Fiber Optics Revolutionizes Lighting Design

Fiber optic lighting systems are extremely versatile, and theoretically can be used in place of any traditional lighting system. However, the industry is still in its infancy. Given today's level of technology, it makes sense to use fiber optic lighting systems only in certain applications. But don't blink for too long, because the technology is advancing rapidly and in a couple of years it will make sense to use fiber optics even for general lighting.

Fiber optic systems make sense today for application where you must remove heat or UV from the systems (such as in retail displays and in museums). Fiber optics make sense when the electricity in the system should be remote from the light (pools and spas, e.g.). Or when it makes sense to reduce maintenance costs of lighting systems when lamp replacement is a major hassle (some chandeliers).

And fiber optic lighting systems make sense when you're trying to achieve special lighting effects based on a number of small points of light, rather than a single large source (signs, accent lighting, etc.).

What are the basic tenets of fiber optic lighting?

How does the technology work?

What advantages can architects gain through using these systems?

FIBER OPTIC LIGHTING

In fiber optic lighting systems, a lamp transfers its light through to the end of the fiber or linearly through the fiber's transparent sheathing.

The most noteworthy advantage of using fiber optic lighting systems is that the light is separated from the electricity that generates light. And, too, one source can drive many fibers and produce multiple points or lines of light. By separating light and electricity, fiber optic lighting can be used to light electrically or chemically hazardous areas, such as pools, spas, fountains, or in environmentally sensitive industrial situations.

The reason: the light produces no electrical shocks and will not become a fire hazard. A sidelight fiber can be used in places where the potential of breakage or of contact with a high voltage transformer makes a neon light hazardous. In addition, nearly all fiber optic lighting systems use both heat (infrared or IR) and ultraviolet (UV) filters at the light source. As a result, the output light contains no UV and no heat.

This makes the systems especially desirable for lighting retail displays containing products that are sensitive to heat, as well as museum displays of temperature sensitive artifacts and art. Basically, dyes and oil paints won't fade, chocolate won't melt, and fresh flowers won't wilt.

The use of fiber optic lighting systems (FOLSs) can also lead to improved energy efficiency in some cases, particularly through the use of metal halide (MH) light sources. Because a single lamp can illuminate many fibers, maintenance costs can be reduced and maintenance tasks simplified, particularly for the hard-to-reach bulb.

In addition there is economy of scale, as one bulb can light an entire chandelier or a ceiling or wall of sprinkle lights.

Overall, fiber optic lighting systems can be used in almost any lighting situation.

The Lighting Research Center at Rensselaer Polytechnic Institute and others have tracked the following applications of fiber optic lighting:

1) Displays and exhibits—fiber optics replace the traditional linear fluorescent and MR16 lighting in museum and retail displays.

2) Water—fiber optics is used in at least 10 percent of the water lighting market and that market is growing.

3) Architectural highlights—spots of light from end-emitting fibers can dramatically highlight the architectural features of a room or building. Side-emitting plastic fiber and prism light guides can outline the exterior contours of buildings.

4) Signage and visual guidance—fiber optics systems are used to light a variety of signs and are also used in edge-lit exit signs, billboards, and traffic signals. Fiber optics light steps and aisles in theaters and, in turn provide a safer, more accessible environment. Signage projects are perhaps the most dramatic application, in that PMMA fibers can be assembled to create unique and vibrant images ranging from random patterns to intricate designs including logs and animated figures. White light or a variety of colors can be used to achieve versatile and exciting design. Fiber optic cables with larger diameters produce channel lettering, and perimeter, backlight and outline illumination.

5) Decorative—chosen for special effects such as color changes and strobing, FOLS can produce a starlight effect for ceilings and can mimic flickering candlelight for historic ambiance.

6) Downlight and ambient—although the Rensselaer Lighting Research Center found that fiber optic lighting systems are not widely used for downlighting and ambient light in the United States, in Europe such systems are popular for offices and restaurants.

