Electric Lighting Design Using the Zonal Cavity Method

An office is 30' long by 20' wide and the ceiling is 9' high. The sill height is 3' and above the sill is a 6' tall window that runs along the length of the room. Ceiling reflectance is 80%. Wall reflectance is 50%. The floor reflectance is 20%. Since the primary task is reading, the required illumination level is 50 fc on the work surface 2'-6" above the floor. The fixtures (see fixture #47 from Table 15.1) each provide 2900 lumens/lamp in a radial batting distribution from four T8 fluorescent lamps with a flat prismatic lens. These direct lighting fixtures are recessed in the ceiling, are replaced on burnout, and are in a "very clean" environment and are cleaned on a 12 month cycle. The proposed lighting control (a light switch) does not include any daylight sensor features.

I. Based on the above information, determine the number of fixtures needed to provide the required illumination. Ignore the potential effects of daylighting for this step. Design a layout for each potential number of lighting fixtures that meets the lighting level requirements. When possible, use standard geometric layouts (e.g., if your calculations show 12 fixtures are needed then lay out 4 rows of 3 fixtures, 3 rows of 4 fixtures, or 2 rows of 6 fixtures) and confirm that the layout satisfies S/MH requirements.

II. The fixtures each consume 128 watts of power. What is the power required for lighting this space (expressed as watts and watt/sf)? If the energy code allows a maximum of 2.0 watts/sf usage for lighting, which of the proposed schemes meet the energy code if no allowance for daylighting controls are included in the calculation?

III. Consider using a daylighting sensor that includes a 3-step controller (PAF=0.20). What impact will using this control have on the energy consumption? Which of the proposed layouts, if any, now meet the energy code?

IV. If the space is used 8:00AM-5:00PM weekdays throughout the year and electricity costs $0.081/kwh, what does it cost annually to operate these lights without the daylight controls? With the daylight controls?

V. Your client will accept energy conservation upgrades with simple paybacks of less than three years. If the daylighting control costs an additional $100 beyond what the simple light switch control would have cost, should you recommend the inclusion of the daylighting control?
Follow form given on page 656, Fig. 15.37

1. Project Identification: Office
2. \( E = 50 \text{fc} \)
3. \( \text{N/A} \)
4. \( \text{N/A use #47 from Table 15.1 p 632} \)
5. \( T-8 \)
6. 4 lamps
7. \( 4 @ 2900 \text{ lumens} = 11,600 \text{ lumens} \)
8. \( \theta = 0.8^\circ \)

\[ \begin{align*}
\rho &= 0.5 \\
\rho &= 0.5 \\
\rho &= 0.5 \\
\theta &= 0.8^\circ \\
L &= 20 \\
W &= 20
\end{align*} \]

9. Determine cavity ratios

9.1 \( \text{CCR} = \frac{5(h_{cc})(L+W)}{L\times W} = \frac{5(0)(30+20)}{30\times 20} = 0.0 \)

9.2 \( \text{CCR} = \frac{5(h_{rc})(L+W)}{L\times W} = \frac{5(6.5)(30+20)}{30\times 20} = 2.71 \)

9.3 \( \text{CCR} = \frac{5(h_{fc})(L+W)}{L\times W} = \frac{5(2.5)(30+20)}{30\times 20} = 1.04 \)
10. Obtain effective ceiling cavity reflectance \( \rho_{cc} \)

See Table 15.2 p. 657

\[ \rho_c = 0.80 \]
\[ \rho_w = 0.50 \]
\[ CCR = 0 \]

\[ \therefore \rho_{cc} = 80\% \text{ or } 0.80 \]

11. Obtain effective flat cavity reflectance \( \rho_{fc} \)

See Table 15.2 p. 657

\[ \rho_f = 0.2 \quad \text{interpolation needed to fill in} \]
\[ \rho_w = 0.5 \]
\[ \rho = 0.20 \]

\[ \rho_f = \begin{array}{c} 0.30 \quad 0.20 \quad 0.10 \\ \rho_w = \begin{array}{c} 0.50 \quad 0.50 \quad 0.50 \\ \end{array} \end{array} \]

\[ \begin{array}{c|c} \rho_{fc} = & 1.00 \quad 0.27 \quad 0.19 \quad 0.11 \\ \end{array} \]
\[ \begin{array}{c|c|c} \rho_{fc} = & 1.04 \quad 0.19 \quad 0.12 \\ \end{array} \]

\[ \rho_{fc} = 0.19 \text{ avg } 0.20 \text{ or } 20\% \]
12. Obtain coefficient of utilization (CU) for fixture # 47 (p.682)

\[
\begin{align*}
P_c & = 0.86 \\
P_w & = 0.50, 0.30, 0.10 \\
P_f & = 0.20 \\
R_C & = 2.00, 0.55 \\
2.71 & = 0.50, \text{ by interpolation: } CU = 0.50 \\
3.00 & = 0.48
\end{align*}
\]

**Light Loss Factors**

13-16. Default 0.88

17. Room Surface Dirt Depreciation

Direct Lighting 0.92

18. Lamp Lumen Depreciation

Fluorescent, replaced on burnout 0.85

19. Lamp Burnout Factor

Replaced on burnout 0.95

20. Luminaires Dirt Depreciation (LDD)

Category V 0.83

21. \( LLF = 0.88 \times 0.92 \times 0.85 \times 0.95 \times 0.83 = 0.54 \)

