Daylighting

Daylight & Architecture
Michael D. Kroelinger, Ph.D., AIA, FIIDA, LC
Outline

- Benefits of daylighting
- Climate & weather
- Source characteristics
- Design criteria
- Design strategies
- Energy savings
- Case studies
- Summary; Q&A
Benefits of Daylighting

- **Energy savings**
  - Conservation by using daylight
  - Peak demand cost savings

- **Design & construction**
  - Integrate systems
  - Key element of architecture & interiors
  - Building form factor
  - Low or no cost additions
Benefits of Daylighting

• **Occupant issues**
  – Dynamic quality
  – Always changing intensity & color of light
  – View an important psychological element
  – Effect on impressions of activity setting & mood
  – People want daylight inside buildings
  – Architecture & space primarily experienced through vision
Climate & Weather

• Sky conditions
  – Clear sky
  – Overcast sky
  – Partly cloudy sky
Climate & Weather -- Sky conditions
Climate & Weather

- Climate types
  - Hot, arid
  - Hot, humid
  - Cold
  - Temperate
Climate & Weather

• **Daylight availability**
  - Varies by climate type & cloud conditions
  - Impacted by pollution & emissions
  - Varies by solar altitude & azimuth
  - Varies by season
  - Directly impacted by geometry of space
  - Impacted by obstructions on adjacent site
Source Characteristics

- **Sun**
  - High levels at higher solar altitude

- **Overcast sky**
  - Higher levels at higher solar altitude

- **Clear sky**
  - Higher levels at lower solar altitude when compared to overcast skies

The graph below presents average illuminance (in fc) for clear and overcast sky conditions. Actual levels may vary considerably due to changes in weather conditions.

Note: For additional illuminance data, refer to J. E. Kaufman (ed.), *IES Lighting Handbook* (1981 Reference Volume), p. 7-8. Maps of the United States showing available daylight in numbers of days and hours per year are also presented in Chapter 7 of the handbook.
Source Characteristics

- Solar altitude & azimuth
- Winter & summer solstice; spring & fall equinox

**SOLAR ANGLES**

The position of the sun varies according to latitude (see map on preceding page), season, and time of day. As shown by the orbit sketch below, solar altitude angle (\( \alpha \)) is measured between the horizon and the position of the sun above the horizon. Solar bearing angle (\( \beta \)) is measured from the north-south axis to the vertical plane through the sun.

The table below presents solar altitude angle and bearing angle at various latitudes. Noon is the instant when the sun is at the highest point in its daily orbit.

### Solar Angles Table

<table>
<thead>
<tr>
<th>North latitude (degrees)</th>
<th>Winter solstice (21 Dec.)</th>
<th>Spring equinox (21 Mar.)</th>
<th>Fall equinox (21 Sep.)</th>
<th>Summer solstice (21 June)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 a.m.</td>
<td>8 a.m.</td>
<td>10 a.m.</td>
<td>Noon</td>
</tr>
<tr>
<td>46°</td>
<td>2</td>
<td>15</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>38°</td>
<td>4</td>
<td>19</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>34°</td>
<td>9</td>
<td>26</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>30°</td>
<td>12</td>
<td>29</td>
<td>37</td>
<td>26</td>
</tr>
<tr>
<td>28°</td>
<td>15</td>
<td>32</td>
<td>40</td>
<td>29</td>
</tr>
<tr>
<td>42°</td>
<td>4</td>
<td>19</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>46°</td>
<td>2</td>
<td>15</td>
<td>21</td>
<td>20</td>
</tr>
</tbody>
</table>

**Note:** For comprehensive tables of solar angles at various latitudes, seasons, and times of day, refer to ASHRAE Handbook (1981 Fundamentals Volume), Atlanta, Ga., pp. 27.3 to 27.8, or J. E. Kaufman (ed.), IES Lighting Handbook (1981 Reference Volume), p. 7-4. For a graphic presentation of solar angles, sun angle calculators are available from Libbey-Owens-Ford Co., 811 Madison Avenue, Toledo, OH 43695.

