Illuminating Passive Houses
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What is *daylighting*?

The *controlled* distribution of natural light in a space.
What is daylighting?

NOT: sunlight
What is daylighting?
Lake/Flato recommendation: 20-30% WWR
TABLE 8-1 Percentage of Total Energy Use and Carbon Dioxide Emissions Attributable to Specific Applications in US Buildings in 2006 (DOE, 2010)

<table>
<thead>
<tr>
<th>Energy Use</th>
<th>Energy Use</th>
<th>Carbon Dioxide Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>Residential</td>
</tr>
<tr>
<td>Space heating</td>
<td>19.8</td>
<td>26.4</td>
</tr>
<tr>
<td>Lighting</td>
<td>17.7</td>
<td>11.6</td>
</tr>
<tr>
<td>Space cooling</td>
<td>12.7</td>
<td>13.0</td>
</tr>
<tr>
<td>Water heating</td>
<td>9.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Electronics</td>
<td>7.8</td>
<td>8.1</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>5.8</td>
<td>7.2</td>
</tr>
<tr>
<td>Cooking</td>
<td>3.4</td>
<td>4.7</td>
</tr>
<tr>
<td>Wet cleaning&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3</td>
<td>6.2</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>2.8</td>
<td>—</td>
</tr>
<tr>
<td>Computers</td>
<td>2.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Other</td>
<td>8.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Attributable to buildings but not directly to specific end uses</td>
<td>6.3</td>
<td>5.7</td>
</tr>
</tbody>
</table>

<sup>a</sup>Primarily automatic washers, dryers, and dishwashers.
Figure 7.0 Coal Flow, 2010
(Million Short Tons)

Bituminous Coal 509.0
Subbituminous Coal 801.2
Lignite 73.2
Anhydrite 1.6
Production 1,065.3
Stock Change 20.5
Imports 19.4
Waste Coal Supplied 13.9
Exports 81.7
Stocks and Unaccounted for 8.9
Residential 0.3
Commercial 2.7
Industrial 69.6
Electric Power 973.5
Figure 8.0  Electricity Flow, 2010
(Quadrillion Btu)
Remember:
...the electricity grid is primarily fed by fossil fuels (71% on average): with the current power mix, it is reasonable to argue that electricity is America’s dirtiest fuel.

-John Straube
Why is daylighting so important?

• Energy Efficiency
• Health
• Productivity
• (Almost) Perfect Color Rendering
How does daylighting save electricity?
Rainha Santa Isabel Secondary School/Oficina - Ideias em Linha
Jet Blue terminal at JFK
Basic Daylighting Strategies

• Solar Geometry
• Sidelighting
• Toplighting
• Form
• Programming
• Space Planning
• Surface Reflectances
Solar Geometry
Free University Library, Norman Foster
Genzyme Center, Stefan Behnisch
Sana’a, Yemen
Solar Development, Georg Reinberg, Vienna
Southern Orientation
Southern Orientation
A Pattern Language, Alexander, pattern #128: Indoor Sunlight
From UTSoA Facade Thermal Lab:
Stefan Bader
Dr. Werner Lang
Professor Matt Fajkus, Thermal Lab Director

- a) Horizontal shading devices
- b) Vertical shading devices
- c) Eggcrate shading structure - square
- d) Honeycomb shading structure - horizontally oriented
- e) Honeycomb shading structure - vertically oriented
- f) Honeycomb shading structure - vertically oriented - 4’ circumference
From UTSoA Facade Thermal Lab:
Stefan Bader
Dr. Werner Lang
Professor Matt Fajkus, Thermal Lab Director

Monthly solar radiation - comparison of shading structures per orientation (Austin, TX)
5pm
South
June 5
West, South
Summer
Northern Orientation
Eastern Orientation
Eastern Orientation
A Pattern Language, Alexander, pattern #138: Sleeping to the East
10am, 12pm
East
September 8
Western Orientation
Western Orientation
7pm
West
July 12
5:00 pm, Overcast
SE, SW
July 24
The Galvestonian – West Facade
The Galvestonian – West Facade
The Galvestonian – West Facade
8:00 am
August 4
The Galvestonian – East
Objectives: Toplighting & Sidelighting

- Solar Geometry
- Sidelighting
- Toplighting
- Form
- Programming
- Space Planning
- Surface Reflectances
Perception of brightness:

1. **Luminance** of object

2. **Contrast:**
   - Brightness of adjacent objects
   - Luminance Ratios

3. **Biology of Individual:**
   - Health/Age
   - Accommodation
   - Adaptation (time dependent)
Eye Adapts to bright background leaving subject in silhouette, Fuller Moore
Excessive luminance ratios

**Figure 12.10a** In this photograph, the camera was adjusted to correctly expose the high brightness of the exterior. We cannot see indoors because the brightness there is too low compared to the outdoors. This is a problem of excessive brightness ratios.

