MEASURE 8.3.5 Install a system of light shelves and shading.

RATINGS

New Facilities	Retrofit	O&M
C	C	

SUMMARY

Used with tall windows and clerestory windows. In most cases, light shelves cannot exploit the portions of windows below head height.

SELECTION SCORECARD

Savings Potential	$	$	$
Rate of Return, New Facilities	%	%	%
Rate of Return, Retrofit	%	%	
Reliability	✓	✓	✓
Ease of Retrofit	☺	☺	

You can make tall windows effective sources of daylighting by using "light shelves." Figure 1 shows how they are installed.

Light shelves avoid the glare problem that limits the use of diffusers to exploit daylighting through windows (see Measure 8.3.1). Light shelves also provide the unique advantage of shifting the light from the window so that it comes from a more overhead direction, improving the quality of illumination.

The light shelf itself is a simple device that is installed inside the window. In most applications, it must be combined with other devices to avoid glare from sunlight entering the lower portion of the window. The light shelf itself is not difficult to install. Light shelf systems, including exterior shading devices, are now available from manufacturers as prefabricated units.

A serious disadvantage of light shelves is that only the portion of windows above head height is usable for daylighting. Light shelves require periodic cleaning, which is easy to neglect.

Where to Install Light Shelves

Light shelves require direct sunlight. The windows should face toward the sun for a large fraction of the time that the space is occupied.

Tinted or reflective glazing may greatly reduce the potential benefit of light shelves, or make them uneconomical. These types of glazing typically block about 70 to 80 percent of incoming sunlight.

Light shelves are useful primarily with windows that have a large amount of glazing area at a height greater than about 6.5 feet (2.2 meters). Applications include tall conventional windows and clerestory windows. (A "clerestory" is an elevated vertical section in a wall or roof that is intended to have windows for illuminating the interior portion of a space.)

Light shelves may be used with glazing at lower heights in some specialized cases where people cannot get close to the glazing.

As with any kind of daylighting, the electric lighting must be arranged and controlled so that it can be turned off to exploit the daylight provided by the light shelf system.

Energy Saving Potential

Light shelf systems provide useful daylighting of a zone that lies along the exterior wall. The width of this zone depends on the height of the top of the window, the orientation of the window, the latitude of the site, the time of day, and the clarity of the sky. The width of the zone varies with sunlight conditions. With typical clear windows, the zone may extend inward a distance of 10 feet to 20 feet (3 meters to 7 meters). 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 (30 to 120 watts per meter) along the wall. This assumes that no daylighting is available without the light shelves.

If the windows are tall, light shelves can provide deeper penetration than daylighting that is achieved by shading windows. This is because light shelves can throw all the energy of direct sunlight into the space. In contrast, using shading to tame sunlight for daylighting leaves most of the potential daylighting energy outside the building.

As with any kind of daylighting, the daylight entering the space becomes heat energy. This increases the cooling load in warm weather and reduces the heating load in cold weather. Light shelves disperse sunlight fairly efficiently, so the amount of heat energy added to the space is not much greater than would be added by an equivalent amount of electric lighting. (This is true of electric area lighting. Electric task light is much more efficient in terms of localizing lighting energy.)

What is a Light Shelf?

Windows that face the sun receive an enormous amount of energy that could be used for daylighting. In principle, if a window faces anywhere between southeast and southwest and if it receives direct sunlight, each unit of window area could illuminate 20 to 100 units of interior area. However, this is possible only if the sunlight can be distributed efficiently.

The challenges in distributing this free lighting energy are lighting geometry and glare. In order for illumination to be useful, it must come from overhead. Raw sunlight coming through a window falls on the floor, so some method is needed to redirect the sunlight so that it comes from overhead.

The problem of glare is explained in Measure 8.3.1. In brief, if the light entering a window is simply deflected toward the interior of the space, occupants looking toward the window are blinded by glare.

Many concepts have arisen for taming the sunlight that enters through windows. A concept that appears promising at the present time is the "light shelf." A light shelf is essentially a mirror that is installed inside a window, facing upward. The mirror reflects incoming sunlight toward the ceiling. The ceiling then distributes the light into the working areas of the space.

