Electromagnetic Spectra of Light Bulbs

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Introduction

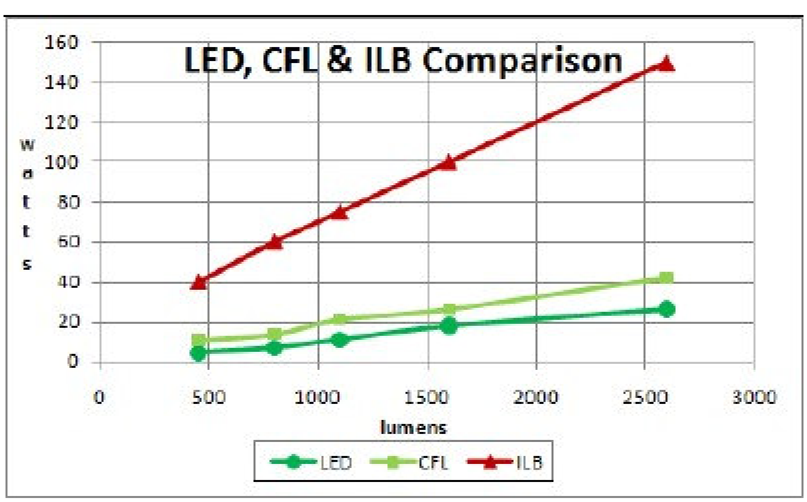
Many homes are replacing incandescent light bulbs (IL: http://en.wikipedia.org/wiki/Incandescent_light_bulb) with compact fluorescent light bulbs (CFL: http://en.wikipedia.org/wiki/Compact_fluorescent) to save energy, because the CFL bulbs use about one-fourth of the energy that IL bulbs use to produce the same amount of light energy to which human eyes are sensitive (lumens: http://en.wikipedia.org/wiki/Lumens).

IL bulbs produce a continuous electromagnetic spectrum and CFL light bulbs produce a discrete spectrum or a discrete spectrum superimposed on a continuous spectrum. So, besides the amount of energy used to produce lumens, there is a consideration regarding the spectrum produced. Some people object to the spectral quality of CFL bulbs.

Light-Emitting Diode bulbs (LED: http://en.wikipedia.org/wiki/LED_lamp) use much less energy than IL bulbs and about half the energy used by a CFL bulb.

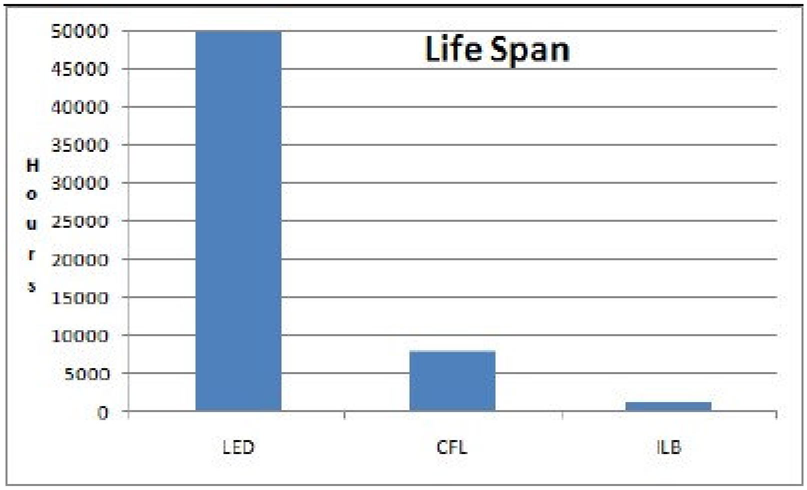
This article compares the spectra of IL and CFL bulbs with the solar spectrum at the Earth surface and with the sensitivity spectrum of the human eye and makes recommendations about matching the CFL spectra with the human-eye spectrum, the solar spectrum and the incandescent spectrum.

