Introduction to Lighting Systems and Controls

Course No. ENRG 54

Outline

A. Introduction to fundamentals of lighting

- Lighting terminology
- Physics and principles of lighting
- Units of measurement
- Vision and colors
- Ambient, directional and task lighting
- Over- and under-illuminance

B. Lighting systems

- Components
- Types of lamps
- Ballasts
- Lamp comparison matrix
- Types of lighting luminaires and intensities
- Energy efficiency measures (EEMs)

C. Lighting controls

- Basic concepts of effectiveness of lighting control
- Types and appropriate applications of lighting controls
- Lighting control equations
- Energy efficiency measures (EEMs)

D. Additional EEMs

- De-lamping
- Scotopic lighting
- Task and ambient light levels
- Circadian rhythms

E. Lighting measurements

- Tools
- Data loggers and applications

F. Lighting calculations

- Equation and method of calculating lumens (zonal cavity formula)
- Equation and method of calculating energy savings
- Method of calculating skylight energy savings

G. Lighting standards, codes and regulations

- Underwriters' Laboratory (UL)
- Uniform Building Code (UBC)
- Americans with Disabilities Act (ADA)
- Title 24 applications

H. O&M measures to assure optimal performance

F. Lighting calculations

1. Equation and method of calculating lumens (zonal cavity formula)
2. Equation and method of calculating energy savings
3. Equation and method of calculating skylight energy savings

Zonal Cavity Procedure (Lumen Method)

Zonal Cavity Formula

$$E_{ave} = \frac{\#Fixture \times \#Lamps \times LampLumens \times CU \times LLF}{Area}$$

E ave = Average Illuminance (fc)

CU = Luminaire Coefficient of Utilization

LLF = Light loss factor

Luminaire Coefficient of Utilization

$$CU = \frac{LumensStrikingWorkPlane}{LumensEmittedBytheLamps}$$

- Depends on Room Cavity Ratio (RCR) and room reflectance
- Accounts for the percentage of light that will reach the workplane from a given luminaire under specific room conditions
- Requires user to make assumptions about ceiling and wall reflectances
- Requires user to calculate RCR

Room Cavity Ratio (RCR)

$$RCR = \frac{5h \times (L + W)}{L \times W}$$

or

$$RCR = \frac{2.5h \times P}{L \times W}$$

- h = Distance from luminaire plane to work plane
- L = Room length
- W = Room width
- P = Room perimeter

Light Loss Factors (LLF)

- Recoverable LLFs
  - Lamp Lumen Depreciation (LLD)
  - Luminaire Dirt Depreciation (LDD)
  - Room Surface Dirt Depreciation (RSDD)
- Non-Recoverable LLF
  - Ballast factor
  - Voltage
- Total LLF = LLD X LDD X RSDD X BF X Other LLFs

Zonal Cavity Procedure (Lumen Method)

- Provides a single value of average illuminance

- Advantages

  - Provides a quick, easy way to estimate illuminance or fixture quantities needed

  - An easy means of comparing different luminaires or lamps

Another Use for Lumen Method

- To determine the number of luminaires rquired to achieve an average illuminance:

$$\#Fixtures = \frac{E_{ave} \times Area}{\#Lamps \times LampLumens \times CU \times LLF}$$

E_{ave} = Average Illuminance (fc)

CU = Luminaire Coefficient of Utilizaiton

LLF = Light loss factor

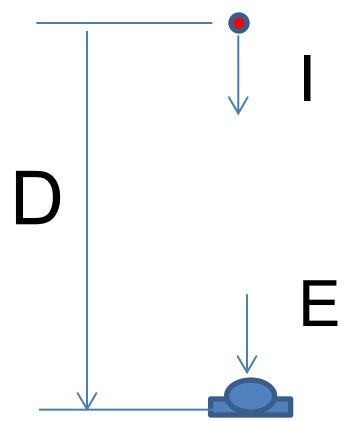
Point by Point Calculations

- Useful for determining illuminance at a specific point
- Accounts for angle of incidence
- Requires knowledge of inverse square law and basic trig. Functions
- Limitations
  - Labor intensive
  - Requires separate calculation for each point
  - Applicable for point sources
  - Does not account for interreflections

Inverse Square Law

- Basic equation to find illuminace

$$E = \frac{I}{D^2}$$



Where

E = targe Illuminance (fc)

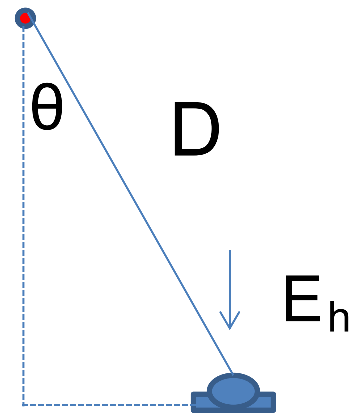
I = Source Intensity (cd)