An effective light shelf system needs four components:

- ***the light shelf itself.*** The light shelf is simply a reflector. It could be as simple as aluminum foil taped to a piece of cardboard. Commercial light shelves include features that ease cleaning and enhance safety. See Figures 2 and 3.
- ***the window.*** The light shelf distributes daylighting only from the portion of the window that extends above the light shelf . The bottom portion of the window contributes daylight only to the narrow zone underneath the light shelf. The window must face toward the sun for a large fraction of the time, and it cannot be shaded by outside objects. If the window glazing is tinted or reflective, the daylighting potential is reduced substantially.
- ***the ceiling.*** The light shelf aims sunlight at the ceiling. The ceiling then distributes the light to the

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Fig. 1 Light shelves These are installed directly against the windows, just high enough to avoid being a hazard. The top of each shelf is a mirror, and it must be kept clean. Only windows exposed to direct sunlight are eligible. Glare must be avoided from the portion of the window below the shelf. The windows at left have internal shades. The windows at right are shaded by an external fixture, shown in Figure 4.

occupants. The ceiling plays the same role as the fixtures in electric lighting. In most cases, the ceiling should be highly reflective to conserve as much light as possible. The height and orientation of the ceiling, and the diffusion characteristics of the ceiling surface, determine how the ceiling distributes the daylight.

- ***shading device(s) to prevent glare from the bottom portion of the window.*** A window must be exposed to direct sunlight to be a candidate for a light shelf. The portion of the window below the light shelf needs separate treatment to prevent glare. For example, you may install a shade or diffuser inside the lower portion of the window, as recommended by Measure 8.1.1. Or, you may install an external shade that increases the light collection of the upper part of the window, as we discuss below.

The rest of this Measure covers these components in greater detail. Think of light shelves as a system. Study Measures 8.1.1 (exterior shading devices), 8.1.2 (interior shading devices), and 9.5.3 (automatic light switching) before attempting to install light shelves.

Effective daylighting by any method is still a rarity. It is impossible to convey the visual effect of daylighting by words or pictures. If you are interested in using light shelves, visit sites where they are installed, and judge their performance over a range of sunlight conditions.

The Lighting Pattern of a Light Shelf System

The pattern of illumination depends on the reflection characteristics of the light shelf, and it depends on the geometry and reflection characteristics of the ceiling surface. If the reflection by the light shelf is specular (like a mirror), the reflection is controlled by the law of optics that says the angle of reflection equals the angle of incidence. If the sun is low in the sky, sunlight penetrates deeply into the space. 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. This may not be considered attractive, and it may be bright enough to annoy occupants. You can reduce this effect by making the reflecting surface of the light shelf more diffuse. This spreads out the light on the ceiling. However, it also concentrates the ceiling illumination close to the

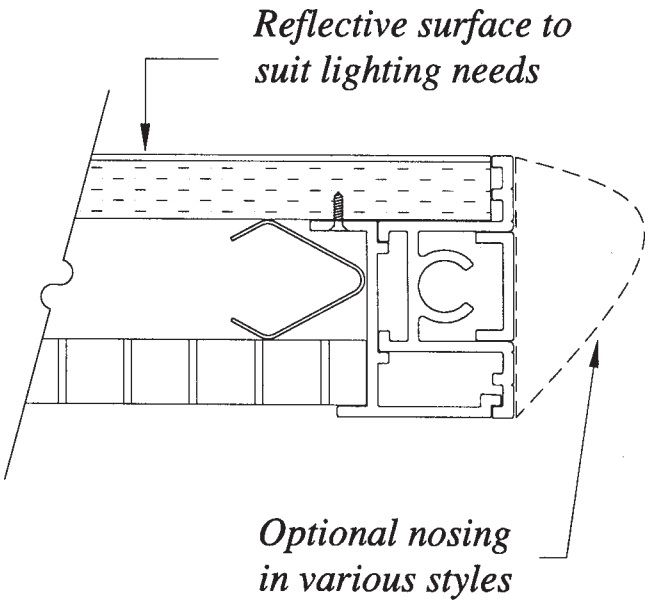

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Fig. 2 Detail of typical light shelf The main feature is the reflective upper surface. A soft edge is valuable for safety. A sign is needed somewhere that the shelf is not for storage and that it should be cleaned at stated intervals.

