ASSIST *recommends...*

A Guide to Residential Directional Lighting

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Lighting Research Center

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What is Directional Lighting?

Lighting applications are primarily categorized as general lighting, directional lighting, and aesthetic lighting. Whereas general (or ambient) lighting provides a uniform amount of lighting throughout an area, directional lighting provides illumination on a work surface (such as a desk or countertop), on an object (such as artwork), or in a particular direction.

Directional lighting is typically used to provide a higher light level than that of the surrounding area and can be used alone or as a complement to ambient illumination. Directional lighting is used when high light levels are required for demanding visual tasks or for accenting purposes. For the purposes of this discussion, direct, task, and accent lighting all belong to the directional lighting category.

Directional accent lighting in a home office.

Types of Directional Lighting Fixtures

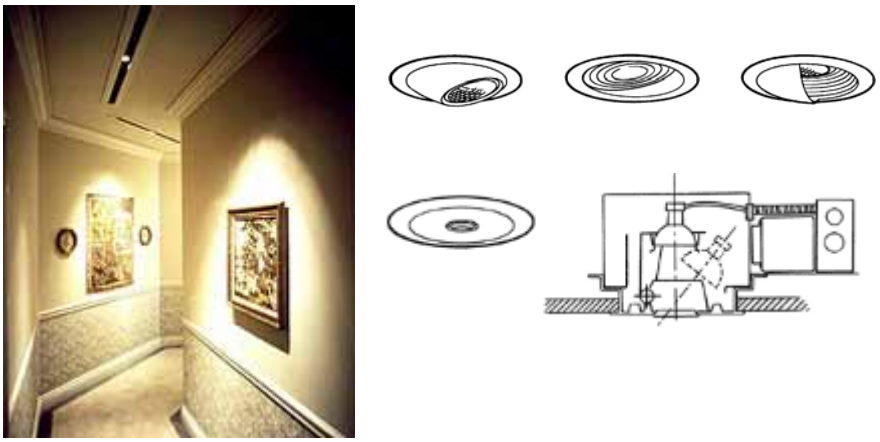
Directional lighting fixtures can be purchased at home improvement centers and specialty lighting showrooms, as well as from online distributors. The three primary types of directional lighting are accent lighting, downlighting, and track lighting. These may be “dedicated” fixtures, where the same type and style of lamp must be used every time or the fixture must be replaced; or “non-dedicated” fixtures, where any replacement lamp that fits the fixture, regardless of the type of light source, can be used.

Accent Lighting Fixtures

The most common use of directional lighting is for accenting purposes. Accent lighting is used to highlight works of art, architectural features, plantings, and other items of interest. Most accent lighting fixtures can be aimed to direct light where it is needed for emphasis, usually with an adjustment range of 35 degrees from vertical, meaning from the ground up to a certain height on the wall; and 350 degrees around, meaning the fixture could swivel horizontally almost all the way around. The most important feature of accent lights is their ability to provide a controlled beam of light.

Recessed accent lights are similar to downlights (see below), but the fixture opening is cut at an angle so that the bulb, or lamp, can be aimed without blocking any light. Some also look like an “eyeball.” Average aperture (i.e., fixture

opening) sizes for accent lights and downlights range from 3 in. to 6 in., with a similar range of diameters for track lighting.



Accent lighting application and fixtures.

Recessed and Semi-recessed Downlights

As their name implies, downlights direct light straight down from the fixture. Recessed and semi-recessed downlights come in a variety of shapes and sizes. Recessed downlights are usually less conspicuous than other types of directional lighting. The shape and size depends on the type of light source, which may require a ballast or transformer. The aperture size, which can range from nominally 3 in. to 8 in., usually depends on the size of the lamp or the size of the reflector used to collect and re-direct the light from the light source.

Downlighting application and fixtures.

Track Lighting

Track lighting is very flexible and can be focused at almost any position to light different objects. It is usually easier to install and maintain than recessed lighting. Track lighting can come in many shapes and forms and allow for fun, creative installations. However, if not done with care, it can be visually cluttering, distracting, and glary, especially in low ceilings. Unless there is a provision in the fixture, track lights need refocusing after replacing lamps or cleaning. One advantage of track lighting is that it is usually not restricted by the type of ceiling

construction. This allows for a wider selection of lamps, wattages, and aiming angles.