22. Number of Luminaires

\[
N = \frac{E \times (\text{AREA})}{\text{LUMENS/LUMINAIRES} \times CU \times LLF} = \frac{50(600)}{14600 \times 0.50 \times 0.54} = 9.6
\]
...22 (continued) 9.6 fixtures are required to meet 50 fc.

\[ \text{Range } \pm 10\% : \quad 45 \leq E \leq 55 \]

8 fixtures produce \( 41.8 \text{ fc} \) \( \times \)
9 fixtures produce \( 47.0 \text{ fc} \) \( \text{ok} \)
10 fixtures produce \( 52.2 \text{ fc} \) \( \text{ok} \)
11 fixtures produce \( 57.4 > 55 \text{ fc} \) \( \times \)

**Scheme #1:** 9 fixtures. 3 rows of 3 fixtures

![Diagram](image)

Verily \( S/MH \leq 1.7 \)

\[ MH = 0.5' \quad \therefore \text{Smallest} = 11.05' \text{ or } 11' - \frac{1}{2}'' \]

6' - 8" \( \leq \) 11' - \(\frac{1}{2}\)" \( \text{ok} \)
10' \( \leq \) 11' - \(\frac{1}{2}\)" \( \text{ok} \)

Note: Fixtures could also be mounted parallel to 20' wall
22. Schema #2: 2 rows of 5 fixtures

Verify: S/m A ≤ 1.7

6' 0" ≤ 11' - 0' 1/2"
10' 0" ≤ 11' - 0' 1/2"

Note: Fixtures could be mounted parallel to 20' wall but not as 5 fixtures along 20' dimension

15' > 11' - 0' 1/2"
II. Scheme #1: 9 fixtures @ 128 watts/fixture

... Total Power = 1152 watts
... Power Density = 1152 / 600 = 1.92 w/sf

... Scheme #2: 10 fixtures @ 128 watts/fixture

... Total Power = 1280 watts
... Power Density = 2.13 w/sf

ENERGY CODE < 2.0 w/sf

Scheme #1: 1.92 < 2.0 w/sf ✓ passes
Scheme #2: 2.13 > 2.0 w/sf X fails

ONLY SCHEME 1 PASSES ENERGY CODE

III. Use Daylight Control with 3-step Controller

PAF = 0.20

Scheme #1

Connected Lighting Power (CLP) = 1.92 w/sf
Adjusted Lighting Power (ALP)

ALP = (1 - PAF) x CLP = (1.0 - 0.2) x 1.92 = 1.54 w/sf
III. continued

Recheck Scheme 2 to see if lighting control
will allow it to pass energy code.

\[ CLP = 2.13 \, \text{w/sf} \]
\[ ALP = (1 - 0.2) \times 2.13 = 1.71 < 2.0 \, \text{w/sf} \] \( \checkmark \) passes
code

Both Scheme 1 + 2 pass energy code with
daylighting control system

IV. **Annual Operating Cost**

8:00 - 5:00 @ 52 weeks x 5 days/week = 2340 hrs/yr

Without Daylight Controller

Scheme #1 = 2340 hrs/yr \times 1152 \, \text{watts} \times \frac{1 \, \text{kwh}}{1000 \, \text{wh}} \times \frac{0.081 \, \text{kwh}}{1 \, \text{kwh}}
\[ = \$218.35/yr \]

Scheme #2 = 2340 hrs/yr \times 1280 \, \text{watts} \times \frac{1 \, \text{kwh}}{1000 \, \text{wh}} \times \frac{0.081 \, \text{kwh}}{1 \, \text{kwh}}
\[ = \$242.61/yr \]
IV. (continued)

With Daylighting Controls

\[ \text{Scheme } \#1 = 2340 \text{ hrs/yr} \times 1.54 \text{ W/sf} \times 600 \text{ sf} \times 1 \text{kwh/1000 W} \times 0.081/\text{kwh} \]

\[ = \$174.76/\text{yr} \]

\[ \text{Scheme } \#2 = 2340 \text{ hrs/yr} \times 1.71 \text{ W/sf} \times 600 \text{ sf} \times 1 \text{kwh/1000 W} \times 0.061/\text{kwh} \]

\[ = \$194.47/\text{yr} \]

V. Is daylight control economically attractive if simple payback must be \( \leq 3 \) years?

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Added First Cost</th>
<th>Annual Cost</th>
<th>Annual Savings</th>
<th>Payback</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/O Control</td>
<td>( - )</td>
<td>218.35</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>W/Control</td>
<td>100.00</td>
<td>174.76</td>
<td>43.59</td>
<td>2.3 yrs</td>
</tr>
</tbody>
</table>

\[ (PB = 100 \div 43.59 = 2.3 \text{ years}) \]

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<td>( - )</td>
<td>242.61</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>W/Control</td>
<td>100.00</td>
<td>194.47</td>
<td>48.14</td>
<td>2.1 yrs</td>
</tr>
</tbody>
</table>

Recommendation: Adding daylight controller to either scheme has a payback \( < 3.0 \) years and therefore is acceptable. Note: Scheme \#2 has higher operating costs and only meets energy code with daylight controller installed. I.E. Use Scheme \#1 with daylight controller.