Design Guide: Horizontal Shading devices and Light Shelves

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Chapter 1

1.1 Introduction

Natural daylight is a vital element in creating a more efficient and eminently more rewarding interior environment. Daylight is important for its quality, spectral composition, and the variability that it provides to any space. It provides high illuminance and permits excellent color discrimination and color rendering and fulfils two very basic human requirements; (i) to be able to see both a task and the space well, and (ii) to experience some environmental stimulation. Natural light stimulates biological functions that are essential to human health.

Windows receive a large amount of energy from the sun and usually most of the sunlight gets concentrated in certain areas of the space and may even result in glare on work surfaces and computer screens. Usually a single south-facing window can illuminate up to 20 to 100 times its unit area. Such a large amount of direct sunlight can be a source of great discomfort when concentrated on a spot, but is extremely useful if distributed to all parts of the room equally.

Natural Daylight: A vital element for an efficient interior environment. Source: http://www.carson.army.mil
1.2 The Movement of the Sun

The earth rotates on its north south axis in a 24 hour period and orbits the sun in a period of one year. The rotating axis is at an angle of 23 degrees. The height at which an observer sees the sun over the horizon (azimuth angle) depends on its location (latitude), the season (position of the earth in its orbit) and on the time of the day (rotation of the earth). The maximum or minimum height of the sun respectively, with $h=90-j \pm 23$ deg is reached at noon on the summer and winter solstice. The azimuth angle expresses the position of the sun over the horizon.
1.3 Sun path and seasons

Between the maximum elevations of the sun (summer) and the lowest position (winter), both the cardinal point and the time of sunrise and sunset change. In central European latitudes the parameters are as follows: sunrise in summer: northeast; sunset in winter: southwest; sunset in summer: northwest. A shading and glare protection system may therefore be required for the north façade. March 21st and September 21 are the equinoxes. The sun rises at exactly 6am in the east and sets in the west. This is true for all latitudes. At the tropic of cancer, the noon sun can fall directly onto the northern façade in the summer months.

1.4 Solar Radiation Data

Radiation output of the sun per m² of the earth’s surface_1374 W/m²

At sea level_1000W/m²

Illuminance of the direct sun_3000 to 10,000K

Illuminance of direct sun_100,000K

Luminance of clear sky_up to 50,000cd/m²

Luminance of overcast sky_5000 to 20,000cd/m²

Energy component of visible direct solar incidence_60% (approx.)

Energy component of invisible solar incidence_40% (approx.)
1.5 Thermal loads for Roofs and Facades

Generally, roofs are subject to much higher thermal loads in summer than facades. East and west facades are subject to even higher loads in summer than the south facades. South facades however are suitable in winter for solar energy yields since the relatively flat sun falls almost exclusively on the vertical surfaces.

The largest thermal loads on the facades are present in spring and autumn on the south east and south west facades. The south facades are easier to control thermally due to the steep incident sunlight in summer.
1.6 Moving light source

The sun is a moving light source that occupies the same position only twice per year - in the first and second half of the year, respectively. In observing the position of the sun, it is not only necessary to observe the solar azimuth angle, but also the direction of the incident sunlight. Daylighting of interiors is dependent on the orientation and, in particular, latitudes and specific weather data.
Chapter 2

SHADING STRATEGIES

2.1 Shading Strategies (General design guide)

OBJECTIVE: Control intense direct sunlight to ensure a comfortable workspace.

• This is critical for occupant visual and thermal comfort and for minimizing mechanical cooling loads.

• Direct sun is acceptable in less demanding spaces, such as circulation zones, lobbies, eating areas, etc.

KEY IDEAS

Exterior Devices

• Use exterior shading, either a device attached to the building skin or an extension of the skin itself, to keep out unwanted solar heat. Exterior systems are typically more effective than interior systems in blocking solar heat gain.

• Design the building to shade itself. If shading attachments are not aesthetically acceptable, use the building form itself for exterior shading. Set the window back in a deeper wall section or extend elements of the skin to visually blend with envelope structural features.
• **Use a horizontal form for south windows.** For example, awnings, overhangs, recessed windows. Also somewhat useful on the east and west. Serves no function on the north.

• **Use a vertical form on east and west windows.** For example, vertical fins or recessed windows. Also useful on north to block early morning and late afternoon low sun.

• **Give west and south windows shading priority.** Morning sun is usually not a serious heat gain problem. If your budget is tight, invest in west and south shading only.

• **Design shading for glare relief as well.** Use exterior shading to reduce glare by partially blocking occupants’ view of the too-bright sky. Exterior surfaces also help smooth out interior daylight distribution.

• **The shade’s color modifies light and heat.** Exterior shading systems should be light colored if diffuse daylight transmittance is desired, and dark colored if maximum reduction in light and heat gain is desired.

• **Fixed versus movable shading.** Use fixed devices if your budget is tight. Use movable devices for more efficient use of daylight and to allow occupant adjustment; first cost and maintenance costs are higher than with fixed devices. Use movable devices that are automatically controlled via a sun sensor for the best energy savings. Reliable systems have
been in use around the world for years and have only recently become available as cost-effective options in the United States.

2.2 Shading Strategies in the Window Plane

• **Use exterior shades for a smooth facade.** Exterior shade screens are highly effective on all facades and permit filtered view.

• **Use roller shades for a movable alternative.** Open weave exterior shades are not as effective, but acceptable.

• **Don’t rely on dark glazing.** Glazing treatments (reflective coatings, heavy tints, and reflective retrofit film) can be effective at reducing heat transfer. They allow direct sun penetration but with reduced intensity. This may not be an effective shading strategy from an occupant’s perspective unless the transmittance is very low to control glare, e.g., 5-10%. Fritted glass, with a durable diffusing or patterned layer fused to the glass surface, can also provide some degree of sun control, depending upon the coating and glass substrate properties, but may also increase glare.