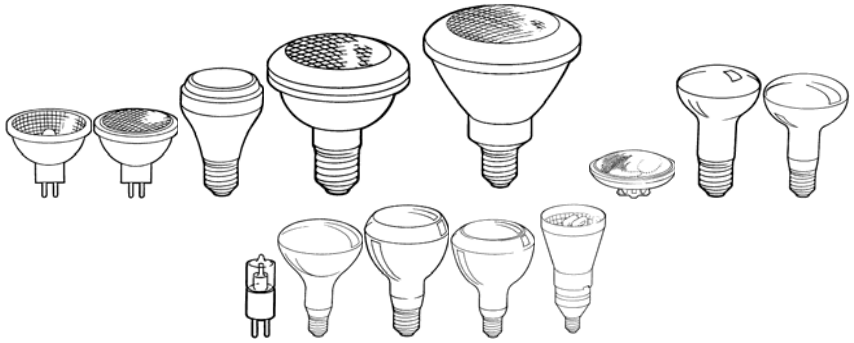
In the case of track lighting, the size of the “track heads” can be quite small if their transformers are placed separately. Small sizes are usually desired to minimize their obtrusiveness within the space.

Track lighting application and fixtures.

Types of Directional Lighting Lamps

Directional lighting fixtures use one of three types of lamp: incandescent, fluorescent, or LED. The type of lamp influences the performance of the fixture, including the amount of light, the light’s color, the life of the lamp or fixture, and its energy use. The type of lamp also often dictates the size and design of the fixture.

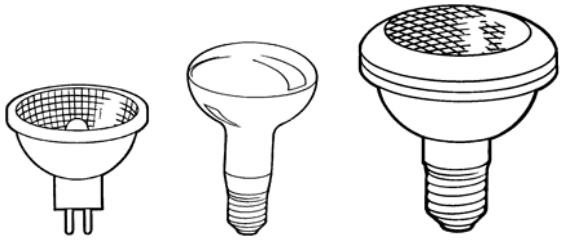
Directional lighting depends on a reflector that controls the beam of light, shaping the light distribution in a rather narrow fashion. The reflector can be part of the fixture or part of the lamp. When discussing directional light sources, the designations “R,” “MR” and “PAR” refer to lamps with reflectors. These lamps are generally incandescent or halogen sources but can also use fluorescent or other lighting technologies, including LEDs. An MR (multifaceted reflector) lamp is a small, low-voltage lamp generally between 1.3 to 2 in. in diameter. A PAR (parabolic aluminized reflector) lamp is a larger lamp anywhere from 3 to 5 in. in diameter. The following section provides more details on the types of light sources used for directional lighting.



A variety of lamps for directional lighting.

Incandescent Lamps

Incandescent lamps are the most common light source found in homes. Incandescent lamps come in a variety of styles for directional lighting, including reflector R, PAR and MR lamps. They are available in different wattages, base types (pin-base or screwbase), and correlated color temperatures (CCT), referring to the color appearance of white light (for example, a yellowish-white vs. a bluish-white). They provide a warm, glowing light, though some types of incandescent, including halogen, are popular because they have a higher CCT. These lamps are a "cooler" white or less yellow in appearance.



From left: MR lamp, R lamp, PAR lamp.

Incandescent lamps are readily available, inexpensive, and easy to replace when one burns out. However, they typically have the shortest life (2 years on average at 3 hours per day) and highest energy use for equal light output of the three types of lamp available.

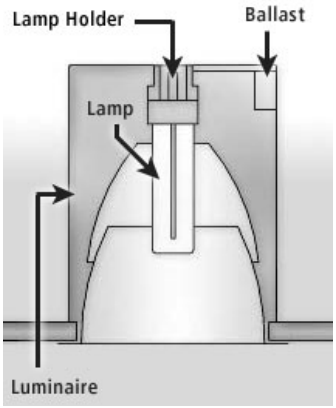
Compact Fluorescent Lamps

Directional lighting is available with compact fluorescent lamps (CFLs). CFLs are used typically in recessed fixtures, though some track CFL fixtures are available.

Newer fluorescent lamps have many improvements over older designs, including choice of light color (from warm to cool), good color rendering, instant-on, no flickering, and no buzzing or humming.

The most common CFLs for directional lighting are twin and triple tube lamps, referring to the number of tubes that make up the lamp. These types of CFLs are used in dedicated fixtures that have reflectors designed specifically around the geometry of the lamp. However, there are reflector CFLs available for track fixtures. Typically, a fluorescent lamp's efficacy (the amount of light, or lumens, emitted per watt of electrical power) improves as the lamp wattage increases. The higher the wattage, the more efficacious the lamp.

Fluorescent lamps have the advantages of high efficacy (a high rate of light output per watt of electrical power), long life (7 years on average at 3 hours per day), and reasonable cost effectiveness. The disadvantage of fluorescent is that its light output depends on the operating temperature. Recessed fixtures trap the heat generated by the lamp, resulting in lower light output. CFLs are available with an amalgam added to the discharge tube that helps to keep the light output constant within a large range of operating temperatures.



