Southwest Energy Efficiency Project

Saving Money and Reducing Pollution through Energy Conservation

Lighting Systems in Southwestern Homes: Problems and Opportunities

By

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Preface

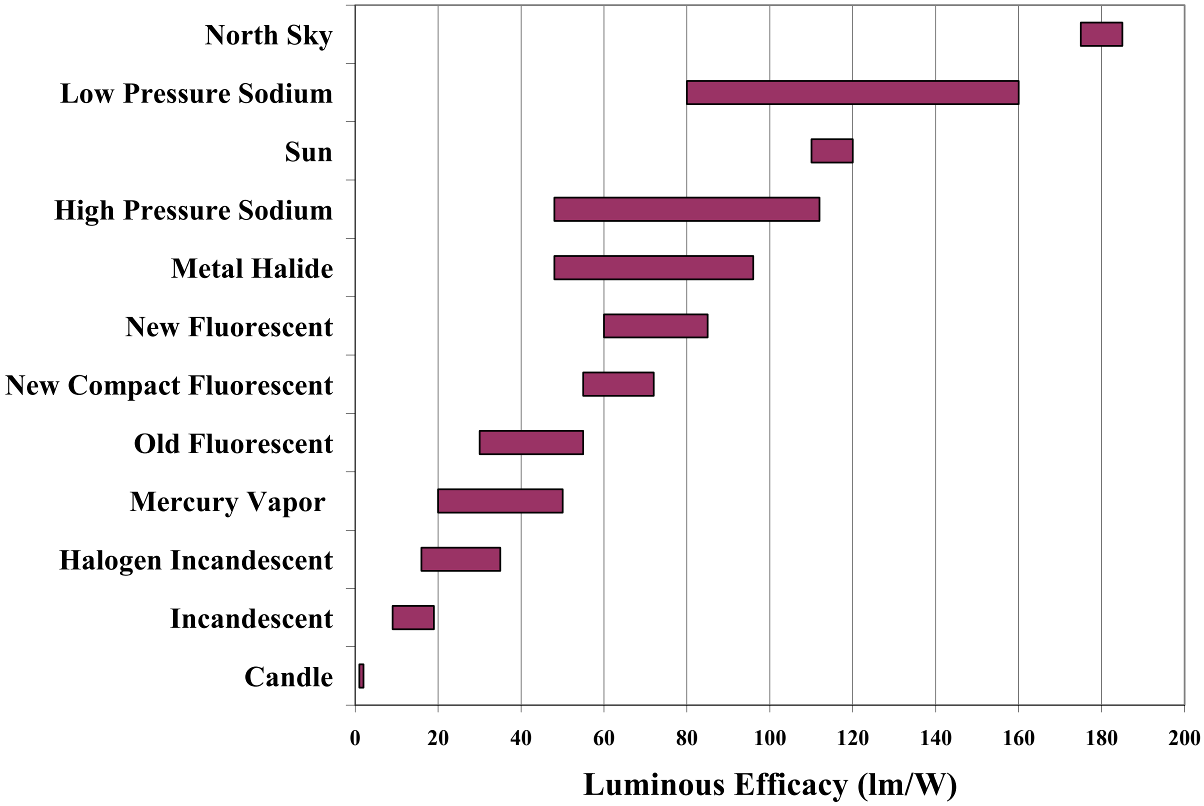
This report on lighting systems in Southwestern homes is one in a series of technical briefs prepared by the Southwest Energy Efficiency Project (SWEEP) in support of the U.S. Department of Energy's Building America Program. Its intended audience is builders and design professionals interested in employing technologies that will reduce energy costs in both new and existing housing stock. Feedback from all readers on the form and content of this report is welcome. A companion report, "Policies and Programs for Saving Energy through Enhanced Lighting Systems," is aimed at energy program policy makers, planners, and analysts. It includes information on energy and economic analyses associated with various levels of the penetration of energy-efficient distribution technology and associated policy options. Both reports are available for downloading at www.swenergy.org.

Introduction

In spite of great progress in the last few years in building new homes whose conditioned envelopes and heating, ventilating and air conditioning (HVAC) systems are of higher efficiency than ever before, most new homes are being built without much attention to the energy consequences of lighting, either electric or natural daylighting. Existing housing stock also has lots of inefficient lighting. According to a recent Residential Appliance Saturation Study conducted in California, homes there use on average 1,200 kWh per year for lighting, 22% of their total annual electricity use (Kema-Zenergy *et al*, 2004). Nonetheless, energy-efficient lighting that is both attractive and cost effective has become widely available. It's time to adopt the best new lighting technology and integrate it into the new and existing homes in the Southwest.

Toward understanding the energy consequences of lighting, it is useful to examine the amount of light produced by various lighting sources per unit of power required to produce it. This is called luminous efficacy, measured in lumens per watt, lm/W (Table 1).

Table 1. Range of luminous efficacy of various common light sources



Everyone knows that a candle puts out a lot more heat than light, but that is also the case for Edison's wonderful invention, the incandescent light. Large wattage incandescents may produce 16 or 17 lm/W, but smaller ones—like those in refrigerators—only 11 lm/W or so. Light sources that require a good deal of electrical energy to produce a given amount of light also produce considerable heat. The consequence of this inefficiency is starkly obvious in the case of lights in refrigerators, but it is also of concern in homes in the Southwest that require cooling for substantial portions of the year. Accordingly, using incandescent lighting costs twice: once for the lighting and a second time for the cooling system to remove the additional waste heat. The obvious solution is to use more efficient lighting in the first place.

Referring again to Table 1, note that the modern fluorescent fixtures have a luminous efficacy on the order of four times greater than do incandescents. In addition, the best compact fluorescent lights (CFLs)—those recognized by ENERGY STAR®—have lifetimes that are typically longer than the lifetimes of incandescent lamps by a factor of 8 to 12. Note that high-intensity discharge lighting like metal halide and high-pressure sodium fixtures, which are used to provide exterior lighting for some residential structures, are more efficient by a factor of 5 than are incandescents, and have lifetimes that are 10 to 20 times longer.

Finally, the table shows that direct beam sunlight has a luminous efficacy of about 113 lm/W. Interestingly, a northern sky has a luminous efficacy of approximately180 lm/W. Of course, unlike electric lighting, the watts in the ratio for sunlight do not make the electric meter run, but they do add to the cooling load. However, since natural light produces seven or more times less heat than does an equivalent amount of light from an incandescent bulb, there are good reasons to design homes to take advantage of natural light.

