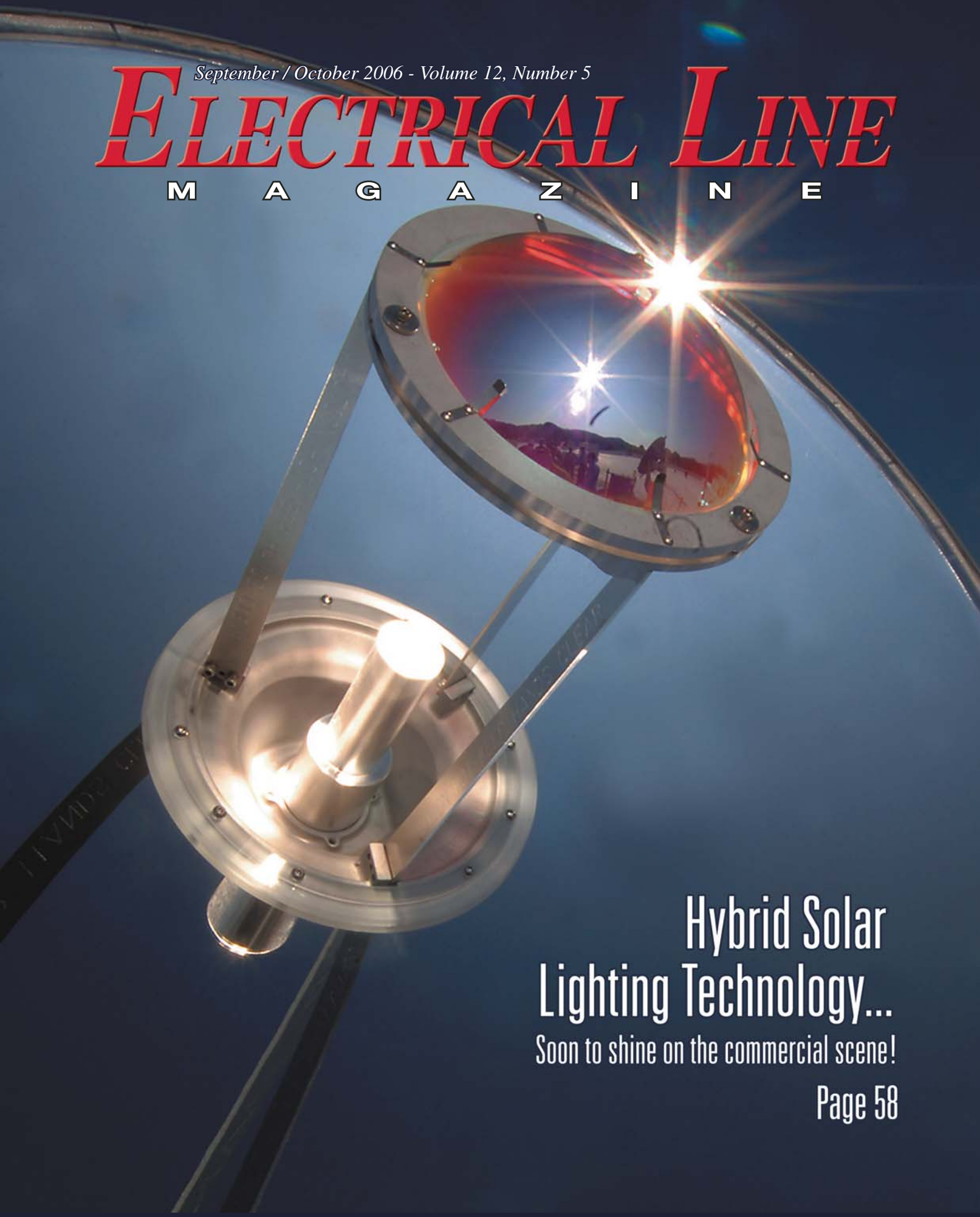
September / October 2006 - Volume 12, Number 5

ELECTRICAL LINE MAGAZINE



Hybrid Solar Lighting Technology...

Soon to shine on the commercial scene!

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Duncan Earl of Sunlight Direct with research assistant Tonya McFadden check out light distribution from hybrid luminaire.