D = Distance from Source to Target (ft)

Inverse Square Law

- Horizontal illuminace – source at an angle:

$$E_h = \frac{I \cdot \cos(\theta)}{D^2}$$



Where

E_h = targe Illuminance (fc)

I = Source Intensity (cd)

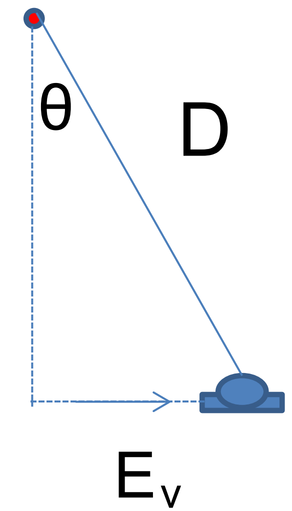
D = Distance from Source to Target (ft)

θ = Angle of incidence

Inverse Square Law

- Vertical illuminace – source at an angle:

$$E_v = \frac{I \cdot \sin(\theta)}{D^2}$$



Where

E = targe Illuminance (fc)

I = Source Intensity (cd)

D = Distance from Source to Target (ft)

θ = Angle of incidence

F. Lighting calculations

1. Equation and method of calculating lumens (zonal cavity formula)
2. Equation and method of calculating energy savings
3. Equation and method of calculating skylight energy savings

Energy saving equation

Power = The Rate of Consumption kilowatts kW

Time = The Duration of Consumption

Energy = Power X Time

= Total Consumption in Kilowatt hours kWh

Control strategy: regulate the rate of consumption (power), or the duration of consumption (time), or both.

Energy saving calculation

Energy = Power X Time = Total kWh

1. If reducing power only (e.g. de-lamping, re-lamping):

   Δ Energy = Δ Power X Time = (Power$_1$– Power$_2$)X Time$_2$

2. If reducing time only (e.g. installing occupancy sensor):

   Δ Energy = Power X ΔTime = Power X (Time$_1$ – Time$_2$)

3. If both power and time reduced (e.g. daylighting control)

   Δ Energy = Power$_1$ X Time$_1$ – Power$_2$ X Time$_2$

Excel practice

1. Δ Energy = Δ Power X Time = $(Power_1 - Power_2)$ X $Time_2$
2. Δ Energy = Power X ΔTime = Power X $(Time_1 - Time_2)$
3. Δ Energy = $Power_1$ X $Time_1$ – $Power_2$ X $Time_2$

	A	B	C	D	E	F	G	H	I	J
1	**Blended energy rate ($/kWh)**									
2	**annual $/kWh**	0.151623								
3										
4					Annual	Annual	Annual	Annual	Annual	Annual
5		Pre kW	Post kW	kW reduced	Pre hours	post hours	hours (savings)	energy savings	energy saving %	dollar ($) savings
6	*Sample - notes*			=B6-C6			=E6-F6	=(B6*E6)-(C6*F6)	=H6/(B6*E6)*100%	=H6*B2
7	Lighting I - de-lamping	1.46	0.96	0.50	1246	1246	0	618.51	34.00%	$ 93.78
8	Lighting II - occupancy	1.46	1.46	0	1246	747.6	498.40	727.66	40.00%	$ 110.33
9	Lighting III - combine I & II	1.46	0.96	0.50	1246	747.6		1,101.46	60.55%	$ 167.01
10										

4. Simple payback period = estimated cost / annual savings

Excel hands-on practice

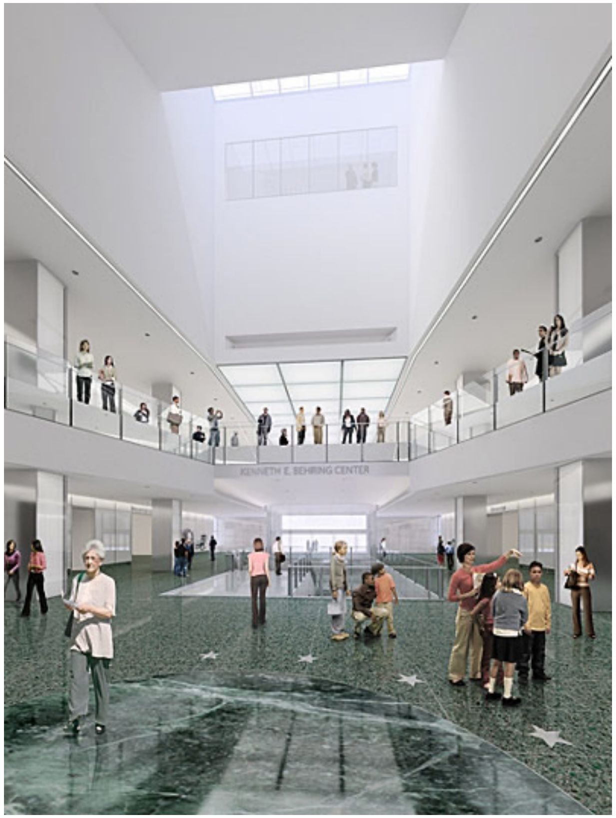
Combining with data logger results, students will calculate energy savings by Excel (at the end of this section)