In spite of the advantages of more efficient lighting, America's love affair with the incandescent light bulb is largely unabated. Of the seven billion lamps that existed in the US in 2001, incandescent lamps constituted 4.4 billion, 3.9 billion of which were in residences where they accounted for 86% of the total bulbs. On a per-household basis in 2001, the average number of lamps per building was 43, 37 incandescent and 6 fluorescent. Potential power draw averaged 67 watts for the incandescent lamps (91% of the total), 38 watts for the fluorescents (Navigant 2002). There are signs that more efficient lamps are making headway in the residential marketplace, but presently incandescents have a commanding portion of the residential lighting market.

This report examines a handful of practical issues affecting lighting in new and existing residential buildings in the Southwest, with a concentration on interactions with heating and cooling. It examines the advantages and disadvantages of various electric lights and lamp combinations, including can lights and torchieres. It also examines strategies for residential daylighting, along with virtues and depravities of various approaches.

A Note on Lighting Terms

In addition to luminous efficacy, several other terms of art in the lighting world are useful to understand. ***Color rendering index*** (CRI) is a figure of merit that ranges between 0 and 100 that expresses the degree to which a given light source renders "true" colors as seen by the human eye. Our sun is an almost perfect black body, which means that there are very few holes in its spectrum so its CRI is counted as 100. (Of course, the atmosphere sometimes selectively absorbs portions of its output, which is manifest at sunrise and sunset when sunlight traverses much more atmosphere on its way to observers than it does at midday.) At the other end of the spectrum, so to speak, are low-pressure sodium lights with a CRI of 0 to only 10. Our eyes are at their peak of sensitivity for the characteristic yellow radiated from low-pressure sodium bulbs, but the absence of other colors makes them fit only for illuminating junk yards and other such spaces. High-pressure sodium lamps have a CRI of 25 or so, but slightly less luminous efficacy. Incandescent bulbs, which include halogens, have relatively high CRIs that approach 100. Good-quality fluorescents have CRIs in the 80+ (some as high as 98) range and the best metal halide lamps have a CRI of 94.

Color temperature is expressive of the characteristic color of a source of radiant energy we can see with our eyes. As a black body becomes hotter, it radiates more energy throughout the spectrum and increasing portions of its output are in the shorter wavelengths. Color temperatures are expressed in degrees Kelvin. A source with a color temperature of 2700K or below has a decided reddish feel to it, usually described as “warm.” A crystal blue northern sky on a clear day may have a color temperature of 10,000K or higher, the sun at noon in the summer 5400K, and at sunset, 2000K. Most people enjoy color temperatures of around 3000K to 3500K or so for most visual tasks, although warmer temperature light tends to be more comfortable in romantic restaurants, for example.

It is interesting to pay attention to the *color* of an incandescent bulb as it is dimmed. It tends to go from white to yellowish to reddish as its filament gets cooler in the dimming process and its color temperature becomes lower. Figure 1 shows the effect of dimming a combination up-and-down torchiere-style lamp versus light from a north-facing skylight.

Figure 1. This torchiere has a 95 watt incandescent bulb that is drawing 95 watts in the left photo, but is dimmed to 48 watts in the photo on the right. The surfaces on the right are illuminated by a 4.5 square foot north-facing skylight on a clear day two hours before sunset. The walls are all painted with the same flat white paint. In principle, the color rendering index of both the sun and the incandescent source are both 100, but the color temperature of the incandescent is well below 3000K and that of the diffuse light from a northern sky is above 10,000K.

Evaluating CFLs

The Environmental Protection Agency’s ENERGY STAR program evaluates a number of appliances, including CFLs. In order to qualify for an ENERGY STAR label, CFLs have to meet or exceed a number of performance characteristics. Current criteria for earning the ENERGY STAR label include having a luminous efficacy of 45 lm/W for bare bulb lamps of less than 15 watts and 60 lm/W for lamps of 15 watts and above. Reflector-type lamps of less than 20 watts must have a luminous efficacy of at least 33 lm/W and those of 20 watts and higher 40 lm/W. All lamps must have a CRI of greater than 80, a two-year guarantee, and a lifetime of more than 6,000 hours. Light levels fall off over time with all lamps, a phenomenon called lumen depreciation. ENERGY STAR-labeled lamps must have a lumen depreciation that retains 80% or more a lamp's initial lumens at 40% of its rated lifetime. Other performance criteria for CFLs are available on the ENERGY STAR web site, http://www.energystar.gov/index.cfm?c=cfls.pr_crit_cfls.

A list of CFLs that have been qualified under the ENERGY STAR program is available for downloading at http://www.energystar.gov/ia/products/prod_lists/cfl_prod_list.xls. There are over 1,675 products listed in the spreadsheet. In every case, the date on which a given product was listed is given, but there are two other columns that give dates when the product was taken off the list either because of being no longer manufactured (7%), usually because older models are replaced by newer models, or becoming disqualified (15%). Both consumers and manufacturers of high-quality products are benefited by EPA's diligence in taking lower-quality products off the list of ENERGY STAR-qualified CFLs.

The list also includes model numbers by manufacturer, packaging description, wattage, rated life, lumen output, color temperature, and type/design. The rated lifetime of all of the CFLs that have qualified for ENERGY STAR labeling averages 7800 hours and the average luminous efficacy is 58 lm/W. This number includes many small wattage bulbs which are inherently difficult to manufacture at high efficiencies, an observation that applies to both incandescent and CFLs. For example, small incandescents designed for use in refrigerators typically have luminous efficacies of 10-12 lm/W.

CFL Economics

In assessing the cost effectiveness of CFLs, it is tempting to calculate simple paybacks that compare the CFL/incandescent option based on time of use. However, in all cases except those in which a bulb may be in a rarely-accessed attic, we believe it is more appropriate to ask the economic question based on lifetime considerations, to wit, "how much energy and money will this CFL save over its lifetime?" To illustrate, take an ENERGY STAR-labeled 24 watt quadruple tube CFL suitable for a floor lamp. This bulb has an output of 1520 lumens, almost exactly that of a 100 watt incandescent, but a luminous efficacy of 63 lm/W, over four times that of the 100 watt incandescent at 15 lm/W. Over its lifetime, the CFL will consume 288 kWh, as compared to 1,200 kWh consumed by the incandescent, a savings of 912 kWh. At 8.5 cents per kWh, the energy savings is worth $77.52 (ignoring the time value of money). Of course, over the lifetime of the CFL, one must replace the incandescent on the order of 12 times. Ignoring labor, runs to the hardware store, and land filling 12 times as many burnt out bulbs, the first costs of the CFL and the incandescents over the lifetime of the CFL are effectively a wash.

What is the 912 kWh savings at the coal-powered power plant? At 10,000 Btu/kWh, a factor that accounts for the carnot effect and line losses, it is over nine million Btus, the energy equivalent of nine person years of labor. It's also associated with the mining, transporting, and burning of 650 pounds of coal, the evaporation of over 450 gallons of water and the release of

0.89 tons of CO_2. Expressed in terms of gasoline, the energy savings are equivalent to 72 gallons of gas, enough to drive from New York to San Francisco in a Prius.