• **Between glass systems.** Several manufacturers offer shading systems (e.g., blinds) located between glazing layers. Some are fixed and others are adjustable. See related comments on interior devices below.

2.3 Interior Devices

• **Interior shading alone has limited ability to control solar gain.** All interior systems are less effective than a good exterior system because they allow the sun’s heat to enter the building. They also depend on user behavior, which can’t be relied upon.

• **If interior devices are the only shading, specify light colors** in order to reflect the sun’s heat back out. Light-colored blinds or louvers are best. Light-colored woven or translucent shades are acceptable, but may not control glare under bright summer conditions.

• **Interior shading is best used for glare control and backup shading.** Supply user-operated devices that occupants can adjust to their individual comfort needs.
• **Use devices that still allow daylight in.** Blinds and openweave shades are good choices for filtering but not blocking all light.

• **Don’t use dark devices unless exterior shading is used.** Darkcolored interior devices offer only small energy savings. Openweave shades are easiest to see through if their interior surface is dark, but perform best if their exterior surface is light colored.

### 2.4 Integration Issues

**Architecture**

Projections work well with an articulated or layered facade and can integrate well with structural members. Exterior screens can make windows look dark.

If interior devices are the only shading, many occupants will always keep them closed. This can mean the window is permanently no longer transparent.

Use exterior shading to avoid the facade clutter of variously adjusted interior coverings.

**Interior**

Choose light-colored window coverings for best energy savings and comfort.

Choose interior window treatments that allow occupants to make adjustments for individual comfort needs.

**HVAC**

Good shading provides cooling load reductions. The mechanical engineer should perform calculations that include shaded windows, but acknowledge that not all shading systems will be deployed when needed.

**Lighting**

Shading devices modify the intensity and distribution of daylight entering the space. Lighting design scheme and placement of control zones may be affected.
Cost-Effectiveness

Proper shading devices can be partially or fully paid for by reduced cooling equipment and cooling energy costs. However the likelihood of proper use by occupants must be accounted for. Mechanical engineer should calculate these savings. Compare to any additional construction costs for the shades and calculate simple payback for the shading.

Automated movable systems can have an added maintenance cost and a higher first cost relative to other shading schemes. However, the operation should be more reliable than with manually operated systems.

Careful calculation of expected energy savings are needed to determine cost-effectiveness for this approach.

Occupant Comfort

Direct sun in the workplace is almost always a comfort problem. Uncomfortable occupants will be less productive, close their window coverings, bring in energy-using portable fans, and reduce thermostat setting if possible. Good shading means occupants will have minimal complaints.

Shading reduces glare. Exterior elements partially shield occupants’ view of the bright sky. Screens, glazing treatments, and shades reduce the brightness of the window. Exterior elements and venetian blinds reduce contrast by sending some light deeper into the space (improving distribution).
Chapter 3

EXTERNAL SHADING

3.1 Determining External shading: Tools and Resources

• Sizing Equations. Use the equations for a simple start at sizing overhangs and fins.

• LOF Sun Angle Calculator. A more thorough and accurate method uses this easy manual tool (available for $10 from Libbey Owens Ford, Exhibit and Display Center, Toledo, OH, (419) 470-6600). A booklet explaining how to use the tool for sizing is included.

• Scale Model (Using sundial). Test your preliminary shading scheme with a simple model. Evaluate whether glare and direct sun are successfully controlled, and make adjustments as necessary. Model studies are especially useful for complex architectural shading forms, which are hard to analyze on paper. Proper model studies are not difficult but do require some knowledge of solar geometry. A simple approach is to use a sundial. Document results with a camera.

• Shading Masks. Use this simple graphic method to study and document shading device performance over the entire year, all captured in a single diagram that is easy to construct. See Architectural Graphic Standards for instructions.

3.1.1 Sundials (used for studying scale models)

Scale models can be studied outdoors under direct sun or indoors using a lamp as a simulated sun. To position the model accurately relative to the sun, place a sundial beside the model and adjust the model position until the desired time is shown on the sundial.

a) Build a simple model with accurate geometry. You can study the whole building or just a portion of the facade.
b) Select the sundial with latitude closest to your site (use 32° for Southern California, 36° for Central, 40° for Northern). Mount a copy of the sundial on your model (enlarge for more accurate positioning). It should be horizontal, oriented properly with true south on the model, and in a position where it will not be shaded by the model (flat roof or southern portion of model base are good places). Note that true north is typically depicted on city property line zoning maps, not magnetic north.

c) Make a peg the length shown and mount it on the cross mark just under the June 21 curve (a straight pin works well for this).

d) Take the model in the sun and tilt it so that the end of the peg’s shadow falls at various intersections of the time and day lines. For example, when the model is tilted so that the peg shadow ends at the intersection of the 3 PM line and the October 21/ February 21 curve, then the sun and shadow effects you observe are exactly as they will be at that time on both those days. You can now quickly see how well your shading scheme works all year round.

e) Photograph it to record results.
3.1.2a Sizing Overhangs and Fins (Equations method)

Use these equations to find starting dimensions for shading elements. Do the calculations to find:

• Depth required for a shading element, or

• Extent of shadow cast by a shading element with given depth.

1. For each facade, select a critical month and time for shading. Suggested: south windows use September noon, east use September 10 am, west use September 3 pm, or ask mechanical engineer for estimate of peak cooling time in east, south, and west zones.

