Recap: Electric Lighting Design Analysis Tools

- **Look-ups**: pre-canned solutions provided by product manufacturers to speed adoption of solutions—usually in graphic or tabular format; product-specific
- **Correlations**: product-generic methods—such as the zonal cavity method—applicable to many solutions
- **First principles**: employing basic physics—such as the point-to-point method
- **Computer simulations**: to tap the data storage and number crunching capabilities of computers—often coupled with graphic rendering routines
- **Analog mock-ups**: not common except for proof of concept demonstrations
Illuminances of Concern

- **Design** illuminance = the design criterion
  - The target or benchmark that defines “success”

- **Initial** illuminance = illuminance experienced upon first operating a system (the space and equipment are new)
  - LLF is assumed to be 1.0 when calculating initial illuminance

- **Maintained** illuminance = illuminance found in a space after some defined time (say 2, or 4, or 5 years)
  - This is the condition that occurs when LLF assumes a real value
  - Maintained illuminance must equal or exceed design illuminance in a successful system

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Design Tool: Lookup Tables

*product driven: for a specific lamp-luminaire combination—
in this case a recessed can-type downlight*

<table>
<thead>
<tr>
<th>MOUNTING HEIGHT</th>
<th>FC/0°</th>
<th>DIAMETER</th>
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<td>10’</td>
<td>9</td>
<td>14.2’</td>
</tr>
<tr>
<td>12’</td>
<td>6</td>
<td>17.0’</td>
</tr>
</tbody>
</table>
Design Tool: Zonal Cavity Method

this method applies ONLY to uniform illuminance situations, and is embodied in a worksheet >>

Zonal Cavity Method: Bottom Line

# luminaires =

\[
\frac{(\text{illuminance}) \times (\text{area})}{(\text{lumens per luminaire}) \times (\text{CU}) \times (\text{LLF})}
\]

where, illuminance = design illuminance
CU = coefficient of utilization
LLF = light loss factor
area = illuminated task area
lumens per luminaire = lamp lumens x lamps per fixture
Zonal Cavity Method: Second Bottom Line

**maintained** illuminance =

$$\frac{(#\text{ luminaires})(\text{lumens per luminaire})(\text{CU})(\text{LLF})}{\text{(area)}}$$

where, # luminaires = realistic design luminaire count
lumens per luminaire = lamp lumens x lamps per fixture
CU = coefficient of utilization
LLF = light loss factor  
area = illuminated task area

Zonal Cavity Method: Unstated Bottom Line

**initial** illuminance =

$$\frac{(#\text{ luminaires})(\text{lumens per luminaire})(\text{CU})(1)}{\text{(area)}}$$

where, # luminaires = realistic design luminaire count
lumens per luminaire = lamp lumens x lamps per fixture
CU = coefficient of utilization
LLF has been set to 1.0  
area = illuminated task area
Zonal Cavity Method: Key Metrics

CU = coefficient of utilization

→ the efficiency (lumens/lumens) of a particular luminaire installed in a particular space in delivering light from lamps to task

-- CU is dimensionless (decimal value)
-- 0.65 means 65% of lamp light reaches task

Zonal Cavity Method: Key Metrics

LLF = light loss factor(s)

→ these represent several factors that will result in a difference between initial and maintained illuminance

-- dimensionless (decimal value)
-- 0.75 LLF means a 25% loss
-- total LLF = product of individual LLFs
Light Loss Factors

**Fixed** (non-recoverable)
- Non-standard voltage
- Non-standard ballast
- Non-standard ambient temperature

- these factors essentially adjust lamp performance to account for non-catalog conditions; they are generally constant over time (they don’t escalate; they can’t be recovered by maintenance)

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**Progressive** (recoverable)
- Burnouts
- Lamp lumen depreciation
- Luminaire dirt depreciation
- Room surface dirt depreciation
- Luminaire surface depreciation

- these factors essentially adjust illuminance estimates for wear and tear on the lighting system; they escalate with time (and can be recovered … at a cost)
Zonal Cavity Method

general data

correlators

LLFs

calculations

Zonal Cavity Walkthrough

start with design illuminance; luminaire selection (often a trial selection); and lamp selection (perhaps also a trial)
Zonal Cavity Walkthrough

select a luminaire (from IESNA Lighting Handbook, textbook, or a www site); find CU data for the fixture ... after the correlating factors are assembled

the IESNA Lighting Handbook, has typical CU data (and more information) for many generic fixture types; manufacturers’ www sites will have specific fixture CU data
Zonal Cavity Walkthrough

Initial luminaire selection will be based upon some design criteria; compliance with these criteria can be roughly evaluated from sample information in the table.