This analysis applies to the savings associated with the lifetime of a single 24 watt CFL. The average American home contains 37 incandescents.

Other considerations

CFL technology has come a long way and improvements are underway. CFLs can be chosen that fit in virtually any lamp of almost any size. It's now possible to purchase 3 watt CFLs useful for illuminating paintings (Figure 2), as well as large 125 watt CFLs useful in industrial applications as well as in home shops. But the small bulbs have much lower luminous efficacy (50 lm/W is common), and lifetimes of all CFLs can be shortened in applications in which the bulbs themselves and (especially) their ballasts run hot. Like all electric lights, the light output of CFLs deteriorates with age, and the lumen depreciation over time runs from 10% to 30% over typical 10,000 hour lifetimes. In general, selecting a long-lifetime bulb whose lumen depreciation is modest makes sense, but front end costs may be somewhat higher.

Figure 2. The painting on the left is illuminated by a pair of 20 watt incandescents while the one in the center by a pair of 4 watt CFLs, an example of which fits in the palm of a hand.

Dimming systems for CFLs have been developed, and are now being sold by large manufacturers like GE and Philips. Their lifetimes are as long or longer than their non-dimmable cousins, their CRIs are 82 to 84, and color temperatures warm, typically 2,700K. In general costs are double or triple those of the low-cost ENERGY STAR-rated bulbs. Dimming down to 20% or so is possible with these, but luminous efficacy drops off at the low end of the dimming curve. This is an area where improvements in both quality and lower costs will be seen soon. In the meanwhile, it is important in replacing incandescent bulbs with CFLs controlled by a conventional dimmer to replace the dimmer with an on/off switch before installing the CFL.

A few years ago, purchasing a CFL bulb at a big box retail outlet cost $7 to $10, and that's still the case in Europe. However, it's now possible to purchase ENERGY STAR labeled CFLs for $3 or so, even less in four-packs. Bulk purchasing of several thousand CFLs, useful for production builders or for campaigns, can get the price down to less than $2.50 for ENERGY STAR CFLs whose lifetime is 12,000 hours.

The Conundrum of the Can

The choice of lamps interacts with heating and cooling costs, but so does the choice of light fixtures in the case of recessed downlights ("cans") in ceilings. Cans are becoming the light fixture of choice for many builders, and over 20 million are sold each year. The Pacific Northwest National Laboratory (PNNL) estimates that there are at least 350 million currently installed in US homes, and average new homes in the Northeast have 23 cans (PNNL 2005). Sadly, only a tiny fraction of the recessed downlights in new homes have CFLs installed, probably less than 2 percent.

Many cans in new homes are installed in the ceiling of the top story where they interact with the home's thermal envelope. In most homes during the winter, the most powerful force that causes convective leaks is called "stack effect." Warm air is less dense than cool air, so it tends to rise. This puts a negative pressure on the bottom of the home's thermal envelope and a positive pressure on the top. The magnitude of the force of stack effect depends on the difference in temperature between inside and outside of the building and its height. As shown in Figure 3, the pressure differences due to stack effect are greatest at the top and bottom of the envelope. Further, flow across an orifice is proportional to both the size of the hole and the difference in pressure from one side to the other. Accordingly, in most homes, holes at the bottom and top of the thermal envelope account for more infiltration/exfiltration problems than anywhere else.

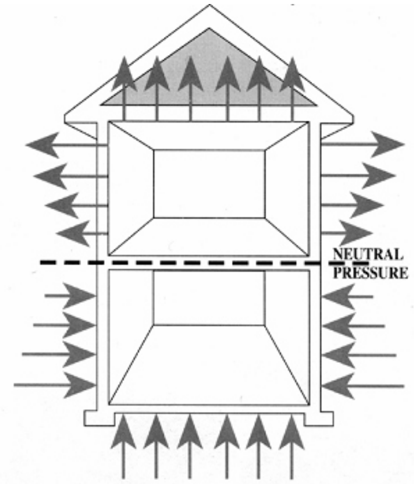


Figure 3. Stack-effect infiltration

Figure 4. Can light in a kitchen ceiling with a blower door depressurizing the home. Smoke indicates openings to the vented attic above.

Source: Rana Belshe, Conservation Connection

Figure 5. Charred insulation due to a hot can

Savvy builders and practitioners of residential retrofit understand this and make it a point to spend most of their efforts at air sealing in the basement/crawl space and in the attic. They know that putting leaky can lights in ceilings is an open invitation for costly air leaks and a challenge to fix (Figure 4). The problem is made worse in several ways by inefficient lights. First, they raise the temperature of the air and objects in their immediate vicinity, thus increasing the force of stack-effect induced air leakage. All other factors being equal, a 13 watt bulb increases infiltration through a leaky can by 60% when it's on, a 50 watt by 170% and a 100 watt by 400% (Bennett and Perez-Blanco, 1994). Second, they heat up the can itself to the point where placing insulation on top of it may risk fire (Figure 5). The result is conductive energy losses as well as convective ones, an unhappy combination that raises energy costs and may cause discomfort as well.

Figure 6 shows a can light being scanned by infrared thermometer. Figure 7 shows a snowy roof with leaky cans in the attic below.

Figure 6. Kitchen light in a home heated to 68ºF, outside air temperature of 34ºF, blower door depressurizing the home

Figure 7. The two holes in the snow above the skylight correspond to recessed can lights in a bedroom that are almost never turned on. Melting is due only to air exfiltration from the conditioned space below the cans and the lack of insulation on top of them. The larger melted hole in the snow to the left of the vent pipe is due to a similar can above the shower which has a 250 watt infrared bulb in it. This light is on a timer and on average is illuminated about 12 minutes a day.

In many homes, can lights cause quite significant energy losses. Since they allow warm, moist air to enter the attic, they can cause moisture problems, ice damming, and premature roof failure in addition to energy waste and discomfort.

So what is the solution to the problem? Avoiding can lights altogether comes easily to mind, particularly can lights that penetrate the thermal envelope. Wall sconces are widely available at prices similar to those of can lights. They produce nice light and can be fitted with CFLs.

McStain Neighborhoods, Inc., a progressive production builder in Boulder, Colorado, has started to use four foot long 32 watt T-8 florescent bulbs with electronic ballasts as wall and ceiling "washers." The bulbs are mounted in simple fixtures McStain fabricates on site from wheat board. Wheat board is a renewable resource that comes in 4 x 8 foot sheets and costs about $1 per square foot. After fabrication, the fixture is painted with a white semi-gloss low VOC interior latex paint.