2. Find solar altitude and azimuth for target month/hour from the sun path diagrams.

3. Use the formulas below to size overhang, fin, or both. Results are a minimum starting point.

4. If overhang is too big, try breaking it into several smaller elements or dropping part of it down for an equivalent depth.

5. If sizing overhang for east or west window, you may notice that a fin must be added for adequate shading; otherwise overhang becomes unreasonably deep.

6. Test solution with a physical model and sundial.

7. Improvements: Extend ends of overhang wider than window or use a continuous element. Make overhang deeper or add another horizontal element part-way down the window. Add vertical elements to the scheme.

For an overhang: 

\[ h = D \times \tan \left( \text{solar altitude} \right) / \cos \left( \text{solar azimuth} - \text{window azimuth} \right) \]

• For total shade at your target month/hour, set \( h \) to height of window from sill to head and solve for \( D \), required overhang depth.

• For partial shade, set \( h \) to acceptable
height of shadow (perhaps 2/3 of window height) and solve for D, required overhang depth.

• With a given overhang, set D to its depth and find h, the height of shadow it will cast at your target month/hour.

For a fin: \( w = D \times \tan(\text{solar azimuth} - \text{window azimuth}) \)

• Solve for either \( w \), width of shadow, or \( D \), depth of fin, as with the overhang equation

‡ Be sure to observe proper signs. If both solar and window azimuths are on the same side of the south vector, then both values are positive. If they are on opposite sides of south, then set one azimuth as negative. For example: \( \text{solar azimuth} - (-\text{window azimuth}) = \text{solar azimuth} + \text{window azimuth} \).

3.1.2b Calculating Shading Devices using the Factor method

Window locations call for the major glass areas in the building to be oriented south. This pattern describes methods for shading these glass areas in summer.

Large south facing areas, sized to admit solar gain in summer when it is not needed. Although there is less sunlight striking south facing vertical glass in summer, it is usually enough to cause severe overheating problems. Fortunately, by using an overhang with south glazing, summer sunlight can be effectively controlled. The effectiveness of any shading device, however, depends upon how well it shades the glass in summer without shading it in winter.

The Recommendation

Shade south glazing with a horizontal overhang located above the glazing and equal in length to roughly one fourth the height of the opening in the southern latitudes (36 NL) and one half the height of the opening in the northern latitudes (48 NL)

When possible, design shading devices to act as both Reflectors to increase solar gain in the winter, and as insulating shutters – movable insulation to reduce building heat loss.
**Equation**

The most effective method for shading south facing glass in summer is with an overhang. This shading device is simply a solid horizontal projection located at the top exterior of a window. The optimum projection of the overhang from the face of the building is dependent upon window height, latitude and climate. For example, the larger the opening (height) the longer the overhang. At the southern latitudes (36 NL) the projection should be slightly smaller than at northerly latitudes (48 NL), because the sun follows a higher path across the summer ksydome. An overhang when tilted up will not only function as a shading device in summer, but also as a reflector in winter.

The following equation provides a quick method for determining the projection of a fixed overhang.

\[
\text{Projection} = \frac{\text{window opening (height)}}{F}
\]

\[
F = \text{factor from the following table}
\]

<table>
<thead>
<tr>
<th>North latitude</th>
<th>F factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>5.5 – 11.1</td>
</tr>
<tr>
<td>32</td>
<td>4.0- 6.3</td>
</tr>
<tr>
<td>36</td>
<td>3.0- 4.5</td>
</tr>
<tr>
<td>40</td>
<td>2.5- 3.4</td>
</tr>
<tr>
<td>44</td>
<td>2.0- 2.7</td>
</tr>
<tr>
<td>48</td>
<td>1.7- 2.2</td>
</tr>
<tr>
<td>52</td>
<td>1.5- 1.8</td>
</tr>
<tr>
<td>56</td>
<td>1.3- 1.5</td>
</tr>
</tbody>
</table>

Select a factor according to your latitude. The higher values will provide 100% shading at noon on June 21st, the lower values until August 1.
A fixed overhang is not necessarily the best solution for shading south facing glass since climatic seasons do not correspond to the sun’s movement across the sky. In the northern hemisphere, for instance, the middle of the summer climatic season does not coincide with the longest day of the year (June 21st), nor the middle of the winter of the winter season with the shortest day (December 21). In most regions there is a time lag of at least a month. In addition, fixed exterior shading device will provide the same shading on September 21, when the sun is warm, and on March 21 when it is cold. This happens because the sun’s path across the sky is the same on those cold days.

Adjustable overhangs provide a potentially better solution. They can be regulated seasonally, for example to partially shade a window in September and then adjust to admit full sunlight in March. However, these devices may be more expensive to build due to additional hardware. Also, they are sometimes difficult to design and maintain, and they require the correct seasonal adjustments to be effective.

Interior shading devices, such as roller shades, venetian blinds, drapes and panels, while not as effective in keeping sunlight from the building, offer ease of operation and maintenance. It should be noted that interior shading devices often eliminate, or severely limit, a view to the outside. A seasonal self adjusting shading device for south glazing in a vine-covered, trellised overhang. Since vegetation closely follows climatic rather than solar variations, a vine will be covered with leaves in summer and bare in winter.

Overhangs do not provide adequate shading for east and west facing glass, whereas trees and tall hedges, when properly located, will block the low morning and late afternoon summer sun.

Adjustable vertical louvers and awnings or retractable exterior curtains are also effective methods of shading east and west glazing. Vertical louvers adjusted to face south will admit the afternoon winter sun, but when pivoted to face north, they shade the glazing from morning and afternoon summer sun. Perhaps a simpler and less expensive solution is an awning or exterior curtain set in front of the window.
Sun Path Diagrams

Use a Sun Path Diagram to find solar altitude and azimuth for any given time, to help in sizing shading devices. Choose the sun path diagram with latitude closest to your site (use 32° for Southern California, 36° for Central, and 40° for Northern). Find the intersection of the two curves corresponding to the month and hour of interest. From this point, read solar altitude from scale at right and read solar azimuth from scale below. This is the sun’s position at that month and hour.