CFL-dedicated downlight fixture with pin-based lamp.

LEDs (light-emitting diodes)

White LEDs have become popular for a variety of directional lighting uses because of their low energy use. LED fixtures may use one of several types of LED, including small 5 millimeter (mm) LEDs, which use 1/10 W of energy, or larger high-power LEDs of 1/2 W or 1 W. While some LEDs may be quite small, they still require other components that enable their proper operation, making the size of an LED fixture about the same as other fixtures used for directional lighting. PAR and MR reflector lamps with LEDs are becoming very popular, though they are typically only available with 5 mm LEDs and their light output is only a fraction of their incandescent counterparts.

LEDs are also popular for their long life. Properly designed LED fixtures can last longer than 10 years. Unlike incandescent and fluorescent lamps, LED lamps typically do not burn out. Rather, they get dimmer over time to a point where they do not produce enough light to see by, even though they are still operating.

White LEDs are generally a bluer-white in color appearance than incandescent lamps, though warm-white LEDs that mimic incandescent are becoming more common. White LEDs are generally available in the same color range as fluorescent lamps. While their operating life is long and they use less energy than incandescent (and less than fluorescent in some cases), their initial purchase price is currently much higher. Another type of white LED lighting is the RGB LED fixture. The light from a mixture of red, green, and blue LEDs can be combined in certain proportions to create any light color, including white.

One consideration for LEDs is heat. Though LEDs are generally thought of as cool compared to incandescent lamps (which put out approximately 90% of their energy as heat), LEDs still produce heat and are susceptible to high temperatures. Under high temperatures, LEDs will have a shorter life and will fade more quickly.

5 mm LED high-power LED

Design Considerations for Directional Lighting

The following are general design considerations when using directional lighting:

Beam Spread

Different techniques are used for accentuating two- and three-dimensional objects. For example, three-dimensional objects are generally lighted from different directions (each side). It is also common to use a combination of narrow and wide beam angles to bring out a particular feature of the object or simply create a dramatic scene.

Beam spreads should match the sizes of the objects being illuminated. This creates a dramatic effect that draws the viewer's eye directly to the object being lighted. The most common beam spreads used for accenting are 10 and 30 degrees. The beam spreads are usually noted on the package.

PAR and MR accent lights produce circular patterns of light called "scallops." When illuminating vertical surfaces with more than one light fixture, these can be aimed such that the beams overlap to produce a uniform light distribution. The scallops align to avoid visual confusion, as shown below.

The accent light fixtures are aimed so that the scallops are uniformly aligned along the wall.

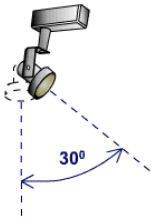
However, to create a more dramatic effect and draw the viewer's eye directly to the object, you may choose to match the beam angle of each lamp as closely as possible to the size and shape of the object being illuminated. This allows the light to essentially "frame" the object and focus attention on it, rather than the surrounding wall. This also might allow you to use lamps of lower wattages.

One drawback of traditionally diffuse light sources, such as incandescent or CFL, is that they produce a beam that is essentially too wide. Much of the light is wasted by being focused on the wall beyond the area needed to actually light the object. Wasted light leads to wasted energy. This also produces a less dramatic effect because the light does not effectively frame each object. Reflector CFLs typically cannot produce narrow beams. As point sources, reflector lamps using incandescent, halogen, and LEDs have much better optical control of the beam, making them the best option for accent lighting.

Light Levels, Brightness and Glare

The brightness of the object being highlighted usually needs to be 3 to 10 times more than that of the surrounding area, depending on the desired effect. Higher light levels may be needed to accentuate dark-colored objects. In order to determine how to increase brightness from the general area to accent areas, you can check the center beam candlepower (CBCP), or intensity in units of candela (cd), of the lamp. MR16s, for example, range in CBCP from 500 cd to 15,000 cd, according to beam distribution. Narrower beam distributions result in higher CBCP values. This allows you to select the intensities you will need to create the light levels you want. In the picture below, a single MR16 accents a group of pictures on a fairly dark wall.

An MR16 accents this grouping. It has a 15° beam distribution and CBCP of 9,100, resulting in an average illuminance level of 44 fc compared to a background illuminance of 1 fc. The difference in intensities creates sufficient contrast to make these dark-framed pictures stand out against their fairly dark background



Directional lighting should not be glaring to anyone. Correct location and aiming are critical. Prevent offensive viewing situations by maintaining an angle equal to or less than 30° from the vertical to the lighted surface, and use shielding accessories, such as hexcell louvers, to reduce the impression of glare from the source.

