Choosing the best light source for your application

Technical white paper

Dr Ian Rowbottom

November 2, 2009

LUTRON®

save energy with Lutron™

Choosing the best light source for your application

Lighting designers consider several factors when selecting light sources for a given application. Here are some of the criteria they consider most important.

- Efficacy (how much light is delivered per watt of power to the bulb)
- Color performance (how faithfully colors are reproduced compared to daylight)
- Controllability (whether the light can be dimmed, or controlled with sensors and/or timers)
- Lifetime cost (a light's initial cost plus how much it costs to use over its entire operating life)

In large-scale commercial applications like office buildings, efficacy and lifetime costs are often the most important considerations. In museums and galleries, color performance is more important. In hotels and conference centers, controllability is important. In residential applications, the homeowner's preference is most important.

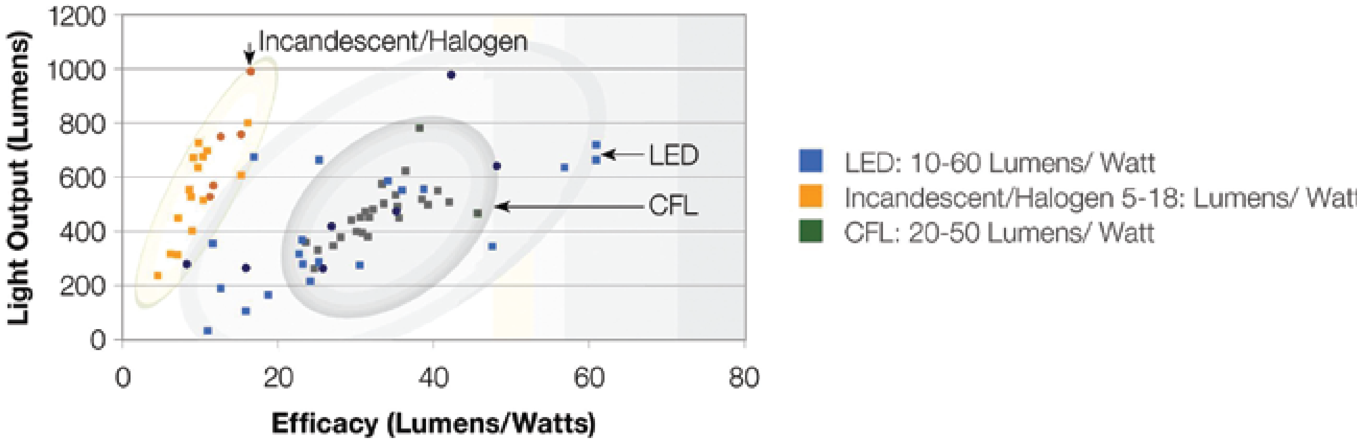
However, lighting designers have found that homeowners rarely have all the data they need to make an informed decision. The most common light sources for residential applications – incandescent, halogen, compact fluorescent (CFLs) and light-emitting diodes (LEDs) – are sometimes the subject of biased media reports motivated more by politics than by scientific principles.

Stripping away the sensationalism, here is technical information about the most common light sources used in homes around the United States.

Efficacy

Efficacy is a measure of how efficient a bulb is in converting electricity (measured in watts) to light (measured in lumens). This is the headline number for news reports on trendy light sources, as if efficacy were the only thing that mattered.

Efficacy varies widely, but generally falls into three "buckets," as illustrated in Figure 1[1]. As a group, LED lights have the highest efficacy, followed closely by CFLs. Incandescent and halogen bulbs have the lowest efficacy. It should be noted that even the most efficient LED lamps have an efficacy of around 60 lumens/watt. Compare this to the theoretical maximum efficacy of 683 lumens/watt[2], and you can see that even the best light sources are still very inefficient. [Of course the theoretical maximum efficacy is obtained for a pure green light source, which would do a poor job rendering colors. So there is a trade-off between efficacy and color-rendering.]



Color performance
For many lighting professionals, color performance is a critical factor because of its effect on the inhabitants of a space. Subjective responses to poor color performance can be quite extreme.