As shown in Figure 8, the result is nice diffuse light that washes walls and ceilings without causing glare. In addition to energy savings of both electricity for lights and gas for space heating, McStain avoids the use of cans that produce visual hot spots in the ceiling, sharp shadows, and glare.

Source: Jeff Medanich, McStain Neighborhoods

Figure 8. This wall washer is simple to build yet yields excellent, efficient, glare-free light.

All of the over 400 homes McStain builds each year are ENERGY STAR® rated; many have a Home Energy Rating System (HERS) rating of 90, 20% better than needed to qualify as an ENERGY STAR home. They are built "tight and right" and are 100% inspected with blower doors and duct blasters. In consequence, annual energy use for space conditioning has become a relatively small portion of the whole. A recent analysis of typical 1800 square foot McStain homes showed annual energy costs of $251 (33%) for space conditioning, $221 (29%) for hot water, and $288 (38%) for lights and appliances (Wilson 2005).

Since the lighting costs are substantial, as an experiment, Justin Wilson, a building scientist with McStain, equipped a model home with CFL lighting throughout instead of incandescents. In his analysis, he assumed that the lights would be on for 8 hours a day for 24 months in the model home, that the incandescents would last for 1500 hours and CFLs for 8000 hours, quite conservative assumptions. His spreadsheet analysis showed (1) purchase plus replacement costs for the incandescents over the period would be $394 versus $372 for the CFLs, and (2) that the electric costs (at 8.5 cents/kWh) would be $1894 for incandescents and $445 for CFLs, a combined savings of $1470 over the two-year period. Of significance, he changed out all 60 bulbs in the model home without the knowledge of his colleagues. After a full day at the model home opening, in which senior managers, sales people, and others of McStain showed the model to hundreds of potential customers, he revealed to his colleagues that every bulb in the home was a CFL. No one had noticed the changes (Wilson 2005).

Retrofit

If cans already exist, the retrofitter has four choices:

- Remove the can and seal up the hole, insulating above the sealed-up space;
- Seal up the space, but plug into the electric socket and install a surface-mounted fixture in its place;
- Use the existing can, but build a large fireproof box around it in the attic, then seal and insulate the box; or
- Replace the old can with one that is sealed and can be insulated with impunity or install a retrofit device over the old can that achieves the same result.

The surface-mount-fixture option

Autocell Electronics is a California company that manufactures and markets a range of energy-efficient lamps and fixtures, all of which are ENERGY STAR approved. Figure 9 shows a fixture designed to get power via a screw-in plug from the electrical outlet in an old can, but to be mounted so that it covers the hole. It uses a 32 watt circular fluorescent bulb, which, with an electronic ballast, achieves a luminous efficacy of 68 lm/W and is rated for a 10,000 hour lifetime. Equally important, it allows for sealing and insulating the old can.

Figure 9. Autocell ceiling-mounted fixture. Both acrylic and alabaster glass cover are available.

The add-a-box option

Since 1995, the Model Energy Code and its successors (in particular, the International Energy Conservation Code which is in force in most areas of the Southwest) have included language allowing a box to be made of metal or ½-inch gypsum board that is installed in an attic surrounding a recessed can whether it is leaky or not. The box must be made so that it keeps combustible material at least three inches away from the can. As a matter of practice, this isn't always easy to do since there are typically no small number of accoutrements associated with cans in attics. These include mounting hardware, an electrical box, and Romex® wire. The trick is to build and install a box that will meet the three-inch constraint while being as well sealed as possible. Once fitted and sealed—ideally with a high-temperature caulk—the box can be insulated.

One practical consideration for retrofitters is that some old-style wiring has a temperature rating that is only 60ºC (140ºF), far below the temperature rating of modern Romex (typically 90ºC, 194ºF) as well as below the temperature of the high temperature limit switches typically installed in cans. If this is found to be the case, the most prudent options would be to select another method for retrofitting or do some rewiring. Choosing another option is likely to be more cost effective unless new wiring is desirable for other reasons.

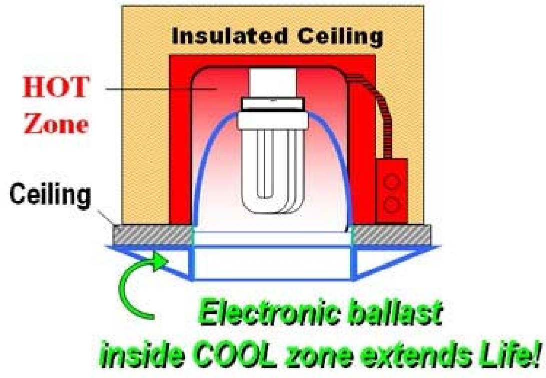
The install-a-better-can option

Given the popularity of recessed downlights, it is desirable to develop can/lamp products that maintain the integrity of the thermal envelope of the home while supplying efficient, long-lasting illumination. Hot spaces—which small, well-insulated cans with lights in them can easily become—tend to shorten the lifetime of both CFL bulbs and (especially) their electronic ballasts. Accordingly, the design problem is not trivial, and few companies have solved it.

Toward stimulating the development of products that meet the criteria of safeguarding the integrity of the thermal envelope while delivering light efficiently over the long term, scientists at the Pacific Northwest National Laboratory (PNNL) initiated a Recessed Downlight Project (www.pnl.gov/cfldownlights). The project solicits lighting companies to submit their products for testing at the lab. The lab verifies that lighting systems tested meet the ENERGY STAR specifications and a sub-set of specifications specific to CFL downlights. “Insulated Ceiling” (IC) cans and associated pin-based CFLs and ballasts are tested in a special facility designed for the job. The primary aim is to stimulate the development of an energy-efficient solution for the hundreds of millions of recessed cans already installed as well as the millions of new ones added every year.

One test is designed to determine if the temperatures in the can ever exceeds some specified maximum—typically the warranteed temperature rating of the electronic ballast—even when left on for 12 hours while covered by insulation rated at R-45. A longer-term test measures fixture performance and longevity as well as lumen depreciation over a year period under the stress of being turned on for three hours, then off for 20 minutes, then on again for three hours, etc. As of the spring of 2005, several vendors have had their products pass these tests, two of which are currently available in the market, PowerLux Corporation (www.powerlux.com) and Technical Consumer Products (www.tcpi.com).

PowerLux® solves the problem by keeping the small electronic ballast in a rim outside of the can itself (Figure 10). The advantage of this approach is that the ballast stays quite cool, only slightly warmer than the air at the ceiling. Thus, the ballast never approaches its rated maximum temperature, with the consequence that its lifetime is quite long. A general rule-of-thumb in the electronics industry is that the life of electronic ballasts is doubled for each 10 degrees C it is operated below its maximum rated temperature (McCullough 2005.)