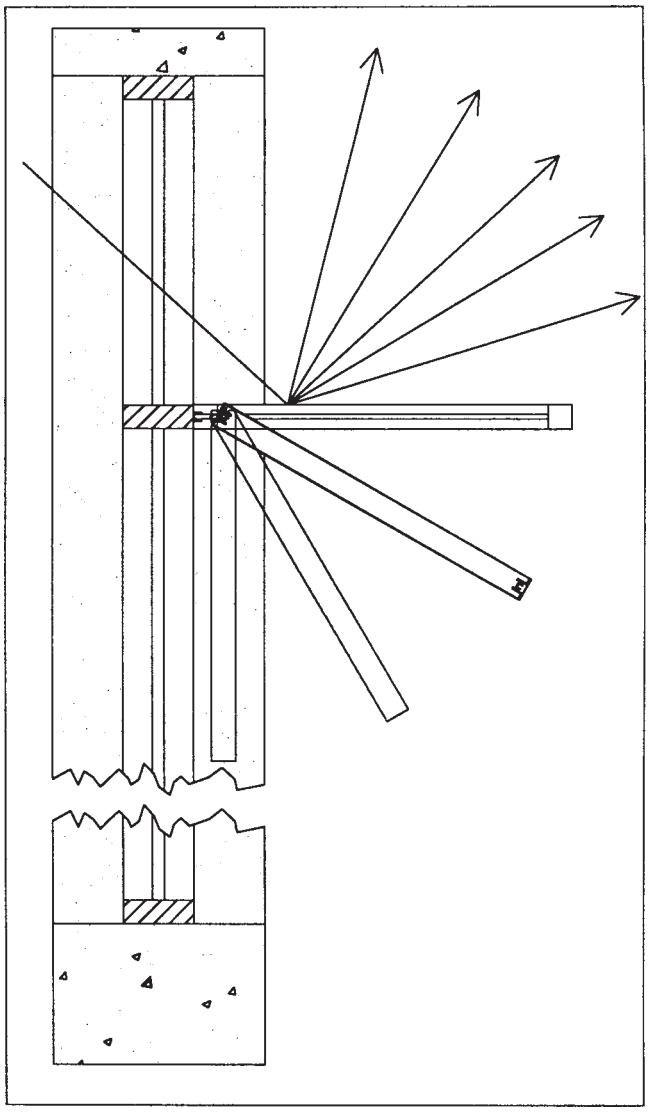

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Fig. 3 Tilting light shelf Ability to tilt is most valuable for making the top surface easy to clean. A small amount of tilt may also improve performance. Tilting the shelf downward increases the penetration of light into the space, but it also introduces 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.

light shelf. If the reflection is very diffuse, penetration into the space is sacrificed.

A taller ceiling provides deeper light penetration, and it also distributes the light more widely within the space.

It helps to think of a light shelf system 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 light shelf. The exterior zone is partially shaded from the ceiling light by the light shelf itself. (A light shelf could be made of partially transparent material to allow the exterior zone to be illuminated through the light shelf.)

The boundaries of these two zones change as the sun moves and sky conditions change. Both zones move toward the interior when the sun is low in the sky, and they move toward the exterior when the sun is high in the sky. Both zones move in and out together. However, diffuse reflection by the light shelf reduces the movement of the interior zone as the sun angles change.

When the sun is higher, less sunlight is able to enter the window. At the same time, the sunlight is concentrated in a smaller area, closer to the exterior. Therefore, the illumination level within the zones tends to remain constant.

On the other hand, if the sun is obscured, there is less total daylight, but it is distributed more deeply into the space. As a result, the illumination level within the zones falls dramatically, perhaps to the point that artificial light is needed.

Equipment Choices and Layouts

You have two main design issues with a light shelf system: (1) where to locate the light shelf, and (2) how to avoid glare and excessive heat gain adjacent to the portion of the window below the shelf. With typical windows, the window area above the shelf cannot provide as much light as you want, and the window area below the shelf provides too much. We will look at that

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Fig. 4 Exterior shades that work with light shelves These are unusual because they are installed below the tops of the windows, at the same height as the light shelves. Their purpose is to keep direct sunlight from entering the portions of the windows below the light shelves. The shadow pattern shows that the shades would be more effective if they were installed as a continuous unit. Exterior shades can increase daylighting by reflecting more light into the top portions of the windows. This design fails to exploit that opportunity.

problem first, and then look at several practical equipment layouts.