3.1.3a Sizing Horizontal shades Using Shadow Masks

Looking from a window, a shading device or any obstruction for that matter (such as a tree or building) will block part of the sky dome from view. To put it another way, the window will be in shade when the sun travels across the obstructed part of the sky dome.

For any surface (such as a window or clearstory), the sky dome obstructions and shading devices can be graphically plotted to construct a shading mask. This mask when superimposed over a sun chart, accurately determines the times the direct sunlight is blocked from reaching that surface. Since the masks are geometric descriptions of the shading characteristics of a particular device or obstruction, they are not dependent on latitude, orientation or time. Once plotted for a particular device, they can be used over any sun chart.
Shading devices can be grouped into three categories: the horizontal overhang, vertical fin, and overhang-fin combination or eggcrate.

The horizontal overhang is characterized by a shading mask with a curved shadow line running from one edge of the mask to the other; the vertical fin is characterized by a shading mask with a vertical shading line; and the combination horizontal overhang/vertical fin is characterized by a combination of both curved and vertical shading lines.

The shading masks are independent of the size of a shading device, but instead depend upon ratios generated by the dimensions of the device and the window. These ratios are expressed at the angle the window makes with the shading device.

The shading calculator has been printed on the transparent material and is located in the separate envelope that also contains the solar radiation calculator. It will assist you in generating a shading mask.

The curved lines that run from the lower right hand corner of the calculator to the lower left hand corner are used to plot horizontal obstruction lines parallel to a window and the vertical line on the calculator serve to plot vertical obstruction lines parallel to the window.
3.1.3b Plotting the shading Mask

Horizontal Overhang

To construct a shading mask for a window with a horizontal overhang, first determine the angle from a line perpendicular to the bottom of the window to the edge of the overhang (angle a), and the angle from the middle of the window to the edge of the overhang (angle b). These angles represent 100% and 50% shading of the window. Then, using the shading calculator, draw in the shade lines that represent angle a and angle b.

This completes the shading mask. The mask has a pointer and a baseline for alignment with the sun chart. Select the sun chart for your latitude, then keeping the baseline of the mask directly over the base line of the sun chart, shift the pointer of the mask line up with the number of degrees (azimuth angle) your window faces to the east or west of true south. The window will be completely shaded during the times that the sun is above 100% shading line, and partially shaded during times that the sun is above the 100% shading line, and partially (50%) at the 50% shading line.

Although the mask plots 100% and 50% shading of a window, the procedure can be repeated to generate a more complex mask which includes 25% and 75% shading.
3.1.3c Vertical Fins

There are basically two types of vertical fin shading devices: those that project out perpendicular from the face of the window and those that project out at an angle. To construct a mask for either device:

First determine angles a and b as shown. These angles represent 100% shading lines. Then determine angles c and d: these represent the 50% shading line. From the base line of the shading calculator draw vertical lines that correspond to the angles a, b, c and d. This completes the shading mask. Then align the shading mask over the sun chart to the angle the window faces to the east or west of the true south. The window will be completely shaded during the times the sun is outside of the 100% shading lines and partially shaded (50%) at the 50% shading lines.

Combined Horizontal Overhang / Vertical Fin

To construct the shading mask for a combination horizontal overhang/vertical fin, simply combine the shading masks for each device.
3.1.3d Step by step Method (using shading masks) – (Victor Olgyay, 1992)

In order to use shading masks for design purposes it is necessary first to define the times – hours and seasons- and then to define the direction- orientation and altitude- where shading is needed.

STEP1 to define times when shading is needed: Data should be collected for the daily temperature changes throughout a year at the place in question. Average daily temperatures should be used with hourly or two hourly data for each month of the year. The temperatures which fall over the bottom line of comfort zone (70 in the temperate zone, and rising as the latitude decreases) will define the overheated period. This can be tabulated on a chart where the hourly and monthly divisions serve as ordinates.

STEP 2: to determine the position the sun when shading is needed: on the sun path diagram the curved lines represent the movements of the sun for the dates shown. Lines “radiating” from the north pole indicate the hours the lighter lines show 20 minute intervals. The sun’s position is usually expressed by altitude, or angular distance above the horizon, and azimuth, or angular distance measured along the horizon in the clockwise direction. When the overheated period is transferred to this chart, the resulting sun path diagram will not only show the position of the sun, but will indicate whether shading is desirable at a given time.

By the nature of the diagram, each line represents two dates when the sun has the same path during a year. The plotted overheated period will have areas (indicated in dark tone) to show when shading is needed on both these dates, and other areas (in light tone) to show when shading is needed on only one of them, which is usually the autumn date. This diagram provides the basis for the evaluation of shading devices.

STEP3 to determine the type and position of a shading device for the overheated period: Masks can be drawn for any shading device even for very complex ones, by geometric methods. A protractor serves
to plot the projection of a device onto the sky vault much as the shading mask of the surroundings is chartered.

Since the masks are conventionalized geometric description, they are independent of latitude, orientation and time. Once plotted for a specific device, the shading mask can be used in any situation.

Shading devices can be tabulated according to their masks in three main categories.

**Horizontal Overhangs:** Their typical mask characteristics are segmental areas

**Vertical Louver:** their typical shading masks are bounded by radial lines

**Eggcrate types:** basically combinations of horizontal and vertical devices, their mask characteristics are accordingly a combination of these.