Hybrid Solar Lighting Technology Gaining Momentum

This is an update of the article "Letting The Sun Shine In" by Jeff Muhs that appeared in the September/October 2003 issue of Electrical Line. Jeff, along with Duncan Earl, were co-developers of hybrid solar lighting technology at the Oak Ridge National Laboratory (ORNL) in Tennessee. This new technology is now on the brink of commercialization.

With five hybrid solar lighting systems already in place and another 20 scheduled to be installed in the next couple of months, the forecast is looking sunny for a technology developed at the Department of Energy's ORNL.

Preliminary data from field units, which collect sunlight and pipe it into buildings using bundles of small optical fibres, show potentially significant energy savings in lighting and maintenance costs. An added benefit is that, for most uses, natural light is vastly superior to artificial light.

"This is the ultimate 'green' technology," said Duncan Earl, Chief Technology Officer of the Oak Ridge startup company Sunlight Direct, which licensed the technology from ORNL last year. "In fact, we have received many inquiries and are working with several organizations that are aiming to build LEED (Leadership in Energy and Environmental Design) certified buildings."

Researcher Dave Beshears examines an optical fibre bundle being tested at Oak Ridge National Laboratory.

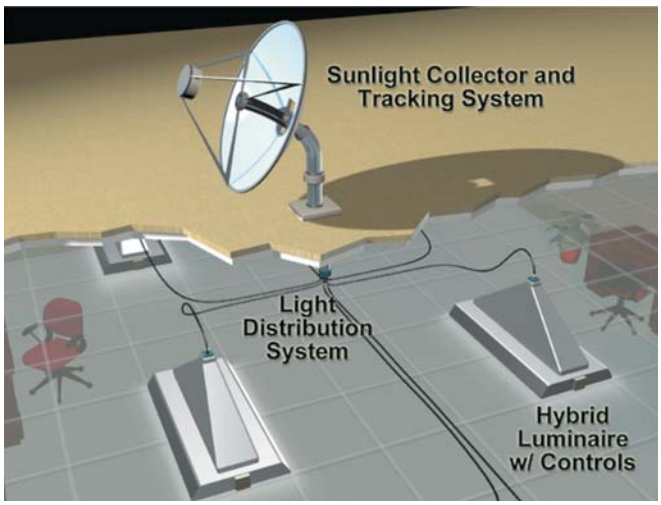
How It Operates

The hybrid solar lighting technology uses a rooftop-mounted 48-inch diameter collector and secondary mirror to track the sun throughout the day. When first developed, the system employed a glass primary mirror that was heavy and expensive. It relied on a third-party tracking system that was not optimized for the product, not easily adapted, and used large-diameter optical fibres whose sustained availability was not assured by the manufacturer. The design used eight individual 1/2 inch diameter fibres, each in a separate holder. Eight flat secondary mirrors were required as well. The design was costly and difficult to align. Since that time the design of the system has evolved to use a custom plastic mirror that is one-fifth the weight and one-tenth the cost of the original mirror. The eight individual fibre holders/adjusters were simplified to a single holder for one bundle of 127 individual fibres, each 3 millimeters in diameter.

The collector system focuses the sunlight into 127 optical fibres connected to hybrid light fixtures equipped with diffusion rods visually similar to fluorescent light bulbs. These rods spread light in all directions. One collector powers eight to 12 hybrid light fixtures, which can illuminate about 1,000 square feet. During periods of little or no sunlight, a sensor controls the intensity of the artificial lamps to maintain a constant level of illumination.

The sun-tracking control board that calculates the sun's position, based on latitude, longitude and time of day, uses a

A 48-inch diameter collector and secondary mirror accurately track the sun throughout the day by a microprocessor control board that computes astronomical equations good to 1/60°. It enables the system to track at 0.1° accuracy, focusing the sunlight onto a bundle of fibre optic cables.



Schematic showing hybrid solar lighting distribution system.