To predict accurate color performance, designers refer to the Color Rendering Index (CRI), which is a quantitative measure of the ability of a light source to faithfully reproduce the color of an object when compared to the color it looks under natural daylight. The higher the CRI, the more accurate the color rendition.

The CRI is calculated by complex mathematical equations[3] that quantify the interactions between the wavelength of the light source and the wavelength of the object being illuminated. CRI is normalized to a value of 100, obtained when an incandescent light source is used as a reference. The incandescent lamp was chosen because it is an artificial light source with a very broad spectrum, which means that it emits light at each wavelength over the whole visible spectrum.

Figures 2, 3 4 5 and 6 show how the sun and four main light sources emit wavelengths of electromagnetic radiation in the 350-750 nanometer range, which is roughly the visible light spectrum from violet through indigo, blue, green, yellow and orange to red[4]. In other words… if you were to shine each of these lights through a prism, these are the colors you would get.

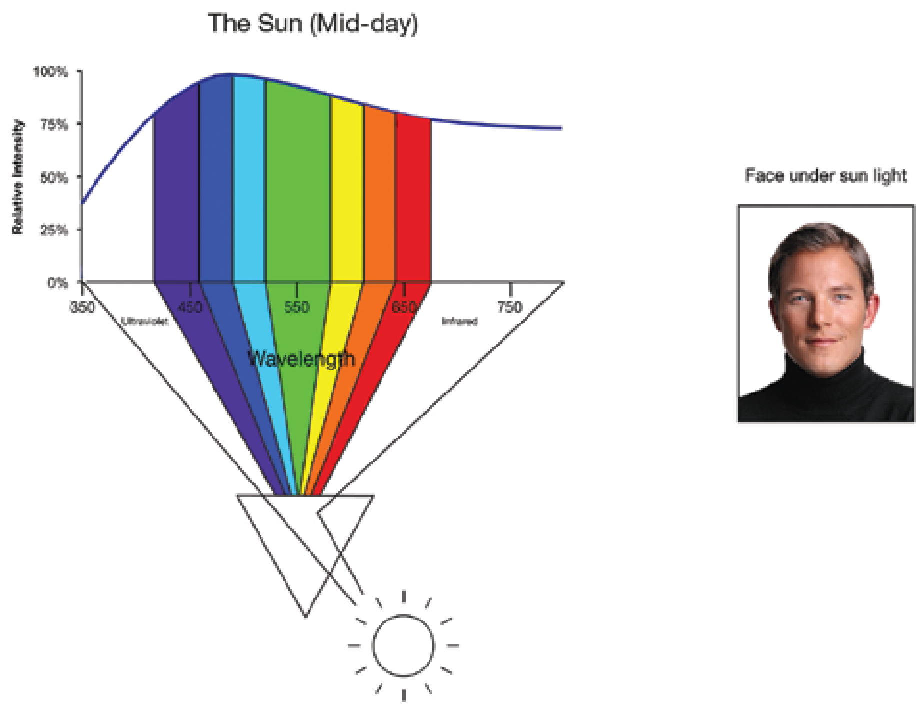


Figure 1: Sun light emissions in the visible light spectrum

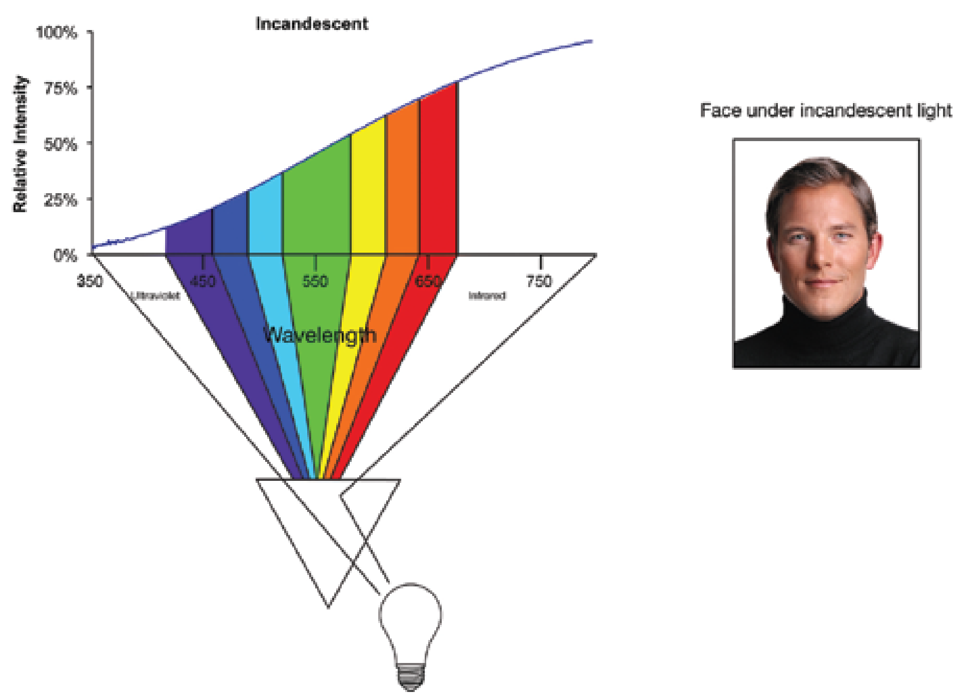


Figure 2: Incandescent light emissions in the visible light spectrum

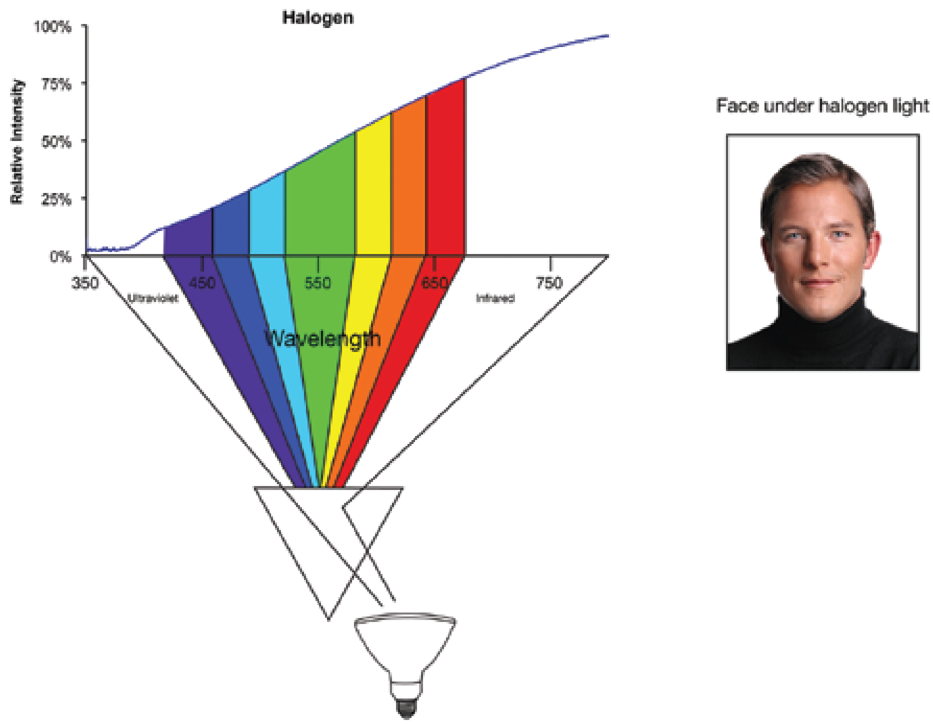


Figure 3: Halogen light emissions in the visible spectrum

