

NEW DESIGNS IN ACTIVE DAYLIGHTING

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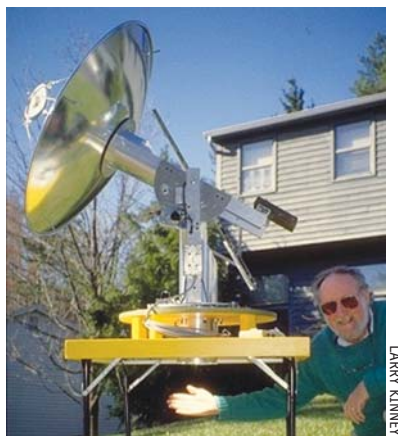
By LARRY KINNEY and ROSS McCLUREY

Daylighting offers many important benefits. First, there are a variety of psychological benefits associated with human needs for connections with the outdoors. We evolved mostly under tree canopies and on open plains, almost totally immersed in the natural environment. It is not surprising, then, that we have strong needs for continuous interaction with that environment. The second most important benefit is for interior illumination. Daylighting was necessary before inexpensive, smokeless electric lighting came along, so our architectural design traditions have provided us with extensive knowledge and many ancient strategies for introducing natural light into structures.

Finally, using natural light to provide illumination saves energy by diminishing the use of electricity for electric lighting while lowering cooling loads. Since the sun is available when utilities experience peak demand, well-designed daylighting systems help to limit demand on the grid, thereby delaying the need for new power plants and associated infrastructure.

Existing Technology

It is difficult to beat a conventional window for the many benefits it provides. Proper design, of course, is critical in order to avoid problems of glare and overheating, or draftiness on cold winter nights. However, unless windows extend upward a significant distance, or are turned into roof monitors or clerestories, their benefits decrease rapidly with distance from exterior walls. In attempts to



Larry Kinney demonstrates the Daytracker system, which focuses light through a parabolic mirror to send it deep into a home's interior.

provide good illumination deeper into a living or working space, scientists have designed and constructed various systems that combine glazing with reflectors (see Figure 1). As the sun moves through the sky, however, passive versions of this strategy have difficulty working well all day long. When the window is south facing, active tracking can improve performance.

Conventional roof skylights are another widely used passive daylighting strategy. The principal problems with this approach are that clear skylights transmit direct beam daylight that is hardly impeded. This can result in localized overheating and glare from the very bright sunbeams directly or from the light reflected from surfaces they strike inside the room. The use of diffusing glazing can soften the glare somewhat, but this kind of glazing rejects much of the incident light, due to reflection and

scattering, resulting in a ceiling that alternates between quite bright areas and quite dark areas. The use of deep wells below the skylight glazing can help ameliorate glare problems but the deep wells further reduce light transmission.

Tubular skylights composed of clear glazing on top, a highly reflective light pipe from roof to ceiling, and a diffusing glazing at the ceiling height can solve many of these problems, but not the hot-and-cold spot issue. Further, both kinds of skylight result in substantially reduced light levels when the sun is low in the sky—during mornings and late afternoons. Some reflecting and refracting elements have been added to the top domes of tubular daylighting devices in an attempt to catch and use low sun rays, but the effectiveness of these approaches has proved poor so far. When placed on east and west sides of the light tubes, the reflecting and refracting devices generally block about as much light as they capture.

Many active daylighting systems developed in the past have failed because the systems were overly complex, made of high-cost components, lacked durability, or because low energy costs have reduced people's incentive to save electric light energy. A number of recent developments offer renewed opportunities for reliable active daylighting designs of broad applicability and effectiveness. For example, owing to developments in modern electronics and the emergence of inexpensive computer-controlled mechanisms for the robotics industry, active control mechanisms can be simple, reliable, and relatively inexpensive. In addition, several new, high-reflectivity optical materials are available at modest prices, mainly for

advanced luminaire design in electric lighting applications, but equally applicable for daylighting.

Furthermore, advances over the last couple of decades in our understanding of non-imaging optical systems for illumination have opened the way for controlled beam daylighting systems that can be both cost effective and glare free. Finally, as world oil production peaks and then declines, while large developing countries demand more petroleum for their growing industrial base and transportation uses, energy prices will soar over the coming decade and overdependence on coal will exact high environmental costs. Thus, slightly more expensive daylighting systems will become cost-effective in coming years and the environmental benefits can drive markets for energy-saving technology.

System Development

Practical systems are now available for sensing the visual environment and dimming either fluorescent or high-intensity discharge (HID) light sources to achieve good lighting at night and when daytime weather conditions do not favor 100% daylight. This article discusses several daylighting systems under development by the authors based on smart controls that follow the sun's azimuth and elevation at any location on earth at intervals as short as one minute. These include:

- A two-axis tracker that concentrates daylight 40 fold;
- a system that works from the side of building to either feed a light pipe (achieving a six-fold concentration) or spread daylight across a ceiling and top of a far wall; and
- another sidelighting system that transmits beam daylighting through free space or a light pipe deep within a building.

These active daylighting systems are relatively inexpensive and have a small number of moving parts. Each system controls daylight effectively, spreading it out over light-colored ceilings and the tops of sidewalls to achieve glare-free diffuse illumination of the spaces below. Each also avoids using sensors with

closed-loop controls whose reliability in the field is questionable.