Source: Powerlux®

Figure 10. The PowerLux system keeps the ballast outside of the can. Replaceable CFLs that fit the system are available in 18, 26, 32, and 42 watts, and in color temperatures of 2700, 3000, 3500 or 4100K.

All have a color rendering index of 82 and 12,000 hour lifetimes. Initial luminous efficacy ranges from 67 to76 lm/W. All with ANSI/IEC standardized lamp base configuration. Costs for the fixture, bulbs, and ballasts range from $56 to $100 with volume discounts.

Note that the PowerLux system simply installs in an existing can, whether IC rated or not. Importantly, it seals air leaks to the attic even better than called for in Washington State energy codes and ENERGY STAR 4.0 for IC-rated cans, which is less than 2 CFM (Cubic Feet per Minute) at a pressure of 75 Pascals. (PowerLux has been tested in accordance with ASTM E283 with a leaky non-IC can and showed a result of 0.83 CFM, 60% better. Lau 2005) All cans manufactured after 1983, whether IC rated or not, must have high temperature limit switches mounted in them (Figure 11), so according to PowerLux, the retrofitted can may have insulation installed directly over it. To be sure, while the PowerLux product renders an IC or non-IC substantially airtight, only an IC-rated can be covered with insulation. PowerLux electronic ballast has a built-in EOL (End- of-Life) protection and shut-down circuit. In the unlikely event that the can with an energy-efficient CFL in it does overheat, the high temperature limit switch opens the circuit when it senses temperature reaching 90ºC (194ºF).

Figure 11. Can showing the high temperature limit switch which opens at 90ºC (194ºF) and closes again at 80ºC (176ºF). Other models have the limit switch above the light socket. Note the leakage area between the edges of the can and the hole in the gypsum board ceiling. This is quite common. According to the new Title 24 code energy code in California, this area must be caulked or be fitted with a gasket to prevent air leakage. Some can manufacturers supply a doughnut-shaped annulus of sticky-backed foam with their products. This should be installing before fixing the rim in place.

Other organizations are also involved in developing more efficient can lights. In 2001, the California Energy Commission Public Interest Energy Research (PIER) Program initiated a project to develop more efficient recessed lighting systems for applications in residential kitchens. A team of researchers from the newly-formed California Lighting Technology Center at the University of California at Davis worked with a number of other groups to develop a system that uses a single electronic ballast to drive two 26 watt CFLs in adjoining IC-rated air sealed cans. Wiring connections between each pair of cans simply snap together, thus saving wiring time during installation and improving quality control. The keep-the-ballast-cool issue is resolved by using the can itself and the surrounding sheetrock as a heat sink. A typical large kitchen can thus be nicely lit by six of these cans for an initial installed cost that is claimed by its developers to be virtually identical to that associated with installing 10 conventional cans using 65 watt incandescent lamps. The light levels are better, lighting savings are $55 per year at 8 cents per kWh, and lifetimes of the lamps are a factor of 10 longer. The new system is being sold by Lithonia Lighting, www.lithonia.com (California Lighting Technology Center 2005).

Retrofitting black reflectors

In an effort to control for glare, some manufacturers of can lights deliver them with black “reflectors” which absorb rather than reflect light. If the lamps installed in these have built-in reflectors, the deterioration in performance is moderate. If they don’t, painting the reflectors with a semi-gloss white paint makes a real difference.

Figure 12 shows a typical can with an incandescent reflector-type lamp installed, dimmed for purposes of taking a photograph. Figure 13 shows the same can with its reflector painted white and a CFL installed, and Figure 14 shows the overall effect of a pair that has been painted with CFLs installed. **The dimmer was replaced with an ordinary switch for this retrofit, a critically important detail unless the retrofitted CFL is designed for dimming.** Light levels were measured with a digital light meter at 5.5 feet immediately below the fixtures (at desk level, 30 inches from the floor), 20 inches from the wall and 45 inches from the wall both before and after painting the reflectors. The average improvement in light levels for the incandescents was 7%, but the CFLs improvement was 48%.

Figure 12. Black reflector with incandescent flood lamp

Figure 13. White painted reflector with 23 watt spiral CFL

Figure 14. Light distribution with white reflectors and CFLs

Although this retrofit works well, it does entail painting. It is likely that better long-term performance could be obtained by using reflector compact fluorescent light (R-CFLs). Although they cost more, ($10 to $12 as opposed to $3) their built-in reflectors keep them cooler and achieve good light distribution with minimal glare. PNNL has another project focused on high performance (high temperature) R-CFLs; see www.pnl.gov/rlamps for details.

Figures 15, 16, and 17 show a successful lighting retrofit job in a kitchen. The cans were very leaky (one example is shown above in Figure 4) and had incandescent flood lights installed. Further, there was very little insulating in the attic. The cans were replaced by IC models with 16 watt CFL floods. Then the ceiling was insulated with cellulose.

Figure 15. Leaky cans crisscrossing poorly-insulated attic

Figure 16. Example of new IC can installed. This air tight can costs only a dollar or two more than those that are unsealed.

Source: Eric Doub, Ecofutures Building, Inc.

Figure 17. The finished job. There are 12 inches of cellulose in the attic above the ceiling, but the tops of the IC cans have only several inches covering them.

Torchieres

If recessed light fixtures have consequences for both lighting and space conditioning energy use related to the integrity of the home's envelope, torchieres have consequences for both lighting and safety. Torchieres are designed to provide mostly indirect light by bathing a portion of the ceiling with light from a lamp and reflector combination that is usually above eye level. In consequence, light is diffusely reflected from the ceiling, resulting in virtually glare-free illumination of the surfaces below. As of five years ago, 90 percent of torchieres in the US used 300 watt halogen lamps (Lighting Research Center 2000). These lights have a CRI of over 95 and a color temperature of about 3000ºK when operating at full power. When dimmed, their color temperature shifts into more mellow yellows or even reds. Their popularity stems from the fact that they work in a range of decors, produce attractive lighting, and some models are quite inexpensive, only $20 to $40. Figure 18 shows a range of torchiere styles.

Source: Arcadian Lighting

Figure 18. Several styles of torchiere lamps. All have dimming capability; some combine down light for such tasks a reading with up light that washes the ceiling and results in diffuse light on the surfaces below.

That is the good news. The bad news is that 300 watt halogens have low luminous efficacy. Counting fixture losses, typical torchieres were measured by scientists at the Lawrence Berkeley National Lab (LBNL) at 12 lm/W at full output and only 5 lm/W at half power (Siminovitch *et al*, 1998). This means that they both waste a good deal of electricity and are quite hot, about 1000ºF. Accordingly, they contribute to cooling loads and, since they are subject to being tipped over, torchieres have been the cause of many fires. Over a six-year period ending in 1998, the Consumer Products Safety Commission (CPSC) attributed 20 deaths and over 100 injuries to fires and bulb explosions associated with halogen lamps (Ault 1998). This prompted a ruling requiring a wire guard to be installed to help mitigate fire danger (Figure 19).