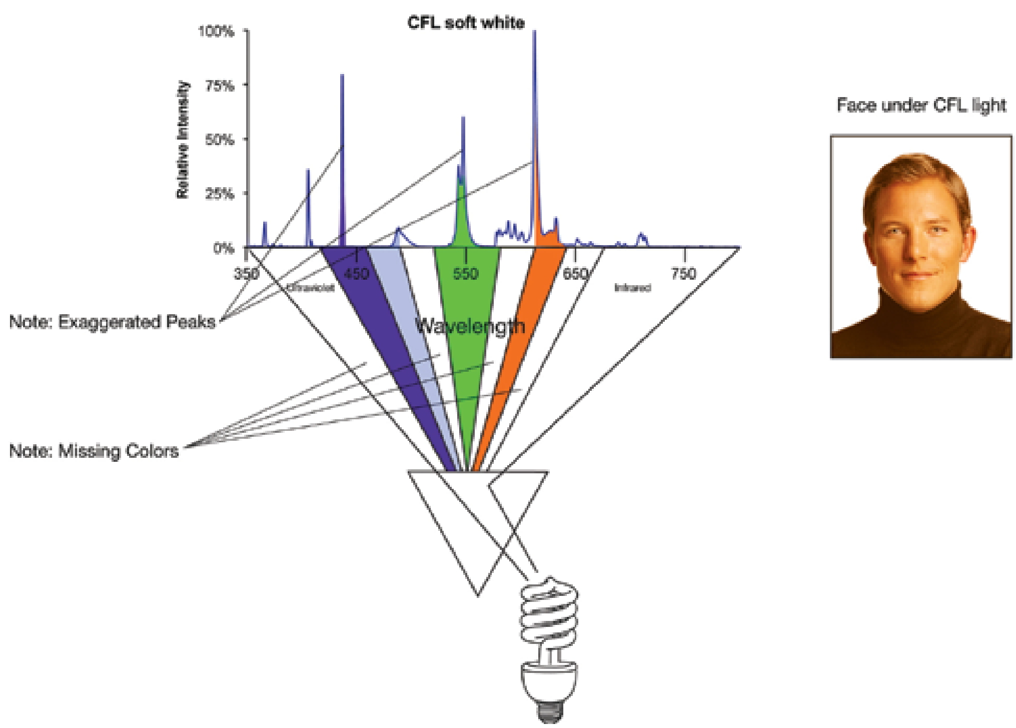
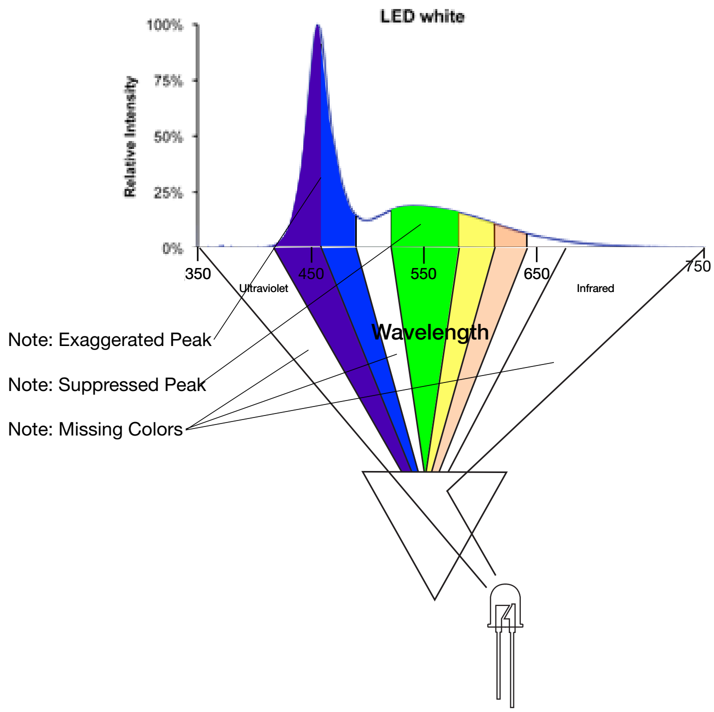


Figure 4 : CFL light emissions in the visible spectrum



Face under LED white light

Figure 5: LED light emissions in the visible spectrum

Notice the smooth curves of the Sun, incandescent and halogen lights, and the spiky emission patterns of the LED and CFL lights. These wave signatures are used to calculate each source's CRI[4], which is…

Light Source	CRI
Sun	100
Incandescent	100
Halogen	100
CFL	82
LED	80

Incandescent and halogen lights have perfect scores, by definition, because they have emissions at every single point of the visible light spectrum. The CFL and LED have gaps in the emission spectrum, especially in the red, so the CRI calculation shows a modest penalty.