Dimming Capability

The ability to control the brightness of directional lighting adds greatly to its value. The tasks or type of object being lighted will dictate the light level required. Incandescent and LED lighting can be dimmed easily, but having this feature may add to the fixture cost. Dimming fluorescent lighting is more costly than dimming incandescent lighting because of the type of dimming components required.

Filters

When directional fixtures are used for accent lighting, they are generally used to complement other lighting systems in a space. Some accent light fixtures can accommodate color filters, spread lenses, or hexcell louvers. Infrared (heat) and ultraviolet (UV) filters are often used to eliminate radiation that may be harmful to some fabrics, dye, watercolors, and papers.

Colored filters will significantly cut down the amount of light that is emitted from the lamp or light fixture. Therefore, a lamp of a higher wattage will need to be


Edison Price Lighting

used if light output is a significant factor in the design. A benefit of LEDs is that they are produced in a wide array of colors. Unlike other light sources, the light from colored LEDs is produced directly by the light source in the particular color selected. No filters or colored gels are needed; therefore, no light is wasted. LEDs are generally the most energy-efficient means of producing colored light.

An additional advantage of LEDs when used in lighting sensitive materials is that they do not produce harmful ultraviolet or infrared radiation. Therefore, additional filters are not required. Because of this feature, LEDs may be one of the most ideal light sources for use in applications sensitive to degradation, such as artwork, clothing, flowers, etc.

Lighting Color

The color appearance of a white light source (e.g. how "warm" or "cool" it appears) and its ability to render object colors naturally is very important in accent lighting. As much as the variety of color temperatures offers design flexibility, color appearance differences among similar light sources in a given space can significantly reduce the visual aesthetics of the lighting design. You should be aware that some light sources, such as CFLs from different manufacturers and halogen MR lamps, can have noticeable color differences from one lamp to the next, and that individual white LEDs within a lighting fixture may also exhibit color differences. Therefore, you must consider the color appearance of individual light sources (designated by lamp correlated color temperature or CCT); each light source's ability to render colors naturally; and the light source's color consistency (potential degree of lamp-to-lamp color difference) when selecting directional lighting. It is possible to compensate for differences in color appearance among light sources. For example, hiding the light sources from direct view can often mitigate the appearance of lamp-to-lamp color differences.

Modeling of Faces or Objects

It is important for lighting to appropriately define faces and objects for easy recognition: Lighting should not create sharp shadows and should illuminate faces in a pleasing way that allows facial expressions to be easily read. Similarly, a lighting technique called grazing is often used to bring out the texture of brick and stone walls by creating controlled shadows that emphasize tri-dimensionality. Avoiding sharp shadows is particularly important in stairwells and thresholds because they can be confused with changes in floor level and lead to tripping.

Sparkle and Highlights

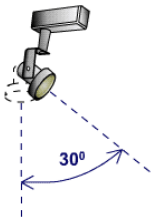
Small points of high brightness can enhance visual interest (e.g., a candle flame or decorative tree lights). Directional lighting fixtures are often offered with optional trims and accessories that provide sparkle and colored highlights. Keep in mind that certain light sources such as compact fluorescent lamps are diffuse and therefore cannot generally produce sparkle or highlights from the objects they are illuminating. On the other hand, point sources such as clear incandescent and halogen lamps are more suited to create sparkle on textured counters and floors, and on glossy objects made of glass or metal.

Uniformity

Uniformity is a measure of the evenness of the lighting. Patterns of light on a work surface can be distracting, confusing, or beneficial. Patterns of light and shadow can affect task visibility, comfort, and perception. Illuminances on the floor or work surface should not vary widely, or else it will be hard to see details in the darker areas. Simple visual tasks, such as orientation and navigation, are more forgiving to non-uniformities than more visually demanding tasks, such as reading small print. Uniform lighting is easier to work under because the task has a constant illumination, rather than “pools” or “spots” of light and dark areas.

Uniformity is typically measured as a ratio of the average to minimum illuminances on the area of interest. The lower the uniformity number, the more even the lighting. Most lighting designers recommend a uniformity of 5 to 1 (5:1) or less for general and task lighting, and a uniformity of up to 10 to 1 for hallways, transitions, and similar areas.

Aiming



Accent lights used to highlight objects on walls are generally placed 2–3 ft. away from the wall and tilted 30 degrees from vertical to avoid reflected glare from glossy artwork. Hot spots or streaks of light may be seen on ceilings if aiming angles are greater than 50 degrees. This rule of thumb applies for ceilings less than 12 ft. high. Aiming track lights where people will see the lamp from normal viewing positions should be avoided.