**Great site for sun angle & sun position calculations:**

Daylighting

Design Criteria

• The following general design criteria, or rules of thumb, must be carefully assessed before using.
• Consider climate, location, site, specific building type, energy issues & human-centered needs before applying.
• What works in Phoenix may not work in Denver, Seattle, Miami or Bangkok!
Daylighting

Design Criteria

- Avoid direct skylight & sunlight on critical tasks
Design Criteria

- Bounce daylight off surrounding surfaces to diffuse light in more even brightness patterns

2. BOUNCE DAYLIGHT AGAINST SURFACES TO SPREAD IT OUT AND GET IT DEEP INTO INTERIOR SPACES.
Design Criteria

• Bring daylight in from above to obtain deeper penetration into space
Design Criteria

- Filter daylight to avoid harshness of direct sun & sky light

Louis Kahn used vines to soften flow of daylight to interior.
Kimble Art Museum, Ft. Worth, Texas.
Design Criteria

- Maximize ceiling heights to gain better light distribution
Daylighting

Design Criteria

- Use design strategies that separate view glass from daylight glass. Example - light shelf
Daylighting

Design Criteria

• Use ambient or task lighting to relieve visual gloom
Design Criteria

- Consider color of daylight combined with other sources
Design Criteria

- Develop appropriate control strategies
  - Glare
  - Thermal
  - View
  - Time of day at differing orientations
  - Nature of light due to controls and orientation
  - Climate type & sky conditions
Design Criteria

- Building geometry & spatial arrangement should promote, rather than preclude, distribution of daylight.
Design Criteria

- Buildings should be massed & configured so maximum # of spaces are near daylight

FIGURE 1.8
Articulated plans showing increased daylighting zones.
Room Geometry

• The following room geometry rules of thumb may vary significantly with sky conditions, climate type or floor level.

• Site obstructions can have a major impact on light distribution & spread.

• Exterior & interior materials all effect reflected light within spaces.
Room Geometry

- **Single Sidelighting**
  - High E levels near window; low rear of room
  - 2.5 x Ht. To 10%
Room Geometry

- **Bilateral lighting**
  - Better distribution balance
  - Less glare than single side lighting
  - Glare can still be a problem without filtering or bouncing light
Room Geometry

• Multilateral lighting
  – Light from multiple directions
  – Better brightness balance
  – Glare control still needed
  – Less use of artificial lighting during daylight hours
  – Controls by zone
Daylighting

Room Geometry

- Top lighting
  - Atria & lightcourts
  - Skylights
  - Sunscoops (south)
  - Lightscoops (north)
Room Geometry

- **Borrowed light**
  - With acceptable depths, light can be shared to hallways & other spaces
  - Interior partitions must have glass or open space to share lighting
  - Noise/security concerns
  - Usually uses clerestories or glass located high in the exterior wall for best distribution.
  - Ceiling is a secondary light source!
Energy Savings

- Integrate with other systems: lighting, mechanical, electrical, communications & others
Energy Savings

- Integration with electric lighting through differing control strategies:
  - Stepped
  - Dimming
  - Load shedding
  - Occupancy scheduling
Daylighting

Energy Savings

- Daylight is the most efficient source of light
- 1 watt of light equals 3.4 BTU of heat
- Efficacy & control strategies result in energy savings

### Comparative Efficiencies of Different Illumination Sources

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Efficacy (lumens/watt)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun (altitude = 7.5 degrees)</td>
<td>90 lm/w</td>
<td>(a)</td>
</tr>
<tr>
<td>Sun (altitude &gt; 25 degrees)</td>
<td>117 lm/w</td>
<td>(a)</td>
</tr>
<tr>
<td>Sun (suggested mean altitude)</td>
<td>100 lm/w</td>
<td>(a)</td>
</tr>
<tr>
<td>Sky (clear)</td>
<td>150 lm/w</td>
<td>(a)</td>
</tr>
<tr>
<td>Sky (average)</td>
<td>125 lm/w</td>
<td>(a)</td>
</tr>
<tr>
<td>Global (average of sky and sun)</td>
<td>115 lm/w</td>
<td>(a)</td>
</tr>
<tr>
<td>Incandescent (150 w)</td>
<td>16–40 lm/w</td>
<td>(b)</td>
</tr>
<tr>
<td>Fluorescent (40 w, CWX)</td>
<td>50–80 lm/w</td>
<td>(b)</td>
</tr>
<tr>
<td>High Pressure Sodium</td>
<td>40–140 lm/w</td>
<td>(b)</td>
</tr>
</tbody>
</table>

4-1. Efficacy of various forms of daylight and electric lamps (sources: (a) Hopkinson et al., 1966; (b) I.E.S., 1981).
Case Study: CA Schools
Case Study: Kimball Art Museum
Case Study: Mt. Angel Abby Library
Case Study: TVA Building
Case Study: High Museum of Art
Case Study: Denver Airport
Case Study: Harmony Library

Main section oriented so that most windows face North or South, for year-round sun control.

Long, narrow forms and stepped roof bring daylight into the core of the library.

Bookshelves are oriented north/south for effective daylighting.
Summary & Discussion

- Integration is key