F. Lighting calculations

1. Equation and method of calculating lumens (zonal cavity formula)
2. Equation and method of calculating energy savings
3. Method of calculating skylight energy savings

Skylights

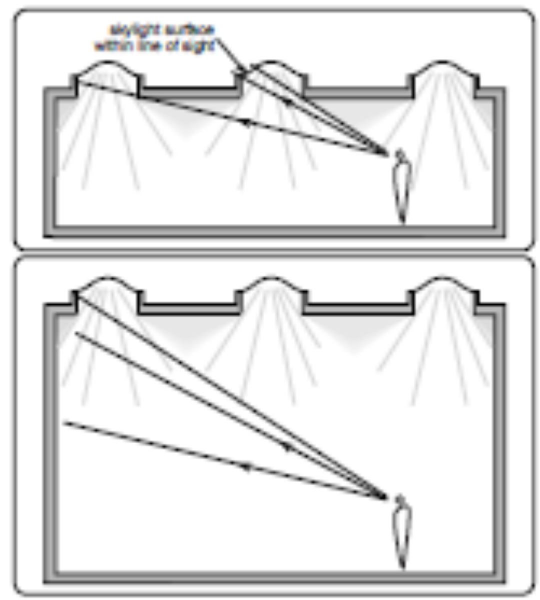
- Provide excellent lighting conditions to the interior of buildings
- Reduce the use of electric lighting, to save energy and reduce peak electric loads when combined with photocontrols
- Satisfy human needs for contact with outdoors
- Increase safety and security with highly reliable daytime lighting
- Provide emergency smoke vents



Americanhistory.si.edu

Considerations when designing skylights

- Visual and thermal comfort
- Seasonal and daily shifts in daylight availability
- Heat loss and heat gain
- Integration with the electric lighting system
- Choice of daylighting control strategy
- Integration with the roofing system
- Integration with the HVAC design
- Utility costs and peak electric demand
- Structural and safety concerns



How skylights save energy?

- Cons :

  - Provide adequate daylight to turn off electric lights

  - Add less heat to a space and reduce cooling

- Pros:

  - Allow more heat to escape through the roof

  - Increase cooling loads by letting more sun’s heat in.

- The optimum balance is a function of the building design, the building operation, and the local climatic conditions.

Who need skylights?

- Buildings with large open areas.
  - retail stores and shopping malls
  - grocery stores
  - schools
  - single-story office buildings
  - manufacturing
  - warehouses
  - distribution centers
  - agricultural building

% of commercial buildings in California?

Retail buildings	18%
Grocery Stores	8.5%
Schools	8.5%
Small offices	5.0%
Warehouses	12%

Total	52%

Significant energy saving opportunities by skylights.

Related materials – Skylighting Guidelines

http://www.energydesignresources.com/resources/publications/design-guidelines/design-guidelines-skylighting-guidelines.aspx

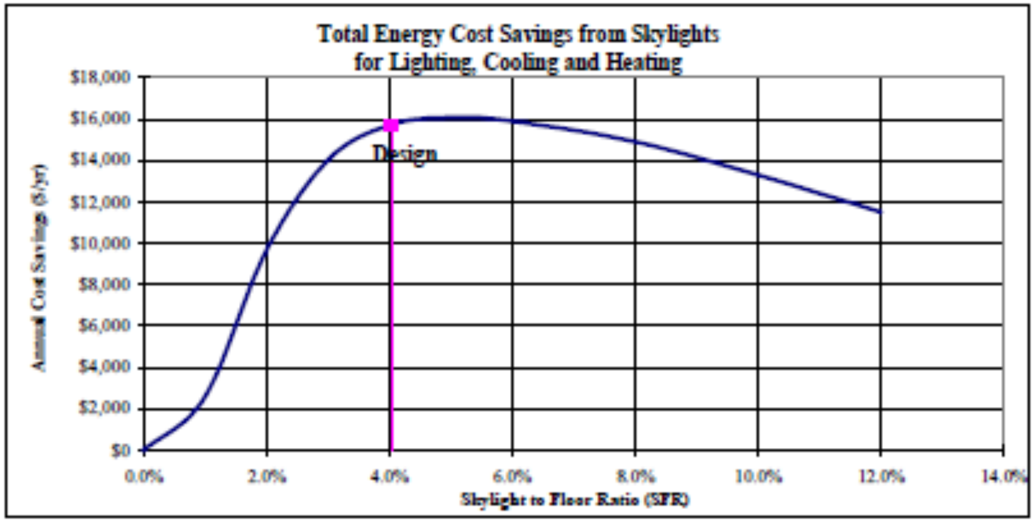
energydesignresources
Your guide to energy efficient design practices.