Fixture Appearance

Unless purposely hidden from view, accent lights and, in particular, track lights will be visible. This means that you must consciously decide whether to use unobtrusive shapes and colors, or select more obvious decorative designs. With the variety of light fixtures available, either design goal may be easily satisfied.

Maintenance

Another important consideration is maintenance. In the case of accent lighting fixtures, it is important to keep a maintenance schedule because burned-out lamps will be very noticeable. When selecting any light fixture, it is always important to think about the life and cost of the lamp, as well as the frequency, cost, and ease of relamping. High ceilings and lamps with relatively short lives can prove to be a nightmare. After relamping or cleaning accent lights, be careful to refocus them.

Directional Lighting Performance

All directional lighting fixtures do not perform the same, as illustrated by the table on the next page. Performance can vary widely depending on the type of lamp and the design of the fixture. Performance can also differ by the place of purchase. Specialty lighting retailers and manufacturer distribution representatives may offer specification-grade products that provide better quality but for a higher price. These may be available only through electricians and contractors. The main differences between products is in the quality of the materials used in their construction and the quality and finish of the reflectors, if the fixture requires one for creating the desired light distribution.

The table below lists estimates of the number of fixtures and the corresponding amount of power, in watts, needed for each type of downlight in order to provide an appropriate ambient light level (110 to 180 lx) in a kitchen measuring 16 ft. by 16 ft. In turn, the estimated number of fixtures and wattages were used to calculate purchase, installation, lamp replacement, and energy costs for each type of lighting.

Table Definitions

Average horizontal illuminance. A measurement of the amount of light falling on a work surface, such as a kitchen counter. The illuminances listed here are appropriate as general illumination for a 16 ft. by 16 ft. kitchen using the number of fixtures specified. The Illuminating Engineering Society of North America (IESNA) recommends an appropriate range of light levels for critical tasks. In the kitchen, these could be cooking, chopping, or other activities requiring an attention to detail. It is assumed that the recommended light levels for critical tasks would be complemented by task lighting, such as under-cabinet lighting.

Power per kitchen. The wattage (W) of the fixtures needed for one 16-ft by 16-ft kitchen in order to provide an initial average ambient illuminance ranging from 110 lx to 180 lx at counter height.

Initial purchase cost. The cost to purchase a lighting fixture varies greatly by the types of light source and supplier. The table gives an estimate of the purchase cost based on retail prices.

Initial installation cost. The installation cost considers the labor cost and incidental costs of small hardware to install the fixtures to existing electrical outlets. The calculations assume an average rate of $56 per hour for a qualified electrician.

Annual lamp replacement cost. The cost noted here is the average expense to replace lamps each year, considering an average daily use of 3 hours.

Annual energy cost. This is the expected yearly electricity bill cost to operate the lighting, considering an average daily use of 3 hours at 10 cents per kilowatt hour (kWh).

Lamp replacement frequency. The average number of years that the lamps are expected to last before needing replacement.

Directional Lighting Fixture Performance and Cost

Estimates are for a 16-ft. by 16-ft. kitchen and provide an initial average of 110 lx to 180 lx at counter height.

light source	lamp type (number of fixtures)	average horizontal illuminance	power per kitchen (W)	initial purchase cost ($)	initial installation cost ($)	annual lamp replacement cost ($/yr)	annual energy cost ($/yr)	lamp replacement frequency (years)
Incandescent	A19 75W (4)	113 lx	300 W	$ 212	$ 148	$ 4	$ 33	0.7
	R30 75W halogen (4)	157 lx	300 W	$ 212	$ 148	$ 9	$ 33	2.7
	PAR38 55W HIR (4)	195 lx	220 W	$ 212	$ 148	$ 16	$ 24	3.7
Compact fluorescent	Twin tube 18W (4)	156 lx	74 W	$ 388	$ 148	$ 4	$ 8	9
	Two triple-tube 26W (4)	179 lx	224 W	$ 552	$ 148	$ 25	$ 11	9
LED*	White LEDs Mfr. A (6)	161 lx	168 W	$ 2952	$ 222	$ 0	$ 18	>10**
	White LEDs Mfr. B (8)	167 lx	200 W	$ 2384	$ 296	$ 0	$ 22	>10**
	RGB LEDs (6)	139 lx	234 W	$ 5100	$ 222	$ 0	$ 26	>10**

*Because LED lighting is a relatively new technology, performance and cost are changing on a regular basis. Check for updates to this table at www.lrc.rpi.edu/programs/solidstate/assist.