ANATOMY OF AN FOLS

A fiber optic lighting system (FOLS) consists of three principle components—the illuminator, the fibers, and the output fixture. Note that for sidelight applications, the fiber doubles as the output fixture. The color of the emitted light can easily be changed through the use of a color wheel and the intensity lessened with a mechanical dimmer.

Fibers. Optical fibers for illumination are either glass or plastic and at least two layers—an inner core surrounded by a thin cladding. There may be an additional third layer or sheathing for protection of the inner fiber. Bundling individual fibers together is a common practice, with this assembly referred to as bundled fiber. Nonbundled fibers are commonly called solid core fibers, or large diameter fibers.

The core and cladding must be of different materials for the system to function properly. Nearly all cladding layers are made of some kind of fluoroplymer (an example being Teflon FEP™). The core is either glass or plastic, with the plastic being either an acrylic or methacrylic copoloymer. The most common plastic core for bundled fiber is PMMA (poly methyl methacrylate), known by the trade name Plexiglas™. If present, the sheathing is PVC (vinyl) or polyethylene.

Bundled Plastic Fibers. Made of extruded PMMA, individual plastic fibers are commonly .030 inches to .060 inches, or about 20 times the size of glass fibers. The diameter of the individual fiber is determined by brittleness of the PMMA; if the fiber is larger than 1 mm, the fibers may not be bent to a reasonable radius without breaking. PMMA fibers are separated and used individually for such applications as signs, star ceilings, and fiber optic curtains.

PMMA fibers are considered very durable compared to other plastic fibers.

HOW IT ALL WORKS

All optical fibers work on the principal of total internal reflection, or TIR. Whenever light traveling in one material approaches another material (such as the movement from the core to the cladding), the light is bent somewhat as it enters the second material. If the light approaches the second material at a shallow enough angle (known as the critical angle), then it is bent so much that it never enters the second material at all. It is totally reflected back into the first material—an amazingly efficient process. For instance, a typical glass mirror may reflect only about 90 percent of the light that hits it.

However, total internal reflection reflects essentially all of the light. This allows the light to travel far distances, undergoing many hundreds of bounces along the light pipe without being absorbed.

How shallow the light rays must be in order to be totally reflected is determined by how different the core and cladding are. This is measured by the refractive index, which is essentially a measure of the speed of light in the material.

The greater the difference between the indices of refraction, the more light (over steeper and steeper angles) will undergo TIR. All optical fibers are characterized by an acceptance angle—the maximum angle (away from “straight on”) at which light can enter the fiber and be totally internally reflected down its length. The acceptance angle is determined only by what the core and cladding are made of. For plastic optical fibers, the acceptance angle is usually about 35º to 40º.

This means that all lighting hitting the face
of the fiber in a cone of 70º to 80º (from +35º or +40º to -35º to -40º) will be internally reflected. The rest of the light is reflected back out the face or absorbed by the core, cladding, or sheathing.

Another measure of the ability of a fiber to gather light is the numerical aperture (NA). This is defined as the square root of the difference between the squares of the refractive indices: NA=Square roof of (n^2core – n^2clad) where n is the index of refraction. The acceptance angle is simply the arcsine of the NA. The bigger the acceptance angle (or NA) the better, because the fiber collects more light.

Also note that if the fiber is bent, the angle at which light approaches the cladding from the core changes.

For this reason, bending an optical fiber results in some light loss. Tests to measure loss under various bending conditions are not well-defined. In general, though, the more sweeping the bend, the less light is lost. The tighter the bend, the more light is lost.

Color. All optical fibers change the color a bit as the light travels through them. Look at the color of light transmitted through 40 feet or more of fiber. Assuming that you start with white light, absorbing red will make the light appear greenish.

Absorbing blue will make the light appear yellowish.

All types of plastic optical fibers absorb some red light. The absorption of blue differs, however, and is not fundamental to plastic fibers. This results from broad absorption bands in the UV that “tail” into the visible region.

These UV absorptions are generally caused by “stuff” in the fiber left over from the polymerization. So, the cleaner the manufacturing process, the less blue is absorbed.

Therefore, a greenish cast to the transmitted light implies a cleaner fiber and lower overall attenuation.