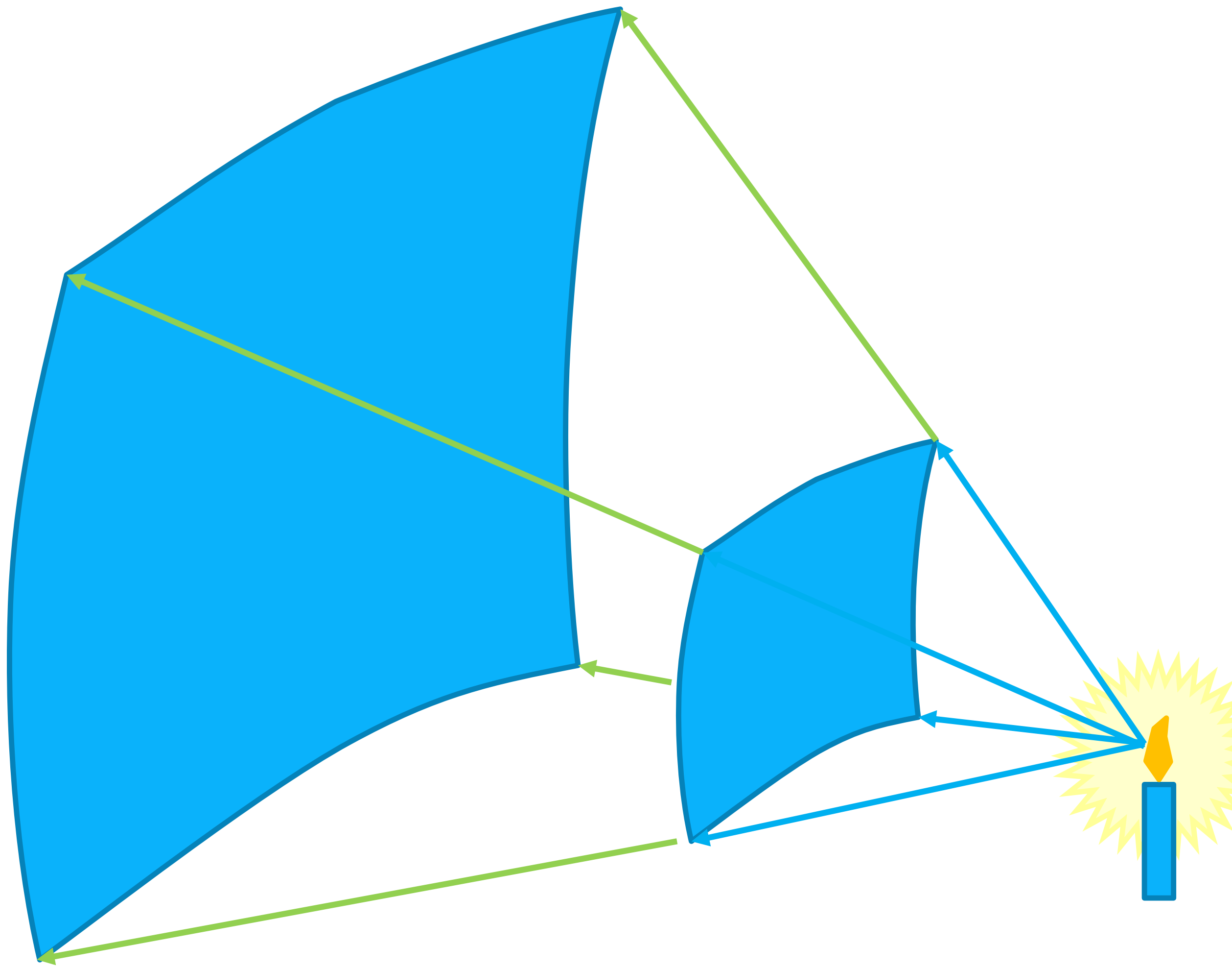
- Calculates illuminance at a point from a point source
- Valid when distance between light source and measurement exceeds 5 times the maximum dimension of the bright surface
  - Incorporates the light source error

Error >1%



Inverse Square Law

- Light obeys the inverse square law.
- Energy twice as far from a point source is spread over four times the area and is ¼ the intensity.
- Valid when distance between light source and measurement exceeds 5 times the maximum dimension of the bright surface



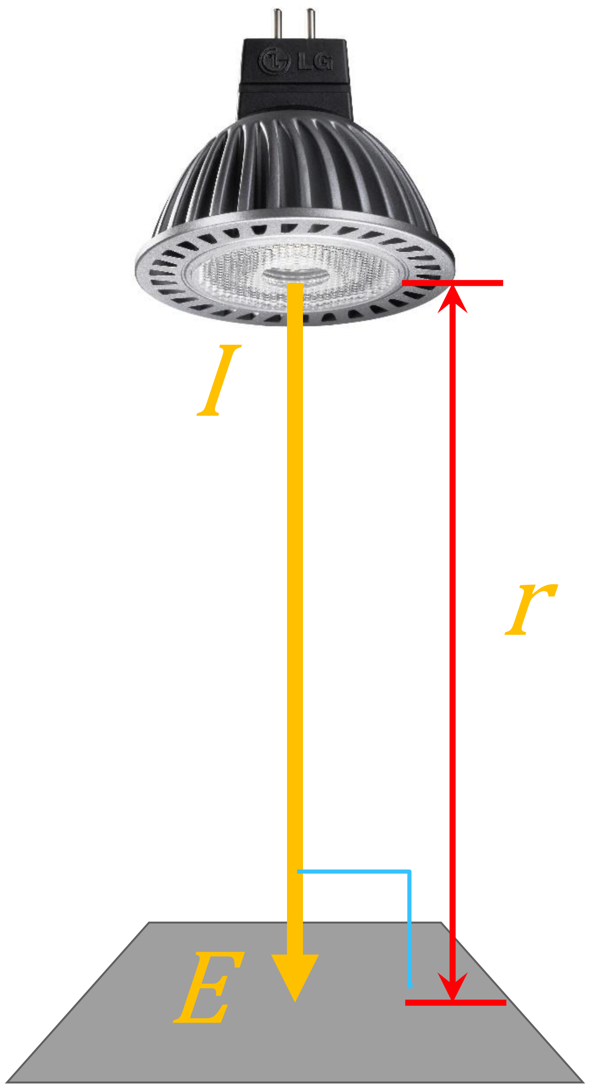
Inverse Square Law

$$\text{Illuminance } (E) = \frac{\text{Intensity}(I)}{[\text{Distance}(r)]^2}$$

$I = \text{Intensity (candela)}$

$r = \text{Distance (ft)}$

$E = \text{Illuminance (fc)}$



Point-source Illuminance Example

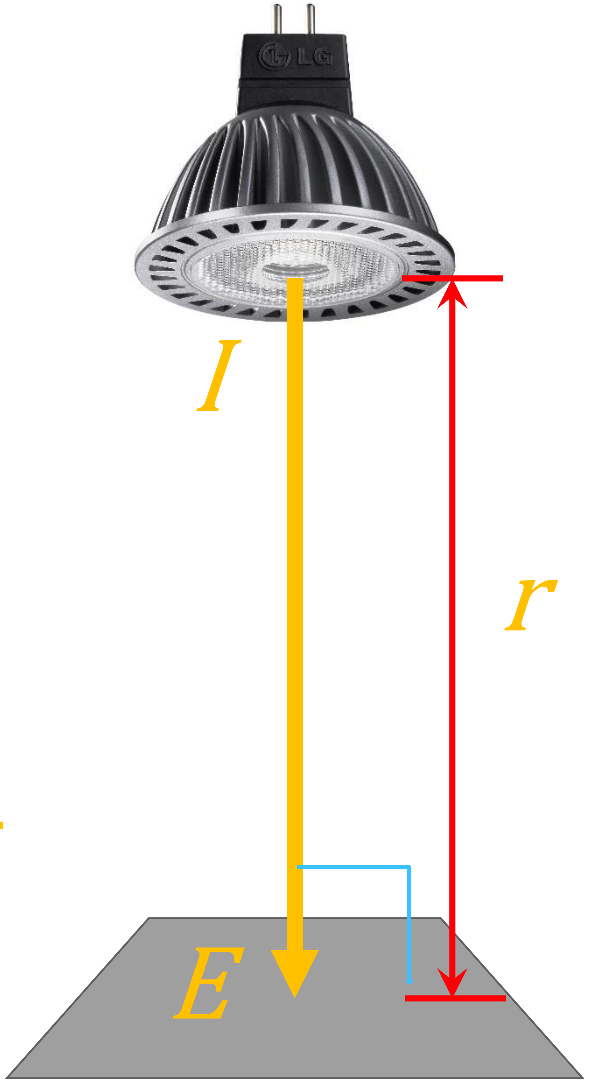
- Given a 100 cd source at 5 feet away, calculate the illuminance directly below the lamp.

$$I = 100\ \text{cd}$$

$$r = 5\ \text{ft}$$

$$E = \frac{I}{r^2} = \frac{100\ \text{cd}}{(5\ \text{ft})^2} = \frac{100\ \text{cd}}{25\ \text{ft}^2}$$

$$E = \boxed{4\ \text{fc}}$$



Getting Intensity Data for Real Products

- Luminaire Cut Sheet
- Lamp Cut Sheet
- Photometric (.ies) file
- LM-79 Test Report

Indoor Report: SORAA SM16-07-25D-927-03.IES

Summary | Candela Array | Zo

Candela Array

Vertical Angles	0.0	22.5	45.0	67.5
0.0	2210.960	2210.960	2210.960	2210.960
0.5	2207.618	2207.618	2207.618	2207.618
1.0	2195.788	2195.788	2195.788	2195.788
1.5	2173.559	2173.559	2173.559	2173.559
2.0	2143.602	2143.602	2143.602	2143.602
2.5	2112.538	2112.538	2112.538	2112.538

NVLAP Lab Code: 200952-0

Verification Services

Project No.: 4786480425-3
Report No.: 4786480425-3a
Report Issued Date: 2015-01-04

Test Report

Intensity Data(cd)

	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	360
0	2408	2408	2408	2408	2408	2408	2408	2408	2408	2408	2408	2408	2408	2408	2408	2408	2408
1	2390	2390	2390	2390	2390	2390	2390	2390	2390	2390	2390	2390	2390	2390	2390	2390	2390
2	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334
3	2243	2243	2243	2243	2243	2243	2243	2243	2243	2243	2243	2243	2243	2243	2243	2243	2243
4	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126
5	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
6	1863	1863	1863	1863	1863	1863	1863	1863	1863	1863	1863	1863	1863	1863	1863	1863	1863
7	1725	1725	1725	1725	1725	1725	1725	1725	1725	1725	1725	1725	1725	1725	1725	1725	1725
8	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576	1576

Model #	Product Code	CCT (K)	Beam Angle	CBCP (Cd)	Halogen Equivalent	Total Flux (Lm)
VIVID SERIES						
SM16-07-10D-927-03	00919	2700	10	5710	50	390
SM16-07-25D-927-03	00931	2700	25	2260	50	410
SM16-07-36D-927-03	00943	2700	36	1070	50	410
SM16-07-10D-930-03	00923	3000	10	6000	50	410
SM16-07-25D-930-03	00935	3000	25	2400	50	435

Example #1
Point Source Display Lighting

- You're lighting a small jewelry display with a 7-watt, 25° narrow flood MR-16 lamp. The lamp is positioned directly above the display, 7 feet away. What is the horizontal illuminance on the display?

Lamp Type	Base Type	Watts	PC	Description	Volts	Case Qty	MOL (in)	Lumens	CBCP	Color Temp.	CRI	Watt Replacement	Rated Life Hours L70	Dimmable	Energy Star	Location	Additional Info
MR16	GU5.3	5.5	35542	LED5.5DMR1684035	12	6	1.8	460	1100	4000	80	35W	25,000	Yes	★	Damp	Flood, 35° beam, White
			35535	LED5.5DMR1683035	12	6	1.88	420	1000	3000	80	35W	25,000	Yes	★	Damp	Flood, 35° beam, White
			35540	LED5.5DMR1682735	12	6	1.88	400	1000	2700	80	35W	25,000	Yes	★	Damp	Flood, 35° beam, White
		7	35546	LED7XDMR16-22725	12	6	1.8	500	2350	2700	80	50W	25,000	Yes	★	Damp	Flood 25° beam, White
			35543	LED7XDMR16-28325	12	6	1.8	500	2350	3000	80	50W	25,000	Yes	★	Damp	Narrow Flood, 25° beam, White
			35544	LED7XDMR16-28335	12	6	1.8	500	1350	3000	80	50W	25,000	Yes	★	Damp	Flood 35° beam, White
PAR30 	MED	12	98755	LED12DP303W83035	120	6	3.66	950	2600	3000	80	75W	25,000	Yes	★	Damp	Flood, 35° beam, White, STIR
			98811	LED12DP3L3W83035	120	6	4.61	950	2600	3000	80	75W	25,000	Yes	★	Damp	Accent, 35° beam, White, STIR
PAR38	MED	11	91360	LED11P38W830/25	120	6	5.04	950	4000	3000	80	90W	10,000	-	-	Wet	Flood, 25° beam, White, STIR
		15	32213	LED15DP38W830/40	120	6	5.04	1300	2300	3000	81	90W	25,000	Yes	★	Wet	Flood, 40° beam, White, STIR

CBCP = Center-beam Candle power

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			35544	LED7XDMR16-28335	12	6	1.8	500	1350	3000	80	50W	25,000	Yes	★	Damp	Flood 35° beam, White
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		15	32213	LED15DP38W830/40	120	6	5.04	1300	2300	3000	81	90W	25,000	Yes	★	Wet	Flood, 40° beam, White, STIR

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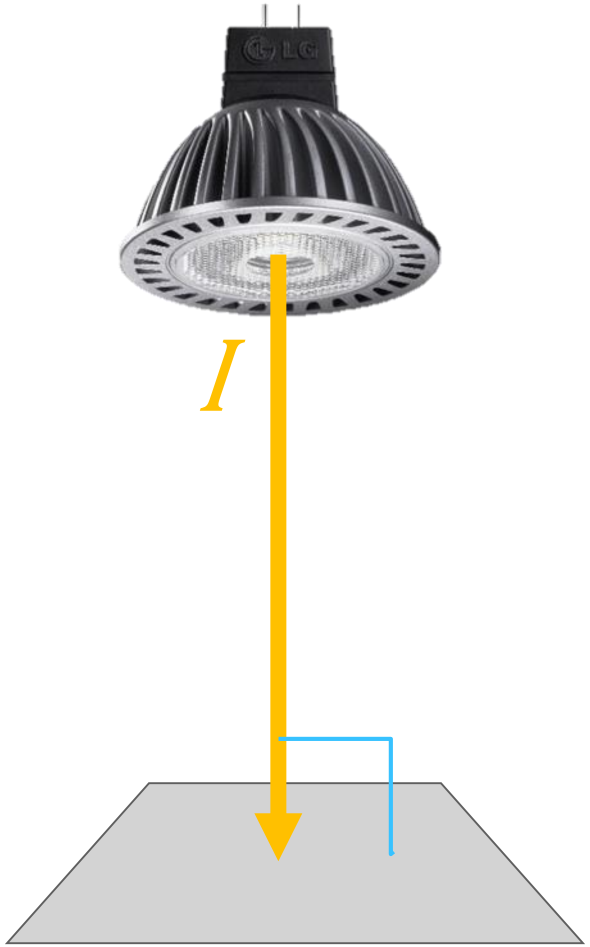
$$E = \frac{}{r^2} = \frac{}{(7\ \text{ft})^2} = \frac{}{49\ \text{ft}^2} = \boxed{48.0\ \text{fc}}$$

Point Source Illuminance at an Angle

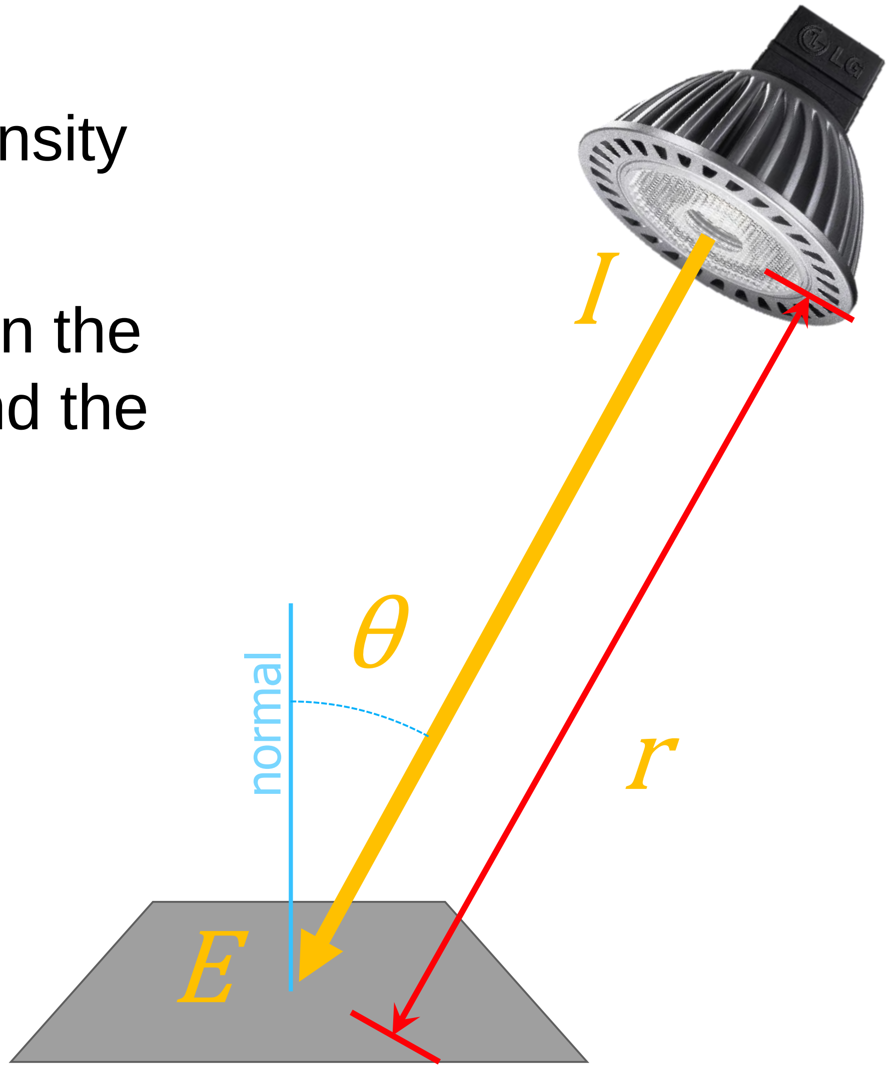
- The basic calculation only handles point-source illuminance at right angles
- Illuminance at an angle involves cosines or additional data



Lighting at an Angle

- Illuminance at an angle is less than illuminance overhead at the same intensity and distance
- The angle is always evaluated between the normal from the illuminated surface and the angle of the beam.

$$E = \frac{I}{r^2}\cos(\theta)$$



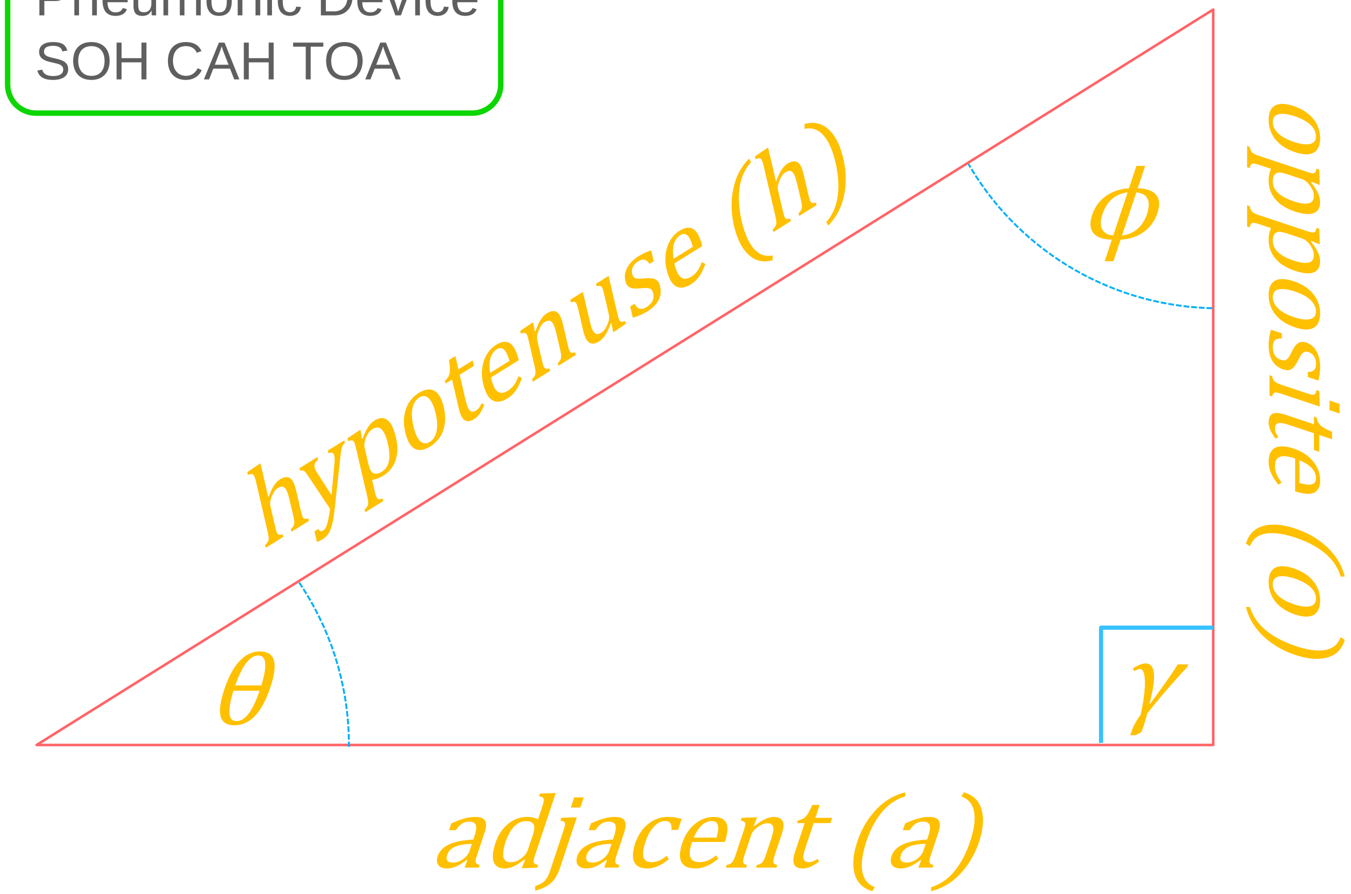
Triangle Trigonometry

$$\cos(\theta) = \frac{a}{h}$$

Pneumonic Device
SOH CAH TOA

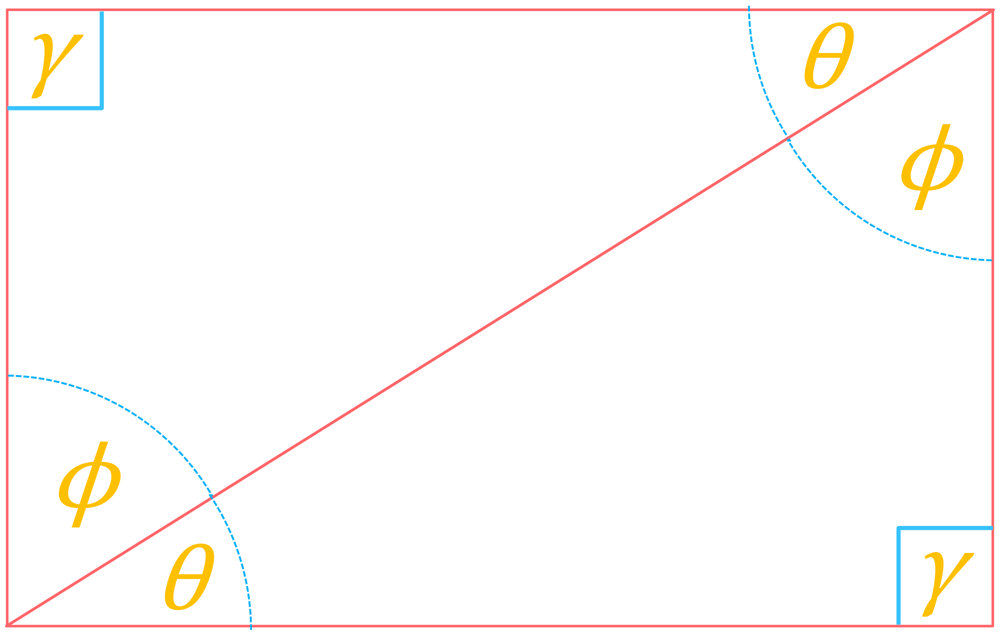
$$h = \sqrt{a^2 + o^2}$$

$$180 = \theta + \phi + \gamma$$



Parallel Angles

When one angle is known to be 90°, the other angles must sum together to equal 90°



Example #2 Angled Point Source

- Given a light source with a center beam candela of 3,200 cd pointed at a display above a display 8 feet below and 6 feet to the right, what is the horizontal illuminance?