CFLs and LEDs have lower CRIs because some wavelengths have zero emissions, while others are skewed abnormally high. These characteristic spectra give rise to the typically blue appearance of LED lights, and the blue-to-green appearance of CFLs. It's interesting to note that the spike in the LED spectrograph is actually in the ultraviolet range, which is invisible to the human eye.

Color temperature

Correlated Color Temperature (CCT) of a light source is expressed in degrees Kelvin. Temperature is used because it is a comparison to the color given off a black body radiator as it is heated. The CCT is the theoretical temperature of a black body whose spectrum would best match the spectrum of the light source[5]. As the black body radiator is heated its color changes from black to red to yellow to white and finally to blue. Confusingly, the higher the color temperature the more "cooler" the color is said to be! Different light sources can have different color temperatures and these are used for differing applications. Often warmer colors are used in public and private spaces to promote relaxation, while cooler colors are used in office environments to aid concentration.

Controllability

Another important consideration for lighting designers is controllability, which has multiple aspects.

First, can the light be switched on and off with timers or sensors? This comes into play with little-used rooms and rooms that receive a lot of natural daylight. Most of the primary residential light sources can be controlled with timers/sensors. However, CFLs cannot be controlled with timers/sensors because the bulb can be damaged if you run it through too many on/off cycles.

Another question is whether the intensity of the light can be controlled through dimming. This is especially important in multi-use spaces such as conference facilities, meeting spaces… and homes.

The main residential light sources are a mixed bag when it comes to controllability. Incandescent and halogen lamps are easily controlled with simple phase control dimmers that can take the bulb from full power down to the merest glow. This type of dimmer is widely available at most electrical retailers.

On the other hand, CFLs and LEDs are more complicated.

The curly fluorescent tubes in a CFL need a ballast in order to work, and this ballast is located in the large plastic bowl just below the bulb in a screw-in CFL. If you want to dim the CFL, you have to put additional circuitry in the ballast, and that drives the bulb cost way up because of technical factors. Furthermore, even state-of-the-art dimmers can only dim CFLS down to about 10% of full power. (Compare that to 1% for halogen or incandescent dimmers.)

Where CFLs need a ballast, LEDs need a driver in order to work. However, LED drivers can accommodate dimming circuitry fairly easily, and there are currently LEDs on the market that can be dimmed down to 1%, even this dimming level cannot equal that which is possible with incandescent and Halogen bulbs.

Being able to control a light's intensity has implications beyond dimming performance. In some cases, dimmed lights last longer. Figure 5 summarizes current knowledge about lamp life extension.

Light Source	**Dimming by…**	**Extends lamp life by…**[6, 7]
Incandescent	25%	4 times
	50%	20 times
Halogen	25%	4 times
	50%	10 times
Dimmable CFL	25%	No life extension
	50%	No life extension
LED	25%	Unknown
	50%	Unknown

Figure 5: How dimming extends lamp life

Lifetime Costs

Another consideration is how much a lighting source costs to purchase and operate over the course of a system's lifetime. Figure 6 compares the costs of various light sources over 10 years, for a lamp that is used three hours a day, 365 days a year, at an electricity rate of 12 cents/kWh. Where the light can be dimmed, costs are calculated for dimming at 20% and 50%.

Source	Cost per bulb[8]	Full Power use (in watts)	Dimmed power use (in watts)		Lamp life (hrs)		
			20%	50%	Full Power	Dimmed	
						20%	50%
Incandescent	$1.75	60	48	30	1,000	4,000	20,000
Halogen	$5.00	40	32	20	3,000	12,000	30,000
Non Dim CFL	$1.75	15	N/A	N/A	12,000	NA	NA
Dimmable CFL	$15.00	15	12	8	12,000	12,000	12,000
Screw in LED	$100	15	12	8	25,000	?	?