Find lamp data; from generic tables or manufacturer's catalog information for zonal cavity method need initial lumens and lumen maintenance (lamp LLF).
Zonal Cavity Walkthrough

define space geometry and reflectances, calculate correlation variables (cavity ratios and effective reflectances); establish CU value

extracting CU values—to do so one needs to know RCR, \( \rho_{ocw} \) and \( \rho_{ow} \) values (\( \rho_{ocw} \) is assumed to be 20%)
Zonal Cavity Walkthrough

start with space dimensions (L, W, and H of three "cavities")

Zonal Cavity Walkthrough

Ceiling Cavity Ratio (CCR) = \( \frac{5 \, hcc \, (L+W)}{L \times W} \)

Room Cavity Ratio (RCR) = \( \frac{5 \, hrc \, (L+W)}{L \times W} \)

Floor Cavity Ratio (FCR) = \( \frac{5 \, hfc \, (L+W)}{L \times W} \)

calculate cavity ratios for three cavities using above equations (or look-up tables)
a non-existent cavity has a ratio of "0" (h = 0)
Zonal Cavity Walkthrough

Cavity Ratio = \(\frac{2.5 \times \text{height of cavity} \times \text{cavity perimeter}}{\text{area of cavity base}}\)

cavity ratios can be calculated for non-rectilinear spaces using a more basic equation.

Zonal Cavity Walkthrough

\[\rho_{w} = \frac{(\rho_{1})(\text{area}_{1}) + (\rho_{2})(\text{area}_{2}) + \ldots}{\text{area}_{1} + \text{area}_{2} + \ldots}\]

wall reflectance (\(\rho_{w}\)) is the weighted average reflectance of wall surfaces
\(\rho\) = visible reflectance (\%)
area = surface area
1, 2, \ldots are different finishes or materials in the cavity being considered.
Zonal Cavity Walkthrough

Table A
Percent effective ceiling or floor cavity reflectance for various reflectance contributions.

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<th>% Ceiling or floor reflectance</th>
<th>20</th>
<th>30</th>
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establish effective cavity reflectances for ceiling and floor cavities—using this chart; ceiling/floor reflectance, wall reflectance, and cavity ratio are variables

Zonal Cavity Walkthrough

Table B
Multiplying factors for other than 20 percent effective floor cavity reflectance.

<table>
<thead>
<tr>
<th>% Effective floor cavity reflectance, ( \rho_{fc} )</th>
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<th>60</th>
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For 30 percent effective floor cavity reflectance (20 percent + 1.00)

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For 10 percent effective floor cavity reflectance (20 percent + 0.50)

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CU adjustment factors are used if floor cavity reflectance (\( \rho_{fc} \)) is not 20%
Zonal Cavity Walkthrough

spacing criterion is the maximum distance luminaires may be spaced apart (usually taken as center line to center line) if illuminance is to be reasonably uniform

| Spacing Criterion, d | 50% | 55% | 60% | 75% | 90% | 95% | 50% | 55% | 60% | 75% | 90% | 95% | 50% | 55% | 60% | 75% | 90% | 95% | 50% | 55% | 60% | 75% | 90% | 95%
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CU values are extracted from data tables on the basis of rho_{cc}, rho_{cr}, and RCR in this case from manufacturer’s catalog data

note spacing criterion value (near top of table)

Zonal Cavity Walkthrough

establish LLF values

LLF_{total} = (LLF_1) (LLF_2) (…)

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Zonal Cavity Walkthrough

Lamp Lumen Depreciation

As a lamp ages and nears end of life, it produces less and less light on a predictable curve, the extent of which depending on the type of lamp. If group relamping is employed as a planned maintenance strategy, then take the LLD factor for the point in life at which the lamps are replaced en masse. Otherwise, use an average, which is at 40% of life. See the Table below for typical LLD values for various lamps.