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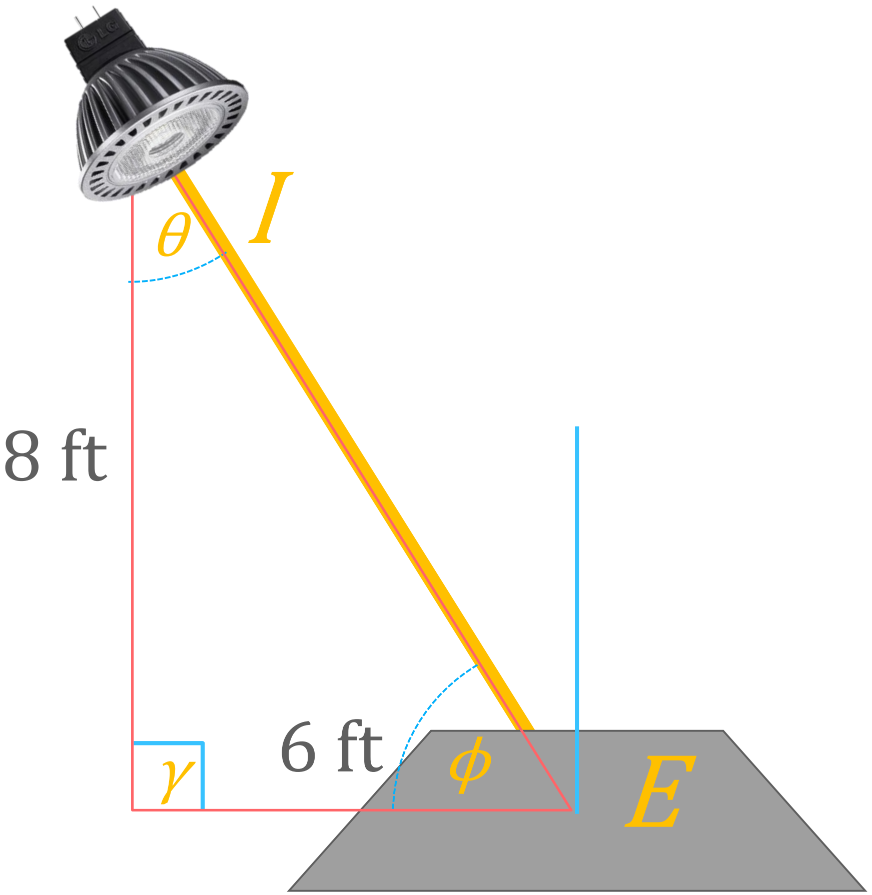

$$\cos(\theta) = \frac{a}{h}$$

$$= \frac{8}{\sqrt{8^2 + 6^2}}$$

$$= \frac{8}{10}$$

$$= \underline{0.8}$$

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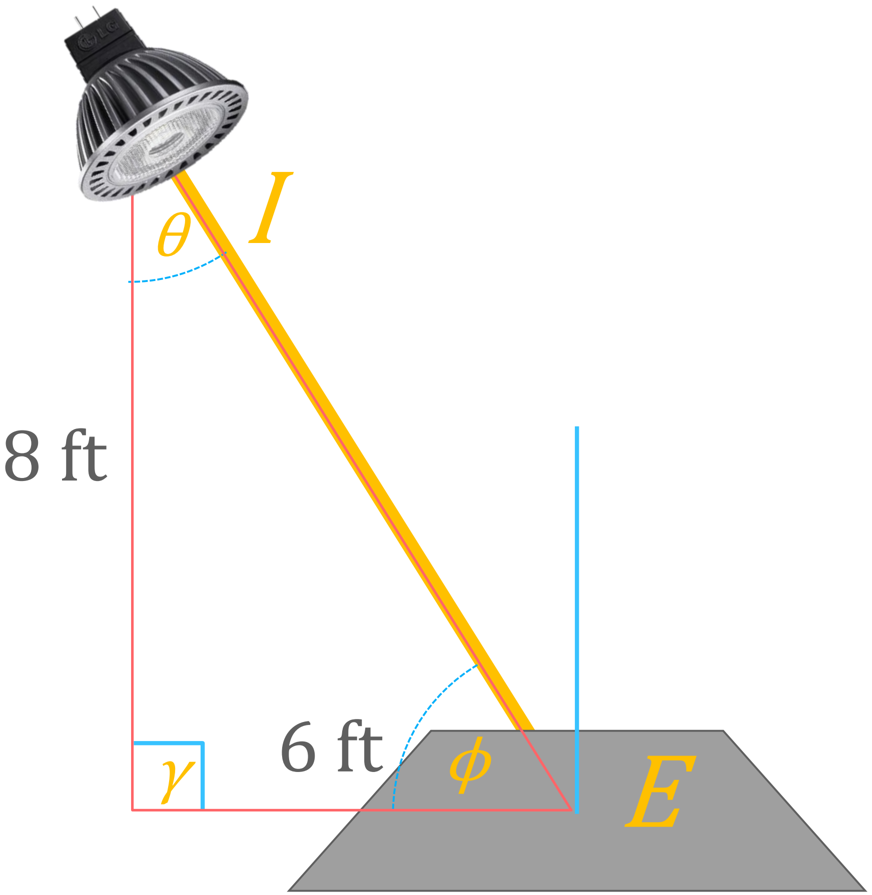

$$E = \frac{I}{r^2}\cos(\theta)$$

$$E = \frac{3{,}200}{10^2}(0.8) = 32(0.8)$$

$$E = \boxed{25.6 \text{ fc}}$$

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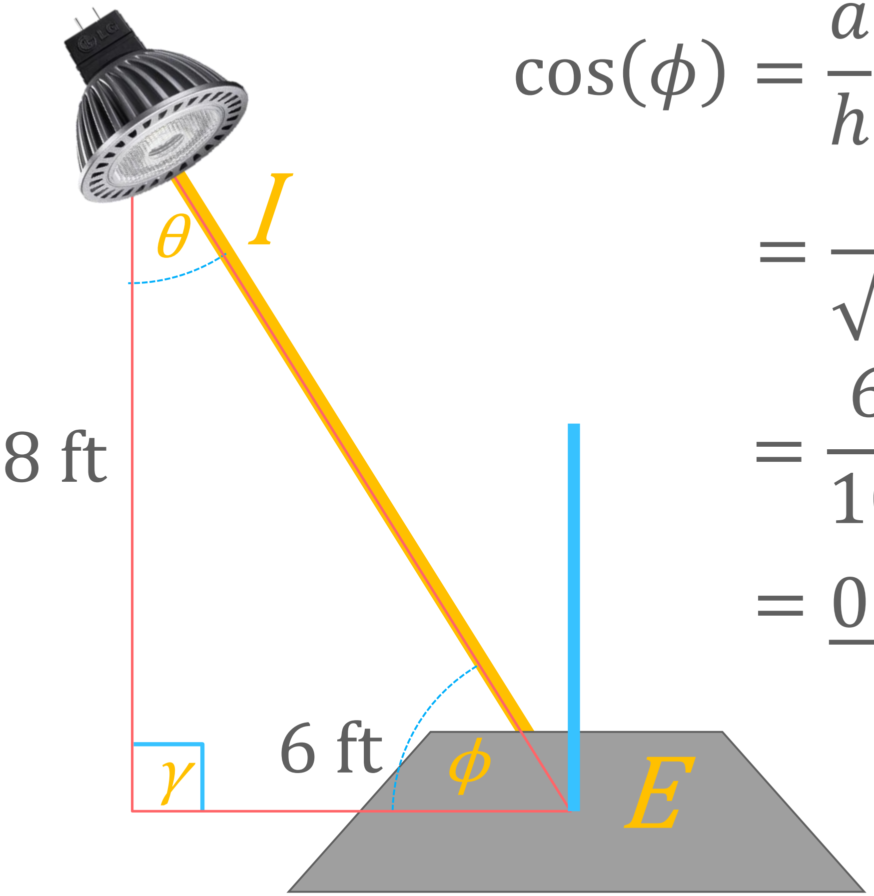


$$\cos(\phi) = \frac{a}{h}$$

$$= \frac{6}{\sqrt{8^2 + 6^2}}$$

$$= \frac{6}{10}$$

$$= \underline{0.6}$$

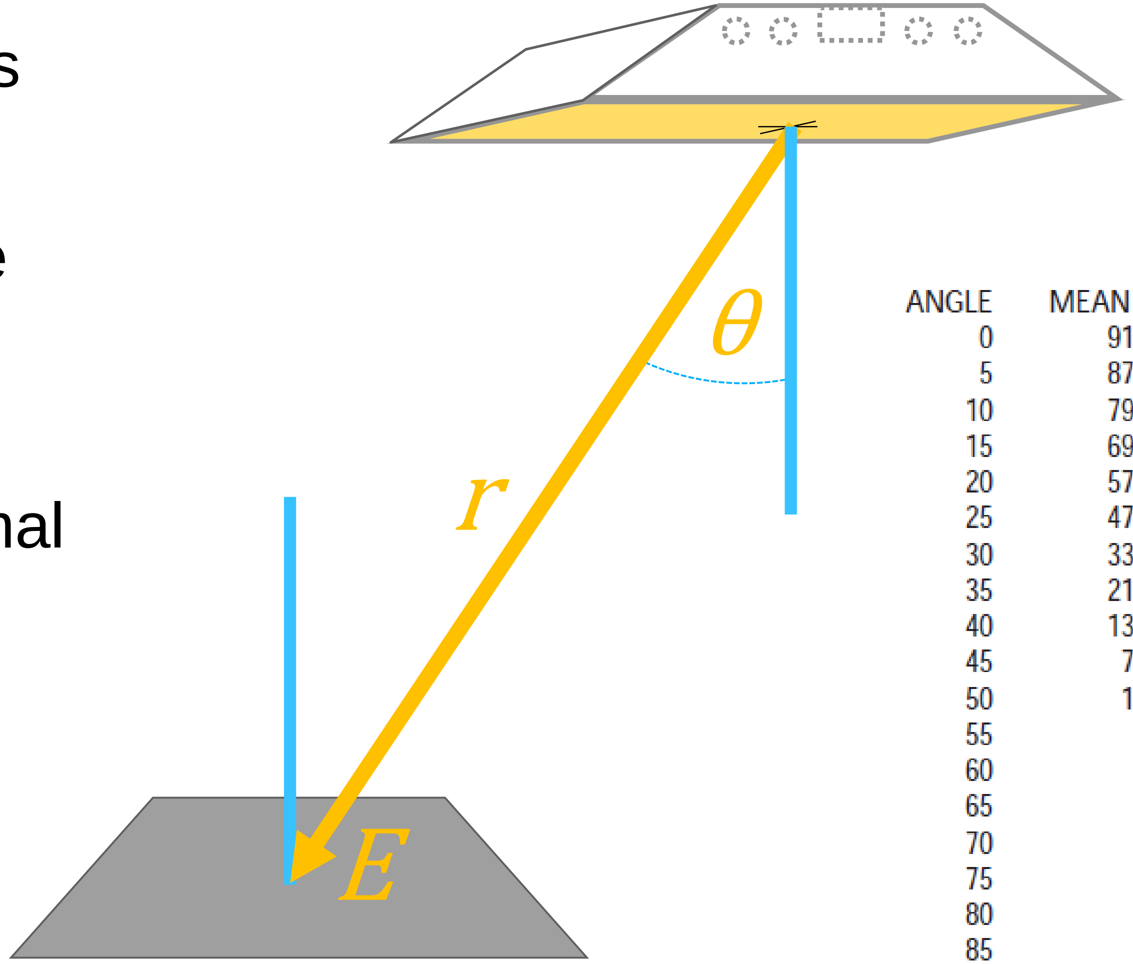
$$E = \frac{I}{r^2}\cos(\theta)$$

$$E = \frac{3{,}200}{10^2}(0.6) = 32(0.6)$$

$$E = \boxed{19.2\ \text{fc}}$$

Offset Illuminance at the a Point

- Given a light source oriented near an object, but offset from the beam, what is the illuminance?
- Requires more information than just the light source center-beam candela
- Once we have the intensity in the specified direction, we proceed as normal



ANGLE	MEAN CP
0	9142
5	8732
10	7907
15	6927
20	5787
25	4726
30	3385
35	2193
40	1397
45	758
50	152
55	24
60	9
65	1
70	0
75	0
80	0
85	0
90	0

Example #3

Solve for the distance

$$r = \sqrt{horiz.^2 + vert.^2}$$

$$r = \sqrt{4^2 + 8^2} = 8.9$$

Solve for the missing angle

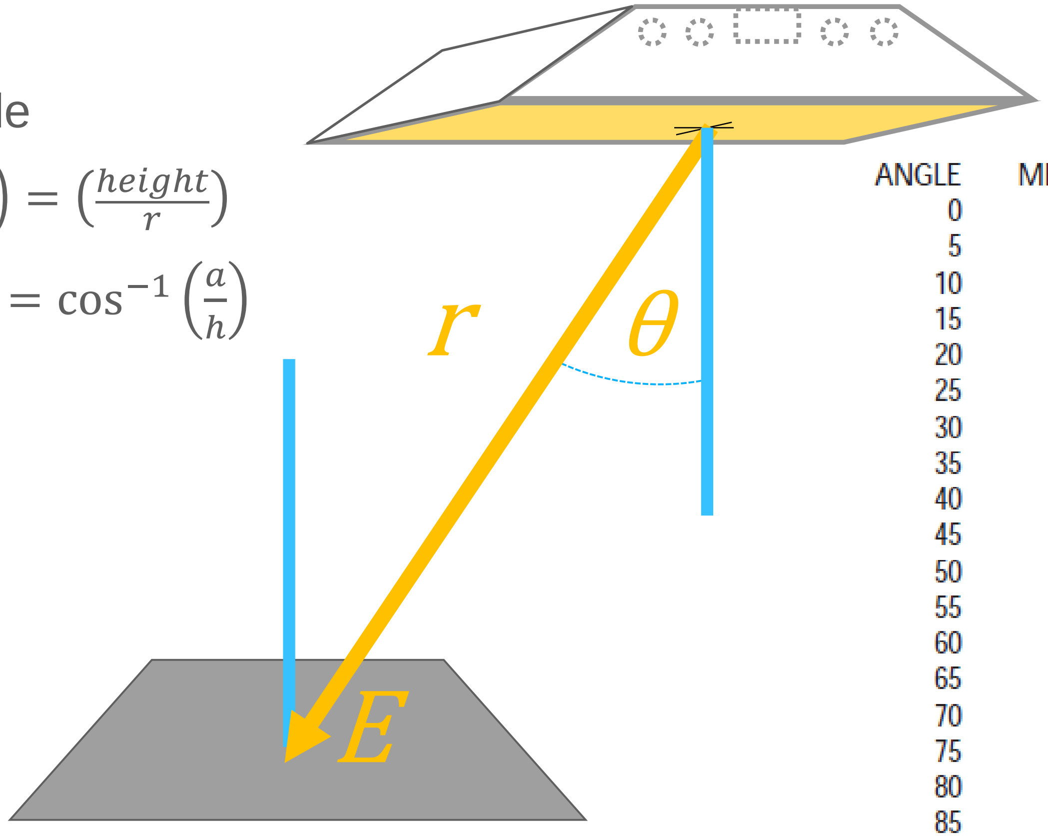
$$\cos\theta = \left(\frac{adjacent}{hypotonuse}\right) = \left(\frac{height}{r}\right)$$

$$\theta = \arccos\left(\frac{a}{h}\right) \text{ or } \theta = \cos^{-1}\left(\frac{a}{h}\right)$$

$$\theta = \cos^{-1}\left(\frac{8}{8.9}\right)$$

$$\theta = \cos^{-1}(0.89)$$

$$\theta = \underline{26}$$



ANGLE	MEAN CP
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15	6927
20	5787
25	4726
30	3385
35	2193
40	1397
45	758
50	152
55	24
60	9
65	1
70	0
75	0
80	0
85	0
90	0

Example #3

- Given a two by four troffer, what is the illuminance at a point 8 feet below and 4 feet to the left

$$\theta = 26.6$$

It's time to interpolate

$$\frac{\text{Bigger } I - \text{Smaller } I}{\text{Bigger } \theta - \text{Smaller } \theta} = \frac{\text{Bigger } I - \text{Target } I}{\text{Bigger } \theta - \text{Target } \theta}$$

$$\frac{3385 - 4726}{30 - 25} = \frac{3385 - I}{30 - 26}$$

Solve for I

$$I = 3385 - \left(\frac{3385 - 4726}{30 - 25}\right)(30 - 26)$$

$$I = 3385 - (-268.2)(30 - 26)$$

$$I = 3385 - (-1073) = \underline{4458 \text{ cd}}$$

ANGLE	MEAN CP
0	9142
5	8732
10	7907
15	6927
20	5787
25	4726
30	3385
35	2193
40	1397
45	758
50	152
55	24
60	9
65	1
70	0
75	0
80	0
85	0
90	0

I

Example #3

- Given a two by four troffer, what is the illuminance at a point 8 feet below and 4 feet to the left

$$\theta = 26.6 \qquad I = 4{,}458\ \text{cd} \qquad r = 8.94\ \text{ft}$$

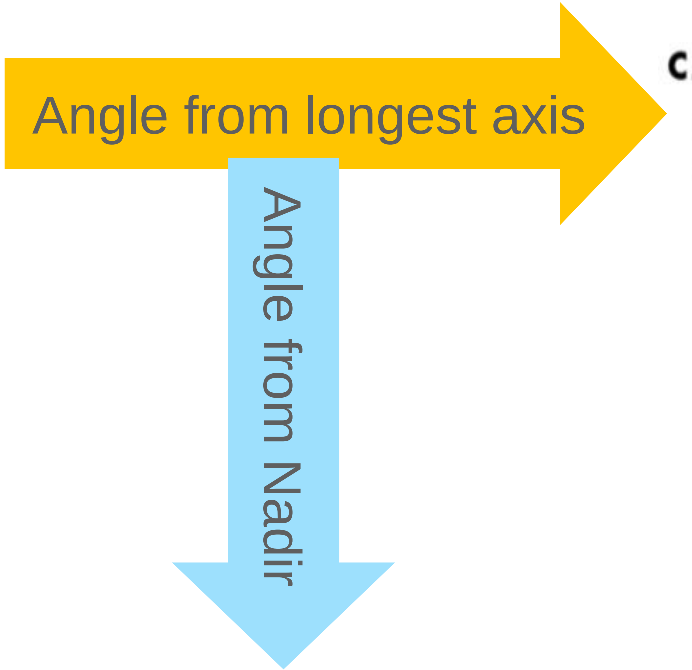
$$E = \frac{I}{r^2}\cos(\theta)$$

$$E = \frac{4{,}458\ \text{cd}}{(8.9\ \text{ft})^2}\cos(26) = (56\ \text{fc})(0.90)$$

$$E = 51\ \text{fc}$$

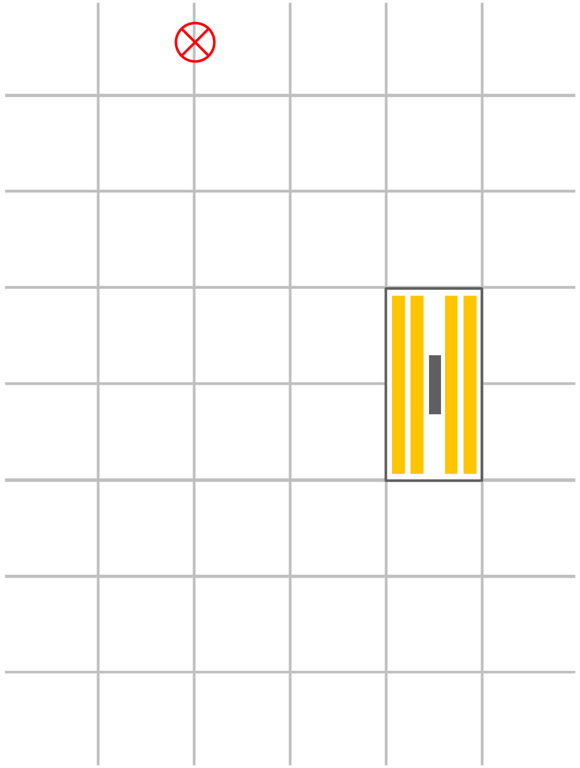
Compound Angles

- Previous example had the measurement point aligned with the light fixture
  - What about a measurement point offset from the axis of symmetry?
- We'd need even more information



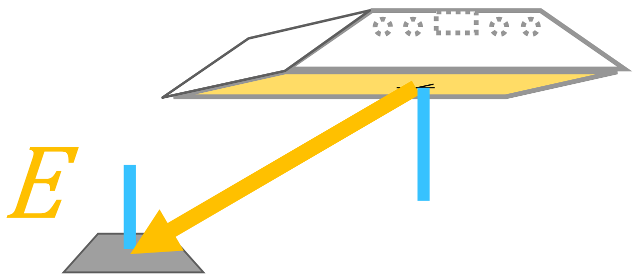
CANDLEPOWER DISTRIBUTION

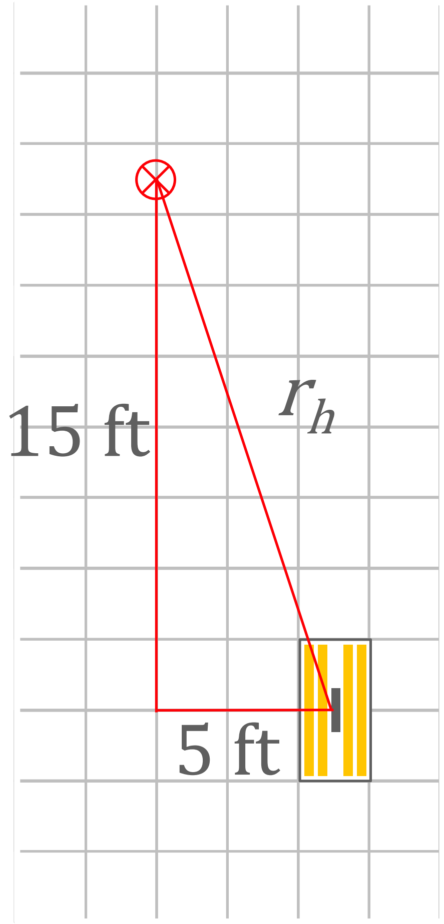
VERT.	HORIZONTAL ANGLE		
ANG.	0	45	90
0	2793.	2793.	2793.
5	2773.	2792.	2806.
15	2710.	2730.	2922.
25	2482.	2705.	2889.
35	2113.	2448.	3077.
45	1855.	2446.	1846.
55	1299.	1025.	681.
65	412.	277.	189.
75	49.	44.	42.
85	12.	15.	12.
90	0.	0.	0.