The LBNL scientists in conjunction with several lighting industry representatives also designed several CFL-based torchieres, variations of which are currently available in the market place. They were able to achieve total luminous efficacies (counting fixture losses) of from 48 (when dimmed) to 62 lm/W, an improvement of from 5 to10 fold over the halogen lamps.

Source: Lighting Research Center 2000

Figure 19. Wire guard over 500 watt tubular halogen lamp

In a press release issued in 2003, the CPSC noted that “more than 40 million halogen floor lamps made before 1997 need the guard. CPSC knows of 290 fires and 25 deaths since 1992 related to halogen torchiere floor lamps.”

The obvious solution to the problem is to use CFLs in torchiere lamps. A number of lamp manufacturers have developed such products, and ENERGY STAR-labeled products are now widely available. They feature cool bulb temperatures (surface temperatures of ENERGY STAR CFLs cannot be above 100ºF), lifetimes that are 6 to 10 times those of halogens, and energy savings of over 80 percent.

In addition, most of the new generation of efficient torchieres have ballasts that allow dimming or use several bulbs that can be step switched.

Researchers at LBNL conducted an experiment in the service territory of the Sacramento Municipal Utility District (SMUD) to test consumer acceptance of four torchieres produced by different manufacturers (Page 2001). Taking a sample of 60 customers, all of whom used torchieres with halogen bulbs at least five hours per week, technicians measured the time of use and consumption of the existing lamp for four weeks, then switched the torchiere with the halogen lamp for one with a CFL. After the second four-week period, another switch was made until over a five-month period the halogen light and four CFL-equipped torchieres were installed and monitored. Customers were paid $60 for their participation in the study and got to keep the torchiere of their choice.

Usage patterns were almost identical with all of the lamps tested, about 3.4 operating hours per day, 1242 hours per year. About half of the time the lamps were operated at close to full output and half the time the lamps were dimmed. The average demand of the halogen-based lamp was 237 watts, versus 43 watts for the CFL torchieres. The halogen fixtures averaged an energy use of 900 Wh/day and the CFLs 155 Wh/day.

Of course, there is interaction with cooling and heating costs since the less efficient halogen fixtures will cause higher cooling costs and lower heating costs (of the primary fuel, assuming it is less expensive than is electricity) than the more efficient CFLs.

As shown in Table 2, the net of these interactions strongly favors more efficient lighting.

Table 2. Cost savings considering space conditioning interactions associated with using CFL-based torchieres versus halogen-based torchieres

	Lighting (kWh/yr)	Lighting ($/yr)	Extra Cooling (kWh/yr)	Cooling Costs ($/yr)	Less Heating (Therms/yr)	Heating savings ($/yr)	Net Energy Costs ($/yr)
Halogen	329	$27.94	44	$3.73	8.0	$7.21	$24.45
CFL	57	$4.81	8	$0.64	1.4	$1.24	$4.21
Difference	272	$23.13	36	$3.08	6.6	$5.97	$20.24

The figures in the table are based on the assumptions of a cooling season of four months with an overall cooling system coefficient of performance (COP) of 2.5 as well as a heating season of six months with an overall heating system efficiency of 70%. Electricity costs are assumed at $0.085/kWh; gas costs at $0.90/therm. With these assumptions, energy cost savings with the CFL fixtures are 83% versus the halogens. Longer winters and higher gas costs will diminish dollars savings and longer cooling seasons and higher electricity costs (like those in Arizona and Nevada) will increase savings.

Of course, the economics depend on first costs and (especially) the lifetime of the lamps themselves. In general, first costs of CFL-based torchiere fixtures with high-quality electronic ballasts with dimming features are higher than the first-costs of torchieres with halogen bulbs by $10 to $30. For example, fully-dimmable torchieres with a 58 watt fluorescent lamp are available to commercial customers at $43 (EFI 2004). However, lifetimes of halogen bulbs are rated at 2,000 hours at most, with a replacement cost of around $10. Replacement costs for CFL lamps with pin-style bases and separate ballasts are $5 to $10, but the ballasts themselves have much longer lifetimes. Accordingly, within roughly half of the lifetime of the CFL-based torchieres, they become more cost effective than do torchieres with halogen bulbs, and the CFL torchieres outperform their more wasteful rivals from then on.

Other ENERGY STAR Light Fixtures

ENERGY STAR rates a wide variety of lighting fixtures suitable for residential use; thousands are listed on their web site at www.energystar.gov under lighting. In addition to torchieres, ENERGY STAR rates lights for kitchen cabinets, sconces, a variety of ceiling mounted fixtures, suspended fixtures, and outdoor lighting systems. They even rate ceiling fans and the energy-efficient lighting packages that accompany them.

Criteria fixtures must meet to qualify for being ENERGY STAR-rated are as follows:

- Must have a lifetime of 10,000 - 20,000 hours.
- Must distribute the light more efficiently and evenly than standard fixtures.
- Must carry a two-year warranty (double the industry standard).

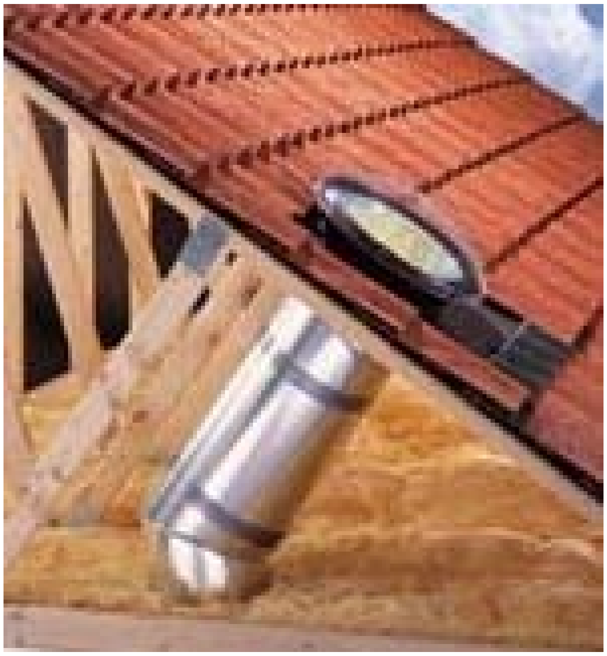
In general, ENERGY STAR qualified lighting uses about 66% less energy than standard lighting.