Their characteristics of a shading mask are independent of the scale of the devices; the ratio of the depth of the device to the proper dimension of the wall surface is the determining factor. This is expressed by the angle, which shows this ratio in a plane normal to the wall. The shading effect, and therefore the mask depend on this angle. A very small scaled device, like the “cool shade” or an outside venetian blind will have the same shading mask as a balconied apartment house if their angles are the same.

**STEP 4:** To evaluate the shading device. Two masks can be shown one for 100% shading in which case the total wall surface is in shade, and one for 50% shading when only half of the surface is in shade. The mask of grams superimposed on the sunpath diagram and the plotted overheated period will show this device. As a rule of thumb, it can be said that if 50% border of the shading mask covers the overheated periods shown on the sun path diagram, the shading device will work well. For detailed evaluation of course ration calculations will be needed.

The process of evaluation will be reversed for design purposes. With the use of a sun path diagram with the overheated period plotted on it, a proper overlapping mask can be determined and an appropriate shading device for the situation developed. Since various devices have the same mask,
and therefore the same shading characteristics there will be many technically correct solutions for each situation. To choose between them is the designers’ task.

3.1.3e Shading masks and shading devices

Any building will define a characteristics form in these projection diagrams, known as “shading masks”. Masks of horizontal devices (overhangs) will create a segmental pattern; vertical intercepting elements (fins) produce a radial pattern; shading devices with horizontal vertical members (eggcrate type) will make a combinative pattern.

A shading mask can be drawn for any shading device, even for very complex ones, by geometric plotting. Because the shading masks are geometric projections, they are independent of latitude and exposed directions. Therefore they can be used in any location and at any orientation. By overlaying a shading mask in the proper orientation on the sun path diagram you can read off the times when the sun rays will be intercepted.

Masks can be drawn for full shade (100% mask) when the observation point is at the lowest point of the surface needing shading, or for 50% shading when the observation point is placed at the halfway mark on the surface. It is customary to design a shading device in such a way, as soon as shading is needed on the surface, the masking angle should exceed 50%. Solar calculations should be used to check the specific loads. Basic shading devices are shown, with their obstruction effect on the sky vault with their projected shading masks.
**Shading mask protractor**

The half of the protractor showing segmental lines is used to plot lines parallel and normal to the observed vertical surface. The half showing bearing and altitude lines are used to plot shading masks of vertical fins or any other obstruction objects. The protractor is in same projection and scale as sun–path diagrams. Therefore it is useful to transfer the protractor to a transparent overlay to read the obstruction effect.

**Shading devices**

The effect of shading devices can be plotted in the same manner as the solar path was projected. The diagrams show which part of the sky vault will be obstructed by the devices and are projections of the surface covered on the sky vault, as seen from an observation point at the center of the diagram. These
projections also represent those parts of the sky vault from which no sunlight will reach the observation point; if the sun passes through such an area, the observation point will be shaded.

There are a number of basic types of shading devices’ horizontal, vertical, and eggcrate are the most common. Some general rules can guide in the selection of the type of device for a particular application.

Southerly orientations call for shading devices with segmental mask characteristics and horizontal devices work in these directions efficiently.

For easterly and westerly orientation, vertical devices work well, having radial shading masks. If slanted, they should incline toward the north, to give more protection from the southern positions of the sun.

For north walls, fixed vertical devices are recommended; however, their use is needed for only large glass surfaces, or in hot regions.

At low latitudes, on both south and north exposures, eggcrate devices work efficiently. The eggcrate type of shading device works well on walls facing south east, and is particularly effective for southwest orientations. Because of this type’s high shading ratio and low winter head admission, its best use is in hot climate regions.

Whether the shading device is to be fixed or movable, the same recommendations apply in respect to the different orientations. The movable types can be most efficiently utilized where the sun’s bearing angles change rapidly: on the east, southeast, and especially, because of the afternoon heat, on the southwest and west. Notes:

- Horizontal overhangs are the most efficient toward or around southern orientations. Their mask characteristics are segmental
- Louvers parallel to the wall have the advantage of permitting air circulation near the elevation. Slanted louvers will have the same characteristics as the solid overhangs and can be made retractable.
When protection is needed for low sun angles, louvers hung from solid horizontal overhangs are efficient.

A solid or perforated screen strip, parallel to the wall, cuts out the lower rays of the sun.

Moveable horizontal louvers change their segmental mask characteristics according to their positioning.

Vertical fins serve well toward the near east and near west orientations. Their mask characteristics are radial.

Vertical fins oblique to the wall result in an asymmetrical mask. Separation from the wall prevents heat transmission.

Movable fins shade the whole wall or expose different directions, according to the sun’s position.

Eggcrate types are combination or horizontal and vertical types and their masks are superimposed diagrams of the two masks.

Solid eggcrate with slating vertical fins result in an asymmetrical mask.

An eggcrate device with movable horizontal elements shows flexible mask characteristics. Because of their high shading ratio eggcrates are efficient in hot climates.
3.2 Conclusions on shading effectiveness

The sun protection effect for glass surfaces depends on several factors: the reflectivity of the solar radiation of the applied material and its color coating.

The location of the shade protection which influences the re-radiation and convection heat impacts the specific arrangement of the applied shading and method.

Because of the interplay of the above factors, it is difficult to separate the influences; however, generalized conclusions about their effect can be drawn.