Example #4

- Given a two-by-four troffer positioned 5 feet to the east and 15 feet to the south of our work surface. If the work surface is 12 feet below the luminaire plane, what is the horizontal illuminance





- Let's first solve for *r*.

$$r_h = \sqrt{(5\text{ ft})^2 + (15\text{ ft})^2} = 16\text{ ft}$$

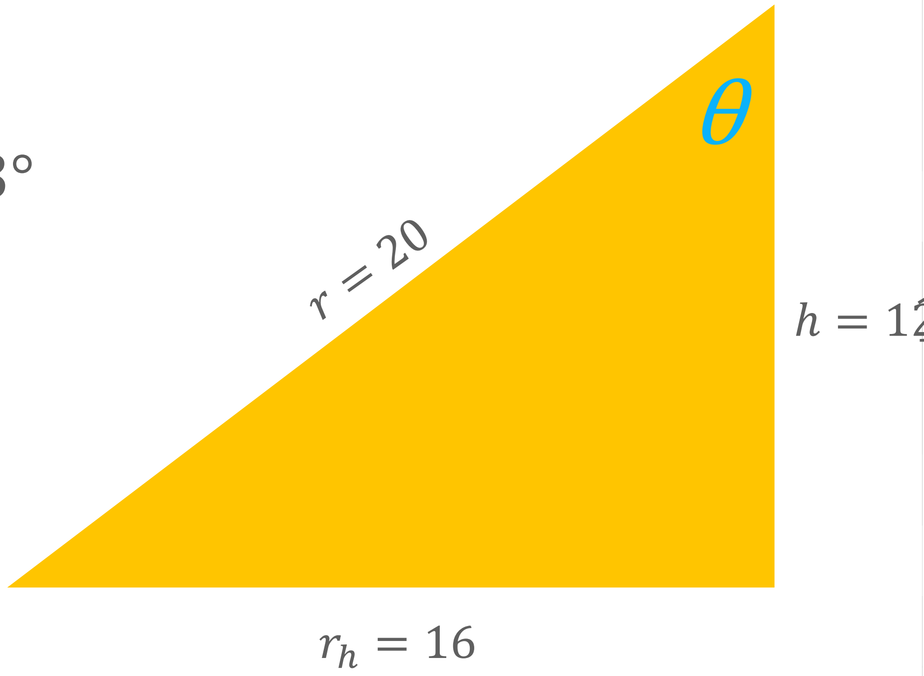
$$r = \sqrt{(12\text{ ft})^2 + (16\text{ ft})^2} = 20\text{ ft}$$

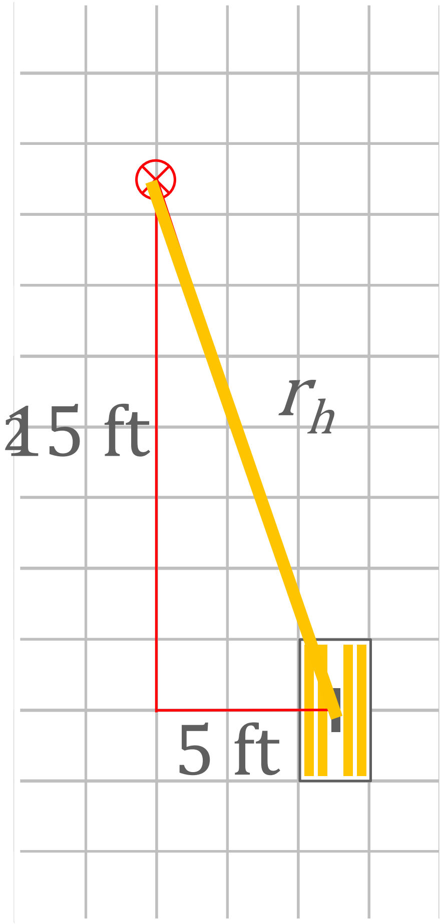
Example #4

$r = 19.8$

- Now let's solve our angle from nadir

$$\theta_{\text{nadir}} = cos^{-1}\left(\frac{12}{20}\right) = 53°$$





Example #4

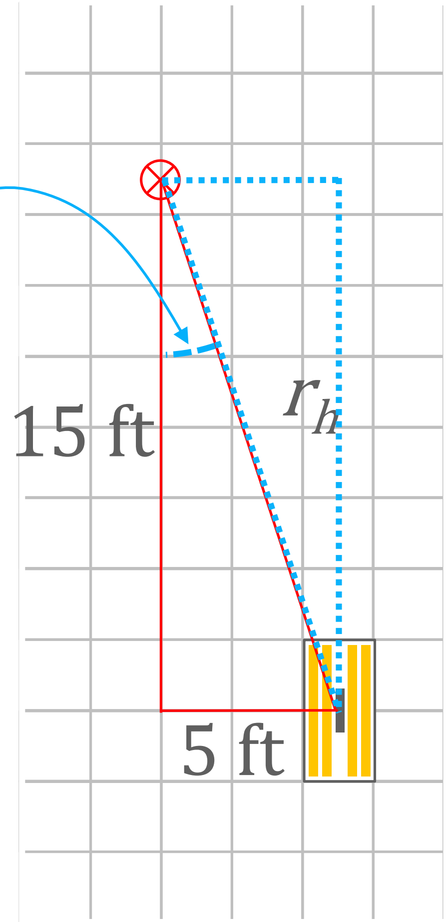
- Now let's solve our rotated angle for the long axis

$$\theta_{\text{rotation}} = cos^{-1}\left(\frac{15}{16}\right) = 20°$$

- We now have enough data to look-up the intensity from our candela table

CANDLEPOWER DISTRIBUTION

VERT. ANG.	HORIZONTAL ANGLE 0	45	90
0	2793.	2793.	2793.
5	2773.	2792.	2806.
15	2710.	2730.	2922.
25	2482.	2705.	2889.
35	2113.	2448.	3077.
45	1855.	2446.	1846.
55	1299.	1025.	681.
65	412.	277.	189.
75	49.	44.	42.
85	12.	15.	12.
90	0.	0.	0.



Example #4

$r = 20 \qquad \theta_{\text{nadir}} = 53° \qquad \theta_{\text{rotation}} = 20$

- Solve for the angle from nadir

$$I_{0°} = 1299\text{ cd} - \left(\frac{1299\text{ cd} - 1855\text{ cd}}{55 - 45}\right)(55 - 53) = \boxed{1410\text{ cd}}$$

$$I_{45°} = 1025\text{ cd} - \left(\frac{1025\text{ cd} - 2446\text{ cd}}{55 - 45}\right)(55 - 53) = \boxed{1309\text{ cd}}$$

- Now solve for the rotation angle

$$I = 1410 - \left(\frac{1410 - 1309}{45 - 0}\right)(45 - 20) = \boxed{1354\text{ cd}}$$

Example #4

$r = 19.8 \quad \theta_{\text{nadir}} = 52.7° \quad \theta_{\text{rotation}} = 18.3° \quad I = 1354$

- Solve for the Illuminance

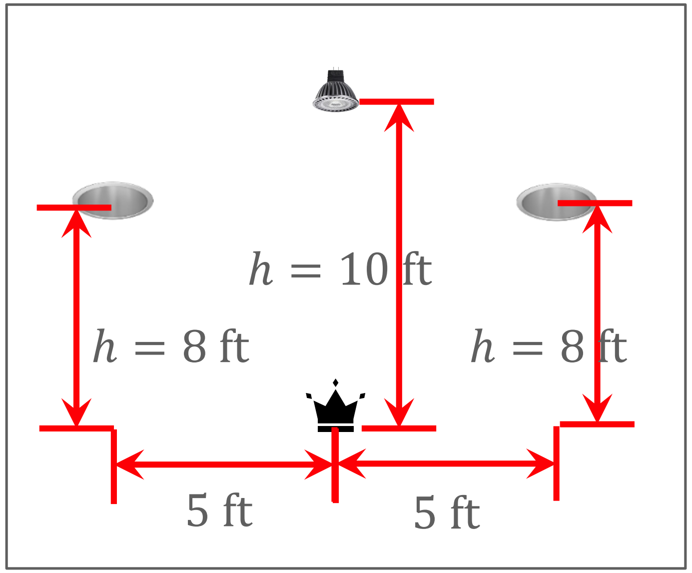
$$E = \frac{I}{r^2}\cos(\theta)$$

$$E = \frac{1354}{20^2}\cos(53)$$

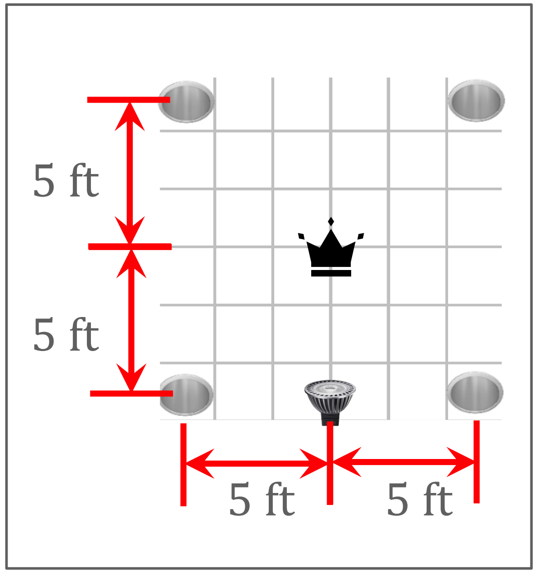
$$E = 2.0 \text{ fc}$$

Example #5
One Last Example for Your Own

- You are lighting a museum exhibit featuring a crown on a pedestal. There is one narrow spot lamp (4,000 cd) pointed directly at the pedestal and 4 general downlights identically spaced around the pedestal. Calculate the horizontal illuminance on the pedestal.



Elevation View



Plan View

CANDELA TABLE - TYPE C									
	0	22.5	45	67.5	90	112.5	135	157.5	180
0	2245	2245	2245	2245	2245	2245	2245	2245	2245
5	2358	2350	2330	2317	2335	2348	2343	2337	2352
10	2544	2486	2412	2398	2444	2506	2498	2450	2465
15	2635	2535	2398	2406	2467	2606	2606	2487	2513
20	2537	2407	2250	2325	2351	2581	2581	2371	2455
25	2244	2112	1966	2052	2102	2361	2353	2106	2205
30	1767	1698	1634	1687	1756	1916	1913	1785	1789
35	1348	1322	1310	1360	1363	1457	1463	1396	1439
40	901	921	946	975	991	996	1027	1038	1037
45	534	541	554	576	605	597	612	635	603
50	310	272	253	270	297	348	335	296	292
55	90	83	72	73	89	103	105	93	76
60	18	17	15	17	19	24	25	22	19
65	7	7	7	5	7	7	7	7	6
70	3	3	3	3	3	4	3	3	5
75	3	2	2	2	2	2	2	2	2
80	1	0	0	1	1	1	1	1	1
85	1	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0

Downlight Data

Example #5 Solution

- Solve one lighting system, then the other
- Spot light
  - First find the distance

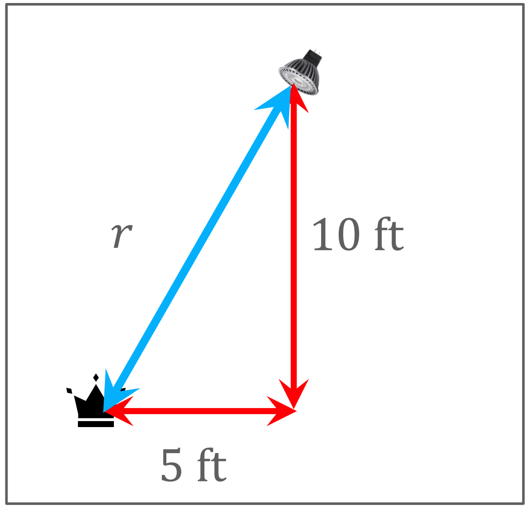
$$r = \sqrt{10^2 + 5^2} = \sqrt{125} = 11.2 \text{ ft}$$

  - Find the angle from nadir or use the radio of sides

$$\theta_{\text{nadir}} = \cos^{-1}\left(\frac{10}{11.2}\right) = 26.8°$$

  - Inverse Square Law

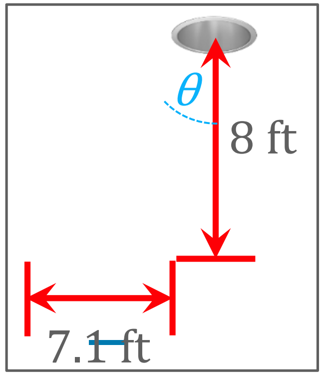
$$E = \frac{4000 \text{ cd}}{(11.2 \text{ ft})^2}\cos(26.8) = \frac{4000 \text{ cd}}{(11.2 \text{ ft})^2}\left(\frac{10}{11.2}\right) = 28.5 \text{ fc}$$



Elevation View

Example #5
Solution - Downlights

- Symmetrical, do once, multiply by 4
  - Angles for angles for nadir and rotation are



$$\theta_{\text{nadir}} = \cos^{-1}\left(\frac{8}{\sqrt{8^2 + 7.1^2}}\right) = 41.6°$$

$$\theta_{\text{rotation}} = \cos^{-1}\left(\frac{5}{7.07}\right) = 45°$$

ROTATION

NADIR

CANDELA TABLE - TYPE C

	0	22.5	45	67.5	90	112.5	135	157.5	180
0	2245	2245	2245	2245	2245	2245	2245	2245	2245
5	2358	2350	2330	2317	2335	2348	2343	2337	2352
10	2544	2486	2412	2398	2444	2506	2498	2450	2465
15	2635	2535	2398	2406	2467	2606	2606	2487	2513
20	2537	2407	2250	2325	2351	2581	2581	2371	2455
25	2244	2112	1966	2052	2102	2361	2353	2106	2205
30	1767	1698	1634	1687	1756	1916	1913	1785	1789
35	1348	1322	1310	1360	1363	1457	1463	1396	1439
40	901	921	946	975	991	996	1027	1038	1037
45	534	541	554	576	605	597	612	635	603
50	310	272	253	270	297	348	335	296	292
55	90	83	72	73	89	103	105	93	76
60	18	17	15	17	19	24	25	22	19
65	7	7	7	5	7	7	7	7	6
70	3	3	3	3	3	4	3	3	5
75	3	2	2	2	2	2	2	2	2
80	1	0	0	1	1	1	1	1	1
85	1	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0

Interpolate Intensity from Table

$$I = 554 - \left(\frac{554 - 946}{45 - 40}\right)(45 - 41.6) = 820 \text{ cd}$$

  - Inverse Square Law!

$$E = \frac{820 \text{ cd}}{(10.7 \text{ ft})^2}\cos(41.6) = 5.4 \text{ fc}$$

Example #5
Drum roll please…

- Add it all together

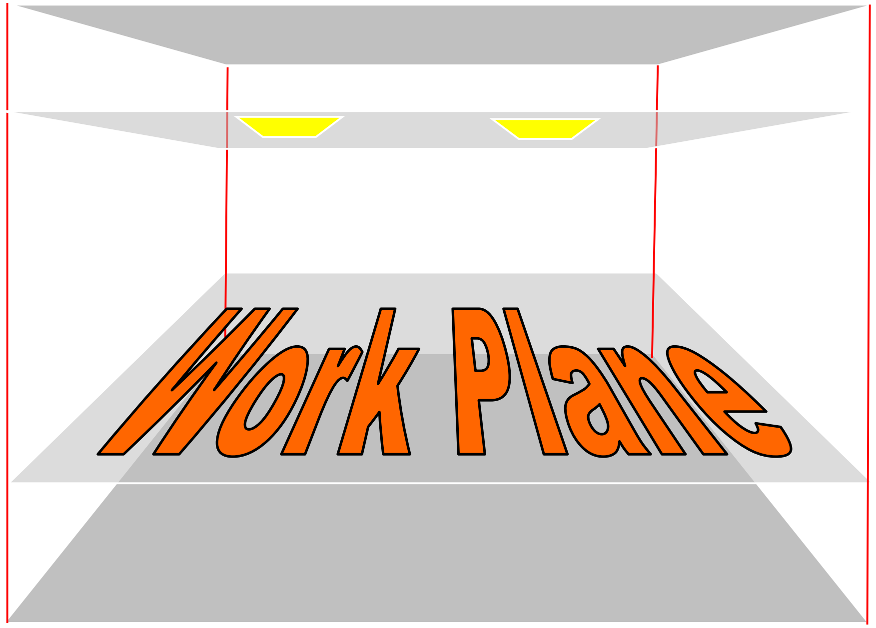
$$E = E_{\text{spot}} + E_{\text{downlights}}$$

$$E = 28.5\ \text{fc} + (5.4\ \text{fc})4 = 50.1\ \text{fc}$$

LUMEN METHOD CALCULATIONS

Lumen Method

- Useful for determining either:
  - Number of luminaires to meet an **average** illuminance target
  - **Average** illuminance given a number of luminaires
- Calculations focused on illuminance on work plane
  - Work plane height above the floor usually defined in IES handbook or Recommend Practice documents



Lumen Method

- Light reaches the work plane in one of two ways:
  - Direct light
  - Reflected light
- Lumen method considers direct and reflected light from luminaires only
- Based on the following relationship:

Measured in Lumens

Measured in Footcandles or Lux

$$Illuminance\ (E) = \frac{Luminous\ Flux\ (\Phi)}{Area\ (A)}$$

Measured in ft² or m²

Lumen Method

Should match recommended practices

From luminaire, & surfaces

$$Illuminance\ (E) = \frac{Luminous\ Flux\ (\Phi)}{Area\ (A)}$$

From space or architectural plans

- Area (A) must be known
- Luminous flux (Φ) on the workplane or lumens depends on luminaire, surface reflectances, space size.
- This requires some more complexity in our basic calculation

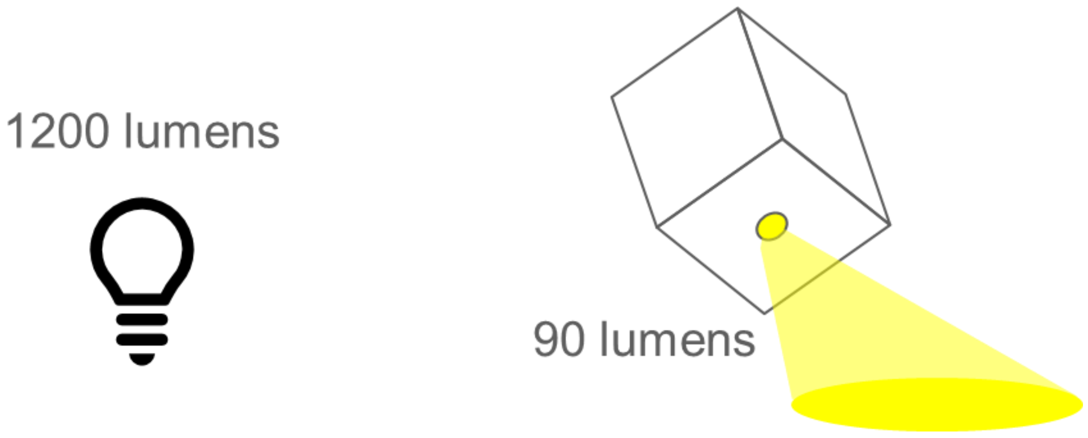
Total Luminous Flux

- Total Luminous Flux has three components
  - Total lamp lumens inside the luminaire
  - Quantity of luminaires in the space
  - Coefficient of utilization (CU)
    - Measures light lost inside luminaires or reflecting onto other surfaces beside the work plane.

$$Illuminance\ (E) = \frac{\binom{Luminaire}{Lumens}\binom{\text{Luminaire}}{\text{Quantity}}CU}{Area\ (A)}$$

Total Luminous Flux

- Total Luminous Flux has two components
  - Total Lamp Lumens Inside Luminaire
  - Coefficient of Utilization
    - Measures light lost
      - Inside luminaires (luminaire efficiency)
      - Reflecting onto other surfaces beside the work plane.