Information on fixtures that are ENERGY STAR qualified constitutes thousands of pages of downloadable material. In making purchasing decisions, it is certainly worthwhile to verify that a given fixture under consideration is indeed ENERGY STAR qualified. However, to simplify purchasing decisions by builders, ENERGY STAR has begun to develop "Advanced Lighting Packages" consisting of fixtures which are matched aesthetically and functionally, all of which are ENERGY STAR qualified. Information on these is available at the ENERGY STAR web side under lighting, "Advanced Lighting Package" (http://www.energystar.gov/index.cfm?c=fixtures.alp_consumers).

Skylights

There are two varieties of skylights in general use in residential structures, conventional skylights and tubular skylights (Figures 20 and 21). A full discussion of skylights is beyond the scope of the this report, but it is useful here to examine the consequences on the home's space conditioning costs associated with opening a hole in a roof to install a skylight in typical homes in the Southwest.

Figure 20. A fixed skylight with a double wall plastic dome is shown at top and a double-glazed skylight that may be opened to provide ventilation is shown below.



Source: Velux

Figure 21. A tubular skylight. Advanced light pipe technology (V_t of 98%) helps deliver light to rooms below even when sun angles are not very favorable.

For present purposes, it is helpful to think of skylights as being windows in the roof. Like windows installed in walls, some skylights (not all) can be opened for ventilation or even emergency egress. Second, they have several energy-related properties of relevance to their function and cost. Like windows, these include U-value, solar heat gain coefficient (SHGC) and visual transmittance (V_t), as explained in a companion publication in this series, “Windows and Window Treatments” (Kinney 2004). Finally, some skylights include roller-style shades that can be used during summer months to provide shading, effectively lowering both SHGC and Vt. The most effective shades for this purpose are on the outside of the skylight, for they intercept sunlight before it penetrates the home’s conditioned envelope.

Direct sunlight beaming in from the clear skies that characterize much of the Southwest most of the year can be the source of a substantial amount of light, on the order of 10,000 lumens per square foot. Even days with high clouds can yield 2,000 lumens per square foot. Thus, a skylight of only four square feet and a Vt of 0.80 can produce the equivalent illumination of from 6,400 to 32,000 lumens, the output of from 4 to 20 100-watt incandescent bulbs with only about 1/10th the heat. Accordingly, the illumination provided by a skylight can be quite substantial, although the distribution of light is usually far from optimal. Beam sunlight can be a source of glare and make surrounding areas appear dull in comparison, prompting the use of electric lighting. Further, even skylights on north-sloping roofs capture a considerable amount of direct beam sunlight, particularly in the summer. Solutions to the problem include using light wells between the skylight in the roof and the ceiling to diffuse the direct beam sunlight and to use plastic or glass diffusers at the point of entry into the daylit space, as is common with tubular skylights.

In general, skylights should be chosen with a strong emphasis on the esthetics and functions of the spaces in the home. However, in terms of achieving good light distribution in a living area with a cathedral ceiling, for example, a pair of symmetrically-spaced four square foot skylights achieve much more satisfactory light distribution than does a single eight square foot skylight.

Effect of Skylights on Space Conditioning Energy Use

RESFEN (for “residential fenestration”) is an hourly simulation program based on DOE 2.1E software developed at the Lawrence Berkeley National Laboratory. It is a tool for evaluating the energy consequences of various fenestration systems in a number of cities using typical meteorological year weather data. We made a number of runs on homes in six Southwestern cities with RESFEN version 3.1 to evaluate the effects of skylights. In all cases, we assumed single-story, frame, 2,000 square foot homes with 300 square feet of fenestration systems distributed evenly on the four facades of the homes plus 24 square feet of skylights as explained below. Homes in Albuquerque, Las Vegas, and Phoenix were assumed to have slab-on-grade construction; those in Cheyenne, Denver, and Salt Lake City had basements. The homes modeled in Albuquerque, Cheyenne, Denver, and Salt Lake City had ceilings insulated to R-38 and walls to R-19; ceilings in Las Vegas and Phoenix had R-30 insulation and walls of R-14 and R-11 respectively. Furnace seasonal efficiency was assumed to be 78 % and cooling systems 10 SEER. Duct leakage was set at 10% summer and winter.

We looked at two sets of skylight systems totaling 24 square feet, whose characteristics are described below:

- Clear, single-pane skylights with a U-factor of 1 and SHGC of 0.8; and

- Double-pane insulating glass units with an overall window system U-factor of 0.6 and a SHGC of 0.4. These skylights meet current energy codes in all of the Southwestern states and qualify for ENERGY STAR ratings.

Table 3 shows average residential energy costs and weather data for the states for which simulations were run and Table 4 shows simulation results.

Table 3. Residential Electricity and Gas Costs and Weather in Southwest States

State	**Elec $/kWh**	**Elec $/MBtu**	**Gas $/Therm**	**Gas $/MBtu**	**Heating Degree Days**	**Cooling Degree Hours**
Arizona	$0.074	$21.68	$1.31	$13.13	1,444	54,404
Colorado	$0.080	$23.15	$0.92	$9.19	6,023	5,908
Nevada	$0.090	$26.37	$1.06	$10.60	2,535	43,153
New Mexico	$0.084	$24.32	$1.00	$9.93	4,415	11,012
Utah	$0.066	$19.34	$1.00	$9.93	5,805	9,898
Wyoming	$0.066	$19.05	$0.94	$9.35	7,315	2,087

Source: Energy Information Administration. Assumes 1 ft^3 of gas = 860 Btu. Heating Degree Days and Cooling Degree Hours from ANSI/ASHRAE Standard 90.2 for cities analyzed.

Table 4. Heating and cooling energy, electricity peak, and costs associated with two varieties of skylights in six southwestern cities

City	**SHGC**	**U Factor**	**Cooling**	**Heating**	**Cooling**	**Heating**	**Peak**	**Peak**	**Annual Cost**
			kWh/ft^2	**kBtu/h/ft^2**	**kWh**	**MBtu**	**W/ft^2**	**kW**	**$**
Albuquerque	0.8	1.0	8.8	63.1	211	1.5	6.3	0.15	$32.89
Albuquerque	0.4	0.6	4.2	55.8	101	1.3	2.5	0.06	$21.84
Cheyenne	0.8	1.0	3.3	141.2	79	3.4	6.5	0.16	$37.44
Cheyenne	0.4	0.6	1.5	106.3	37	2.6	3.1	0.07	$26.65
Denver	0.8	1.0	5.9	109.0	142	2.6	9.3	0.22	$34.88
Denver	0.4	0.6	2.7	86.4	64	2.1	4.7	0.11	$23.78
Las Vegas	0.8	1.0	14.9	34.4	357	0.8	13.7	0.33	$29.95
Las Vegas	0.4	0.6	7.4	30.4	176	0.7	7.2	0.17	$17.01
Phoenix	0.8	1.0	19.1	21.6	458	0.5	15.9	0.38	$40.67
Phoenix	0.4	0.6	9.3	17.6	223	0.4	8.3	0.20	$22.02
Salt Lake City	0.8	1.0	7.9	100.1	189	2.4	11.9	0.29	$40.12
Salt Lake City	0.4	0.6	3.8	78.9	91	1.9	6.1	0.15	$26.58