**Figure 12.10b** In this photograph, the camera was adjusted to correctly expose the interior. Consequently, we cannot clearly see the outdoor view because it is too bright compared to the interior. This is a problem of excessive brightness ratios.

<table>
<thead>
<tr>
<th>Contrast Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>Contrast is necessary for visibility</td>
</tr>
<tr>
<td>MEDIUM</td>
<td>Contrast is necessary for visibility</td>
</tr>
<tr>
<td>LOW</td>
<td>Contrast is necessary for visibility</td>
</tr>
</tbody>
</table>

*Mechanical and Electrical Equipment for Buildings*, Kwok/Grondzik
Light Shelf

- Most effective on south façade
- East and west – must be longer
- Not effective on north
Light Shelf
Light Shelf
Assessing Light Shelf and Optical Louver Systems in Multi-Story Office Buildings by Using Experimental Methods
Presented at ASES 2011 by Dr. Jianxin Hu, NC State University

Experiments test:

• Light Shelf Top Surfaces
• Partition Materials
• Placement of Partitions
• Ceiling Height
• Comparisons of the Light Shelf & FISCH system

Figure 1: Exterior Image of the Test Cell
Figure 2: Interior Dimensions of the Test Cell
Figure 3: Four Reflectors and Their Optical Properties.
Assessing Light Shelf and Optical Louver Systems in Multi-Story Office Buildings by Using Experimental Methods
Presented at ASES 2011 by Dr. Jianxin Hu, NC State University
Assessing Light Shelf and Optical Louver Systems in Multi-Story Office Buildings by Using Experimental Methods
Presented at ASES 2011 by Dr. Jianxin Hu, NC State University

Data Sheet 1-1

<table>
<thead>
<tr>
<th>system</th>
<th>ceiling HGT</th>
<th>top of V.G.</th>
<th>L.S. length</th>
<th>REPL. MTRL.</th>
<th>layout type</th>
<th>PAR. MTRL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Shelf</td>
<td>11’ – 2”</td>
<td>7’ - 2”</td>
<td>6’ – 0”</td>
<td>mirror</td>
<td>0</td>
<td>opaque</td>
</tr>
<tr>
<td>FISCH</td>
<td>12’ – 0”</td>
<td>8’ – 0”</td>
<td>12’ - 0”</td>
<td>white tile</td>
<td>1</td>
<td>translucent</td>
</tr>
<tr>
<td></td>
<td>9’ – 0”</td>
<td></td>
<td></td>
<td>white board</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>foil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Building Form

Figure 13.1d These were the common floor plans for large buildings prior to the twentieth century because of the need for light and ventilation.
Alvar Aalto Mount Angel

Space Planning: stacks (or desks) perpendicular to windows
Alvar Aalto Mount Angel
Space Planning: translucent interior partitions
SMP Architects
Space Planning
Color, Surface Reflectances
Glazing Selection

**U-Factor**
- U-factor measures how well a window prevents heat from escaping.
- Ratings generally fall between 0.20 and 1.20.
- The lower the U-value, the greater a window's resistance to heat flow and the better its insulating value.

**Visible Transmittance**
- Visible Transmittance (VT) measures how much visible light comes through a window, expressed as a number between 0 and 1.
- The higher the VT, the more light is transmitted.

**Condensation Resistance**
- Condensation Resistance (CR) measures on a scale of 0 to 100 the ability of a window to resist the formation of condensation on the interior surface.
- The higher the rating, the better the product is at resisting condensation. While this rating cannot predict condensation, it allows consistent product comparisons.

**Solar Heat Gain Coefficient**
- Solar Heat Gain Coefficient (SHGC) is the fraction of incident solar radiation admitted through a window as heat gain, either directly transmitted or absorbed by the glass and then released inward.
- SHGC is expressed as a number between 0 and 1.
- The lower the SHGC, the less solar heat is transmitted.

**Air Leakage**
- Air Leakage (AL) through a window is expressed as the equivalent cubic feet of air passing through a square foot window area (cfm/sq ft).
- The lower the AL, the less air will pass through cracks in the window assembly.

**Energy Performance Ratings**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U-Factor</strong></td>
<td>0.35</td>
</tr>
<tr>
<td><strong>Solar Heat Gain Coefficient</strong></td>
<td>0.32</td>
</tr>
</tbody>
</table>

**Additional Performance Ratings**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visible Transmittance</strong></td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Air Leakage</strong></td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Condensation Resistance**
- 51
Top Lighting
Advantages:
- Potential for uniform illumination over great floor areas
- Receive greater amounts of illumination

Disadvantages:
- Intensity of light is greater in summer than in winter
- Difficult to utilize other than 1-story buildings or the top floor
- Difficult to shade – therefore try to use vertical glazing on the roof (clerestories, monitors, sawtooths)
The Menil Museum, Renzo Piano
Side Lighting
2.5H Rule of Thumb Assumes:
- Clear Glazing
- Overcast Skies
- No major obstructions
- Total window width approximately 1/2 of perimeter wall