Comparing IL (Incandescent Light Bulb) and LED (Light Emitting Diodes) and CFL (Compact Fluorescent Light Bulb) for Energy Efficiency:



The comparison is for 40, 60, 75, 100 and 150 watts IL bulbs.

Since a 1500-lumens LED bulb is about 5 times as energy efficient as an IL, it could cost 5 times more than an IL bulb to make them have the same energy value.



Since a 1500-lumens LED bulb has about 10 times the life span as a CFL and about 50 times the life span as an IL, it could cost 10 times more than a CFL and 50 times more than an IL bulb to make them have the same longevity value.

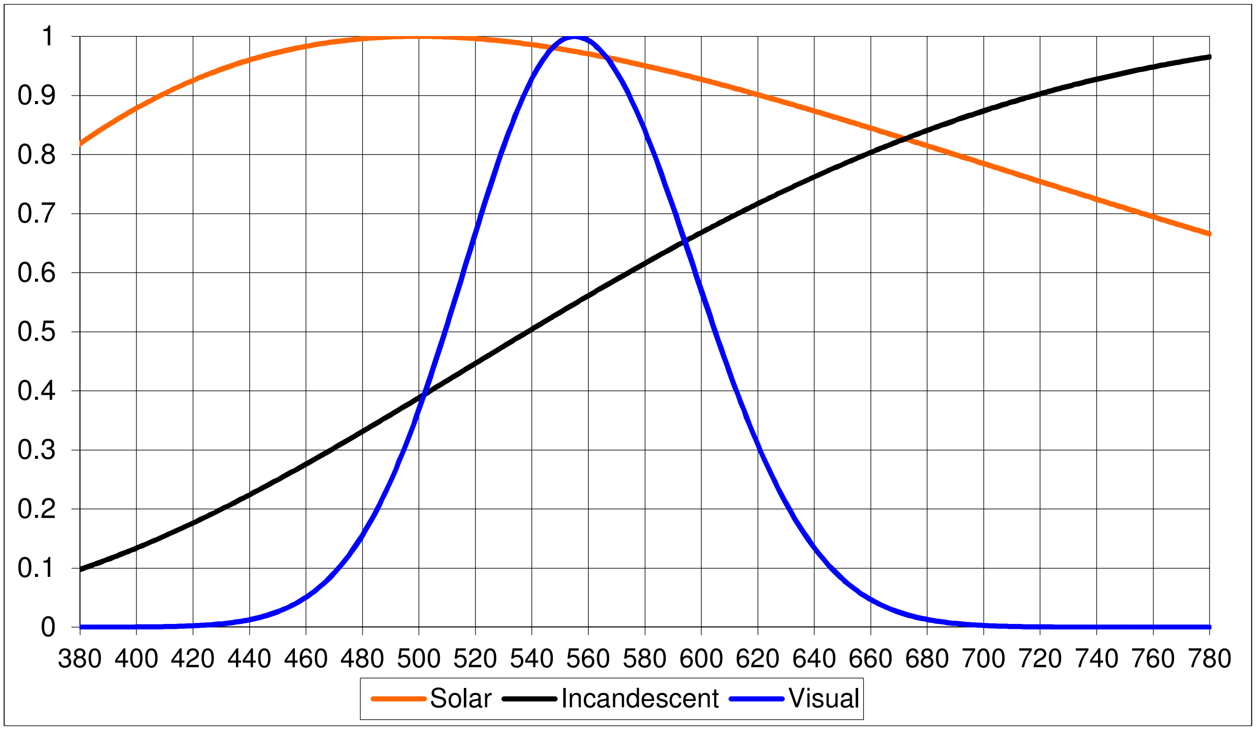
Since a 1500-lumens LED bulb is about 5 times as energy efficient and has about 50 times the life span as an IL, it could cost 250 times more than an IL bulb to make them have the same energy and longevity value.