Coefficient of Utilization

- Unique for each luminaire type
  - Provided by manufacturers on product specification sheets
  - Shown as decimals or as percentages (91)
  - Can be greater than 100
    - reflected light near-by surfaces, but from the same light source

Coefficients of Utilization
EFFECTIVE FLOOR CAVITY REFLECTANCE 20 PER (pfc=0.20)

pcc	80			70			50	
pw	70	50	30	70	50	30	50	30
RCR								
0	118	118	118	115	115	115	111	111
1	108	103	97	105	101	95	95	93
2	97	89	81	94	86	81	83	78
3	89	78	69	86	77	68	73	67
4	81	68	59	79	68	59	65	57
5	75	61	53	72	60	52	58	51
6	68	56	46	67	55	46	53	45
7	64	51	41	63	50	40	47	40
8	59	46	38	57	46	36	44	36
9	56	42	34	55	41	34	40	33
10	53	39	30	51	39	30	38	30

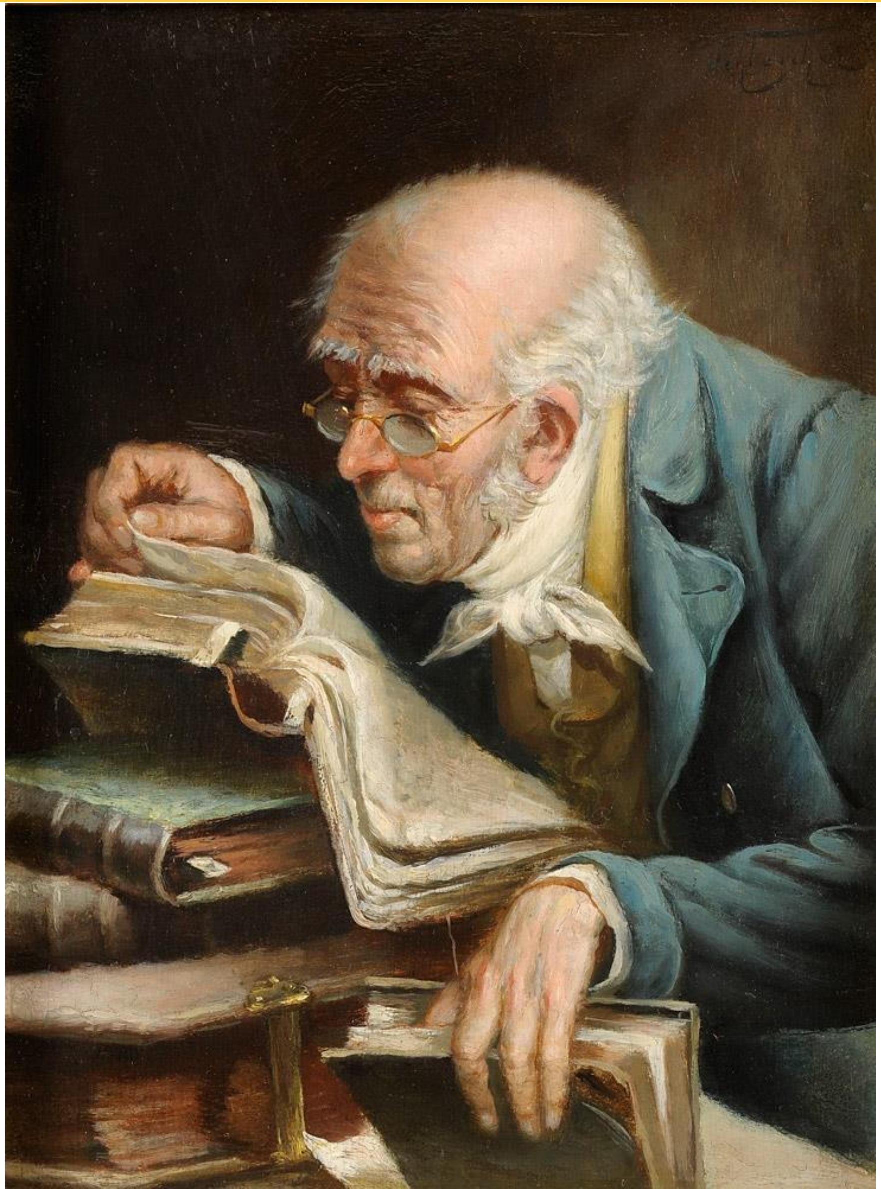
Coefficient of Utilization

Ceiling	80%			70%			50%		
Wall	70%	50%	30%	70%	50%	30%	50%	30%	10%
1	73	70	68	71	69	67	66	64	63
2	67	62	58	65	61	57	59	56	53
3	62	55	50	60	54	50	52	49	45
4	57	49	44	55	48	43	47	43	39
5	52	44	39	51	44	38	42	38	34
6	48	40	34	47	39	34	38	33	30
7	45	36	31	44	36	30	35	30	27
8	42	33	28	41	33	28	32	27	24
9	39	30	25	38	30	25	29	25	21
10	37	28	23	36	28	23	27	23	19

Coefficient Tables courtesy Philips Lighting and Lithonia Lighting

Reading a CU Table

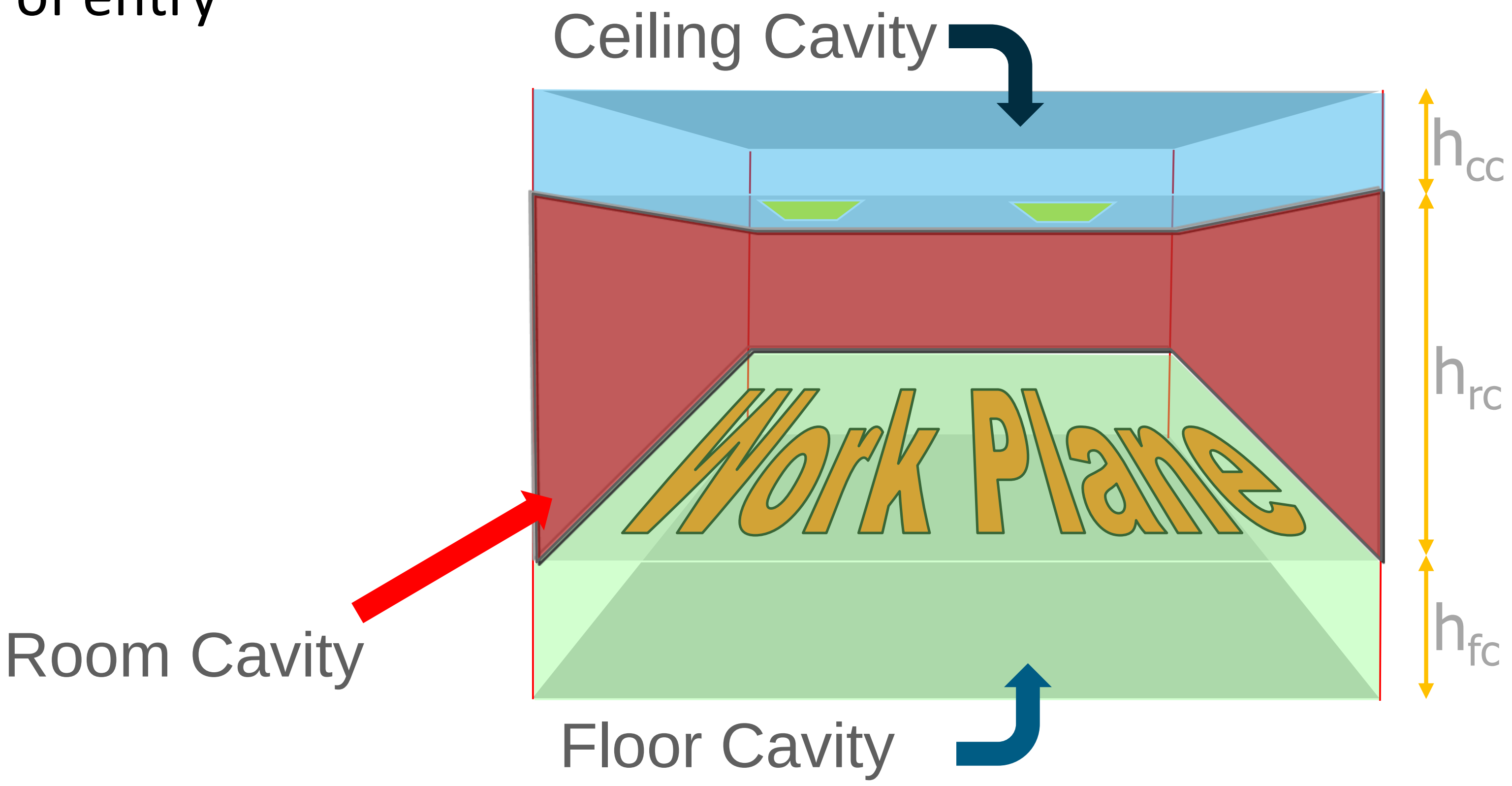
- To use a CU table, we must have a few variables determined:
  - Room Cavity Ratio
  - Surface Reflectances (ρ) for:
    - Ceiling cavity
    - Room cavity
    - Floor cavity



Carl Schleicher, *Der Bücherwurm*

Surface Reflectances and Cavities

- Surface reflectances: ratio of light reflected off a surface
- Cavity reflectance: ratio of light reflected off the surfaces in a cavity back through the plane of entry



Cavity Ratio

- A geometric relationship of the space
  - Long and narrow
  - Short and square
  - Wide and high
- Room cavity ratio used for illuminance calculations
- Ceiling & Floor cavity ratio used for “effective reflectance” calculations

Cavity Ratio Calculation

$$Cavity\ Ratio = \frac{2.5\ h\ P}{A}$$

Where

h: cavity height

P: cavity perimeter

A: cavity area

- Cavity height depends on the cavity measured

$$Room\ Cavity\ Height = h_{\text{luminaire}} - h_{\text{workplane}}$$

$$Floor\ Cavity\ Height = h_{\text{workplane}} - h_{\text{floor}}$$

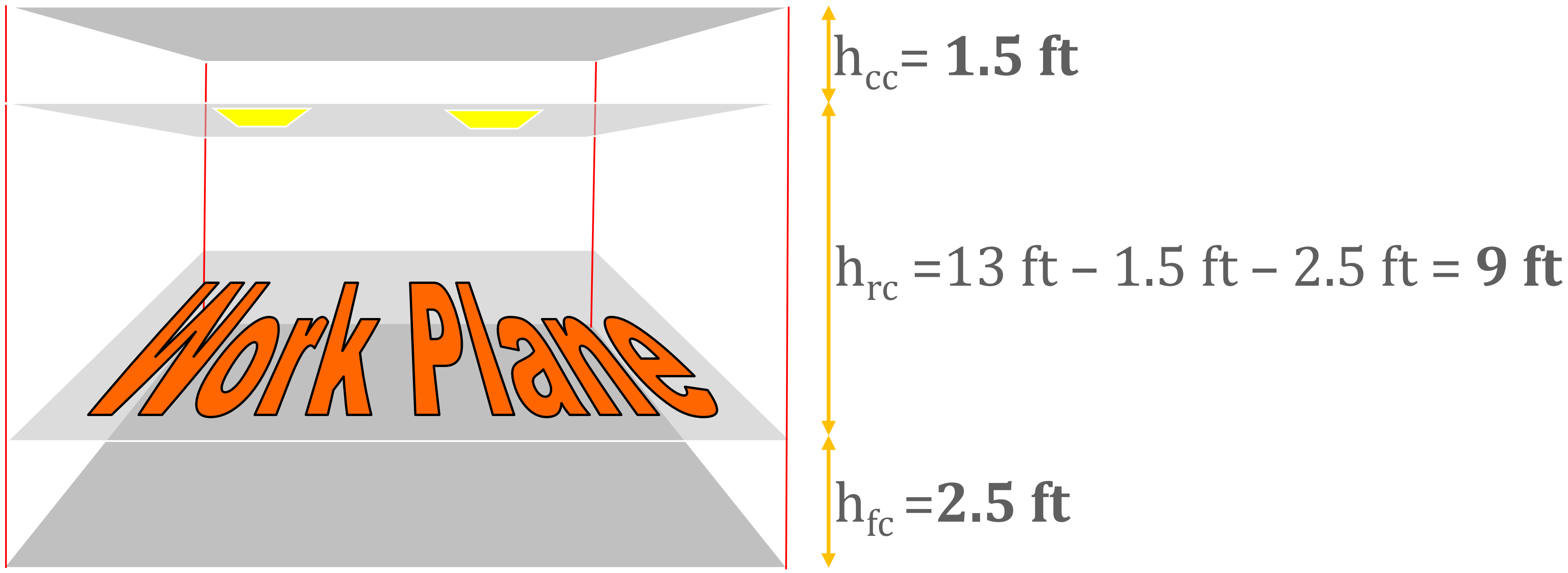
$$Ceiling\ Cavity\ Height = h_{\text{ceiling}} - h_{\text{luminaire}}$$

Example #6
Cavity Ratio Example

An open office area 48 feet wide and 24 feet long has 13-foot tall ceilings. The lighting designer picked out three 20-foot long direct indirect pendants with an 18-inch aircraft cable support. The desks in the office are 30 inches high. Calculate the room cavity ratio.

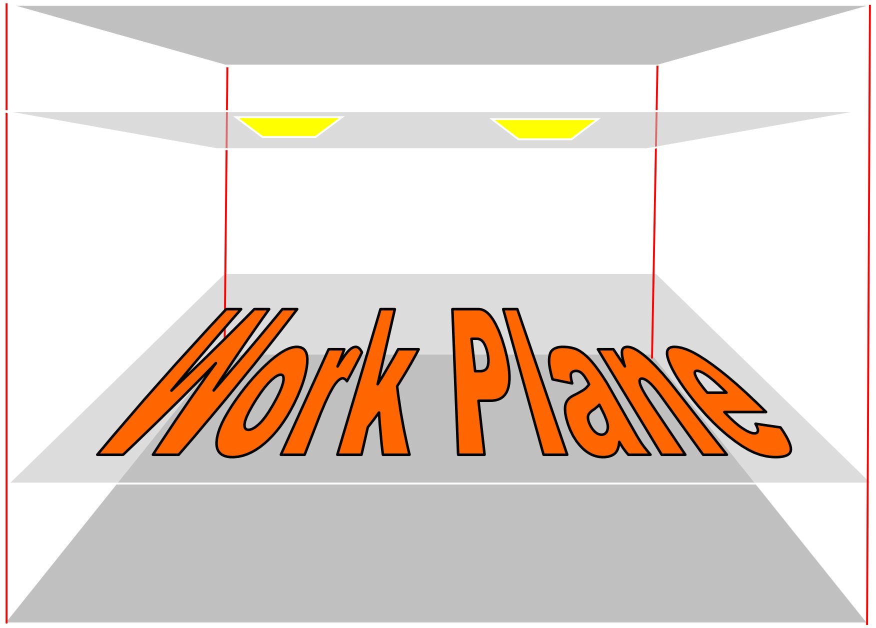
Example #6
Cavity Ratio Example

An open office area 48 feet wide and 24 feet long has 13-foot tall ceilings. The lighting designer picked out three 20-foot long direct indirect pendants with an 18-inch aircraft cable support. The desks in the office are 30 inches high. Calculate the room cavity ratio.



Example #6
Cavity Ratio Example

An open office area 48 feet wide and 24 feet long has 13-foot tall ceilings. The lighting designer picked out three 20-foot long direct indirect pendants with an 18-inch aircraft cable support. The desks in the office are 30 inches high. Calculate the room cavity ratio.

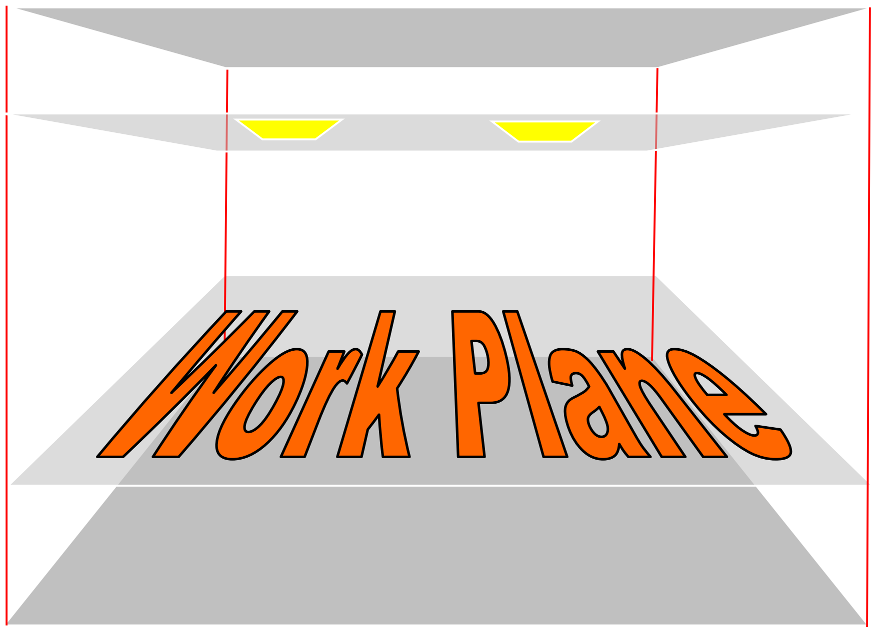


$$Area = 48\ \text{ft} \times 24\ \text{ft} = \underline{1{,}152\ \text{ft}^2}$$

$$Perimeter = (48\ \text{ft} \times 2) + (24\ \text{ft} \times 2) = \underline{144\ \text{ft}}$$

Example #6
Cavity Ratio Example

An open office area 48 feet wide and 24 feet long has 13-foot tall ceilings. The lighting designer picked out three 20-foot long direct indirect pendants with an 18-inch aircraft cable support. The desks in the office are 30 inches high. Calculate the room cavity ratio.



$$Cavity\ Ratio = \frac{2.5\,h\,P}{A}$$

$$= \frac{(2.5)\,(9\text{ft})\,(144\text{ft})}{(1{,}152\ \text{ft}^2)}$$

$$= \frac{(3{,}240\text{ft}^2)}{(1{,}152\ \text{ft}^2)}$$

$$= \boxed{2.81}$$

Why Not Just Use Floor Surface Reflectance?

We mentioned floor & ceiling cavity effective reflectance…

$\rho_{rc,w}$=50%

$\rho_{fc,w}$=80%

$\rho_{fc,w}$=20%

Image courtesy Angie's List

Why Not Just Use Ceiling Surface Reflectance?

$\rho_{cc,c}=80\%$

$\rho_{cc,w}=50\%$

Image courtesy Angie's List

Surface Reflectance Readings

- Identify an unobstructed surface
  - As least 1-foot by 1-foot square
- Place your illuminance meter on the surface, pointing in, toward the space
  - Record your reading
- Hold your illuminance meter 1 foot away from the surface, pointed toward the surface
  - Record your reading

$$Reflectance = \frac{\text{To Wall Reading}}{\text{To Space Reading}}$$

Effective Cavity Reflectance

- Considers the walls and "base" reflectance in each cavity.
  - We'll use a table for simplicity.
    - Base: floor or ceiling surface
    - Wall: walls above luminaire plane (ceiling) or below workplane (floor)
  - Result is "effective" reflectance of the cavity

Base Reflectance	90										80									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0	90	80	70	60	50	40	30	20	10	[illegible]
Cavity Ratio																				
0.2	89	88	88	87	86	85	85	84	84	82	79	78	78	77	77	76	76	75	74	[illegible]
0.4	88	87	86	85	84	83	81	80	79	76	79	77	76	75	74	73	72	71	70	[illegible]
0.6	87	86	84	82	80	79	77	76	74	73	78	76	75	73	71	70	68	66	65	[illegible]
0.8	87	85	82	80	77	75	73	71	69	67	78	75	73	71	69	67	65	63	61	[illegible]
1	86	83	80	77	75	72	69	66	64	62	77	74	72	69	67	65	62	60	57	[illegible]
1.2	85	82	78	75	72	69	66	63	60	57	76	73	70	67	64	61	58	55	53	[illegible]
1.4	85	80	77	73	69	65	62	59	57	52	76	72	68	65	62	59	55	53	50	[illegible]
1.6	84	79	75	71	67	63	59	56	53	50	75	71	67	63	60	57	53	50	47	[illegible]
1.8	83	78	73	69	64	60	56	53	50	48	75	70	66	62	58	54	50	47	44	[illegible]
2	83	77	72	67	62	56	53	50	47	43	74	69	64	60	56	52	48	45	41	[illegible]
2.2	82	76	70	65	59	54	50	47	44	40	74	68	63	58	54	49	45	42	38	[illegible]
2.4	82	75	69	64	58	53	48	45	41	37	73	67	61	56	52	47	43	40	36	[illegible]
2.6	81	74	67	62	56	51	46	42	38	35	73	66	60	55	50	45	41	38	34	[illegible]
2.8	81	73	66	60	54	49	44	40	36	34	73	65	59	53	48	43	39	36	32	[illegible]
3	80	72	64	58	52	47	42	38	34	30	72	65	58	52	47	42	37	34	30	[illegible]

Example #7a
More Cavity Ratios

- Recall our open office:

  A open office area 48 feet wide and 24 feet long has 12 foot tall ceilings. The lighting designer picked out three 20-foot long direct indirect pendants with a 18-inch aircraft cable support. The desks in the office are 30 feet high.

- If the flooring is dark grey carpet ($\rho_{\text{fc,b}} = 20\%$) and the walls are a textured off-white($\rho_{\text{fc,w}} = 50\%$), what is the effective floor reflectance?

