Narrow Spectrum Light Source Matched to Spectral Transmission of Light Filtering Media

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Background:

To perform industrial tasks that include emission of harmful ultraviolet (UV), near ultraviolet, infrared, or extreme luminance demand operators to wear eyewear, hoods, or shields that are designed to filter out harmful light qualities, while affording acceptable vision of the task involved. Welding is one of the most common tasks requiring filters and shading to protect human vision. Utilizing electric arc processes (GMAW, GTAW, SMAW), Gas, or Oxy Acetylene, welding produces high levels of blue, ultraviolet, and infrared radiation that is damaging to the human visual system. To protect the worker from temporary blindness due to the intensity of the work involved and permanent damage from harmful radiation, filter masks or lenses are employed, with limited spectral and light transmission. These safety measures result in a significant reduction in visibility of the task area around the weld pool (arc or flame).

Application in welding operations:

Welding safety shields utilize light filtering media to block radiation that will damage the human eye, while allowing enough light to pass to facilitate adequate vision to perform the welding task itself. The spectral transmission of filters is very narrow, blocking more than 99% of the light on either side of one or more peak transmission wavelengths (which varies based on the filter media or coatings employed.) In general, the peak transmission wavelength(s) of welding filters is between 500nm and 600nm, at roughly 5% to 25%, depending on filter density – which is centered on peak human visual sensitivity - while filtering wavelengths shorter than 500 (blue to UV) and longer than 600nm (red to IR) to as little as .05%, which comprise the regions where high intensity exposure harms the human eye. Figure 1 shows an example of a typical simple single color green filter lens spectral power transmission curve, with a peak transmission of 535nm.