**Rated life of the LED source only, not given as a fixture. The actual rated life for the fixture may be less.

Selecting and Installing Directional Lighting

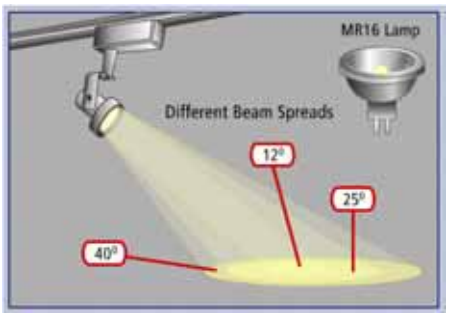
Selecting Directional Lamps

Light source

Your selection of a light source will depend highly on the lighting qualities you desire and the space to be lighted. As described previously, light sources come in a variety of white “colors.” Some have a softer, diffuse glow or appearance, while others are more concentrated, which will affect the uniformity of the lighting. Small, high brightness fixtures will provide more “sparkle,” which can be desirable in spaces like a dining room.

Beam spread

When selecting directional light sources, it is the “beam spread.” The beam spread is typically the angle at which the beam has reached 50 percent of the lamp’s center beam candlepower. This is expressed in terms of degrees. The smaller the beam angle, the more narrow and concentrated the beam. Manufacturers of reflector lamps publish beam angle information that describes the spread of light from the lamps. Beam spreads of traditional light sources generally range from 8 degrees (very narrow spot) to 55 degrees (wide flood).



Examples of beam angles or beam spreads available for an MR16 lamp.

Number of fixtures

When deciding how many fixtures to use, follow these two steps:

1. **Which light source are you selecting?** If it's a 75-watt A19 or 75-watt R30 lamp, then based on the above table for a kitchen, you know four of them would provide the appropriate illuminance level on your work surface in a 16 ft. by 16 ft. (256 sq. ft.) area, which would translate to one fixture per 64 sq. ft. space.

2. **Determine the size of your space and select the number of fixtures accordingly.** If 75 watts of incandescent is sufficient per 64 sq. ft., then one fixture should suffice for every 8 ft. by 8 ft., or 4 ft. by 16 ft. area, realizing that the uniformity of the lighting will be affected by the configuration of the area, but average illuminance will still be the same.

Keep in mind that incandescent and compact fluorescent reflector (R and PAR) lamps generally have a diffuse distribution with some help from the built-in reflector to push the lumens down onto a surface. An incandescent A lamp, or triple tube compact fluorescent with a lens added, whether for safety in the shower or just to soften the beam, will cut out about 40% of the intensity of the light, so you would need to compensate by adding more fixtures to achieve the same light levels listed in the above table.

The same is true when adding accessories to accent lighting. Adding a spread lens to an MR16 lamp focused on a painting will further distribute the beam, thereby softening it. A hexcell louver will reduce light output while shielding the viewer from glare. In both cases, illuminance levels will decrease dramatically.

Examples in a kitchen

To give a better idea of how lamp choice can affect the lighting quality in a space, the pictures below show a kitchen and eat-in dining area using the types of lighting and number of fixtures specified in the performance table above.

Incandescent lamps. The fixtures using A19, R30, and PAR38 lamps, shown in images 1 to 3 below, vary in average illuminance and uniformity. The lamp's distribution becomes progressively more narrow from the A lamp in image 1 to the PAR lamp in image 3, diminishing uniformity, which is evident if you compare the island countertop in image 1 to that in image 3. Conversely, the average illuminance progressively increases from the A lamp, which distributes light all around, to the more focused distribution of the PAR lamp, which directs more

lumens downward. You can improve uniformity by adding more PAR lamp fixtures, but that will impact your cost.

1. Four A19 75-watt incandescent lamps.

2. Four R30 75-watt halogen lamps.

3. Four PAR38 55-watt lamps.

Compact fluorescent lamps. Compact fluorescent lamps offer 3 to 4 times more lamp lumens per watt than their incandescent counterparts, as well as choices in CCT from 2700 K to 6500 K. Images 4 and 5 below illustrate the impact of adding a lens to the fixture. The average illuminance levels and uniformity are similar between the 18-watt CFLs and the double lamp 26-watt CFLs (actually 52 watts for each fixture), when the difference should be greater. The reason for the difference is the 18-watt CFL is using a clear reflector – which may appear to produce more glare, but has the best light output of all reflector choices. Adding the fresnel lens to the double 26-watt lamps softens the beam, but also reduces the intensity by almost half, rendering the light output almost the same while using double the wattage.

4. Four CFL 18-watt twin tube lamps.

5. Four CFL 26-watt triple tube lamps (2 lamps per fixture).

LEDs. The two main issues with current LED fixtures are their relative low light output and high initial cost. To compensate for the lower light output, more fixtures may be needed compared to a CFL solution. This, in turn, will result in a higher initial cost. In the examples below, six white or RGB LEDs are needed to reach the target light level. Six fixtures result in a nice, even distribution, but the

overall power and initial cost are higher than with 18-watt CFLs. On the other hand, the annual costs of LED fixtures have the potential to be lower than their CFL counterparts and are already an energy-efficient alternative to incandescent lighting.