Figure 6: Lifetime cost factors over a 10-year period

Adding up all the various costs, we come to the total lifetime costs contained in Figure 7. From the table, we can see that non-dimmed CFLs are the cheapest alternative over the life of the system. Where controllability is a factor, dimmable CFLs and halogen are comparable, with incandescent running third. LEDs, because of their current high bulb costs, are still too expensive for all but the most committed early adopters

Source	10 year lifetime cost		
	Full power[9]	**Dimmed 20%**	**Dimmed 50%**
Incandescent	$98	$67	$41
Halogen	$72	$47	$31
Non Dim CFL	$22	NA	NA
Dimmable CFL	$35	$31	$26
Screw in LED	$120	$116	$111

Figure 7: Lifetime costs of typical residential light sources

Putting it all together

Efficacy, color performance and controllability are important factors when choosing a light source. Cost is also important – whether it's initial bulb cost, operating cost, or lifetime cost. Other things to consider include performance issues such as whether the bulb responds instantly when you turn it on, operates steadily without flickering, and is easy to install throughout the home. For people concerned about sustainability, mercury content and disposal issues may also come into play.

Many of these considerations are captured in Figure 8.

When selecting a light source you should consider the following:

● Superior
○ Adequate
– Not adequate

		Incandescent		Low Voltage		Fluorescent			LED	
		Standard	Halogen	Electronic	Magnetic	Linear	CFL pin [1]	CFL screw-in	LED	LED screw-in
Efficiency	Reduced energy usage	–	○	–	–	●	●	●	●	●
	3000+ hours	–	●	○	○	●	●	●	●	●
Location	Living Spaces	●	●	–	–	○	●	–	●	○
	Utility Spaces	●	○	○	○	●	●	●	●	●
	Office Spaces	–	○	○	○	●	●	○	●	○
Price	Low operating cost	–	●	–	–	●	●	●	●	●
	Low price	●	○	–	–	●	–	●	–	–
Controllability	Timers and Sensors	●	●	●	●	●	●	–	●	●
	Fully dimmable	●	●	–	●	●	●	○ [2]	● [3]	○
Performance	Instant start-up	●	●	●	●	○	○	○	●	●
	No pop or drop out	●	●	●	●	●	●	○	●	○
Sustainability	Mercury-free	●	●	●	●	–	–	–	●	●
	Easily disposable	●	●	●	●	○	○	–	●	●
Quality	Excellent color rendering	●	●	●	●	–	–	–	○	○
	Flicker-free operation	●	●	●	●	●	●	–	○	○
	Pleasing color temperature [4]	●	●	●	●	○	○	○	○	○

1 A dimming ballast is required when dimming a 4 pin compact fluorescent (CFL).
2 Limited dimming available.
3 Dimming range depends on the LED driver used.
4 Pleasing color temperature (85-100).

Figure 8: Factors affecting choice of light source in residential applications

In conclusion

If color performance, controllability and low operating costs are the prime considerations for choosing a light source, the most logical choice will be a halogen lamp controlled with a dimmer.

If cost savings are the only consideration, then the most logical choice will be non-dim CFL.

References

1. Results compiles from CALiPER and other DOE testing, NLPIP reports, and manufacturer catalogs. A-lamps, R-lamps, and PAR-lamps are tested in situ, or a fixture loss factor is applied to bare lamp performance based on CALiPER in situ versus bare lamp testing. Products featured in this brochure have not been evaluated by and are not endorsed by the United States Department of Energy.
2. IESNA Lighting handbook, 8th edition, page 9: Luminous Efficacy of Light Sources
3. IESNA Lighting handbook, 8th edition, page 125: Color Rendering
4. Light source spectra obtained using Ocean Optics USB 4000 Spectrometer ID: USB4A00340
5. IESNA Lighting handbook, 8th edition, page 6: Color Temperature and chapter 4 color
6. IESNA Lighting handbook, 9th edition, page 6-13, lamp characteristics. Halogen lamp life study under dimming conditions. Dr. S. Pekka Hakkarainen and Dr. R. Nachtrieb
7. IESNA Annual Conference Savannah GA, November 2008
8. Average retail prices: www.homedepot.com
9. Life time costs assuming 12¢ per kWh, 3 hours per day, 365 days per year. Life time costs = Number of lamps for 10950 hours of use + energy usage ($0.12* 10950 hours*running wattage)

Telephone: 610.282.3800
International: +1 610.282.3800

World Headquarters
Lutron Electronics Co., Inc.
7200 Suter Road
Coopersburg, PA 18036-1299
USA

LUTRON®

www.lutron.com