Matching CFL Spectrum to Other Spectra

There are at least three approaches that could be taken about the ideal frequencies that CFL bulbs should have:

1. Match the visual spectrum of the human eye.
2. Match the spectrum of IL bulbs.
3. Match the solar spectrum.

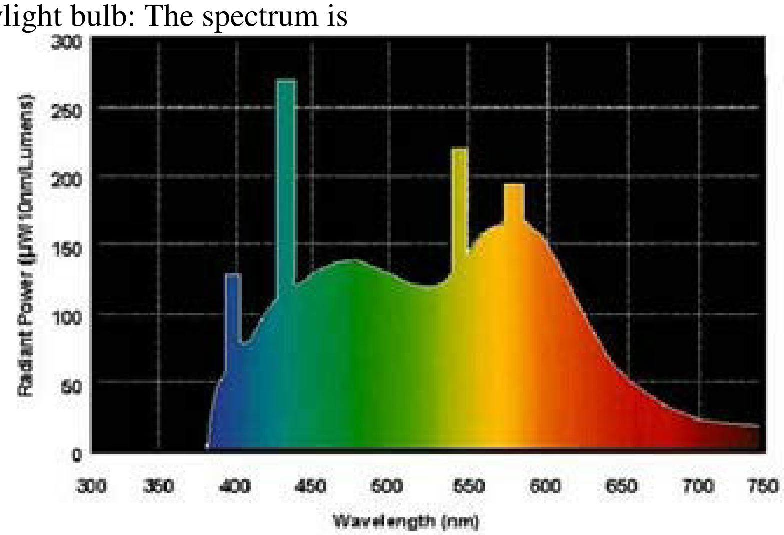
One could argue that #1. is the most important. However, one could also argue that modern humans are used to the IL spectrum, so perhaps it is what should be matched. But, one could also argue that humans evolved bathed in the solar spectrum, so perhaps it is what should be matched. The following graph shows these three spectra all normalized to 1. (Temperature = 3300 K for the IL bulb. Surface temperature of the Sun = 5800 K.)



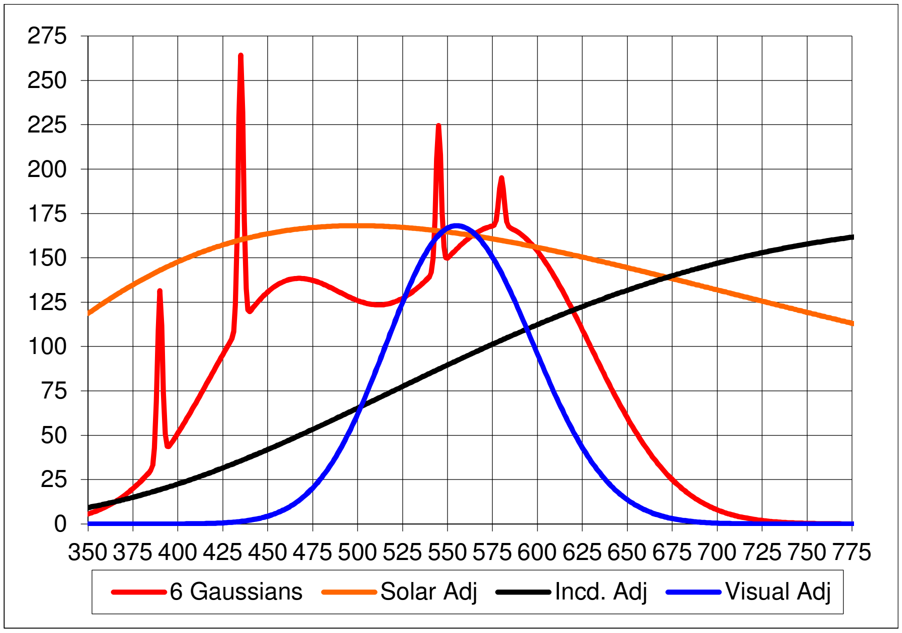
So, matching these three spectra are three completely different approaches, except for the middle frequencies.