Influence of color, and material

It is well known that light colors reflect sun impact and dark colors absorb it. The judgment of the eye gives an approximate measure of the relation of color to the absorption value. Venetian blinds using off-white color gives 20% more shade protection than a dark one. The aluminum blind is 10% more protective.
Location of shade protection

Inside shading protecting devices can only intercept the solar energy which just passes through the glass surface and can eliminate only that portion of the radiant energy which can be reflected through the glass again. Some of the energy striking an interior device is absorbed convected and reradiated into the room. If the interception occurs in or at the surface of the glass, part of the energy will be reflected back at the entry layer, part of it transmitted, and a part absorbed. The absorbed portion will be convected and reradiated both to the outside and into the interior of the room.

The exterior protecting devices dispose the convected and reradiated portion of the energy to the outdoor air.

Effectiveness of various shading methods

The different methods of shade protection can only become categorized under certain assumptions, such as to take certain value (as medium color or 50% light transmissions) as a measure. With such restrictions the order of effectiveness is as follows.

1. Venetian blinds
2. Roller shade
3. Tinted glass
4. Insulating curtain
5. Outside shade screen
6. Outside metal blind coating on glass surface
7. Trees
8. Outside awning
9. Outside fixed shading device
10. Outside moveable shading device
Chapter 4

DESIGN GUIDELINES FOR FIXED HORIZONTAL LIGHT SHELVES

4.1 Introduction

The design of a day lighted space is both an art and a science. The biggest challenge facing the lighting designer is to admit only as much light as necessary and distribute it evenly throughout the space without introducing heat or glare. Improved systems are needed to capture natural daylight and distribute it uniformly throughout a space while controlling heat gain and glare. One such system is the light shelf.

It is possible to improve the behavior of large window systems, by means of the use of passive devices like horizontal light shelves, to reach higher levels of natural light utilization. Light shelves are light-reflecting overhangs that shade the space from direct sunlight and reflect this sunlight onto the ceiling for deeper and more uniform distribution. These passively intercept and redirect sunlight deeper into the building and increase daylight illuminance levels at a distance of even 15 to 30 ft from the window. Light shelves are now being commonly used by many designers to improve the uniformity of the daylight distribution and the luminance gradient across the room under variable sun and sky conditions throughout the year.

4.2 Applications

- Light shelves are generally used for office and commercial buildings.

- Common applications include tall conventional windows and clerestory windows.

Behavior of large window systems can be improved by using passive devices like horizontal light shelves, to reach higher levels of natural light utilization. Source: http://www.carson.army.mil
• These are more appropriate for mild climates and are not recommended for tropical or desert climates due to the intense solar heat gain.

• Most effective when installed on the south side of a building, where maximum amount of sunlight is typically found.

4.3 Components of a Light Shelf

An effective light-shelf system needs four components:

• **Reflector** (the light shelf itself)

• **Window:** the light shelf distributes daylight only from the portion that extends above it. The window must face toward the sun for a large fraction of time and cannot be shaded by outside objects. Ideally it should not even be tinted or reflective.

• **Ceiling:** The light-shelf aims sunlight at the ceiling which then distributes light to the occupants. The ceiling tends to play the same role as the fixtures in electric lighting. In most cases the ceiling should be made highly reflective to conserve as much light as possible.

• **Shading Devices** (to prevent glare from the bottom portion of the window): the portion of the window below the light shelf needs separate treatment to prevent glare. A shade or a diffuser may be installed in the lower portion. Or an external shade that increases the light collection for the upper portion of the window.
4.4 Design Guidelines

The challenge of the design of light-shelves stems from the large variation in solar position and daylight availability throughout the day and year. The intensity of direct sunlight is four to seven times greater than diffuse skylight. The design of light shelves can be tailored to utilize direct sunlight. Light shelves are useful primarily with windows that have large amount of glazing area at a height greater than 6.5 feet (2.2 meters). Generally horizontal overhangs are placed above eye-level in a window dividing the window into two horizontal layers. Generally the light shelf splits the window with one third of glazing above and two-thirds below.

Two key design considerations need to be addressed while designing a light-shelf system:

- where to locate the light shelf (view & safety)
- how to avoid glare and excessive heat gain adjacent to portion of window below shelf

4.4.1 Location

Light shelves are most effective when installed on the south side of a building, where maximum amount of sunlight is typically found. These are usually located high above standard human head height levels. In modern buildings, the ceiling height is typically eight to ten feet, and the windows may not reach all the way to the ceiling. Therefore, only a small fraction of the window area is available for daylighting.

There are two reasons for the light shelf to be installed to high. The first reason is safety; since the light shelf extends into the space. The second is glare. The top of the shelf is a reflecting surface. If the shelf were located below eye level, sunlight could reflect into people’s eyes.

4.4.2 Shape
The light shelf is usually as wide as the window itself and its width is generally proportional to the height of the window above the shelf. The depth required to reflect all entering sunlight depends on the elevation of the sun. If the sun facing the window is low in the sky, it would take a very deep shelf to reflect most of the light to the ceiling. A shelf that deep might be difficult to mount and may interfere with lighting the space under it, or it may even look too strange.

The sides of the shelf should be designed to keep sunlight from shining down the sides when sunlight is entering the space sidewise. The shelf can be made wider than the window, or a side piece can be installed to extend upward from the light shelf.

4.4.3 Sizing

The optimum size of light shelves is governed by several considerations. They should be as low as possible without interfering with view through the lower part of the window, so that as much light as possible reflects off their tops and penetrates deep into the space. For optimum performance, the length of external light shelf should vary with orientation. Following thumb rules can be used as starting point for the design:

- For 20° either side of south (North in southern hemisphere), make the shelf 1.25-1.5 times the height of the clerestory.

- Beyond 20° east or west of south (North in southern hemisphere), extend the length to 1.5-2.0 times the clerestory glass height.