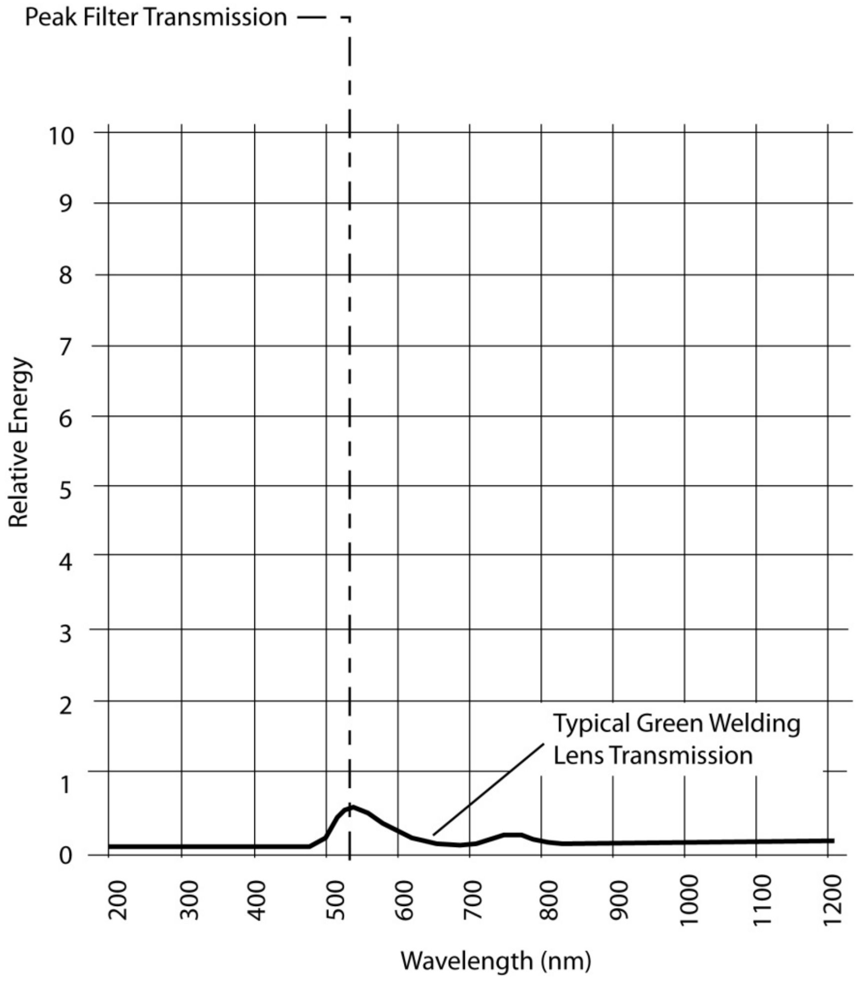

Figure 1: Typical Green Welding Lens Transmission Curve

The alignment of peak transmission of filters and human visual photopic response (the region between 525nm and 565nm) is shown in Figure 2. The narrow filter range produces an apparent green color appearance through the lens as blue and red light used to complete the appearance of white light are captured by filter media as part of the capture of infrared and ultraviolet radiation, and near ultraviolet light. This narrow transmission bandwidth is necessary to capture the range of radiation emission from the range of welding processes used, materials being processed, filler rod or wire material utilized, and shielding gases employed, which produce a wide range of potential spectral distributions and intensities.

To reduce illuminance overall to protect the eye from high intensity radiation at all levels, additional tinting or masking is employed to produce very low overall transmission characteristics. This tinting, as well as the depth of the spectral filtering, may be static, or it may be activated by photo-reactive systems that respond to the presence of the harmful light (welding arc), darkening several shades. This allows the operator to prepare to execute and operation with greater visible general illuminance, while remaining protected when the source of harmful radiation is initiated (arc or welding flame). In the darkened state, whether static or dynamic, contrast between the light source (welding arc) and background task surround is greater than the human eye is able to accommodate. The retina is capable of accommodating a contrast ration of approximately 100:1 (1), while pupil dilation will react to brightness that fills a significant area of the visual field, up to 100:1, resulting in a reduction of surrounding luminance perception, and a contrast ratio as high as 10,000:1 as the pupil closes in response to the weld brightness. Because of this, the contrast between the weld area and the surrounding field exceeds the ability of the visual system to accommodate, effectively making the area beyond the immediate weld target invisible. Further frustrating the visibility of the surrounding work area, welding tasks are completed on a wide range of materials with reflectivity ranging from 10% to 70%.

In order to produce reasonable vision of the surrounding task area, a reflected luminance contrast ratio of 20:1 between the weld region and the surrounding surfaces offers acceptable visibility of the surrounding task area for orientation and observation of welding progress, while viewed under the darkest filter conditions. This small addition of 5% to brightness of the total welding field, as seen through the filter mask, does not produce a significant compromise in eye protection, while the reduction in contrast ratio produces significant improvement in human visual performance in seeing the area surrounding the welding arc or flame..

Table 1 summarizes the effective contrast of luminance between the weld and the task background with no supplemental light and with supplemental light of 5% of the welding arc or flame brightness. The effect of filtering on color perception and actual luminance reaching the operators eye is irrelevant, as it applies to all values shown and will not effect luminance contrast, only absolute luminance values themselves. As shown the contrast in luminance from the weld are against its background, with a nominal 100fc ambient light level, on a 50% reflective surface, results in contrast ratios too high to produce visual acuity of the surrounding work area. While the addition of up to 4000fc, resulting in reflected light of 2000foot lamberts, produces a visually useable 20:1 contrast ratio between the weld area and surrounding surface area.