General Electric has a web page that allows display of the spectra for its light bulbs:
http://www.gelighting.com/na/business_lighting/education_resources/learn_about_light/distribution_curves.htm

Consider the GE Daylight bulb: The spectrum is

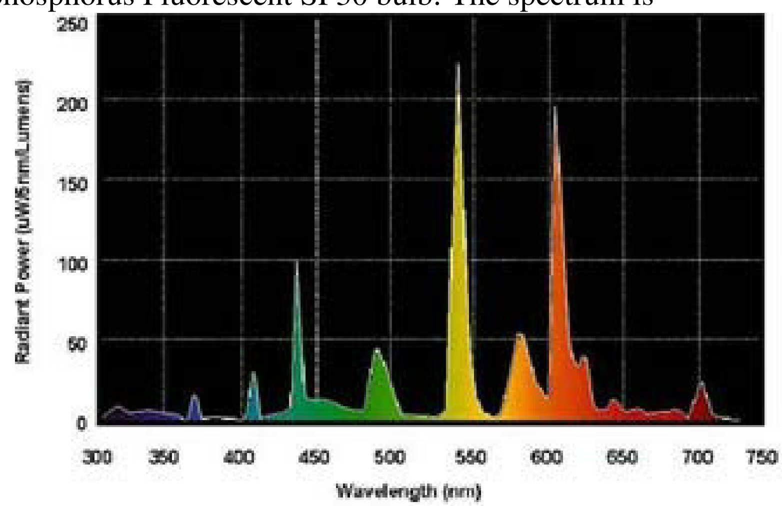


We created a reasonable model of this spectrum with six Gaussians, as shown in this graph:

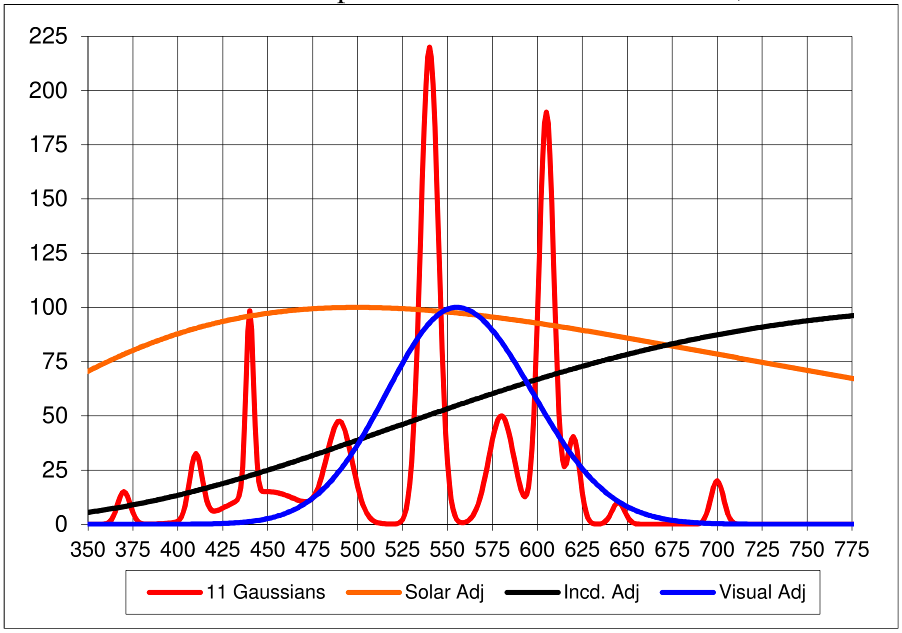


Also shown in the graph are the solar, incandescent and visual spectra normalized to the maximum of the two broad CFL Gaussians. The correlation coefficients between the GE Daylight bulb and the (solar, incandescent and visual) spectra are (+0.906, -0.340 and +0.718).

Consider the GE Triphosphorus Fluorescent SP30 bulb: The spectrum is



We created a reasonable model of this spectrum with eleven Gaussians, as shown in this graph:



Also shown in the graph are the solar, incandescent and visual spectra normalized to approximately resemble the bulb's spectrum. The correlation coefficients between the GE Daylight bulb and the (solar, incandescent and visual) spectra are (+0.376, -0.068 and +0.461).