To prevent excess heat gain, the upper glazing above a light shelf should be shaded on south exposures (north in southern hemisphere) during the cooling season. This can be accommodated with
reflective louvers or by recessing the upper glazing to the back of the shelf. Smaller overhangs above the glazing improve light capture.

4.4.4 Inclination/Tilt

The light shelf does not have to be exactly horizontal, although a horizontal orientation is near optimum if the shelf is fixed. If the surface of the shelf is highly reflective and the shelf is mounted horizontally, then

\[ \text{Angle of incidence of incoming radiation} = \text{Angle that the sunlight is reflected onto the ceiling} \]

Tilting the shelf downward can improve daylight penetration at high sun elevations and tilting it slightly upward would reflect more light at low sun angles. The tilt can be automated with a fairly simple optical sensor.

- For white shelves facing south make the shelf tilt = 40° - (0.5 latitude)
- For east, west and north exposures make shelf tilt=15°.

Optimum Tilt of Light Shelves under Clear Sky Conditions (Baker et al.)
• *Decrease the tilt from these recommendations for diffusing glazing or if an overhang shades the glass. Increase rear wall reflectance with tilt. The optimum tilt is less for shallow rooms than for deep rooms.* (Moore, 1991)

Sloping the shelf reduces the effectiveness at shading the lower glazing, so it should either be lengthened or thickened.

The ability to tilt the light shelf is most valuable for making the top surface easy to clean. A small amount of tilt may also improve performance. Tilting the shelf downward increases the penetration of light but also introduces the possibility of reflecting sunlight into occupants' eyes at low sun angles. By the same token, tilting the shelf upward may avoid glare and increase daylighting at low sun angles.

4.4.5 Sky Conditions

Under clear skies, reflected-beam daylighting on the south side from curved mirrors can increase the daylight zone from about 15-20 ft to about 30-35 ft and up to 45 ft with sun tracking mirrors. Any beam-reflecting design should be evaluated for its potential to increase solar heat gain and glare.

Under clear sky conditions a rule of thumb for daylight penetration with typical depth and ceiling height is 1.5 times head height of standard window for south facing windows under direct sunlight.

For daylight penetration with depth and ceiling height is 1.5 - 2.0 times head height with the light shelf, for south facing windows under direct sunlight.
Light shelves can be used on any orientation if skies are mostly overcast, and on south orientations for reflecting sunlight. Under clear sky conditions, light shelves on east and west orientations should be designed to control glare from low-angle sun.

Both the vertical position in the wall and the length of the shelf outside the glass impact the amount of light reflected to the ceiling. In 1992 Boubekri looked at performance of light shelves under diffused light conditions for clear and overcast skies. With diffused sky, light shelves mainly control glare, increasing the daylight at the back of the room very little.

Performance of light shelves under diffused light conditions for clear and overcast skies.

Boubekri 1992
4.4.6 Materials and construction

For a more diffused spread of light, shelves can be painted with rough, less mirror-like materials. This will scatter light at many different angles, providing a more diverse coverage area on the ceiling.

The upper surface of the light shelf should be white or, if heat gain is not an issue, mirrored. Ceiling reflectance should be high. The top surface of the light shelf should never be seen by occupants, due to the glare potential. A mirrored light shelf with a white ceiling performs better than a white light shelf with mirrored ceiling.

4.4.7 Lighting Patterns

The pattern of illumination depends on the reflection characteristics of the light shelf, and it depends on the geometry and the reflection characteristics of the ceiling. If the reflection by the light shelf is specular (e.g. mirror), the reflection is controlled by the law of optics that says angle of reflection equals angle of incidence. So, if the sun is low in the sky, sunlight penetrates deeper into the space and if the sun is high the ceiling is illuminated close to the wall.
Pure specular reflection creates a sharply defined rectangular bright spot on the ceiling which may not be considered attractive and may even be too bright to even annoy the space users. This effect can be reduced by making the surface more diffuse. A taller ceiling provides deeper light penetration and is also able to distribute light more widely within the space.

A light shelf system can be thought of as having two zones of daylighting. The interior zone is illuminated by light that is thrown on the ceiling by the light shelf. The exterior zone, adjacent to the window, is illuminated by the portion of the window below the shelf. The boundaries of these two zones change as the sun moves and the sky conditions change. Both zones move toward the interior when the sun is low in the sky and toward the exterior when the sun is high in the sky.

4.4.8 Interior Shading

In a typical light shelf installation, most of the window area is underneath the shelf. This provides an excess of sunlight in the exterior zone. An interior shading device can be used to block excessive sunlight e.g. Venetian blinds.

4.4.9 Exterior Shading

If the windows face towards south, lower portions of the windows can be shaded with an external horizontal sunshade. If the light shelf extends beyond the exterior surface of the glazing on sunny exposures, it can be used to shade the view glazing. At the same time, it can...
reflect light off its top surface through its upper glazing to the ceiling, where it is reflected deeper into the space.

4.4.10 Layout with Clerestory Windows

Clerestory windows have a major advantage for light shelves. They are well above head level, so the entire window can be used to capture daylighting to illuminate the interior area of the space. A space with clerestory windows has a tall ceiling. Light reflected from the ceiling can distribute light to the area underneath the light shelf.