■ Shelves are Above Head Height, Usually

A fundamental problem with light shelves is the need to locate the shelf too high for efficient use of the daylight entering the window. As a practical matter, the light shelf usually has to be installed above the level of people's heads. 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 total window area is available for daylighting.

There are two reasons why the light shelf has to be installed so high. One reason is safety. The light shelf extends into the space. People could walk into the shelf if it were low enough. Therefore, the shelf must be installed above the height of a tall person.

The other reason 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.

Light shelves can be installed at a lower level if people are not able to get close to the windows. Such situations are rare, but they do exist.

■ The Shape of the Light Shelf

As the name implies, a light shelf looks like a shelf. It is as wide as the window, or somewhat wider. The depth of the shelf is proportional to the height of the window above the shelf, but the ratio is a compromise. 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 sunlight to the ceiling. A shelf this deep might be difficult to mount, or it might interfere with lighting the space under the shelf, or it might look too strange.

The sides of the light shelf should be designed to keep sunlight from shining down the sides of the shelf when sunlight is entering the window sidewise. You can do this by making the shelf wider than the window, or by installing a side piece that extends upward from the shelf.

The shelf does not have to be exactly horizontal, although a horizontal orientation is near optimum if the shelf is fixed. You could make the shelf adjustable, as in Figure 3. Tilting the shelf downward would improve daylight penetration at high sun elevations, and tilting it slightly upward would reflect more light at low sun angles. However, don't expect the occupants to do this. You could automate the tilt with a fairly simple optical sensor, and win a design award for innovation.

There is another light shelf configuration to consider. It consists of a stack of light shelves, each fairly narrow. It looks something like a venetian blind with the blades adjusted to a horizontal position. However, it behaves differently, because the tops of the blades reflect. If the shelves are narrow enough to fit within the depth of the window frame, they would not pose much of a safety hazard. Also, being horizontal, they would not interfere much with the view. The main disadvantage of this arrangement is that can reflect an image of the sun into the eyes of anyone standing nearby and looking out the window.

■ Relationship to Artificial Lighting

The spaces are illuminated with a combination of daylighting and artificial light. The light fixtures and their power circuits should be arranged so that they can dim or turn off when daylighting can provide sufficient illumination. The layout of the lighting should accommodate changes in sun position and cloud cover. This can be as simple as switching the fixtures in rows parallel to the exterior wall. Lighting switching and dimming should be automatic. See Measure 9.5.3 about automatic lighting controls and Measure 9.6.4 about the arrangement of the light fixtures and power circuits.

At night, the space must be illuminated with artificial lighting. The light shelves may interfere with illumination from ceiling-mounted fixtures. If necessary, modify the electric lighting to provide good nighttime illumination in the exterior zone.

■ Interior Shading for the Lower Window

In a typical light shelf installation, most of the window area is underneath the shelf. This provides an excess of sunlight to the exterior zone. You can use an interior shading device to block the excess sunlight. Refer to Measure 8.1.2 to find your options.

An ordinary venetian blind is probably your best choice. If you want to reduce heat gain in the space, make the outer surfaces of the blades highly reflective. If you want to capture heat gain, make the outer surfaces of the blades moderately absorptive.

■ Exterior Shading

If the windows face toward the south, you can shade the lower portions of the windows with an exterior horizontal sunshade. See Measure 8.1.1 for the issues to consider with exterior shading.

When exterior shading is used with a light shelf, it is installed in an unusual manner, as shown in Figure 4. It must be installed at exactly the same level as the light shelf. If it is higher, it will block the entry of useful sunlight to the space above the shelf. If it is lower, direct sunlight will enter the space through the gap between the light shelf and the shade. Both the shelf and the sunshade must butt against the glass closely to avoid leaving a gap through which sunlight can enter directly.