Example #7a
More Cavity Ratios

- What is the floor-cavity ratio?

$$Cavity\ Ratio = \frac{2.5\ h\ P}{A}$$

$$= \frac{(2.5)\ (2.5\text{ft})\ (144\text{ft})}{(1{,}152\ \text{ft}^2)} = \frac{(900\ \text{ft}^2)}{(1{,}152\ \text{ft}^2)} = \boxed{0.78}$$

- The wall & base reflectance are known, so look-up the effective reflectance:

$$\rho_{\text{fc,b}} = 20\%$$

$$\rho_{\text{fc,w}} = 50\%$$

Example #5a
More Cavity Ratios

Base Reflectance	40										30										20									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0	90	80	70	60	50	40	30	20	10	0	90	80	70	60	50	40	30	20	10	0
Cavity Ratio																														
0.2	40	40	39	39	39	38	38	37	36	36	31	31	30	30	29	29	29	28	28	27	21	20	20	20	20	20	19	19	19	17
0.4	41	40	39	39	38	37	36	35	34	34	31	31	30	30	29	28	28	27	26	25	22	21	20	20	20	19	19	18	18	16
0.6	41	40	39	38	37	36	34	33	32	31	32	31	30	29	28	27	26	26	25	23	23	21	21	20	19	19	19	18	17	15
0.8	41	40	38	37	36	35	33	32	31	29	32	31	30	29	28	26	25	25	23	22	24	22	21	20	19	19	18	17	16	14
1	42	40	38	37	35	33	32	31	29	27	33	32	30	29	27	25	24	23	22	20	25	23	22	20	19	18	17	16	15	13
1.2	42	40	38	36	34	32	30	29	27	25	33	32	30	28	27	25	23	22	21	19	25	23	22	20	19	17	17	16	14	12
1.4	42	39	37	35	33	31	29	27	25	23	34	32	30	28	26	24	22	21	19	18	26	24	22	20	18	17	16	15	13	12
1.6	42	39	37	35	32	30	27	25	23	22	34	33	29	27	25	23	22	20	18	17	26	24	22	20	18	17	16	15	13	11
1.8	42	39	36	34	31	29	26	24	22	21	35	33	29	27	25	23	21	19	17	19	27	25	23	20	18	17	15	14	12	10
20	42	39	36	34	31	28	25	23	21	19	35	33	29	26	24	22	20	18	16	14	28	25	23	20	18	16	15	13	11	9
2.2	42	39	36	33	30	27	24	22	19	18	36	32	29	26	24	22	19	17	15	13	28	25	23	20	18	16	14	12	10	9
2.4	43	39	35	33	29	27	24	21	18	17	36	32	29	26	24	22	19	16	14	12	29	26	23	20	18	16	14	12	10	8
2.6	43	39	35	32	29	26	23	20	17	15	36	32	29	25	23	21	18	16	14	12	29	26	23	20	18	16	14	11	9	8
2.8	43	39	35	32	28	25	22	19	16	14	37	33	29	25	23	21	17	15	13	11	30	27	23	20	18	15	13	11	9	7
3	43	39	35	31	27	24	21	18	16	13	37	33	29	25	22	20	17	15	12	10	30	27	23	20	17	15	13	11	9	7

$$\rho_{\mathrm{fc,b}} = 20\%$$

$$\rho_{\mathrm{fc,w}} = 50\%$$

$$\mathrm{FCR} = 0.78$$

- Normally we’d need to interpolate the results; however, the values are the same in this for the FCR between 0.6 and 1.2

Example #7b
Now it's Your Turn

- A open office area 48 feet wide and 24 feet long has 12 foot tall ceilings. The lighting designer picked out three 20-foot long direct indirect pendants with a 18-inch aircraft cable support. The desks in the office are 30 inches high.
- If the ceiling tiles are very reflective ($\rho_{cc,b} = 90\%$) and the walls are a textured off-white($\rho_{cc,w} = 50\%$), what is the effective ceiling reflectance?

Effective Cavity Reflectance Correction Factor (1.6 length to width ratio)

Base Reflectance	90									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	89	88	88	87	86	85	85	84	84	82
0.4	88	87	86	85	84	83	81	80	79	76
0.6	87	86	84	82	80	79	77	76	74	73
0.8	87	85	82	80	77	75	73	71	69	67
1	86	83	80	77	75	72	69	66	64	62
1.2	85	82	78	75	72	69	66	63	60	57
1.4	85	80	77	73	69	65	62	59	57	52
1.6	84	79	75	71	67	63	59	56	53	50
1.8	83	78	73	69	64	60	56	53	50	48
2	83	77	72	67	62	56	53	50	47	43

Base Reflectance	80									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	79	78	78	77	77	76	76	75	74	72
0.4	79	77	76	75	74	73	72	71	70	68
0.6	78	76	75	73	71	70	68	66	65	63
0.8	78	75	73	71	69	67	65	63	61	57
1	77	74	72	69	67	65	62	60	57	55
1.2	76	73	70	67	64	61	58	55	53	51
1.4	76	72	68	65	62	59	55	53	50	48
1.6	75	71	67	63	60	57	53	50	47	44
1.8	75	70	66	62	58	54	50	47	44	41
2	74	69	64	60	56	52	48	45	41	38

Base Reflectance	70									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	70	69	68	68	67	67	66	66	65	64
0.4	69	68	67	66	65	64	63	62	61	58
0.6	69	67	65	64	63	61	59	58	57	54
0.8	68	66	64	62	60	58	56	55	53	50
1	68	65	62	60	58	55	53	52	50	47
1.2	67	64	61	59	57	54	50	48	46	44
1.4	67	63	60	58	55	51	47	45	44	41
1.6	67	62	59	56	53	47	45	43	41	38
1.8	66	61	58	54	51	46	42	40	38	35
2	66	60	56	52	49	45	40	38	36	33

Base Reflectance	60									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	60	59	59	59	58	57	56	56	55	53
0.4	60	59	59	58	57	55	54	53	52	50
0.6	60	58	57	56	55	53	51	51	50	46
0.8	59	57	56	55	54	51	48	47	46	43
1	59	57	55	53	51	48	45	44	43	41
1.2	59	56	54	51	49	46	44	42	40	38
1.4	59	56	53	49	47	44	41	39	38	36
1.6	59	55	52	48	45	42	39	37	35	33
1.8	58	55	51	47	44	40	37	35	33	31
2	58	54	50	46	43	39	35	33	31	29

Base Reflectance	50									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	50	50	49	49	48	48	47	46	46	44
0.4	50	49	48	48	47	46	45	45	44	42
0.6	50	48	47	46	45	44	43	42	41	38
0.8	50	48	47	45	44	42	40	39	38	36
1	50	48	46	44	43	41	38	37	36	34
1.2	50	47	45	43	41	39	36	35	34	29
1.4	50	47	45	42	40	38	35	34	35	27
1.6	50	47	44	41	39	36	33	32	30	26
1.8	50	46	43	40	38	35	31	30	28	25
2	50	46	43	40	37	34	30	28	26	24

Example #7b
Solution

- Ceiling Cavity Ratio

$$Cavity\ Ratio = \frac{2.5\ h\ P}{A}$$

$$= \frac{(2.5)\ (1.5\text{ft})\ (144\text{ft})}{(1{,}152\ \text{ft}^2)} = \frac{(540\ \text{ft}^2)}{(1{,}152\ \text{ft}^2)} = \boxed{0.47}$$

Example #7b
Solution

Base Reflectance	90									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	89	88	88	87	86	85	85	84	84	82
0.4	88	87	86	85	84	83	81	80	79	76
0.6	87	86	84	82	80	79	77	76	74	73
0.8	87	85	82	80	77	75	73	71	69	67
1	86	83	80	77	75	72	69	66	64	62

$\rho_{\text{cc,b}} = 90\%$

$\rho_{\text{cc,w}} = 50\%$

$\text{CCR} = 0.48$

$$\frac{84 - 80}{0.40 - 0.60} = \frac{84 - \rho_{CC}}{0.40 - 0.48}$$

$$\rho_{CC} = 84 - \left(\frac{84 - 80}{0.40 - 0.60}\right)(0.40 - 0.48) = \boxed{82.4}$$

Example #8
Putting it All Together – CU, RCR, Reflectances

- Let's go back to our open office and everything we've determined so far:

  A open office area 48 feet wide and 24 feet long has 13 foot tall ceilings. The lighting designer picked out three 20-foot long direct indirect pendants with a 18-inch aircraft cable support. The desks in the office are 30 feet high.

- If we used twelve 4,800 lm LED semi-direct pendants, what would the average horizontal illuminance be?

$$\rho_{CC} = 82.4$$
$$\rho_{FC} = 19.0$$
$$\rho_{W} = 50.0$$
$$\text{RCR} = 2.81$$

Example #8
Putting it All Together

- First we need a CU table

Coeffcient of Utilization (CU)

ρ_{CC}	90			80			70			60			50			40			30			20			10			0
ρ_W	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10	0
RCR																												
0	114	114	114	104	104	104	94	94	94	85	85	85	76	76	76	67	67	67	59	59	59	51	51	51	44	44	44	37
1	110	100	92	100	91	85	90	83	77	81	75	70	72	67	63	64	60	57	56	53	50	48	46	44	41	40	38	32
2	106	87	75	96	80	69	86	73	63	76	66	58	68	59	53	60	53	47	52	46	42	45	41	37	38	35	32	27
3	102	77	62	91	70	58	82	64	53	73	58	49	64	52	44	57	47	40	49	41	36	42	36	32	36	31	28	23
4	98	68	53	88	62	49	78	57	45	69	52	42	61	46	38	54	42	34	47	37	31	40	32	27	34	28	24	20
5	95	62	46	84	57	43	75	52	40	67	47	37	59	43	34	52	38	31	45	34	28	39	30	25	33	26	22	19
6	90	54	39	80	50	36	71	45	34	63	41	31	55	37	28	48	33	26	42	30	23	36	26	21	31	23	18	15
7	87	48	33	77	44	31	68	40	29	60	37	27	53	33	24	46	30	22	40	27	20	34	23	18	29	20	16	13
8	83	42	28	73	39	26	65	35	24	57	32	22	50	29	20	43	26	18	37	23	16	32	20	14	27	17	13	10
9	80	38	24	70	35	22	62	32	20	55	29	19	48	26	17	41	23	15	36	20	14	30	18	12	25	15	11	8
10	74	28	14	65	25	12	56	23	11	49	20	9	42	17	8	36	15	6	30	12	5	25	10	4	20	8	2	0

- Holy double interpolation, Batman…
  - Step 1: Pick one set of variables to interpolate
  - Step 2: Interpolate the result.

Example #8
Interpolation is Fun!

- Let's interpolate the reflectance values first.

$$CU_{RCR=2} = 87 - \left(\frac{87 - 80}{90 - 80}\right)(90 - 82.4) = \boxed{81.7}$$

$$CU_{RCR=3} = 77 - \left(\frac{77 - 70}{90 - 80}\right)(90 - 82.4) = \boxed{71.7}$$

- Then interpolate the results.

$$CU_{RCR=2.81} = 71 - \left(\frac{71.7 - 81.7}{3 - 2}\right)(3 - 2.81) = \boxed{72.9}$$

Example #8
One last calculation

$$Illuminance\ (E) = \frac{\left(4{,}800\ \frac{\text{lumens}}{\text{fixture}}\right)(12\ \text{fixtures})(0.729)}{(48\ \text{ft}\ \times 24\ \text{ft})}$$

$$= \frac{(41{,}990\ \text{lumens})}{(1152\ \text{ft}^2)} = \boxed{36.4\ \text{fc}}$$

- But there is still room for refining our calculation…

Modifications to the Lumen Method
-- Light Loss Factors --

- Light loss factors are expected losses that would differ from the rated output.
- Recoverable Light Loss Factors
  - Dirt – Room Surface or Luminaire
    - Recovered by cleaning
  - Lumen Depreciation
    - Recovered by relamping
  - Burnout Factor
    - Recovered by replacing lamps
  - Optical Degradation Factor
    - Recovered by replacing cloudy lenses
- Non-Recoverable Light Loss Factors
  - Temperature Factor
  - Ballast Factor

Modifications to the Lumen Method
-- Solve for Luminaire Quantity--

- Adjust the formula to solve for the number of luminaires needed to meet illuminance target

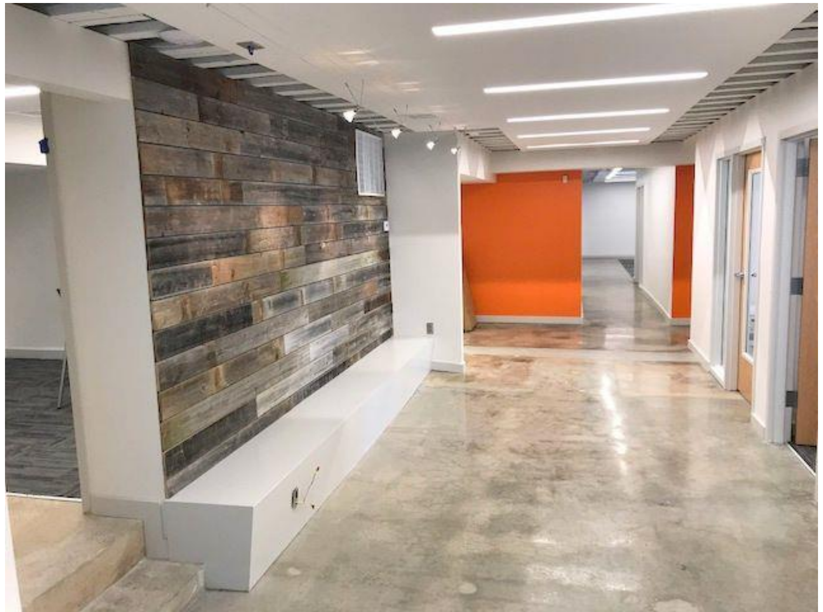
$$Illuminance\ (E) = \frac{\left(\frac{Luminaire}{Lumens}\right)\left(\frac{\text{Luminaire}}{\text{Quantity}}\right) CU}{Area\ (A)}$$

$$\left(\frac{\text{Luminaire}}{\text{Quantity}}\right) = \frac{Area\ (A) \times Illuminance\ (E)}{\left(\frac{Luminaire}{Lumens}\right) CU}$$

Modifications to the Lumen Method
-- Different Reflectance Surfaces in Same Plane--

- A space may have different reflectance values for part of each wall
- Average the reflectance value for each of the cavity surface, weighted by size.
- Given a room with four 100 ft² walls, if one wall is red ($\rho = 35$) and the others are white ($\rho = 50$), the weighted average is:

$$\rho_{W,avg} = \frac{(35 \times 100) + (50 \times 300)}{400} = 46.5$$

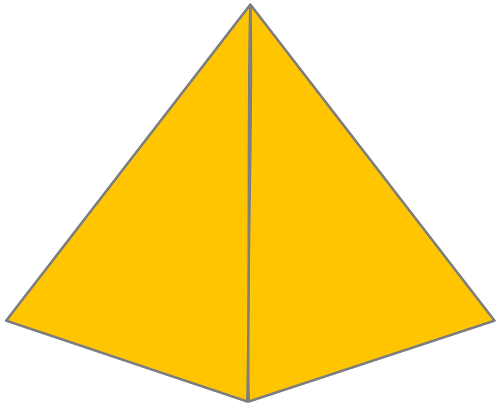


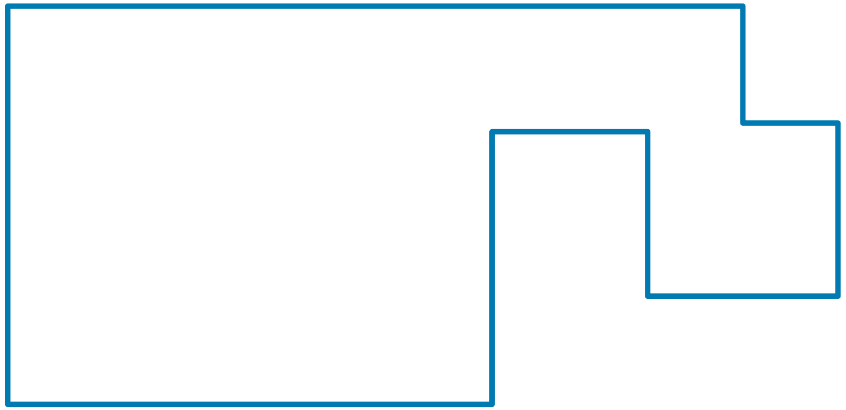
Modifications to the Lumen Method
-- Multiple Light Sources --

- You may have a lighting system where there are two luminaires evenly distributed through the space
- Light is additive – each light source builds on the other.
- Run one calculation for each light source and add the results together.

Lumen Method Weaknesses

- Lumen method doesn’t work well when the room…
  - Is very narrow and has a low ceiling
  - Has “fingers”, small projections, complicated geometry
  - Has big furniture or partitions
  - Has non-uniform lighting (e.g. wall washing) for general lighting.





Example #9
Lumen Method All Of Your Own

- You're asked to design new lighting in portable classrooms for a middle school. The classrooms are 38 feet long and 32 feet wide. The ceiling has a two-by-four grid with 2x4 troffers. The ceiling reflectance is 80%. The walls are 60% and the floors are 18%. The ceiling is 10 feet high. You've selected a three-lamp T8 (3100 lm) troffer with a normal ballast factor (0.88). The illuminance target is 40 fc. How many fixtures do you need to provide?
- The principal decides to relocate a art class into one portable (illuminance target 50 fc), but they accumulate dirt faster (dirt depreciation of 15 percent after 4 years), how many fixtures should you provide?

2GT8 3 32 A12 1/3

Report LTL 7421

Lumens per lamp - 2850 – Lum. eff. - 80.1%

S/MH (along) 1.2 (across) 1.4

Coefficient of Utilization

Ceiling	80%			70%			50%		
Wall	70%	50%	30%	70%	50%	30%	50%	30%	10%
0	95	95	95	93	93	93	89	89	89
1	88	84	81	85	82	79	79	76	74
2	80	74	69	78	72	68	70	66	62
3	74	66	59	72	64	58	62	57	53
4	68	58	52	66	57	51	55	50	46
5	62	52	45	61	52	45	50	44	40
6	58	47	40	56	47	40	45	39	35
7	54	43	36	52	42	36	41	35	31
8	50	39	33	49	39	32	38	32	28
9	47	36	30	45	36	29	35	29	25
10	44	33	27	43	33	27	32	27	23

Example #9
Lumen Method All On Your Own

$$h_{\text{RCR}} = 10\text{ ft} - 2.5\text{ ft} = 7.5\text{ ft}$$
$$h_{\text{FCR}} = 2.5\text{ ft} - 0\text{ ft} = 2.5\text{ ft}$$
$$h_{\text{CCR}} = 10\text{ ft} - 10\text{ ft} = 0\text{ ft}$$

$$RCR = \left(\frac{2.5(7.5\text{ ft})(38\text{ ft} + 38\text{ ft} + 32\text{ ft} + 32\text{ ft})}{(38\text{ ft} \times 32\text{ ft})}\right) = 2.16$$

$$FCR = \left(\frac{2.5(2.5\text{ ft})(38\text{ ft} + 38\text{ ft} + 32\text{ ft} + 32\text{ ft})}{(38\text{ ft} \times 32\text{ ft})}\right) = 0.72$$

$$\rho_{\text{CC}} = 80\%$$
$$\rho_{\text{W}} = 60\%$$
$$\rho_{FC} = ??$$

Example #9
Lumen Method All On Your Own

Base Reflectance	20										10									
Wall Reflectance	90	80	70	60	50	40	30	20	10	0	90	80	70	60	50	40	30	20	10	0
Cavity Ratio																				
0.2	21	20	20	20	20	20	19	19	19	17	11	11	11	10	10	10	10	9	9	9
0.4	22	21	20	20	20	19	19	18	18	16	12	11	11	11	11	10	10	9	9	8
0.6	23	21	21	20	19	19	19	18	17	15	13	13	12	11	11	10	10	9	8	8
0.8	24	22	21	20	19	19	18	17	16	14	15	14	13	12	11	10	10	9	8	7
1	25	23	22	20	19	18	17	16	15	13	16	14	13	12	12	11	10	9	8	7

$$\rho_{\text{Base}=20} = 22 - \left(\frac{22 - 21}{0.8 - 0.6}\right)(0.8 - 0.72) = \boxed{21.6}$$

$$\rho_{\text{Base}=10} = 14 - \left(\frac{14 - 13}{0.8 - 0.6}\right)(0.8 - 0.72) = \boxed{13.6}$$

$$\rho_{\text{FC}} = 21.6 - \left(\frac{21.6 - 13.6}{0.2 - 0.10}\right)(0.2 - 0.18) = \boxed{20}$$

Example #9
Lumen Method All On Your Own

2GT8 3 32 A12 1/3

Floor reflectances are 20%.