6. Six white LED – Mfr. A fixtures.

7. Six RGB LED fixtures.

Selecting Directional Lighting Fixtures

It is important to pay attention to two specific dimensions when selecting recessed or semi-recessed light fixtures: the height of the housing due to plenum constraints (the amount of space available above the ceiling), and the size of the fixture opening, or cone aperture, for aesthetic reasons.

The following are considerations for the correct use of directional lighting with recessed or semi-recessed light fixtures:

- **The placement of directional lights.** Consider this carefully because their installation requires cutting holes in the ceiling and their location most likely will not change.
- **Installation cost.** May be high in existing structures.

- **Ease of relamping.** It could be more difficult to relamp and focus recessed accent lights than track lights due the size of the opening, accessibility to the lamp, and ceiling construction.

Codes, Safety, Standards, and Compliance

California Energy Standards – Title 24

In October 2005, California adopted new energy standards that include comprehensive changes to residential and non-residential lighting. Known as Title 24, the code applies to not only the efficacy of the lighting installation, but also to the fixture itself. Some fixtures may feature a "T24 – 2005" label to help identify whether a fixture is compliant with the code's efficacy requirements.

For kitchens, Title 24 requires that at least 50% of the permanently installed lighting be high efficacy, generally fluorescent, and that no more than 50% of the total lighting wattage be low efficacy, or incandescent. For example, a kitchen with permanently installed lighting fixtures totaling 300 watts cannot have more than 150 watts from incandescent fixtures. High-efficacy lighting and low-efficacy lighting must be controlled by separate switches.

For living rooms, bedrooms, and hallways, Title 24 requires that all permanently installed lighting be either high efficacy, or include a manual-on occupancy sensor or dimming controller if low efficacy.

Although Title 24 applies only to California homes, the regulations are the most prominent guidelines for residential energy savings. For more about designing your lighting based on Title 24, download the "Residential Lighting Design Guide" free at: http://cltc.ucdavis.edu/title-24-residential-lighting-design-guide.

ENERGY STAR

ENERGY STAR, a government program run by the U.S. Department of Energy and the U.S. Environmental Protection Agency, labels residential lighting products for their performance reliability, energy savings, and aesthetic appeal. Purchasing an ENERGY STAR-qualified lighting product can help ensure a minimum standard of reliability and energy efficiency. ENERGY STAR's program requirements for residential light fixtures were updated in October 2005 to fit the new California Title 24 regulations.

Underwriters Laboratories

The Underwriters Laboratories (UL) tests products for safety and writes standards for product safety. Manufacturers may voluntarily submit a product for safety testing and certification. A product that has passed the UL's safety evaluation will have a UL mark on the packaging.

Disposal

Many types of lamps, most notably fluorescent lamps, contain small amounts of hazardous materials. Mercury is the most common, but some lamps also contain lead. Mercury exposure in large amounts or over a long period can cause kidney, nerve, and brain damage in adults, children, and fetuses. In some cases, mercury from municipal landfills can leach into the groundwater and sources of

drinking water. Lamps that go to municipal incinerators can release up to 90% of the mercury they contain if the incinerator does not have emission controls.

State and federal governments regulate the disposal of mercury-containing lamps. Except in a few states and municipalities, residents and homeowners disposing of only a few linear fluorescent or compact fluorescent lamps can generally put these out with their regular trash; however, many towns and cities offer hazardous waste recycling programs at recycling centers and transfer stations, as well as annual hazardous waste recycling events. Check with your state and municipal governments for more information on disposal regulations and opportunities. Those disposing of many lamps need to contact a local lamp recycling company or their local hazardous waste recycling plant. For more information, visit www.lamprecycle.org.

While mercury and other hazardous materials are a concern, this does not mean you should avoid fluorescent lamps. Fluorescent lamps provide many benefits, including energy and cost savings, less maintenance, and longer life. The lower energy use of fluorescent lamps reduces power plant emissions, a far greater contributor to environmental mercury. With proper disposal, fluorescent lamps are a great choice for lighting.

Glossary

Beam spread. The angle at which luminous intensity is 50 percent of the maximum intensity. Also known as beam angle.

Center beam candlepower (CBCP). Center beam candlepower is the luminous intensity at the center of a beam, expressed in candelas (cd).

Color rendering. A general expression for the effect of a light source on the color appearance of objects in conscious or subconscious comparison with their color appearance under a reference light source.