15/30 Rule of Thumb Assumes:
- No assumptions stated
- Very basic guess
Calculating Sidelighting Apertures

\[ A = \frac{(DF_{\text{target}})(A_{\text{floor}}))}{(F)} \]

where,
- \( A \) = required area of aperture, \( ft^2 \) [\( m^2 \)]
- \( DF_{\text{target}} \) = target daylight factor
- \( A_{\text{floor}} \) = illuminated floor area, \( ft^2 \) [\( m^2 \)]
- \( F \) = 0.2 if the target is an average daylight factor OR
  0.1 if the target is a minimum daylight factor

Note: any window area below task height is of little use for daylighting.
Basics Window Strategies:
From *Heating, Cooling, Lighting* - Lechner

1. Place high on the wall, widely distributed, optimize overall area
2. If possible, place windows on more than one wall
3. Place windows adjacent to interior walls
4. Splay jambs to reduce the contrast between windows and walls
5. Filter daylight
6. Shade windows from excess sunlight in summer
7. Use movable shades
8. Additional Strategies
1. Place high on the wall, widely distributed, optimize overall area

*Figure 13.10a* Daylight penetration increases with window height.
Assessing Light Shelf and Optical Louver Systems in Multi-Story Office Buildings by Using Experimental Methods

Presented at ASES 2011 by Dr. Jianxin Hu, NC State University

4. Ceiling Height

Ceiling height is a crucial factor in daylighting design. The purpose of this phase is to demonstrate how much a ten-inch difference in ceiling height could affect the performance of daylighting solutions. The issue is studied in conjunction with several daylighting systems and in a number of space configurations, one of which is shown in Figure 11.

![Figure 11: Configuration for Studying Ceiling Height](image)

In this case, going from the 11'-2" ceiling to the 12'-0" ceiling increases the height of daylight glazing by 21%. However, it increases the average illuminance level for sensors 4-8 by 49%. The benefits of raising the ceiling height by 10 inch are significant. There are certainly many factors motivating towards lowering the ceiling, including construction cost, fire rating, and accommodating structure, duct work, and other utilities. Successful daylighting requires careful integration of systems to assure adequate ceiling height for daylighting.
1. Place high on the wall, widely distributed, optimize overall area

Figure 13.10c Strip or ribbon windows, as seen here in the Maison LaRoche by Le Corbusier, admit uniform light, which is further improved by placing the windows high on the wall. Note that photographic film exaggerates brightness ratios. (Photograph by William Gwin.)
1. Place high on the wall, widely distributed, optimize overall area
2. If possible, place windows on more than one wall.

*Figure 13.10b* These plans, with contours of equal illumination, illustrate how light distribution is improved by admitting daylight from more than one point.

*Figure 13.10d* Bilateral lighting is usually preferable to unilateral lighting (plan view).
A Pattern Language, Alexander, pattern #159: *Light on Two Sides of Every Room*

When they have a choice, people will always gravitate to those rooms which have light on two sides, and leave the rooms which are lit only from one side unused and empty.
3. Place windows adjacent to interior walls.
Figure 13.14e Place a skylight in front of a north wall for more uniform lighting and less glare.
4.72 Multiuse room with toplighting and sidelighting to provide even daylight distribution at the Christopher Center at Valparaiso University, Indiana. © PETER AARON/ESTO
4. Splay window surrounds to reduce the contrast between windows and walls as well as increase daylight penetration.
I am currently working comfortably under daylight at 6.30 PM in a 240 sq ft north-west facing room in a Cornish cottage which has two windows of less than 6 sq ft glass area each with 18" deep splayed reveals in an 8' x 15'6" wall. So the glass area is just under 10% of wall area and 5% of floor area.

With good wishes,
Bill Bordass
Ft. Macon, North Carolina
Splay Window Surrounds
Splay Window Surrounds (same for toplighting)

**Figure 13.14c** Splayed openings distribute light better and cause less glare than square openings.

**Figure 13.14d** In high, narrow rooms, glare is minimal because the high light source is outside the field of view.
The Kimbell Art Museum - Louis Kahn
5. Filter Daylight
Filtered Light

Light filtered through leaves, or tracery, is wonderful...where the edge of a window or the overhang eave of a roof is silhouetted against the sky, make a rich, detailed tapestry of light and dark, to break up the light and soften it.
View glazing versus Daylighting
better daylight distribution

better view
Esherick House, Louis Kahn
6. Shade Excess Sunlight
7. Use movable shades
7. Use movable shades:
Venetian Blinds (horizontal slats)
Is it possible to design a building for daylight only?
Center for Advancement of Public Action, Vermont
Tod Williams Billie Tsien