4.5 Advantages of Using Light Shelves

- Nowadays light shelves are available as prefabricated unit which can be easily installed.
- Using light shelves improves illumination distribution of the space and reduces glare.
- The exterior shelves can be designed to work as shading devices to block direct sun from entering the space. Hence they can help reduce cooling loads of the building.
- Energy Saving Potential of Light Shelves: Light shelves are generally able to increase the amount of daylight that enters a space. The depth to which daylight penetrates a space is largely governed by the height of the top window, the orientation of the window and the clarity of the sky. The width of the daylit zone varies with sunlight conditions. For typical clear windows, daylight may penetrate inward a distance of 10 to 20 feet. The light penetration may be deeper if the window is very tall. With typical interior lighting levels this translates to a saving in electricity ranging from 10 to 40 watts per foot along the wall.
- If windows are tall, light shelves can provide deeper penetration than daylighting that is achieved by shading windows. The conventional horizontal shading structures obstruct most of
the potential daylighting energy outside the building itself. The light shelves on the other hand
direct and distribute sunlight into the space fairly efficiently.

• For illumination to be useful, it must come from overhead. Raw sunlight coming through a
window falls on the floor. A light shelf is able to reflect the direct sunlight onto the ceiling after
which it gets distributed into the working areas of the space.

4.6 Disadvantages of using light shelves

• Problems with low-angle winter sunlight penetration can give rise to glare.

• Difficulties can be experienced in cleaning light shelves, especially the external type.

• The major drawback to a light shelf is that it only works on sunny days. When the sky is
overcast, the light shelf will be able to scatter some light, but not enough to make a significant
difference, and it will usually be necessary to supplement with artificial light.

• When the shelves are installed indoors, people must be reminded not to store or display objects
on the shelf, as this can interrupt the flow of light.

• They are not typically useful in those climates where solar heat gain is particularly intense, such
as tropical climates and deserts.
4.7 Case Studies

4.7.1 Lockheed Building 157

In 1983, Lockheed Missiles and Space Company constructed a new office complex at Sunnyvale, California. Since the building is located in the Bay area, with virtually no heating load, lighting accounts for over half the energy demand and cooling and ventilation account for the rest. The designers have used daylighting design as the main strategy to save energy and to improve the overall work environment inside the building. All aspects of daylight design revolve around two simultaneous goals:

- To bring diffuse daylight deep into the office space and
- To eliminate direct sunlight and minimize brightness at work stations near the windows.

Cross Section of the Lockheed Building 157, Sunnyvale, CA.

Source: Daylighting and Productivity at Lockheed, Burke Miller Thayer
The five-level building is oriented about 15 degrees east of south. Each level has a 90-foot by 420-foot office area on the south and one on the north. In the middle is a 60-foot by 300-foot "litetrium", as the architects call it, which spans from the ground to the roof. Daylight enters the building through glazing on the north and south walls and through the glazed cap at the top of the litetrium.

The east and west windows have been eliminated in order to minimize heat gain and direct sunlight. Glass extends 15ft from floor to ceiling along entire length of each office area on the north and south sides. The height of the glass coupled with the downward slope of the ceiling toward the interior is the key to deep penetration of daylight. Along the north and south perimeters of each level, a light shelf extends 12ft into the office at about a 7.5ft height. The 6ft span of glass above the light shelf is clear to allow as much daylight to enter as possible. The light coming through the glass bounces between the highly-reflective top surface of the light shelf and the ceiling as it penetrates farther into the building.

On the south side, exterior light shelves extend 4 feet out from the building at the same height as the interior light shelves. Each exterior light shelf angles up and away from the building at about 30 degrees to reflect overhead sunlight into interior space. While the architects maximized the diffused daylight entering the building, they also looked at reducing the brightness next...
to the north and the south window areas. To minimize direct solar gain from the south, a 2-ft overhang shades the upper glass from direct summer sun. The exterior light shelves shade the glass below them and the internal operable horizontal blinds cut out the low angled rays in the winter.

On the north, where sky brightness from the high windows could be a problem for workers near the perimeter, the interior light shelves shade the work space below. Tinted glass installed between each light shelf and the floor blocks 60 percent of the light on the north and more than 80 percent on the south.
4.7.2 Elementary School, Albuquerque, NM

An example in which the use of light shelves actually led to the underperformance of the space is illustrated through this example of an elementary school in Albuquerque, New Mexico. As a high performance, green school, the architects incorporated daylighting into the classroom design by making use of clerestory windows and segmented light shelves to bring daylight into the space. A segmented light shelf simply refers to the shelf not being a solid piece, in this case with gaps running down the full length of the shelf to allow a small portion of the direct sunlight through to create aesthetic light/shadow patterns on the wall.

However, the segmented light shelves allow direct sunlight to reach the eyes of the students in the south side classrooms during the winter months. As a result, teachers close the automatic blinds over the clerestory windows and turn on the artificial lights instead, greatly reducing the energy savings that the design team had intended. The fix is relatively simple—replacing the segmented light shelves with solid versions that eliminate the penetration of direct sunlight down to the occupant level. Thus before deciding on any such strategy, analyzing its performance using either actual physical models or even computer simulations can result in better adoption of the strategy.

Elementary School Interior showing segmented light shelves Source: http://www.nrc-cnrc.gc.ca
4.8 Conclusions

Light-shelves are effective passive devices that can be used to increase the amount of natural light that enters the space. Light shelves are able to effectively reflect the direct sunlight onto the ceiling after which it gets distributed into the working areas of the space. Raw sunlight coming through a window falls on the floor and can lead to problems of glare. For illumination to be useful, it must come from overhead and light shelves are able to do that well.

A combination of internal and external light shelves tends to work the best in providing even lighting into the work space. Exterior light shelves shade the outside of the window, reducing solar gain inside the room, interior shelf on the other hand provide visual protection from sun glare at intermediate depths within the room. Light shelves work the best with high ceiling, ideally 10 to 12 ft high or more.

The design of the shelf should be done carefully based on the solar profiles over the whole year. Analyzing its performance using either actual physical models or even computer simulations can result in better adoption of the strategy and help avoid wrong decision making.
Chapter 5

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