Report LTL 7421

Lumens per lamp - 2850 – Lum. eff. - 80.1%

S/MH (along) 1.2 (across) 1.4

Coefficient of Utilization

Ceiling	80%			70%			50%		
Wall	70%	50%	30%	70%	50%	30%	50%	30%	10%
0	95	95	95	93	93	93	89	89	89
1	88	84	81	85	82	79	79	76	74
2	80	74	69	78	72	68	70	66	62
3	74	66	59	72	64	58	62	57	53
4	68	58	52	66	57	51	55	50	46
5	62	52	45	61	52	45	50	44	40
6	58	47	40	56	47	40	45	39	35
7	54	43	36	52	42	36	41	35	31
8	50	39	33	49	39	32	38	32	28
9	47	36	30	45	36	29	35	29	25
10	44	33	27	43	33	27	32	27	23

Interpolate here: CU = 77

Interpolate here: CU = 70

$$CU = 70 - \left(\frac{70-77}{3-2}\right)(3-2.16) = \boxed{75.9}$$

Example #9
Lumen Method All On Your Own

$$\begin{pmatrix}\text{Luminaire}\\ \text{Quantity}\end{pmatrix} = \frac{Area\ (A) \times Illuminance\ (E)}{\begin{pmatrix}Luminaire\\ Lumens\end{pmatrix} CU}$$

$$\begin{pmatrix}\text{Luminaire}\\ \text{Quantity}\end{pmatrix} = \frac{(32\ \text{ft} \times 38\ \text{ft})(40\ \text{fc})}{\left(0.88\ \times 3100\ \frac{\text{lm}}{\text{lamp}} \times 3\ \text{lamps}\right) 0.759}$$

$$\begin{pmatrix}\text{Luminaire}\\ \text{Quantity}\end{pmatrix} = \frac{(48{,}640\ \text{lm})}{(8{,}184\ \text{lm})0.759} = 7.83 \approx \boxed{8}$$

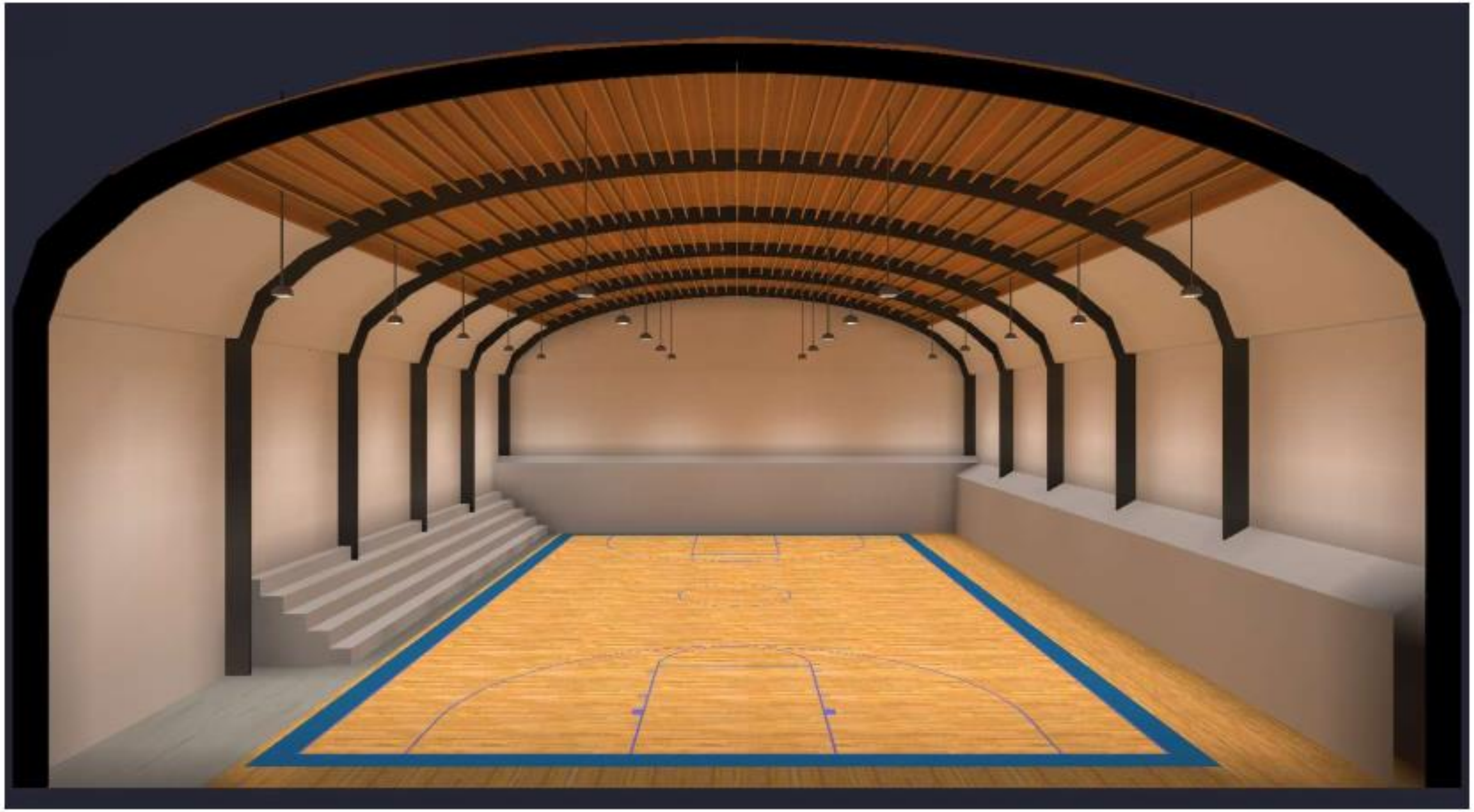
Example #9
Lumen Method All On Your Own

- But what about the art classroom?
- Same thing, but we add another light loss factor

$$\begin{pmatrix}\text{Luminaire}\\ \text{Quantity}\end{pmatrix} = \frac{(32\ \text{ft} \times 38\ \text{ft})(40\ \text{fc})}{\left(0.88 \times 0.85 \times 3100\ \frac{\text{lm}}{\text{lamp}} \times 3\ \text{lamps}\right) 0.759}$$

$$\begin{pmatrix}\text{Luminaire}\\ \text{Quantity}\end{pmatrix} = \frac{(48{,}640\ \text{lm})}{(6{,}956\ \text{lm})0.759} = 9.21 \approx \boxed{10}$$

3D Photometric Models



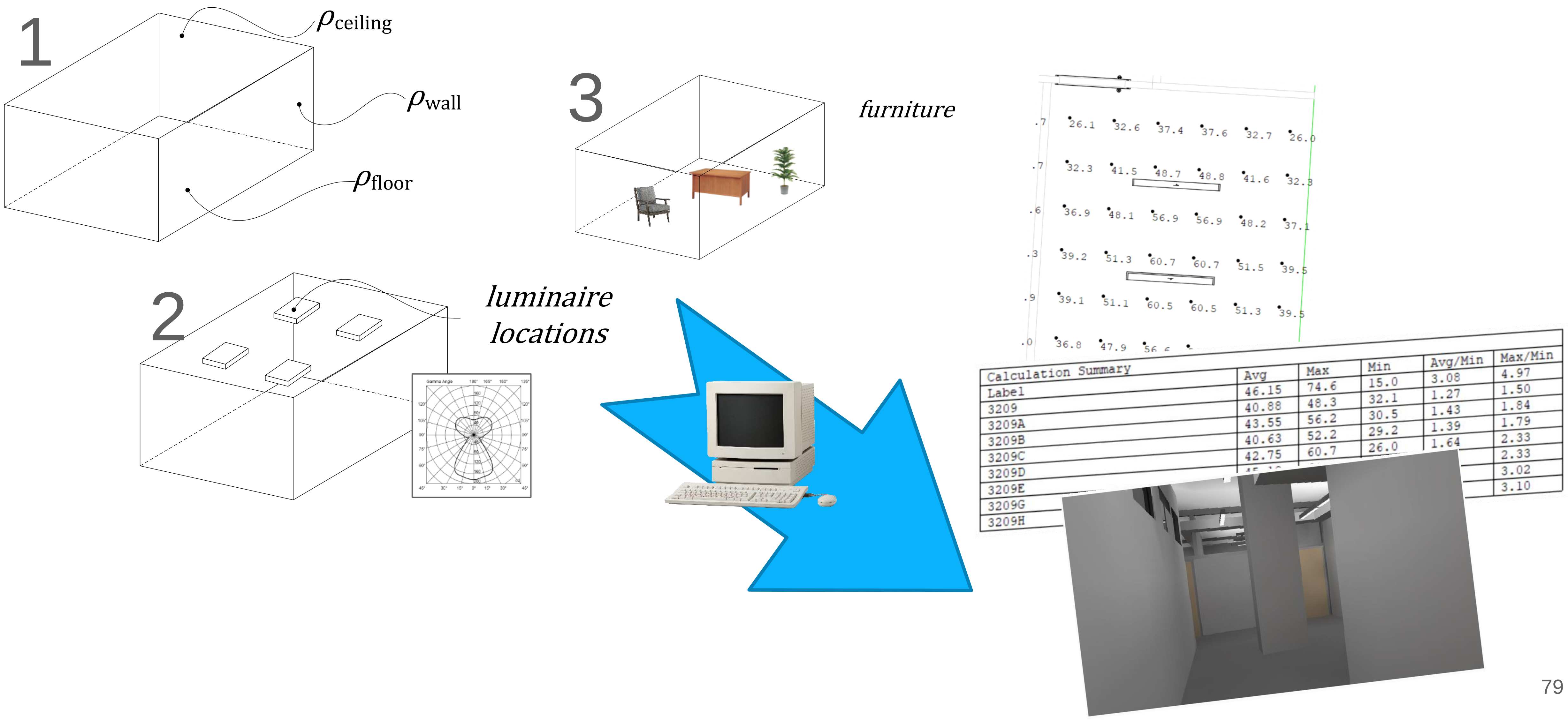
Computer-Aided Lighting Calculations

- Software Modeling
- Software Packages
- Tips & Tricks

Software Modeling

- Combines information about different aspects of a space
  - Space Details
    - Geometry & Surface Finishes
  - Object Details
    - Geometry & Surface Finishes
  - Luminaire information
- Divides each surface into small surfaces
- Calculates light, object, and surface interactions

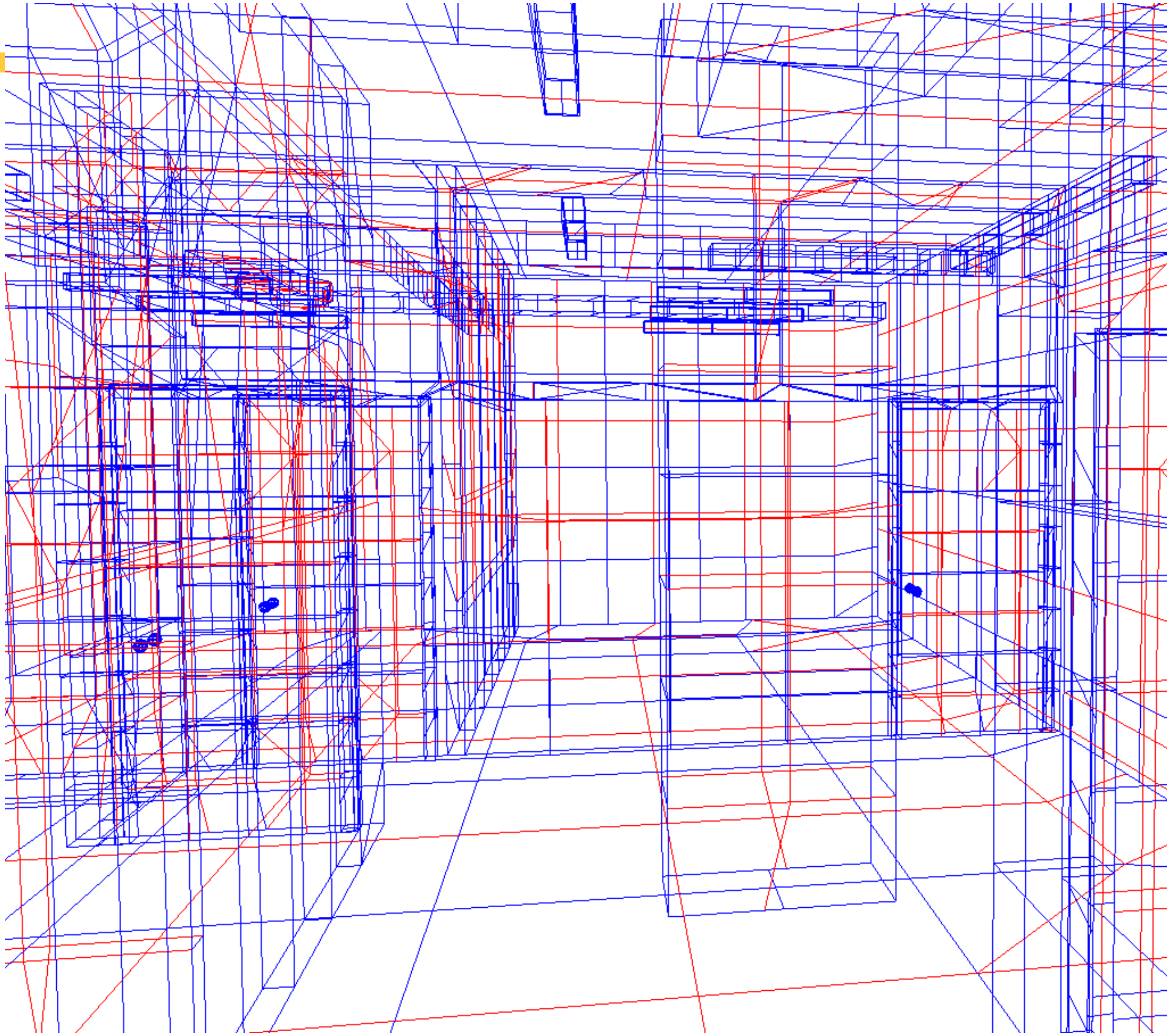
How?



Label	Avg	Max	Min	Avg/Min	Max/Min
3209	46.15	74.6	15.0	3.08	4.97
3209A	40.88	48.3	32.1	1.27	1.50
3209B	43.55	56.2	30.5	1.43	1.84
3209C	40.63	52.2	29.2	1.39	1.79
3209D	42.75	60.7	26.0	1.64	2.33
3209E	[illegible]	[illegible]	[illegible]	[illegible]	2.33
3209G	[illegible]	[illegible]	[illegible]	[illegible]	3.02
3209H	[illegible]	[illegible]	[illegible]	[illegible]	3.10

Software Photometric Approach

- Surfaces divided into small elements
- For each luminaire, calculates
  - Light that lands on each element
- For each element, calculates light
  - Transmitted
    - Refracted less so
  - Reflected
  - Absorbed
- For each element (again) light from other elements
- Calculation grids
- Approach is based on a numerical method that solves a series of partial differential equations

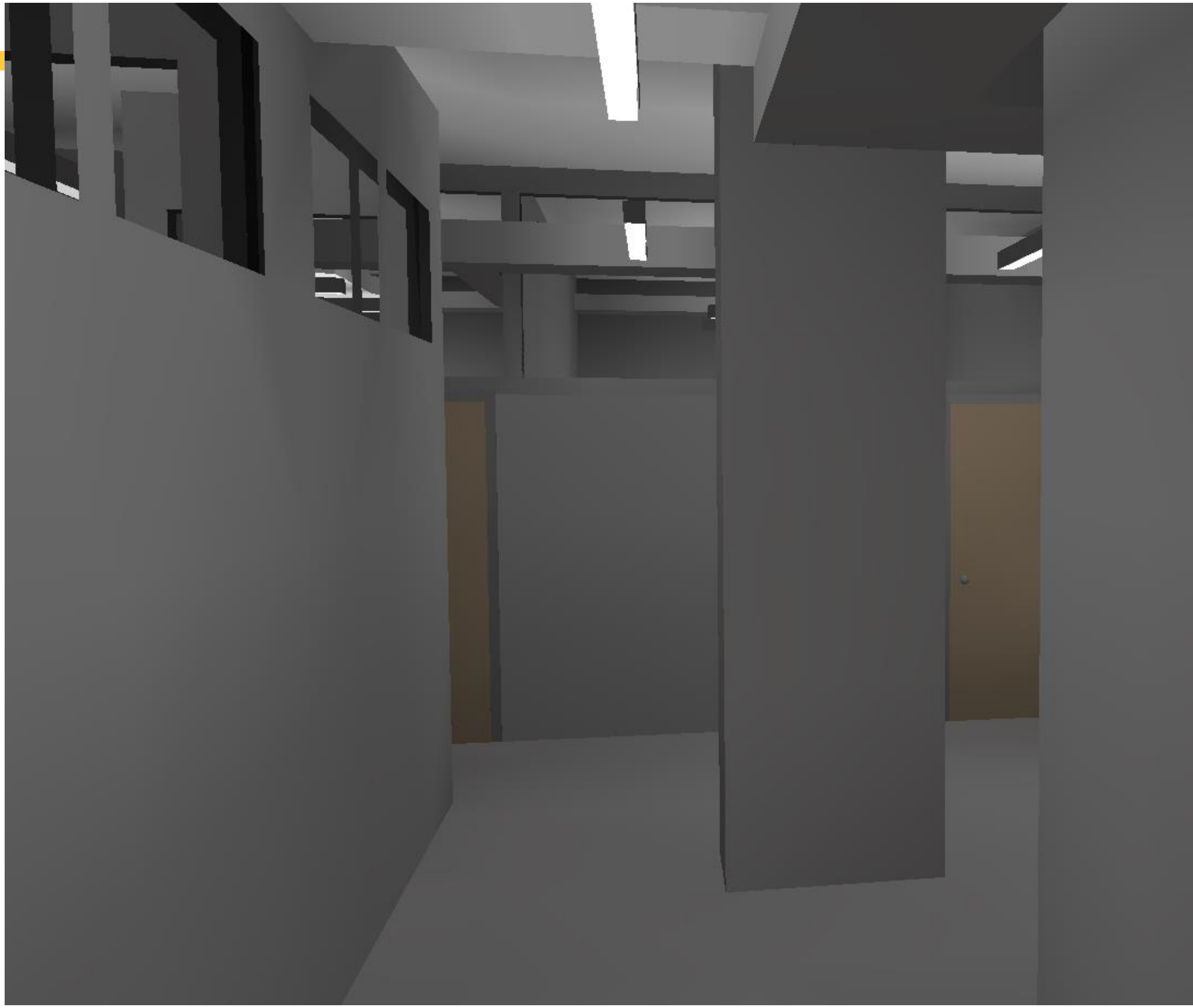


Software Photometric Approach

Usually two options

- Direct-Only – Ignores reflections
  - Good for parking lots
- Full Radiosity – Calculates surface interactive effects
  - Must-have for interior spaces

Calculation Summary					
Label	Avg	Max	Min	Avg/Min	Max/Min
3209	22.68	38.8	3.3	6.87	11.76
3209A	19.47	24.7	13.7	1.42	1.80
3209B	20.60	29.4	12.6	1.63	2.33
3209C	20.60	29.4	12.7	1.62	2.31
3209D	21.21	35.0	9.6	2.21	3.65
3209E	21.51	35.6	9.6	2.24	3.71
3209G	18.12	30.5	5.7	3.18	5.35
3209H	18.01	30.4	5.5	3.27	5.53



Relative Benefits of Calculation Approaches

	Lumen Method	Radiosity Modeling
Speed of Calculation	Very quick	Pretty fast for simple spaces, requires significant times to make it look realistic or model complex spaces
Level of Information Required	Area, Ceiling Height, Surface Reflectances	As lumen method, plus: Luminaire spacing; Space geometry details; Furniture layout and details
Daylighting support	No	Yes, with additional details, site orientation, window shade models, and window dimensions and materials
Calculation output	Average only	Point-by-point, uniformity, luminance
Support for complex geometry	No	Yes
Speed	Very quick, spreadsheet friendly	Simple models quick, complex models can take a lot of time to assemble and calculate

Tool Options

STAND ALONE TOOLS

- AGi32
- Visual
- DIALux
  - Litepro DLX
- Relux
- Elite Software "Light"
  - Only does Lumen Method Calcs

Architectural Suites

- Visual
- ElumTools
- DesignMasterPhotometrics
- Revit
- Relux
- LightStanza

Super User Tools

- Radiance
- LightTools

TIPS & TRICKS

Be successful – diligence & documentation

IES Files – Wuzzat?

- Digital file that records how a luminaire distributes light
- May be a relative or absolute photometry file
- Usually provided by manufacturers via their website
  - Some require direct requests

```
IESNA:LM-63-2002
[TEST] 37019
[TESTDATE] 1/31/2008
[ISSUEDATE]
[TESTLAB]
[MANUFAC]
[LUMCAT]
[LUMINAIRE]
[LAMPCAT]
[LAMP] 150W CLEAR HPS
[BALLAST]
[BALLASTCAT]
[DISTRIBUTION] 4 X 4
[_LAMPPOSITION] 0 , 0
[_LAMPWATTAGE] 150
[_LAMPLUMENS] 16000
[_MOUNTING]
[_FAMILY]
[_PRODUCTID]
[_INFOLINK]
[OTHER] SPOT DISTRIBUTION BEAM FLOODLIGHT
TILT=NONE
1  16000  1  19  20  1  1  0.6  0.8  0
1  1  188
0  5  10  15  20  25  30  35  40  45  50  55  60  65  70  75  80  85  90
0  5  15  25  35  45  55  65  75  85  95  105  115  125  135  145  155  165  175  180
29649  27912  21836  13476  5835  2555  1823  1549  1343
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1550  1409  1245  835  125  26  19  7  0  0
29649  26542  18557  12353  7561  4026  2497  2068  1918
1835  1752  1614  1498  129  55  25  12  1  0
```
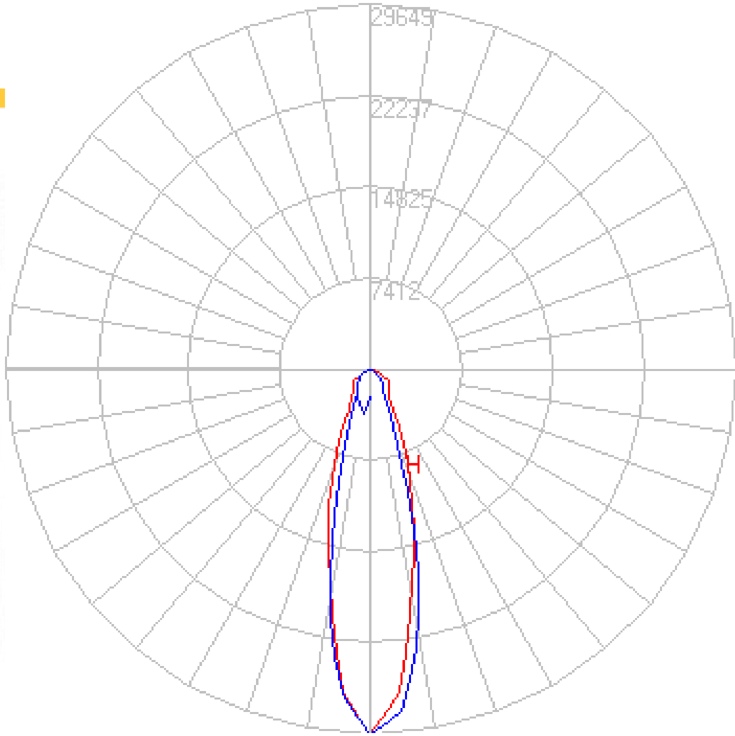
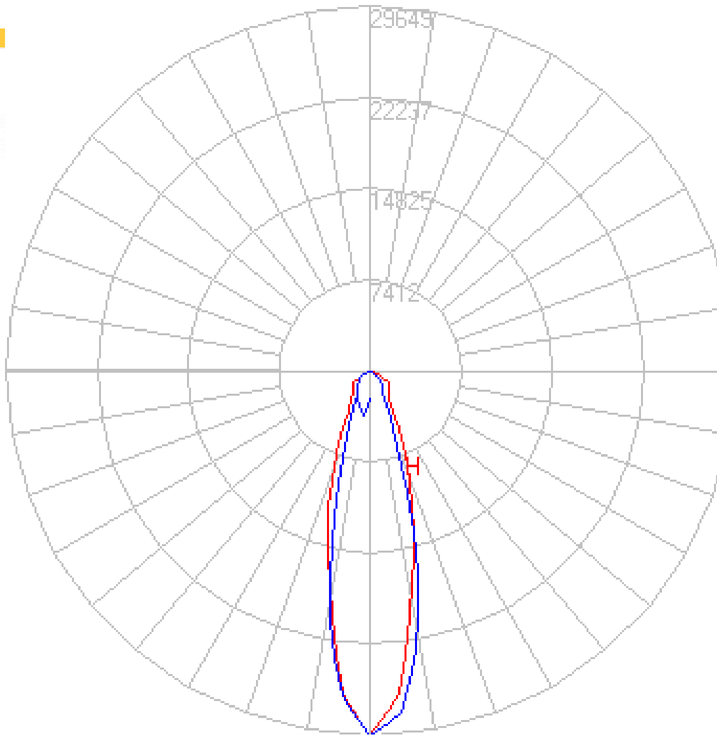