http://apps1.eere.energy.gov/buildings/publications/pdfs/commercial_initiative/toplighting_final_report.pdf

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Building Technologies Program

SkyCalc – Skylight design tool

- Readily available data for most of California Climate Zones
- Built-in basic lighting calculations, energy cost analysis, and other useful information
- Makes skylight sizing quick and easy
- Accounts for:
  - Heating
  - Cooling
  - Lighting
  - Energy rates
  - Occupancy/use



http://www.energydesignresources.com/resources/software-tools/skycalc.aspx

SkyCalc: example input characteristics

Characteristic	Value			
	Office	School	Warehouse	Big-Box Retail
Building				
Applicable Building Area	10,000 ft^2	10,000 ft^2	10,000 ft^2	50,000 ft^2
Ceiling Height	10ft[a]	10ft[a]	20ft	20ft
Wall Color	Off-White Paint; Reflectance = 80%			
Shelf/Partition Height	5ft	n/a	15ft	7ft
Shelf/Rack Width	n/a	n/a	8ft	6ft
Aisle/Cubicle Width	8ft	n/a	12ft	10ft
Cubical Length	8ft	n/a	n/a	n/a
Electric Lighting				
Lighting System	Open cell fluorescent	Open cell fluorescent	Industrial fluorescent	Industrial fluorescent
Lighting Level	31fc	59fc	24fc	63 fc
Power Density	1.02W/ ft^2	1.21W/ ft^2	0.84W/ ft^2	1.49W/ ft^2
Fixture Height	10ft	10ft	16ft	16ft
Lighting Control	3 level + off switching (90% of lights controlled)[b]			
Skylights				
Glazing Type	Acrylic			
Glazing Layers	Double Glazed			
Glazing Color	Prismatic over High White (VT=65%, SHGC=53%, U=0.81)			
Skylight Well				
Light Well Height	4ft[a]	4ft[a]	1ft	1ft
Well Color	White Paint			

SkyCalc: example input characteristics

SkyCalc: Skylight Design Assistant - Graphic Results

Company Name: Company ABC, Inc.

Project Description: Skylighting Project

Dome Skylight Effective Aperture = 1.69%, Skylight to Floor Ratio (SFR) = 4.03%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	2	13	34	57	73	80	77	64	42	19	3	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	5	23	51	74	90	99	94	79	59	33	9	1	0	0	0	0	0
Mar	0	0	0	0	0	0	2	13	41	67	93	108	115	115	101	76	58	20	4	0	0	0	0	0
Apr	0	0	0	0	0	0	8	32	68	98	121	135	141	135	119	93	61	29	7	0	0	0	0	0
May	0	0	0	0	0	3	16	46	81	109	132	143	148	141	126	104	74	40	13	2	0	0	0	0
Jun	0	0	0	0	0	4	18	49	83	111	128	141	147	145	130	108	80	47	18	4	0	0	0	0
Jul	0	0	0	0	0	2	14	41	75	108	131	142	150	147	137	114	83	48	17	3	0	0	0	0
Aug	0	0	0	0	0	0	8	34	69	98	121	138	146	140	122	102	72	36	10	1	0	0	0	0
Sep	0	0	0	0	0	0	6	26	61	92	115	129	132	126	111	81	49	19	4	0	0	0	0	0
Oct	0	0	0	0	0	0	2	15	44	72	93	106	109	100	84	58	28	7	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	7	27	51	73	84	88	79	61	38	14	3	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	3	15	35	55	68	71	64	52	32	10	2	0	0	0	0	0	0

Design Illuminance = 63 fc

< 1 fc; < 32 fc; < 63 fc; > 63 fc;

BEST Center Curricula, Resources & Recordings

Academic Programs
Georgia Piedmont Technical College - Building Automation Systems
Milwaukee Area Technical College - Sustainable Facilities Operations
Laney College - Commercial HVAC Systems
City College San Francisco - Commercial Building Energy Analysis & Audits

Professional Development Materials, Presentations & Videos
National Institutes
Building Automation Systems Instructor Workshops
Webinars (e.g., BEST Talks)

Faculty Profile Videos
Reports & Case Studies
Marketing Resources

BEST
Building Efficiency for a Sustainable Tomorrow

National Science Foundation