Color rendering index (CRI). A measure of the degree of color shift that objects undergo when illuminated by a lamp, compared with those same objects when illuminated by a reference source of comparable correlated color temperature (CCT). A CRI of 100 represents the maximum value. A lower CRI value indicates that some colors may appear unnatural when illuminated by the lamp. Incandescent lamps have a CRI above 95. The cool white fluorescent lamp has a CRI of 62; fluorescent lamps containing rare-earth phosphors are available with CRI values of 80 and above.

Color shift. The change in a lamp's correlated color temperature (CCT) at 40% of the lamp's rated life, in kelvin (K).

Compact fluorescent lamp (CFL). A family of single-ended fluorescent-discharge light sources with small-diameter [16-millimeter (5/8-inch) or less] tubes.

Correlated color temperature (CCT). The general indication of the color appearance of a white lamp, measured in kelvin (K). Lamps, such as incandescent, with a warm or yellowish-white color appearance have a CCT in the 2800–3200 K range. Lamps that are more neutral white, such as some fluorescent lamps, have a CCT in the 4000 K range. Cooler or bluer lamps, such

some LEDs, have a CCT of 5000 K or higher. CCT is a matter of personal preference.

Dedicated fixture. A fixture that must use the same type and style of lamp every time or the fixture must be replaced.

Efficacy. A measure of the amount of light output, or lumens, per watt of electrical power, expressed as lumens per watt (lm/W or LPW). Higher efficacy numbers indicate greater energy efficiency.

Fixture. The complete lighting system, including lamp, housing, electrical cord, and other components.

Hexcell louver. A series of baffles arranged in a hexagonal pattern to shield a source from view at certain angles.

Illuminance. The amount of light falling on a work surface or an object. The Illuminating Engineering Society of North America recommends illuminance levels for different types of lighting applications and tasks. Illuminance is measured in units of lux.

Infrared radiation. Any radiant energy within the wavelength range of 770 to 1400 nanometers is considered infrared energy. (1 nanometer = 1 billionth of a meter, or 1 X 10^{-9} m).

Intensity (luminous intensity) Total luminous flux within a given solid angle, in units of candelas, or lumens per steradian.

Lamp. An industry term for a light bulb.

LED. Light-emitting diode, a semiconductor that converts electricity into light.

Lumen. A unit of measurement (lm) for the rate at which a lamp or fixture produces light. More lumens equals more light output from the lamp or fixture.

Luminaire. A complete lighting unit consisting of a lamp or lamps and the parts designed to distribute the light, to position and protect the lamp(s), and to connect the lamp(s) to the power supply. Also called a fixture.

Luminaire efficiency. The ratio, expressed as a percentage, of the light output of a luminaire to the light output of the luminaire's lamp(s). Luminaire efficiency accounts for the optical and thermal effects that occur within the luminaire under standard test conditions.

Luminance contrast. Luminance contrast quantifies the relative brightness of an object against its background. It can range from zero to one. The closer the luminance contrast is to one, the greater the relative brightness of the object against its background.

Luminance. The photometric quantity most closely associated with the perception of brightness, measured in units of luminous intensity (candelas) per unit area (square feet or square meter).

Luminous flux. The rate of flow of light, measured in lumens. The overall light output of a lamp.

Lux. A unit of measurement for illuminance.

Non-dedicated fixture. A fixture where any replacement lamp that fits the fixture, regardless of the type of light source, can be used. These fixtures usually accommodate a lamp with a screw-in base.

PAR lamp. An incandescent or tungsten-halogen incandescent lamp with a hard glass bulb and an interior reflecting surface, a precisely placed filament, and a lens to control beam spread. The lens is hermetically sealed to the reflector. Metal halide PAR lamps are also now available.

Ultraviolet. Any radiant energy within the wavelength range 100 to 400 nanometers is considered ultraviolet radiation (1 nanometer = 1 billionth of a meter, or 1 X 10^{-9} m).

Uniformity. Referring to the evenness of lighting on a work surface, uniformity is typically defined as the ratio of the average measured illuminance to the minimum measured illuminance. Lighting designers recommend a uniformity of 5 or less.

Resources

Energy Star. *Residential light fixtures product list*. Available at www.energystar.gov.

Leslie RP, Conway KM. 1996. *The Lighting Pattern Book for Homes*. New York: McGraw-Hill.

About ASSIST

ASSIST was established in 2002 by the Lighting Research Center at Rensselaer Polytechnic Institute to advance the effective use of energy-efficient solid-state lighting and speed its market acceptance. ASSIST's goal is to identify and reduce major technical hurdles and help LED technology gain widespread use in lighting applications that can benefit from this rapidly advancing light source.