Modifying IES Files

- Sometimes you might have to modify an IES file
- Usually you can make the modifications in your software suite
- Sometimes the modifications are made at the manufacturer level

```
IESNA:LM-63-2002
[TEST] 37019
[TESTDATE] 1/31/2008
[ISSUEDATE]
[TESTLAB]
[MANUFAC]
[LUMCAT]
[LUMINAIRE] PREDATOR
[LAMPCAT]
[LAMP] 150W CLEAR HPS
[BALLAST]
[BALLASTCAT]
[DISTRIBUTION] 4 X 4
[_LAMPPOSITION] 0 , 0
[_LAMPWATTAGE] 150
[_LAMPLUMENS] 16000
[_MOUNTING]
[_FAMILY]
[_PRODUCTID]
[_INFOLINK]
[OTHER] SPOT DISTRIBUTION BEAM FLOODLIGHT
```



Calculation Grids, Elevations, & Orientations

Table 24.2 | Educational Facilities Illuminance Reco

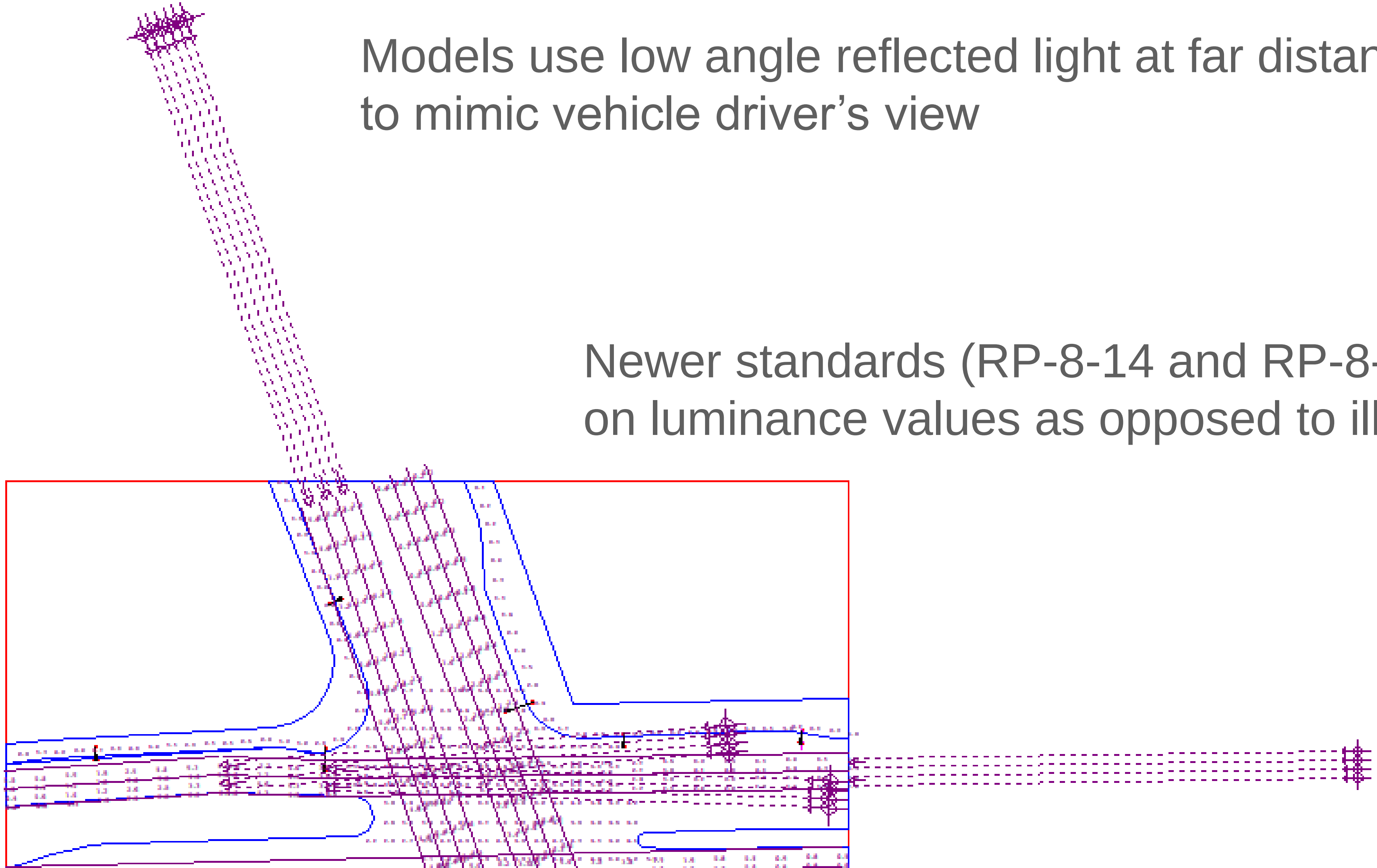
Applications and Tasks[a]	Notes
AUDITORIA	(Multipurpose continued)
• Dancing (Social)	E_h @dance floor; E_v @5' AFF
• Exhibition	E_h @2' 6" AFF; E_v @5' AFF
• Study	Typical paper and/or laptop
• Testing	E_h @2' 6" AFF; E_v @4' AFF
• Combination	Typical paper and/or laptop
• Laptop only	CSA/ISO Type I and II negative polarity screens.[i]
• Paper only	Variety of paper tasks[i]
• Performance	Dedicated to artistic performan ENTERTAINMENT
• House	As the architect coordinates co
• During event	E_h @floor; E_v @4' AFF
• Pre/Post event	E_h @floor; E_v @5' AFF
• Stage	
• Access ramps/stairs	See AUDITORIA/Circulation
• Amateur productions	
• Dance (performance)	E_h and E_v @5' AFF
• Demonstration	E_h @3' AFF; E_v @4' 6" AFF
• Music	E_h and E_v @4' AFF
• Theater	Simple, no stage lighting cues.. E_h and E_v @5' AFF

- Calculating illuminance grids key reason for making a model
- Grids need to be located appropriately
  - IES Handbook & RP's show grid locations
- For vertical grids, you may need to do multiple sets of calculations with different sensor orientations
- Roadway lighting standards are completely different

Roadway Lighting Grids

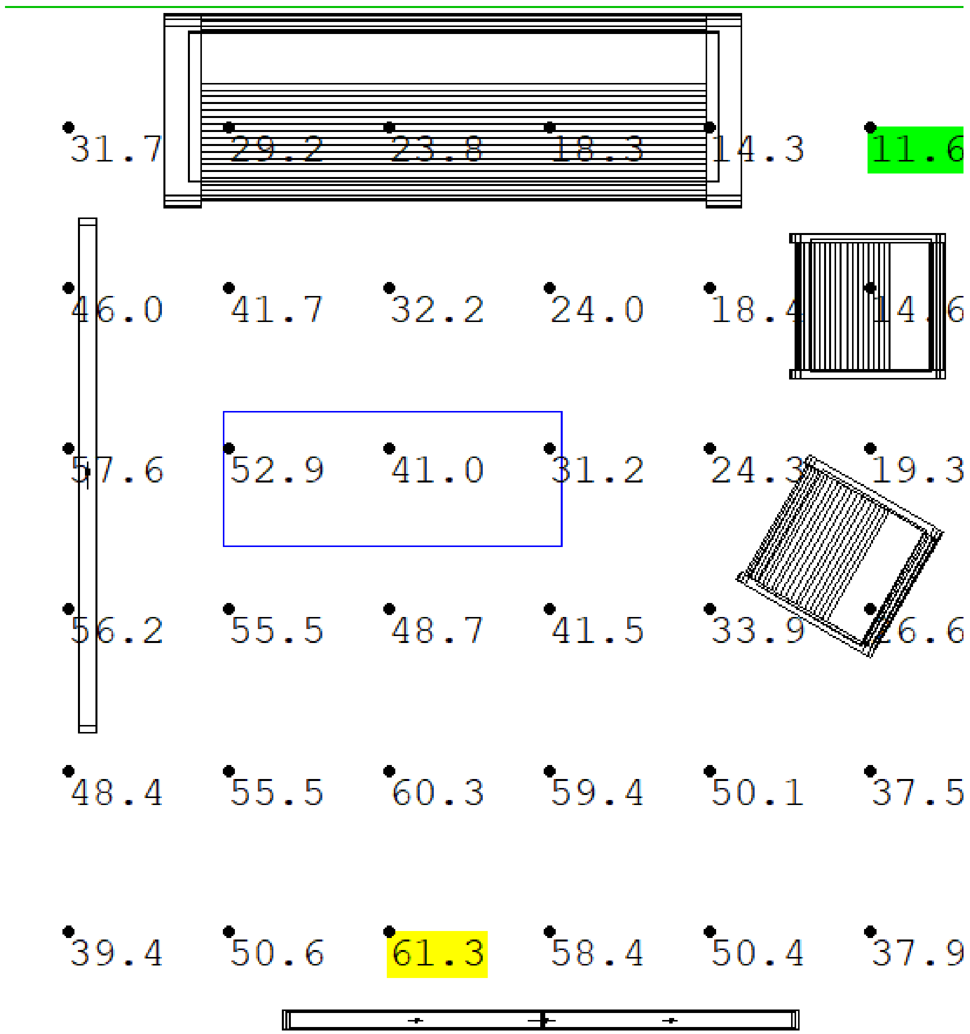
Models use low angle reflected light at far distances to mimic vehicle driver's view

Newer standards (RP-8-14 and RP-8-18) rely on luminance values as opposed to illuminance

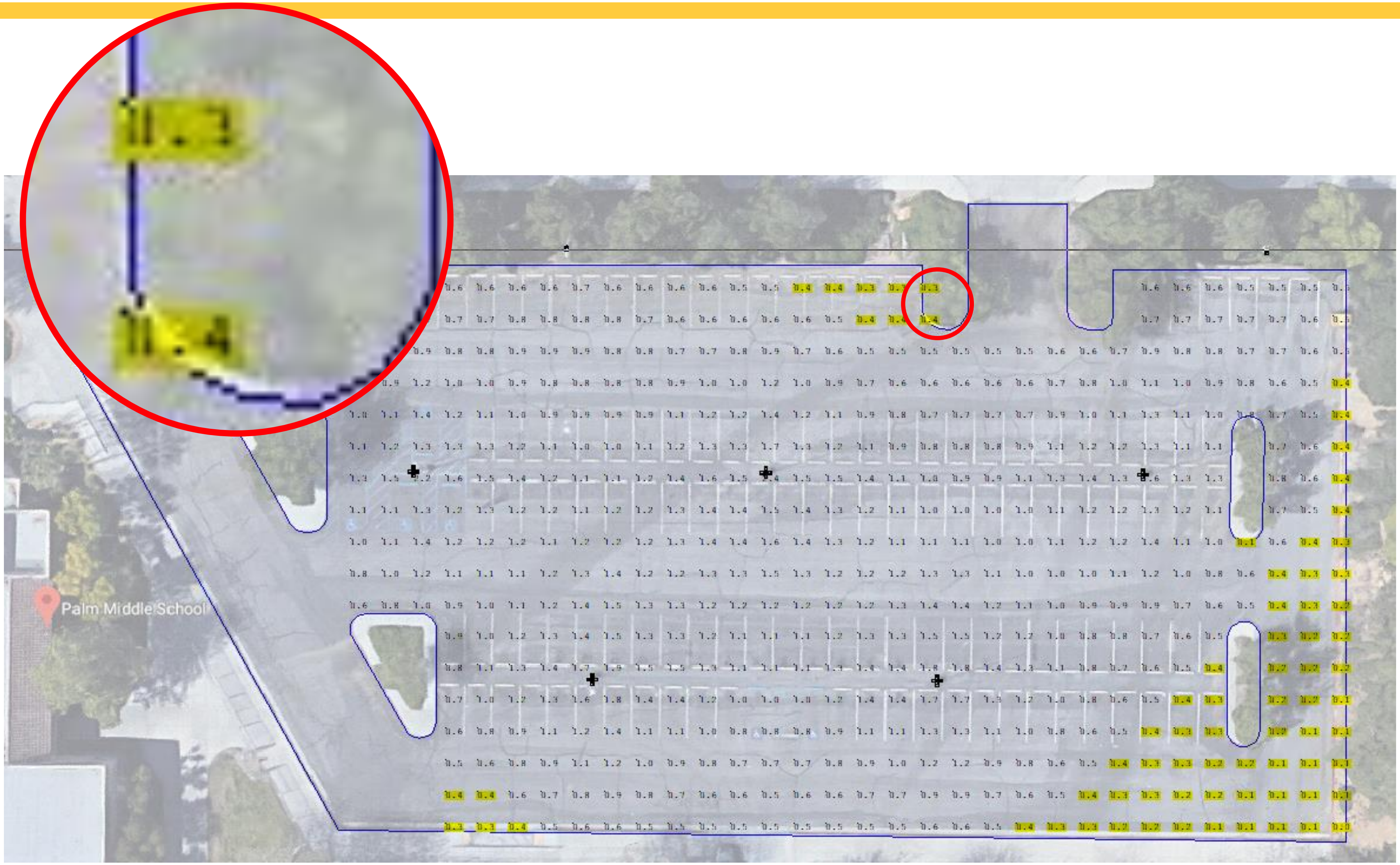


Excluding Points – Being Ethical

- Sometimes your site geometry/furniture plan don't line up exactly
- You may need to exclude points from the grid
  - Improves average and min/max (avg/max) ratios
  - Can obscure real design issues

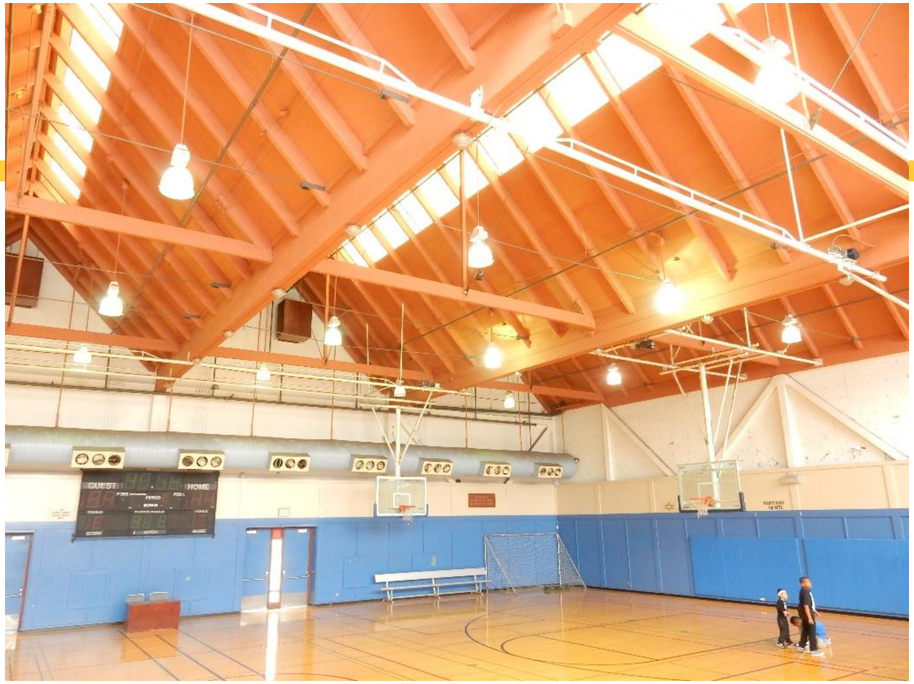


Excluding Points – Being Ethical



Surface Materials, Colors and Specularity

- Surface materials impact the look of your space
  - Reflecting light off colored walls will make the light take on the hue of the wall.
- Be cautious when modeling saturated colors
- Specular surfaces are very reflective, but appearance in models can be inaccurate



Light Loss Factors – Entry & Tracking

- Clearly state your LLFs and show them in your summary tables
  - Notes as applicable
- Allows apples-to-apples or-equal comparisons

	LLD	LDD	UDF	LLF	Watts
16 LED 8ft model, HO/HO	0.900	0.915	2.000	1.647	110
16 LED HO/HO	0.900	0.940	1.000	0.824	43.2
ownlight Pendant (Lo)	0.700	0.915	0.620	0.397	8.8
2x4 Troffer	0.900	0.915	1.000	0.824	48
2x2 Troffer	0.900	0.915	1.000	0.824	24

Light Loss Factor Specification

Specify Light Loss Factor

Description	Abbv.	Factor
Lamp Lumen Depreciation	LLD	0.920
Luminaire Dirt Depreciation	LDD	0.940
Ballast Factor	BF	--
Luminaire Ambient Temperature Factor	LATF	--
Room Surface Dirt Depreciation	RSDD	--
Luminaire Surface Depreciation	LSD	--
Lamp Burnout Factor	LBO	--
Voltage-To-Luminaire Factor	VTLF	--
Ballast-Lamp Photometric Factor	BLPF	--
Heat Extraction Thermal Factor	HETF	--
Equipment Operating Factor	EOF	--
User Defined Factor	UDF	--
Total Light Loss Factor	**LLF**	0.865

OK | Cancel | Help

3. Each calculation grid highlights the maximum illuminance (yellow) and minimum illuminance (green).
4. Lumianire C1, the 8-foot Finelight pendants have a user-defined light loss factor, (UDF) of 2.0 to scale up a 4' luminaire to match the light output of an 8' luminaire.
5. All luminaire (lamp) lumen depreciation (LLD) factors evaluated at end-of-life based on manufacturer listed data.
6. All luminaire dirt depreciation (LDD) factors evaluated for a clean interior environment with 12-month cleaning cycles. The LDD value was evaluated for a WX depreciation curve per IES/NALMCO RP-36-15 Figure 6, where LDD = e^(-0.020t^0.596).

Renaming/Tracking Your Input Files

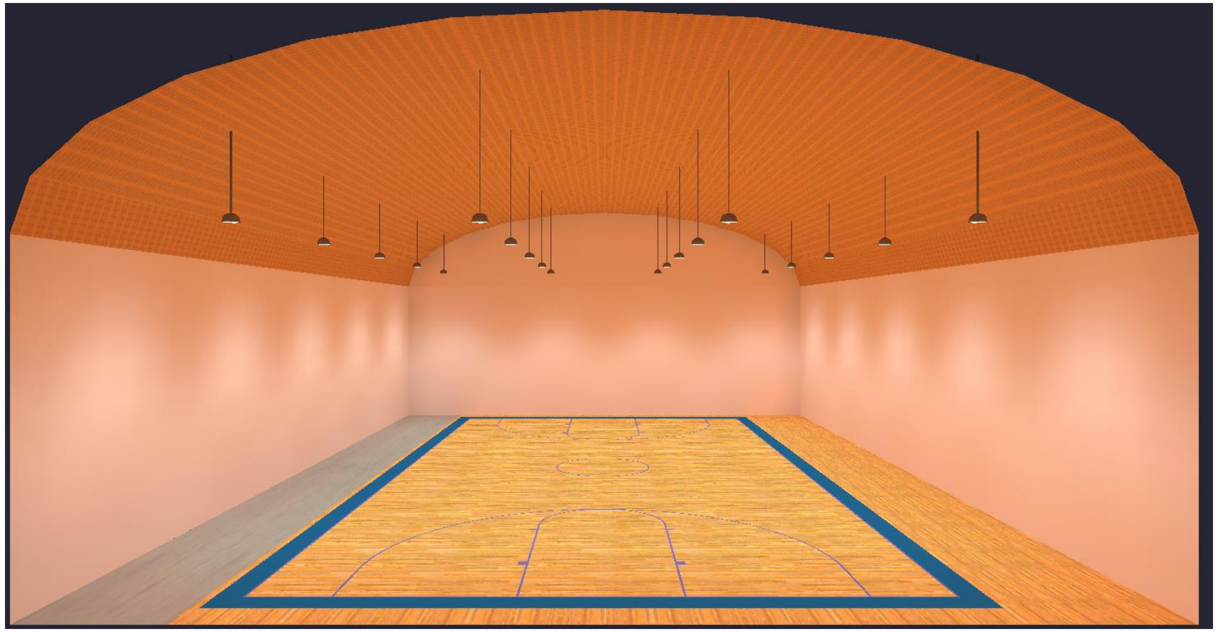
- KBL-A-XX-H-35K-8-UL W_CXBC16_CONFIGURED.ies
- SE130-A5008.ies
- D-1000w-PSMH-SPORT-AR45-A.ies
- H-15112-100W INC.IES
- GV10DMH00XX8NNX.ies
- M9700_100S_TSP.ies
- PD15AHP00XS0X.ies
- STR-SLM-2M-_-04-D-UL-1000-40K.IES
- CNC-B01-LED-E1-RW.ies
- LDRV-5MQ-C03-E.ies
- RO-WO-2T5.ies
- RWW-T1BX40MI.ies
- MAQ-A120-7-LED-E1-SW.IES
- PSL-175-MH-XX-XX.ies
- VPL-B01-LED-E1-GL2.ies
- MHMX-D-W-1000.ies
- AI-WN-1T5.ies

- IES files are invariably named things that are hard to recognize
- IES files may be in various locations on your network or local machine
- Best Practice:
  - Pre-append names with details
    ACME – Cobrahead – WhizBang Line (ACF28300D45MVOLT).ies
  - Save a copy of the cutsheet with the .ies file
  - Keep a copy of these files with your model