The fibre optics serve as flexible light pipes and are connected to hybrid light fixtures with special diffusion rods.

microprocessor to compute the astronomical equations obtained by the U. S. Naval Observatory. The equations have a 1/60° accuracy for the next 300 years. This precision allows the system to track at the 0.1° accuracy required by the two-mirror geometry to keep the focused beam on the fibre bundle. The calculations determine positions in the azimuth and zenith earth-based coordinate system using latitude, longitude, and Coordinated Universal Time (UTC) from a global positioning system receiver. The positions are then converted to units of encoder counts for the two encoders used to detect the location of the collector on each axis. The controller compares the actual position of the collector to the latest computed position of the sun and then determines if the move is to be in a positive or negative direction. The motors then move at a speed proportional to the difference in the actual and computed positions. This process is performed at one-second intervals continuously throughout the day to track the sun accurately. The control board operates on a 12V or 24 V DC supply and uses less than 2 watts. A photovoltaic solar cell can also be used to power the board.

The optical fibres penetrate the roof via a 4" diameter pipe, and distribute the sunlight to multiple 'hybrid' luminaires within the building. The hybrid luminaires blend the natural light with artificial light of variable intensity to maintain a constant level of room lighting. When sunlight is plentiful, the optical fibres in the luminaires provide all or most of the light needed. As mentioned, during periods of little or no sunlight, a sensor controls the intensity of the artificial lamps to maintain a desired illumination level. Unlike conventional electric lamps, the natural light produces little or no waste heat, and is cool to the touch, as the system's solar collector removes the infrared light – the part of the spectrum that generates much of the heat in conventional bulbs – from the sunlight. This hybrid technology also offers the potential to separate and use different portions of sunlight for various applications – visible light directly for lighting applications and the ultraviolet light could be used for heating applications or to produce electricity.

Energy Savings

On a sunny day, one hybrid solar lighting system will deliver 50,000 lumens of sunlight, or the equivalent of 55 60-watt incandescent lamps. For buildings that use incandescent lamps, which have a luminous efficacy of 15-20 lumens/watt, this can result in two forms of energy savings.

First, there is an energy savings of approximately 6,000 kWh per year due to the reduced lighting needs. Second, there is an energy savings resulting from the buildings reduced cooling load. Because the hybrid solar lighting system delivers light with little or no infrared component, there is very little waste heat. The additional energy savings depends on the cooling technology utilized, but is in the order of 2,000 kWh per year, for a total energy savings of 8,000 kWh per year. The cost savings associated with this energy reduction will vary dependent upon local utility rates. As an example, for areas with a 0.10 cost per kilowatt hour, over a ten-year period, a hybrid solar lighting system, working with incandescent lamps, can save a building occupant $8,000 per unit. Operation and maintenance savings, - due to the reduced operating hours of the electric lighting and reduced costs for re-lamping of existing fixtures –

could account for another $2,500 over the same period. For large floor spaces of 100,000 to 200,000 sq. ft., this translates into $1.1 million $2.1 million of energy cost.

Integrating hybrid solar lighting with fluorescent applications has the potential to save building managers $500 per system annually with a life cycle of 20 years and system price of $4 per square foot, estimated for 2008.

Hybrid solar lighting technology could replace less efficient conventional electric lamps.

Type of lighting	Typical energy efficiency (approx. lm/W)
Incandescent	15
Fluorescent	75
Hybrid solar	200

Laboratory space illuminated partially with hybrid lighting (left) and partially with standard fluorescence lighting (right).

Lighting Quality

From a practical point of view, the key features of lighting quality can be captured with the following observations. Almost all artificial light sources emit light that is more reddish than natural sunlight (i.e. their emission spectrum is peaked at a wavelength greater than 500nm). As the relative proportion of blue light increases, the sources tend to more closely mimic natural sunlight and are often preferred in term of aesthetics and illumination comfort. This preference is validated by the fact that lamps with more 'solar-like' spectra command higher prices. There is also a lot of evidence to suggest that retail sales, student scores, and productivity may all improve in the presence of natural sunlight.

Commercialization Potential

The hybrid solar lighting commercialization goal based on market analysis for general consumer use is an installed price of $3000 per 1000 square feet. In the initial product offering from Sunlight Direct, the installed price of $24,000 is less

than half of the early cost projections for the technology. Sunlight Direct has a development plan that aggressively targets the commercialization cost goal of $3.00 per square foot of illuminated space. When that target price is reached, regions of the United States where electricity is most expensive could pay for implementing the new technology in just a few years with the savings on electricity bills alone. Utility companies and their customers directly benefit from the offset in peak summer load. During peak demand periods (clear, hot summer days) hybrid lighting can reduce the amount of expensive supplemental power that must be provided.