Why Do People Prefer IL to CFL or LED Bulbs

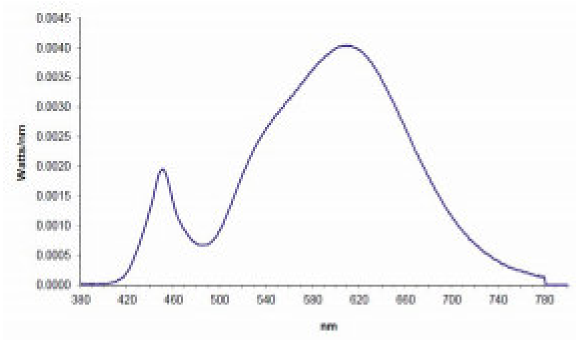
One hears and reads that many people prefer the old IL bulbs to CFL or LED bulbs. I think that there are at least the following two factors involved:

- The earliest CFLs and LEDs were too restricted in the spectra distribution; i.e., they did not match the visible or IL spectra very well.
- The use of IL bulbs for a more than a century has conditioned humans to prefer the IL light spectrum, even though the visible spectrum is quite different.
- IL bulbs are closer to the spectrum of fires. Humans evolved with fire as a very important part of its survival toolkit. However, humans also evolved with sunlight as a very important part of its survival toolkit; so perhaps LEDs will quickly be accepted for indoor lighting since they more closely match the sunlight spectrum.

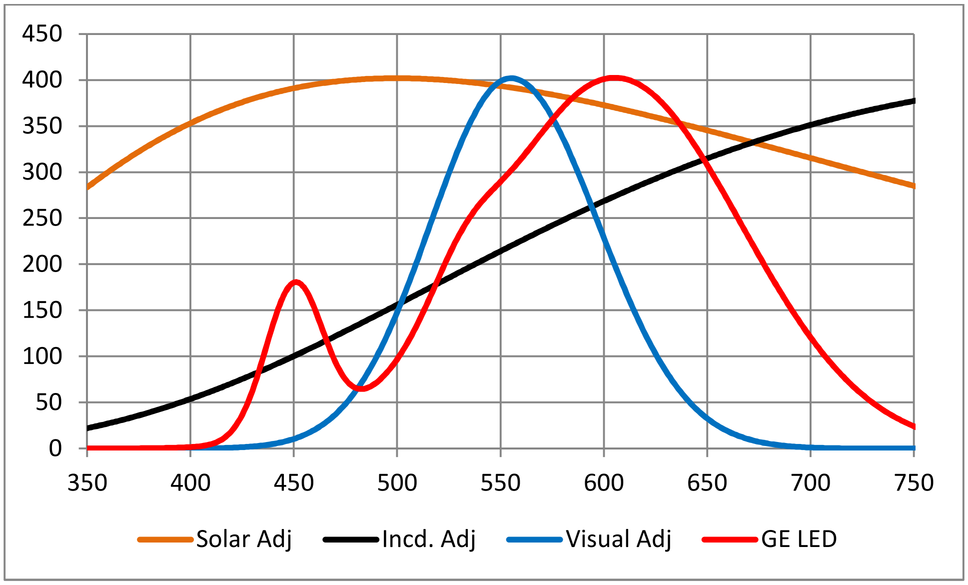
I think that, as LEDs become less expensive and have spectra closer to the visible spectrum, they will be the major light bulbs of the future (http://www.wired.com/magazine/2011/08/ff_lightbulbs/all/1).

Matching LED Spectrum to Other Spectra

General Electric has a web page that allows display of the spectra for some of its LED light bulbs (http://genet.gelighting.com/LightProducts/Dispatcher?REQUEST=SITESEARCH): Consider the GE LED bulb #63556 (http://www.gelighting.com/na/business_lighting/education_resources/literature_library/sell_sheets/downloads/led/63556_GE_LED_GU10_Lamps.pdf): The spectrum is



We created a reasonable model of this spectrum with three Gaussians, as shown in this graph:



Also shown in the graph are the solar, incandescent and visual spectra normalized to the maximum of the LED. The correlation coefficients between the GE LED #63556 bulb and the (solar, incandescent and visual) spectra are (+0.449, +0.319 and +0.653).