In this application, the exterior shade can serve double duty. If it has a reflective upper surface, it will reflect sunlight into the upper portion of the window. If the upper portion of the window is short, this will not help much, because the additional light will strike the ceiling close to the wall. However, if the window extends

well above the exterior shade, the additional light will penetrate farther into the space. The external shade shown in Figure 4 fails to exploit this opportunity.

■ Layout with Clerestory Windows

Clerestory windows offer 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.

With this layout, there are no longer two separate lighting zones, as for windows at lower levels. A space with clerestory windows has a tall ceiling. Light reflected from the ceiling can distribute light to the area underneath the light shelf.

An exception occurs if the clerestory is part of the roof structure, well inside the wall. In this case, the area adjacent to the wall may be shadowed by the light shelf.

Keep the Top Surface Clean

The light shelf is horizontal, or nearly so. This makes it an effective dust collector. Within a period of weeks or months, enough dust can settle on the shelf to seriously degrade illumination. Therefore, light shelves need to be cleaned on a regular basis.

The best approach is simply to make this part of the activity of the cleaning crew. However, contract cleaning crews will overlook this unfamiliar requirement. Therefore, a responsible manager must keep educating the cleaning crews about the need to dust the light shelves.

Some commercial light shelf units are designed to pivot downward to allow cleaning, as in Figure 3. This allows cleaning without a ladder, which is an important feature for increasing the likelihood that the shelf will actually be kept clean..

Cleaning shelves that are located at great heights, as with clerestory windows, can be a major task. Consider this before deciding to install light shelves in such locations.

Cleaning is so important that each light shelf should be marked in a durable, highly visible manner to tell cleaning crews to clean the top surface with each room cleaning.

If you use exterior shades with reflecting top surfaces, you will probably have to depend on precipitation and wind to keep them clean, at least between long intervals of manual cleaning. Select a finish for the top surface that sheds dirt easily. Give the top surface enough slope so that rain flows off the surface freely.

Safety

The height of the shelf is a compromise between lighting effectiveness and safety. It is usually not practical to install the shelf so high that the tallest basketball player cannot run into it. Therefore, the shelf should be designed so that the edge is as yielding as possible. Also, the edge should be made very visible, as with a bright colored stripe. Some commercial units offer a soft rubber bumper around the edge of the shelf, as shown in Figure 2.

Explain It

Install a placard at each light shelf to explain its purpose. Ask the occupants to exploit the daylighting and minimize artificial lighting. (In most cases, there should be automatic lighting controls to do this.) Spell out that the shelf is not supposed to be used for storage. You can use the same placard for the cleaning instructions.

ECONOMICS

SAVINGS POTENTIAL: *If light shelves make daylighting possible where it did not exist before, typical savings are 10 to 40 watts per foot (30 to 120 watts per meter) along the wall. Greater savings are possible with taller windows. This translates to a saving of about $1 to $10 per foot per year.*

If external shading is used, the greatest saving may occur from the reduction of cooling load, especially in warm climates. See Measure 8.1.1 about this saving.

COST: *The light shelf unit itself may cost about $100 per window, subject to wide variation. In addition, see Measure 8.1.1 for the cost of external shading devices, and Measure 8.1.2 for the cost of interior shading devices. See Measure 9.5.3 for the cost of automatic lighting controls. In existing buildings, you may have the cost of rearranging the light fixtures and power circuits to exploit daylighting. See Measure 9.6.4 about this.*

PAYBACK PERIOD: *Several years, in new construction. Ten years or longer, in retrofit.*

TRAPS & TRICKS

CHOICE OF METHOD: *Light shelves are still a novelty, so you are pioneering. Before you make any commitments, visit some sites where light shelves are installed, and judge their performance yourself. Remember that the efficiency objective is to minimize electric lighting and cooling load. See how well they do this.*

SYSTEM FEATURES: *The greatest design difficulties are not in the light shelf itself, but in the related shading. See Measures 8.1.1 and 8.1.2 about this. Include features that enhance cleaning and safety. Consider effective placards to be an integral part of the installation.*

MONITOR PERFORMANCE: *Light shelves are easy to neglect. If you see people storing objects on top of the light shelf, you know the system has failed. Inspect the shelves periodically to make sure that they are being cleaned.*