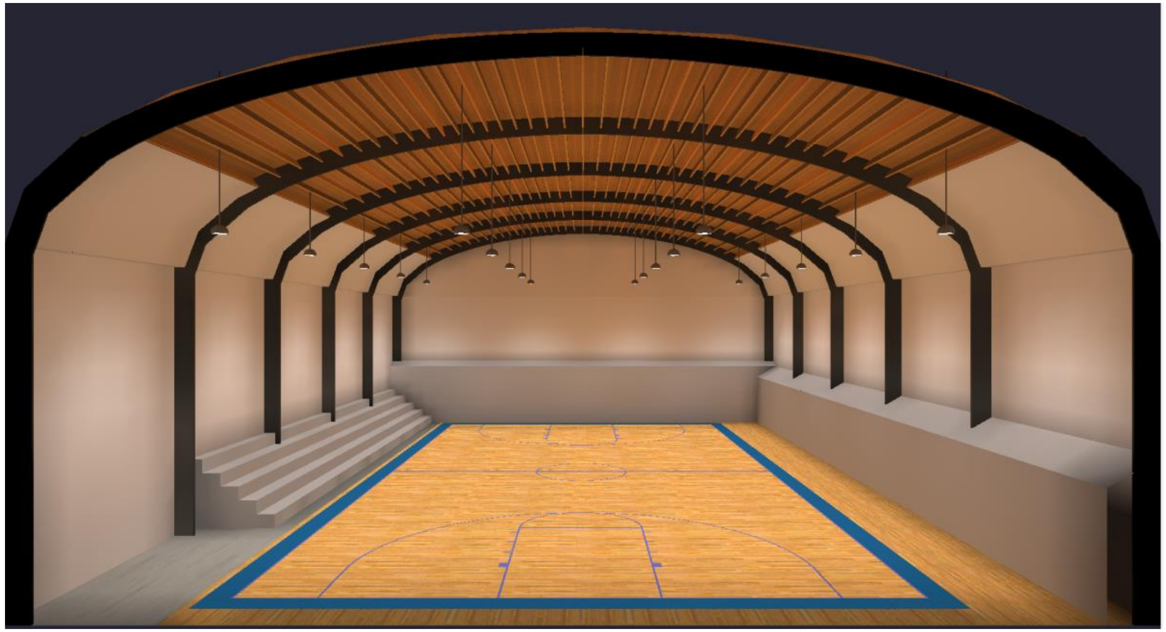
Compound Geometry

- Gage the degree to which fancy geometry will impact your model
  - More surfaces = more analysis time
  - Makes your results look similar to the real world
- Consider turning off detailed surfaces while you narrow in on your proposed layout and fixture lumen package – turn on details when you're nearly ready
- Turn off surfaces that are hidden from view
- Simplify curved surfaces

Compound Geometry



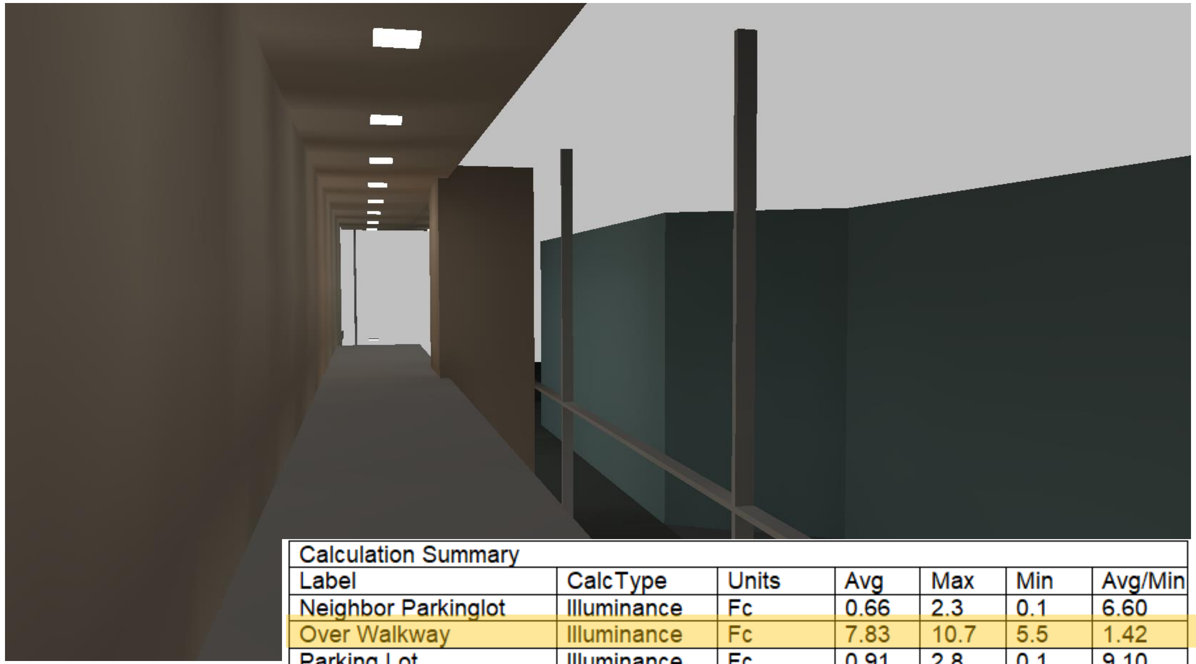
Avg	Max	Min	Avg/Min	Max/Min
55.06	58.9	47.7	1.15	1.23



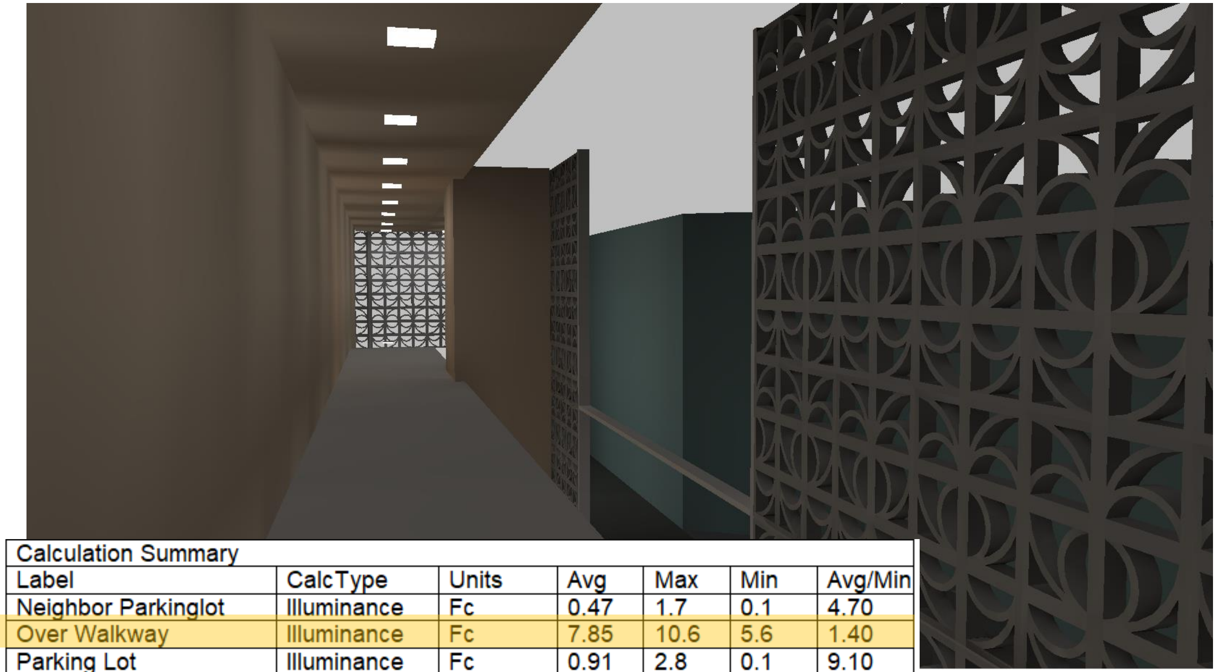
Avg	Max	Min	Avg/Min	Max/Min
47.29	51.1	38.1	1.24	1.34

$$Percent\ Difference = \left(1 - \frac{47.3}{55.1}\right) = 14.2\%$$

Compound Geometry



Calculation Summary						
Label	CalcType	Units	Avg	Max	Min	Avg/Min
Neighbor Parkinglot	Illuminance	Fc	0.66	2.3	0.1	6.60
Over Walkway	Illuminance	Fc	7.83	10.7	5.5	1.42
Parking Lot	Illuminance	Fc	0.91	2.8	0.1	9.10
Rear Alley	Illuminance	Fc	1.02	2.3	0.1	10.20
Side Alley	Illuminance	Fc	2.86	5.9	0.5	5.72
Side Walk	Illuminance	Fc	1.60	6.4	0.0	N.A.
Under Walkway	Illuminance	Fc	6.85	9.2	4.9	1.40



Calculation Summary						
Label	CalcType	Units	Avg	Max	Min	Avg/Min
Neighbor Parkinglot	Illuminance	Fc	0.47	1.7	0.1	4.70
Over Walkway	Illuminance	Fc	7.85	10.6	5.6	1.40
Parking Lot	Illuminance	Fc	0.91	2.8	0.1	9.10
Rear Alley	Illuminance	Fc	1.02	2.3	0.1	10.20
Side Alley	Illuminance	Fc	1.73	4.7	0.2	8.65
Side Walk	Illuminance	Fc	1.26	6.0	0.0	N.A.
Under Walkway	Illuminance	Fc	6.94	9.4	5.0	1.39

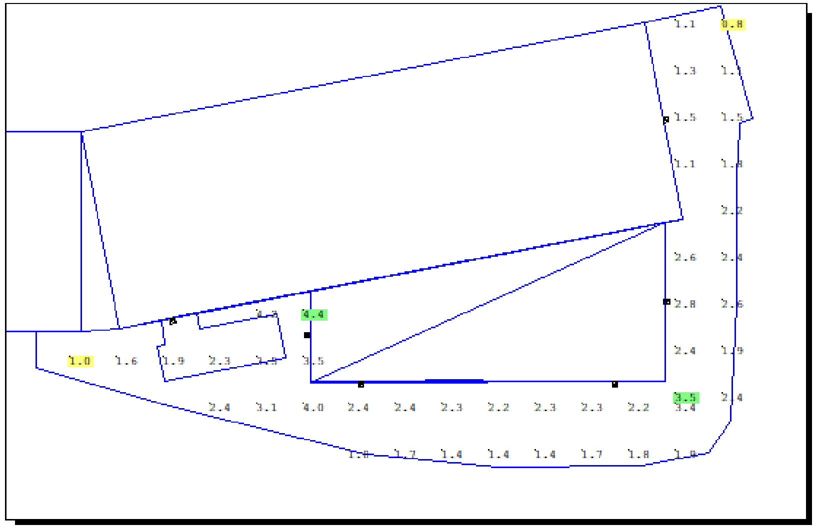
$$2nd\ Floor\ Percent\ Difference = \left(1 - \frac{7.83}{7.85}\right) = 0.2\%$$

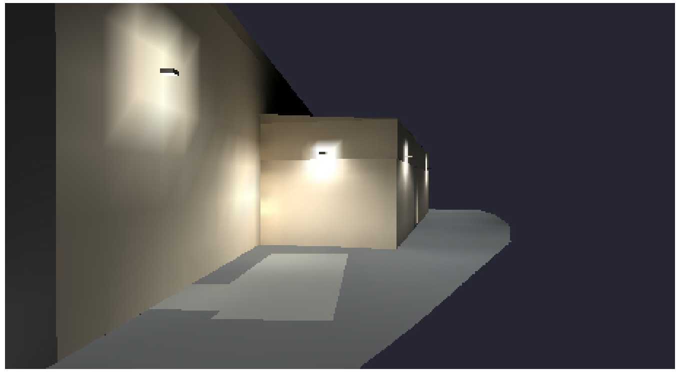
$$1st\ Floor\ Percent\ Difference = \left(1 - \frac{6.85}{6.94}\right) = 1.3\%$$

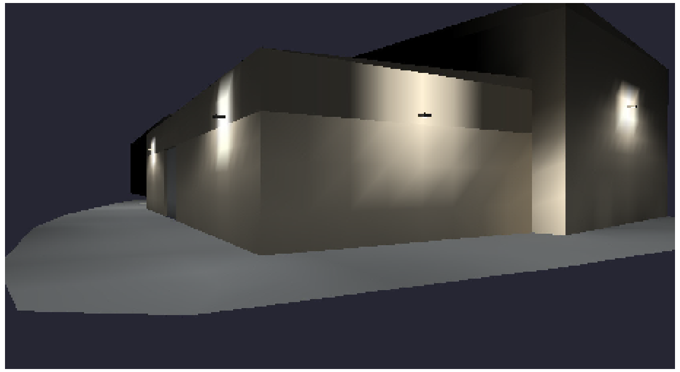
Meaningful Presentation of Data

- Present your results in a way to maximize impact and show your work
  - High light the minimum and maximum values in your calculation grids
  - Include full model numbers of the luminaires you're going to recommend
  - Make notes meaningful and specific
  - Date your drawings
  - Have a 2nd set of eyes review your data

Meaningful Presentation of Data







Notes:

1. Surface reflectance of walls measured in the field, approximately 67%.
2. Luminaire locations and mounting height based on pre-bid MEP drawing set, dated November, 11, 2018. Luminaires mounted 20 ft AFF.
3. Each calculation grid highlights the maximum illuminance (yellow) and minimum illuminance (green).
4. Consider adding an additional luminaire centered on the south wall for higher illuminance levels over the roll-up door.
5. All luminaire (lamp) lumen depreciation (LLD) factors evaluated at end-of-life based on manufacturer listed data, 87% at 100,000 hours.
6. All luminaire dirt depreciation (LDD) factors evaluated for a clean exterior environment with 8-year cleaning cycles, 94%.
7. The UDF is the approximate task-tuned dimming fraction to match the basis-of-design luminaire, a 150W HPS lamp.
8. The Type IV luminaire is installed on the north face of the building extension.
9. The luminaires on B77A over the chiller pad and the south-east corner will be installed by facilities.

Luminaire Schedule

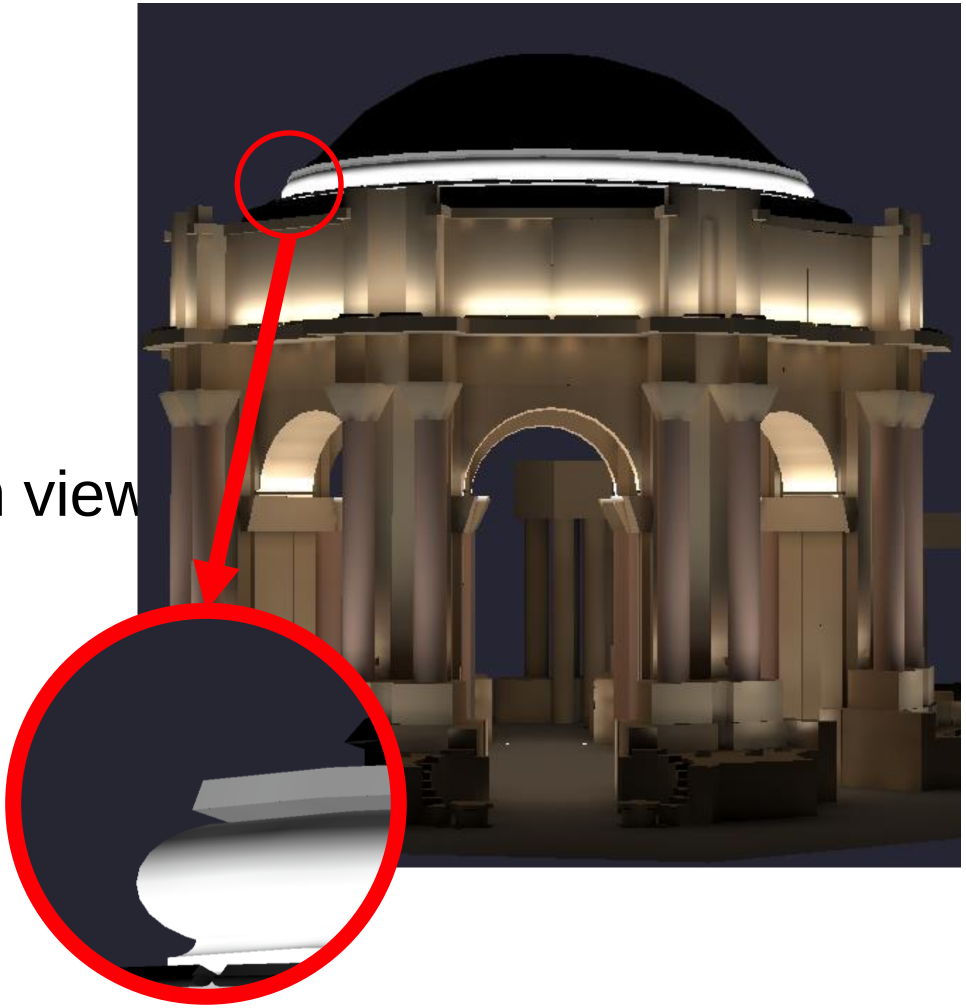
Symbol	Qty	Label	Arrangement	Description	Lum. Lumens	BUG Rating	Lum. Watts	LLD	LDD	UDF
	5	Type II LED Wallpack	SINGLE	Eaton Wallpack GWC AF 02 LED E1 T2 BZ_ 7030 600 PER7 MS/DIM-L20	7109	B1-U0-G2	22	0.870	0.940	0.407
	1	Type IV LED Wallpack	SINGLE	Eaton Wallpack GWC AF 02 LED E1 T4FT BZ_ 7030 600 PER7 MS/DIM-L20	7288	B1-U0-G2	22	0.870	0.940	0.404

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min
East Hardscape	Illuminance	Fc	1.94	3.5	0.8	2.43	4.38
South Hardscape	Illuminance	Fc	2.39	4.4	1.0	2.39	4.40

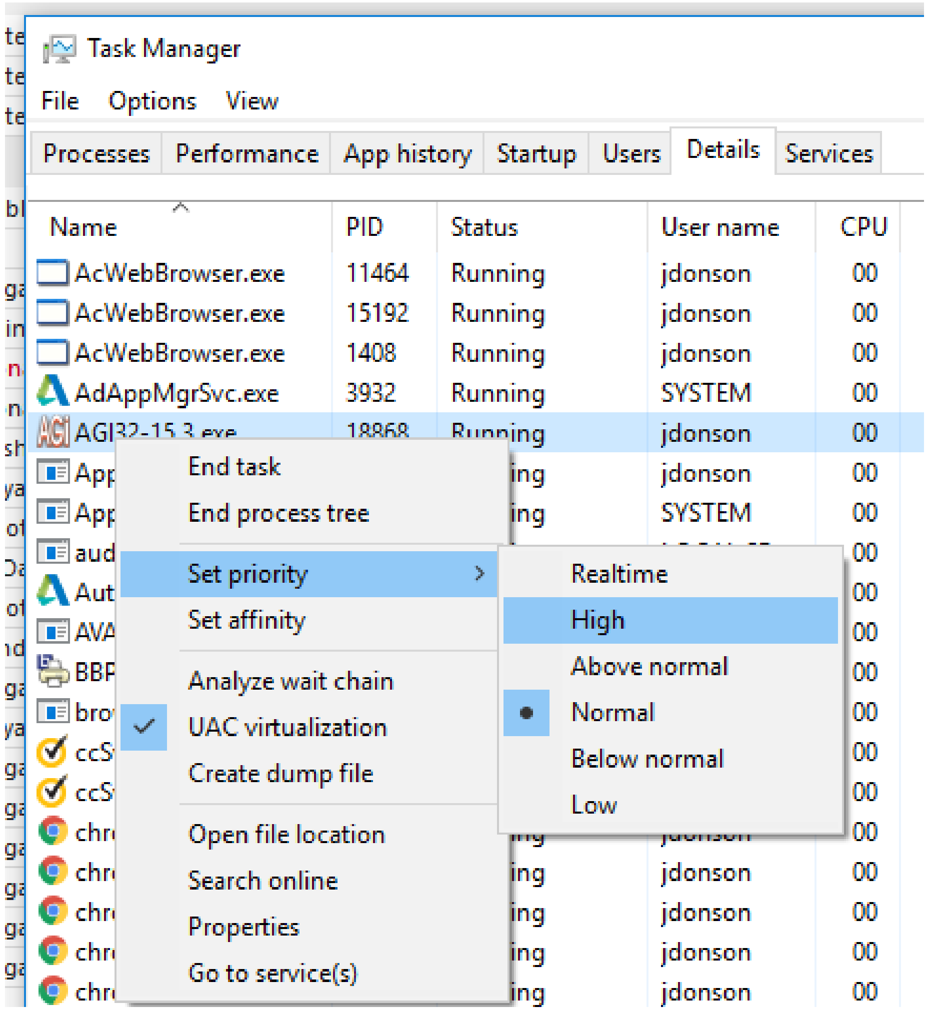
Complexity vs. Simplicity

- Keep things simple, when you can
  - Faster calculations
  - Less visual clutter
- Avoid hidden details
- Turn off surfaces that are hidden from view
- Simplify curved surfaces
  - Don’t flute columns



Faster, Faster… Speed Up Your Calculations

- Particular tricks for Windows users
  - Close unnecessary programs
  - Open Task Manager and assign high processor priority
  - Avoid multitasking
- If your software suite supports it, consider virtualizing parametric runs
  - OpenStudio (NREL) allows this function for energy models



Now for some don'ts…

- Don't use models to set task tuning setpoints
- Don't imply your model is they're photorealistic
  - Don't be afraid of photoshop
- Don't forget to save
- Don't manipulate .ies files directly unless you know what you're doing
- Don't forget to turn on anti-aliasing before taking screen shots

Summary

- Hand calculations are good for quick & dirty analysis
  - Point Source Calculations
  - Lumen Method Calculations
- Software Models
  - Offer greater flexibility and customization
  - Can be quicker, but requires more knowns

Questions?

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(510) 834-6420

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Class Survey (feedback)

- Check email
- Go to survey link
- Written comments are very helpful
- Other topics? Other classes you want?

THANK YOU

Together, Building
a Better California

What is Anti Aliasing

- Anti-aliasing is a term in computer graphics and image rendering
- Graphic engines fundamentally only produce pixels
- Anti-aliasing smears the pixels to create a more realistic appearing edge