Concentrating System

The Daytracker system is an inexpensive, relatively large, parabolic mirror that intercepts approximately 7 ft² (0.65 m²) of beam solar radiation and concentrates it onto a secondary parabolic negative mirror, which reflects the converging solar beam through a hole in

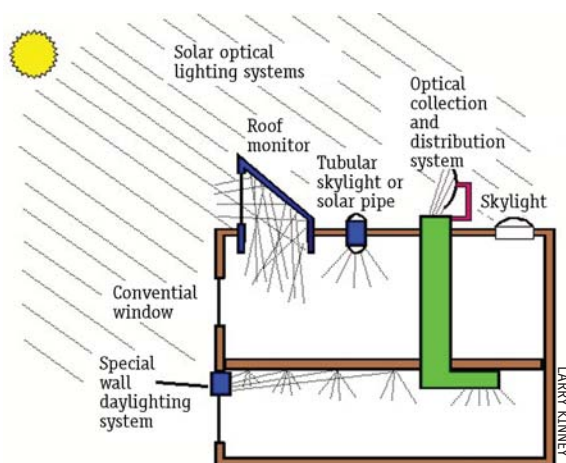


Figure 1. The illustration shows examples of solar lighting systems that take advantage of available daylighting.

the center of the primary mirror and onto an adjustable flat mirror. This latter mirror directs the concentrated beam vertically downward into a system of light pipes, distributing the concentrated illumination to where it is needed in the building below. The system tracks the sun in azimuth and elevation, always directing the beam of concentrated solar flux downward along a vertical axis into the fixed distribution system.

The system of three mirrors is rotated on a lazy susan, which contains the main light pipe that goes into the space below (see photo, p.40). As it tracks, the sun, the three mirrors, and the principal light pipe are maintained in the same vertical plane. Since the flat mirror is effectively a 2:1 optical lever, it rotates vertically at exactly half the rate at which the two parabolic mirrors rotate in tracking the sun in elevation. Accordingly, a simple mechanism rotates the flat mirror instead of a motor. This, plus strategic counter balancing, simplifies the design and

allows for the use of two small stepper motors to manipulate the system.

Concentrated beam sunlight from light pipes can be moved in free space or spread over a ceiling by means of suitably curved mirrors. In the latter case, the ceiling and sidewalls become diffusing sources of light for illuminating the spaces below.

This system has a number of advantages over those that use fiber optics to deliver sunlight delivered by a tracking dish system. The advantages include: better color rendering; the ability to achieve high levels of flux; an order of magnitude less sensitivity to tracking and insertion errors; and substantially higher glare-free light delivered per unit cost to where it is needed.

Ceiling and Piping System

The ASZEN system intercepts beam sunshine using horizontal and vertical reflective elements, typically mounted between glazing near the top of a wall that faces within 45° of south in the northern hemisphere and 45° of north in the southern hemisphere. Sets of elements are moved together, but the elements can be adjusted in relation to one another (see Figure 2).

In this case, a concentration ratio of approximately 6:1 is achieved, and the rectangular light pipe, composed of specularly-reflective material with a reflectivity of 0.98 in the visible, carries flux above dropped ceilings well within a building, 65 ft (20 meters) or more. When light is desired in the space below, a pick-off mirror oriented at 45° to the incoming flux redirects light through the ceiling where it is re-reflected onto the ceiling by a second specular reflector, thus allowing the ceiling itself to shed diffuse lighting onto the space below. A variety of other illuminating effects can be achieved using other reflector shapes or a variety of fiber optical fixtures. For example, elements can be oriented to form a soft focus at the opening of a light pipe above a dropped ceiling.

A second option directs light across a ceiling and onto the tops of the far sidewall. A single microcontroller can control sets of front-end ASZEN light-redirecting systems in a coordinated fashion to achieve uniform glare-free natural lighting in the spaces below.

Rotating System

An example of a two-axis tracking, rotating daylighting system is one that mounts in the sidewall of the façade of a building that faces within 45° of local solar noon. It uses a set of first-surface mirrors parallel to each other, housed in a cylinder that rotates the mirrors in the x-y plane. The mirrors are also rotated on each of their long axes about their centers of mass. Accordingly, the system

The ASZEN Daylighting System

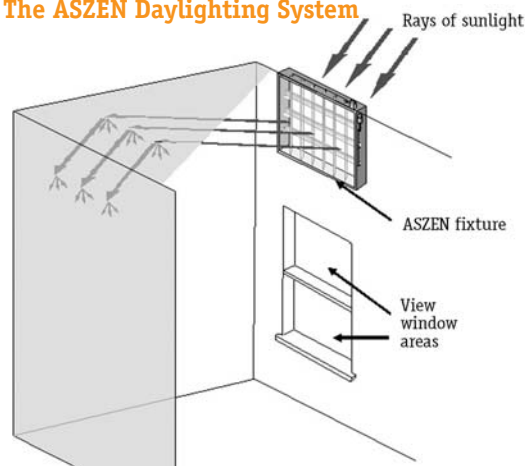


Figure 2. The ASZEN system washes the ceiling and opposite wall with light redirected from a fixture placed high up on an exterior wall.

uses only a pair of motors to form a beam of parallel light that maintains a constant direction throughout the day. The beam can be directed to any area

desired, where it can be redirected onto a ceiling or sidewall, for example, using the techniques discussed above. The result is controlled, diffuse daylighting that can be achieved deep inside a building. The beam may be transmitted either above or below a dropped ceiling, either with the aid of a light pipe or without it. Portions of the beam may be intercepted along the way from the façade of the building, as needed. Note that sets of these systems may be operated parallel to each other toward the top of a wall. If the daylit building is not shaded by an adjacent structure, the system can serve all stories of a multifamily building.



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