Conclusions

Some conclusions that we can draw are:

CFL:

- For CFL bulbs to match better the visual spectrum of the human eye, more or stronger lines are needed between 500 and 525 nm and between 550 and 600 nm..
- To better match the spectrum of IL bulbs, more or stronger lines are needed between 500 and 525 nm, 550 and 600, and above 625 nm.
- To better match the solar spectrum, lines are needed between 380 and 425 nm, 450 and 525 nm, 550 and 600, and above 625 nm.

LED:

- LEDs are very close to the visible spectrum
- A shifting of the major peak to lower wavelengths would be good.

References

- The Future of Light is the LED (http://www.wired.com/magazine/2011/08/ff_lightbulbs/all/1)
- Side by side: LED, CFL, and incandescent bulbs (http://news.cnet.com/8301-11128_3-20087668-54/side-by-side-led-cfl-and-incandescent-bulbs/)
- Incandescent, CFL, LED Light Bulb Showdown (http://keithmac.com/?p=243)
- Light, A Love Story: Why Do We Like the Light We Like? (http://www.txchnologist.com/2011/light-a-love-story-why-do-we-like-the-light-we-like)
- Wikipedia: Phase-out of incandescent light bulbs (http://en.wikipedia.org/wiki/Phase-out_of_incandescent_light_bulbs)
- Solar spectrum at surface of the Earth (http://en.wikipedia.org/wiki/File:Solar_Spectrum.png).
- Frequently asked questions about compact fluorescent bulbs (http://www.gelighting.com/na/business_lighting/faqs/cfl.htm)
- LED Light-Bulbs Recommendations (http://www.roperld.com/science/ledlightbulbsrecommendations.htm)

- Appendix

The solar spectrum and the incandescent spectrum are calculated from the Planck blackbody formula (http://en.wikipedia.org/wiki/Wien%27s_displacement_law) normalized to 1 at its peak:

$$I(\lambda) = \frac{\dfrac{8\pi hc}{\lambda^5}\dfrac{1}{e^{\frac{hc}{k\lambda T}}-1}}{\dfrac{8\pi hc}{\lambda_{\max}{}^5}\dfrac{1}{e^{\frac{hc}{k\lambda_{\max}T}}-1}} = \frac{\lambda_{\max}{}^5\left(e^{\frac{hc}{k\lambda_{\max}T}}-1\right)}{\lambda^5\left(e^{\frac{hc}{k\lambda T}}-1\right)},$$

$$\text{where } \lambda_{\max} \cong \frac{hc}{4.96511\,kT} = \frac{2.89777\times10^6}{T}\ \text{nm-K}.$$

and $2hc = 3.9729\times10^{-16}$ Joules•nanometers.

For the solar spectrum $T = 5800$ K and for the incandescent spectrum $T = 3300$ K.

The visual spectrum is represented by an asymmetric Gaussian:

$$I(\lambda) = \begin{Bmatrix} e^{-\left(\frac{\lambda-\lambda_{\max}}{\Delta_L}\right)^2} & \text{for } \lambda < \lambda_{\max} \\ e^{-\left(\frac{\lambda-\lambda_{\max}}{\Delta_R}\right)^2} & \text{for } \lambda > \lambda_{\max} \end{Bmatrix},$$

$$\text{where } \lambda_{\max} = 555 \text{ nm, } \Delta_L = 55 \text{ nm and } \Delta_R = 60 \text{ nm.}$$

The spectrum for light bulbs is represented by a sum of N Gaussians:

$$I(\lambda) = \sum_{i=1}^{N} e^{-\left(\frac{\lambda-\lambda_i}{w_i}\right)^2}.$$

9 March 2007