Table: Typical LLD factors for several lamp types. Note that additional phosphor coatings to improve CRI in fluorescent lamps improves lumen maintenance.

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>LLD Factor</th>
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<tbody>
<tr>
<td>F32T8, 85 CRI</td>
<td>0.91</td>
</tr>
<tr>
<td>F60T12/CW “Slimline”</td>
<td>0.88</td>
</tr>
<tr>
<td>F60T12 “Slimline,” 85 CRI</td>
<td>0.94</td>
</tr>
<tr>
<td>F60T12/HO/CW</td>
<td>0.83</td>
</tr>
<tr>
<td>F60T12/HO, 85 CRI</td>
<td>0.90</td>
</tr>
<tr>
<td>Compact fluorescent</td>
<td>0.85</td>
</tr>
<tr>
<td>Mercury vapor</td>
<td>0.79</td>
</tr>
<tr>
<td>Metal halide</td>
<td>0.63</td>
</tr>
<tr>
<td>High pressure sodium</td>
<td>0.91</td>
</tr>
</tbody>
</table>

**Lamp Lumen Depreciation**
select a reasonable value for the chosen lamp type

---

Zonal Cavity Walkthrough

Luminaire Dirt Depreciation

A multi-step process …

(1) Establishing categories
Zonal Cavity Walkthrough

Luminaire Dirt Depreciation (continued)
(2) establishing environmental dirt conditions

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Luminaire Dirt Depreciation (continued)
still establishing environmental dirt conditions

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Luminaire Dirt Depreciation (continued)
(3) select a reasonable value for chosen luminaire type, considering environmental dirt conditions, and cleaning schedule

System Voltage Effect (LLF)
establishing building voltage impact on lamp output
Zonal Cavity Walkthrough

- crunch numbers
- a) mathematical fixtures required
- b) actual fixtures desired
- c) maintained illuminance
- d) Initial illuminance

Zonal Cavity Walkthrough

\[ \text{# of luminaires} = \frac{\text{desired footcandles}}{\text{lamp/fixture} \times \text{lumen/lamp} \times \text{CU} \times \text{LLF}} \times \text{area in sq. ft.} \]

yields precise number of fixtures needed to deliver maintained illuminance
this may be 24.7 (not possible) or 11 (not symmetrical)
Zonal Cavity Walkthrough

Footcandles = \frac{\text{# of fixtures} \times \text{lamps per fixture}}{\text{lumens per lamp} \times \text{CU} \times \text{LLF}} \times \frac{1}{\text{area in square feet}}

select architecturally-desired number of fixtures and recalculate illuminance

Another Design Tool: Point-to-Point Method

• Used with *local (or supplemental) illuminance* approach
• Requires access to luminous intensity data
  – Manufacturer’s catalog (specific) – commonly done
  – Lighting handbooks (generic) – less common
• Requires no information about space (considers *direct* illuminance only)
• Does require information about the source-task arrangement
• Should it also require a sense of maintenance??
Point-to-Point Method

\[ E = \frac{(I)(\cos \Theta)}{(d^2)} \]

where,

- \( E \) = illuminance
- \( I \) = luminous intensity in direction “D”
- \( \Theta \) = angle of incidence
- \( d \) = distance (source to task)

see next slide for illustration

Design Analysis:
Point-to-Point Method

establish situational geometry—
find \( d \) (between source and \( P \))
find \( \Theta \)
Point-to-Point Method

\[ E = \frac{(I) \cos \Theta}{d^2} \]

involves the “cosine law” (light is spread over a greater area as angle of incidence increases)

(cos 0 = 1.0; cos 90 = 0)

and also

involves the “inverse square law” (light is spread over a greater area as distance increases)

Design Analysis:
Point-to-Point Method

select luminaire/lamp, then find luminous intensity (candlepower) at appropriate angle(s)
there are several formats for luminous intensity data

LED is NOT – repeat, NOT energy efficient in most applications just yet. There are a few efficient LED products – like the CREE downlight – and a lot of mediocre, inefficient stuff. Be very selective and don’t believe the marketing hype.

A good place to learn more about the problems of current LED products is the US DOE’s CALIPER reports. James Benya-SBSE listserv (7 Nov 2008)