One of the initial targets for hybrid lighting systems is in retail lighting applications that rely on direct lighting from incandescent sources. During a sunny day, those sources can be dimmed or turned off altogether. When incandescent lamps are dimmed, filament temperatures decrease, extending the life expectancy of the lamps and reducing maintenance costs associated with re-lamping.

Although skylights are widely used to include natural light inside buildings, they require large roof penetrations that add to the load on heating and cooling systems and are subject to water leakage. In contrast, the roof penetration for a hybrid solar lighting system is a small pipe similar to the vent pipes that are used throughout the building industry. Smaller penetrations and less leakage save money on the building's heating, cooling and maintenance.

System Advantages

One hybrid lighting solar collector can power 8 to 12 fluorescent hybrid light fixtures or 30 to 40 incandescent accent lighting fixtures, which can illuminate approximately 1000 square feet. Hybrid solar lighting systems are highly efficient and offer significant energy savings by reducing lighting cost. In addition, there are several other advantages that hybrid solar lighting provides:

- Infrared and ultraviolet energy in sunlight is separated from the visible light, rather than being transmitted into buildings. Heating, ventilation, and air-conditioning loads are thus reduced to 5 to 10%, compared with electric lighting systems.
- Hybrid solar lighting systems are readily adaptable to commercial buildings with multiple floors, relatively low ceiling heights, and interior walls. A single system can distribute enough sunlight to illuminate several small rooms in a typical office building.
- The concentrated light travels through optical fibres that require little plenum space so there is little competition with other building services such as HVAC ducts, sprinkler systems, and electrical conduits.
- Hybrid solar lighting can be used for diffuse ambient lighting, as in skylights, as well as focused task and accent lighting.
- In retrofit markets, hybrid solar lighting systems are easily incorporated into existing building designs, and the optical fibres can be rerouted to different locations as lighting needs change.
- When sunlight is plentiful, the fibre optics in the luminaries provide all or most of the light needed in an area. During times of little or no sunlight, a sensor controls the intensity of the artificial lamps to maintain a desired illumination level.
- When necessary, the solar lighting component is easily "switched off" by moving the solar collector to an "off-sun" position.

5000 Hybrid Systems Within Five Years

Over the next several months, researchers in ORNL's Solar Technologies Program will continue to perform beta testing of the units that are installed or are being installed at various locations around the nation, including Sacramento Municipal Utility District customer service headquarters, San Diego State University, University of Nevada, Las Vegas, a Wal-Mart in McKinney, Texas, Pacific Northwest National Laboratory in Richland, Washington, a Staples store in Long Island, N.Y., and Aveda Corp. in Minneapolis.

Bill Lekas, energy manager at San Diego State University, said, "The great thing about hybrid solar lighting is that we're getting peak light output during the time when there's the greatest demand for electricity. That saves us energy during the part of the day when electricity costs the most, and the reduced demand could reduce the incidents of rolling brownouts."

Melissa Lapsa, manager of the lab's Solar Technologies Program, said "As part of ORNL's Sunlight Inside Initiative, a field-trial demonstration program, we will be gathering energy, cost and reliability data and publishing a report.

According to Duncan Earl, "If market projections prove accurate, within five years 5,000 hybrid solar lighting systems could be installed in regions of the nation where solar availability and electricity rates make this technology cost effective, saving 50 million kilowatt hours per year.

The challenge over the next 18 months is to reduce the cost from about $12 to $4 per square foot and with larger collectors and other design improvements researchers say they can achieve that goal. According to Mr. Earl, when that happens, businesses in regions where electricity is most expensive could pay for implementing the technology in three to five years with savings in electricity bills alone.

In addition to the environmental and financial incentives, proponents of hybrid solar lighting note that the higher quality of natural light leads to increased productivity and improved sales in retail outlets. They also note that hybrid solar lighting avoids the environmental problems associated with generating and transmitting electricity.

This hybrid solar lighting technology was developed through funding by Department of Energy and the Tennessee Valley Authority in partnership with utility companies, state energy agencies, industry and universities.

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