The highest annual cost ($40.67) as well as highest peak electric demand (0.38 kW) is associated with the high SHGC skylight system in Phoenix. However, annual costs in Salt Lake City are almost as high ($40.12) with Cheyenne a close third at $37.44, where the high U factor causes winter heat losses to be large. Lowest costs are associated with the low SHGC, lower U factor skylights in Las Vegas ($17.02 annual cost) and Albuquerque ($21.84). Of course, higher costs are also correlated with possible higher levels of discomfort in both summer and winter. So it makes little sense to skimp on quality with skylights. Specularly-selective glazing with good Vt (well above 0.5) at SHGCs of 0.4 is widely available. Incremental costs of upgrading to double glazing with low-e surfaces are only $2 or so per square foot, so paybacks in energy savings are only several years while comfort is improved for the life of the skylight.

In practice, thermal losses with skylight systems with light wells can be substantially higher because of the higher cross sectional areas of the holes in the thermal envelope. It is critical to ensure that the light well is well insulated from the rest of the attic space and that the insulation itself is made continuous with the insulation at the level of the attic floor. This requires attention to detail in installation. A practical solution consists of a combination of rigid insulation (such as polyisocyanurate) cut to fit the attic sides of the light well plus foam around the edges to ensure good thermal integrity.

In general, skylights add natural light and a level of charm to homes and can offset electric lighting without causing undue cooling loads. However, it is important to install only high-quality systems whose thermal and optical characteristics are matched to the weather region. Second, they should be installed carefully to avoid water leaks and thermal losses. Moderation in the use of skylights in homes in the Southwest is generally a virtue.

A glance at the future

Lighting for Tomorrow

It is one thing to produce an energy-efficient bulb, another to design a fixture or family of fixtures which are both aesthetically appealing and integrate energy-efficient bulbs into their design. “Lighting for Tomorrow” sponsors design competitions to stimulate industry to do just that. Co-sponsored by the Department of Energy through PNNL, the Consortium for Energy Efficiency, the American Lighting Association, and a number of utilities, Lighting for Tomorrow’s first design competition launched in late 2002 yielded creative products in seven areas: chandelier, pendant, portable, sconce, surface-mounted, task, and track. The winning entries were shown in a number of venues and were the subject of articles in a variety of trade and popular publications (Figures 22-23).

Source: American Fluorescent

Figure 22. “Salem” was the winning design for chandeliers in the first Lighting for Tomorrow design competition. The “candles” house CFL lamps.

Source: Lightolier

Figure 23. “Soli” is the name of this second-prize-winning glass sconce, which uses CFL technology.

In January of 2005, Lighting for Tomorrow announced three other design competitions. These are “Indoor Fixture Families,” which require at least three matching fixtures, “Outdoor Fixture Families,” which require at least two matching fixtures, and “Technological Innovation.” Concerning the latter, the sponsors of the competition are particularly interested in improvements in the quality, dimming capability, and cost effectiveness of fluorescent lighting sources.

Design competitions are powerful techniques for advancing the state of the art in the lighting area. Even designers who do not win tend to learn something from the process that will likely find its way into energy-efficient lighting fixtures that will be available in the market place sooner than would have otherwise been the case.

Information on past and present design competitions is available at the Lighting for Tomorrow web site, www.lightingfortomorrow.com/.

Solid State Lighting

A great deal of research and development work is underway in the area of solid-state lighting technology. Many scientists believe that light emitting diodes (LEDs) will eventually become the lighting systems of choice in residential and many other applications. LEDs are quite flexible as regards color and mechanical configurations and have long lifetimes, on the order of 50,000 hours or more. At present, the luminous efficacy of LED lights available in the marketplace is not competitive with CFLs, although Cree has a white LED package that puts out 1200 lumens at 32 lm/W, and Lamina Ceramics manufactures a high intensity package that produces 28,000 lumens at 20 lm/W (Rizzo 2005). The rate of improvement in efficiency is growing exponentially and the research community has set a target for getting LEDs to 150 lumens per watt by the year 2012.

Recent breakthroughs appear to lend credence to that goal. For example, scientists at the Lighting Research Center (LRC) in Upstate New York have achieved over 80 lm/W with LEDs producing white light through a technique the lab terms “scattered photon extraction.” An interesting discussion of solid sate lighting technology is available on the Lighting Research Center’s web site at www.lrc.rpi.edu/programs/solidstate/.

According to the Department of Energy, solid state lighting technology may displace 29 percent of current lighting energy use by 2025. In the meanwhile, moving to the excellent technologies of CFLs makes good sense.

Smart bathroom lighting

A team of researchers from the California Lighting Technology Center at the University of California at Davis led by Michael Siminovitch in partnership with the State’s Public Interest Energy Research (PIER) program, the Sacramento Municipal Utility District, and several manufacturers, has developed a bathroom lighting system suitable for both residential applications and hotels and motels. It uses energy-efficient fluorescent fixtures with good color rendering designed to provide excellent illumination without glare. The system is controlled by an occupancy sensor that can be adjusted to wait for up to an hour from last sensing motion to turn off the main light. In addition, it has a one-watt LED night light with back-up battery so that the bathroom can be adequately illuminated for night time use even if electric power temporarily lost. Accordingly, the system should be particularly useful in elderly housing.

As of the present writing, UC Davis is securing the intellectual property associated with the bathroom lighting system and negotiating with manufacturers that will be licensed to produce the product. The developers believe the system will cost installers about $200 (Siminovitch 2005).

Field emission lamps

Promising research is underway at the University of California at Davis to develop a lighting technology that is a variation on the theme of conventional technologies for exciting the phosphors on the inside of a TV tube. Instead of a hot cathode emitting electrons that are in turn accelerated toward a screen using an electron gun, field emission lamps use an electric field to direct electrons to the phosphors. The result is excellent color rendering, luminous efficacies of well above 50 lm/W, and lower costs than the current generation of LED lighting systems. The research team estimates that practical lamps will have lifetimes of 30,000 hours. One advantage of the new field emission lamps is the absence of any environmentally hazardous materials, such as mercury which is used in small quantities in fluorescent lamps.

As of the current writing, the California Lighting Technology Center at UC Davis and the California Energy Commission are involved in licensing the technology to manufacture and market it (www.Physorg.com 2005).

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