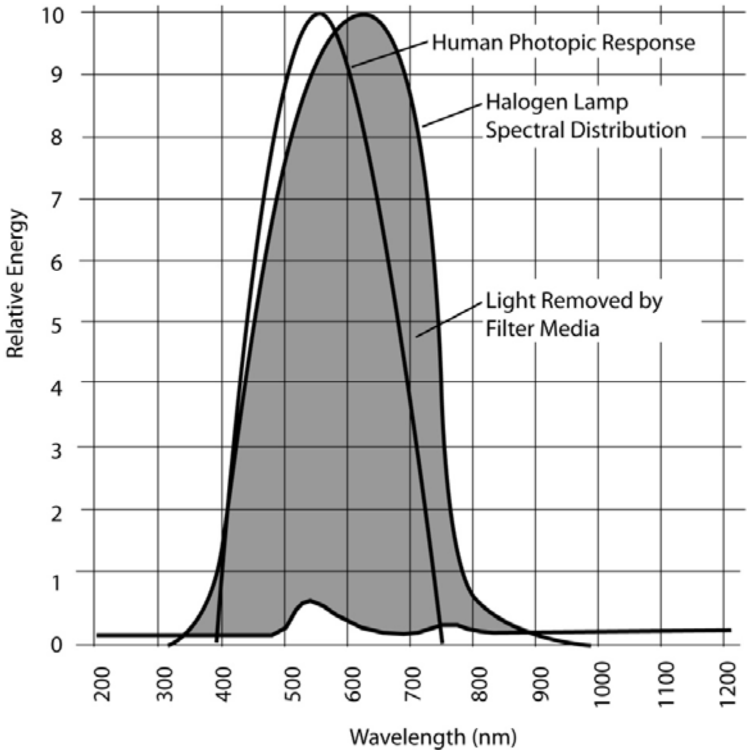

Figure 2: Effect of Spectral Transmission Losses on Light Source Energy Passing Through Filter

Table 1: Contrast Ratio Summary of Task Surround Reflected Luminance to Weld Brightness

	50 Fc Surrounding Luminance			Surround Luminance @ 5% Weld Brightness		
Weld Brightness in Footlamberts	Task Reflectance in Footlamberts	Composite Total Weld Brightness (Fl)	Contrast Ratio :1	Task Reflectance in Footlamberts	Composite Total Weld Brightness (Fl)	Contrast Ratio :1
1,250	50	1300	26	63	1313	21
2,500	50	2550	51	125	2625	21
5,000	50	5050	101	250	5250	21
10,000	50	10050	201	500	10500	21
20,000	50	20050	401	1000	21000	21
40,000	50	40050	801	2000	42000	21

In order to provide the illuminance levels necessary to produce the target 20:1 contrast ratio requires application of very high illuminance levels (up to 4,000 candela per square foot.) When using white light sources (spectral distribution of between 400nm and 700nm), a large portion of the light delivered is captured by the filter, resulting in very poor through-filter efficiency, as shown in Figure 2. This loss is greatest outside the filter's peak transmission wavelength(s).

In addition to any filtering impact on light reaching the operator's eye, white light sources often produce light outside the photopic response region, resulting in energy consumed to generate light that is outside human visual perception, compounded by light loss through the filter media. As shown in Fig. 2, a typical halogen light source generates a significant amount of light outside human photopic vision, primarily in the form of red and infrared radiation. Further, this light is also aggressively filtered by the welding lens and shading media, along with the harmful light produced by the welding arc or flame. The resulting combination of losses results in very low total perceived brightness.

The visual effectiveness of task lighting systems involving filters worn by human operators can be evaluated by considering the composite effect of light source spectral distribution, surface reflective surfaces, the filter media employed and human photopic visual response as shown in Figure 3. The resulting coefficient from compounding losses comprises the apparent light as seen by the observer. For purposes of simplicity, the spectral reflectance of the task surfaces can be set aside as having equal affect on all light sources. As the filter media dictates what light will be dominant to the observer.

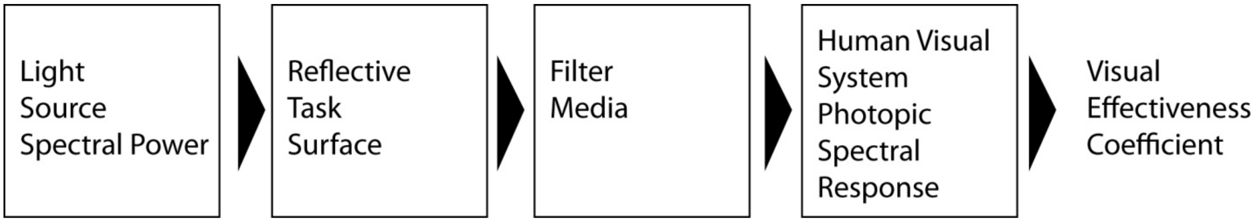

Figure 3: Factors Relative to Total Visual Effectiveness of a Lighting Strategy

In addition to human photopic response, consideration may be given to scotopic visual response, which peaks at 505nm, or mesopic visual response (the combination of photopic and scotopic vision). Depending on the intended application, luminance level requirements, filter media employed, or combination of these, specific response regions may be chosen, with corresponding match of light source spectral power distribution to achieve a desired goal while maintaining proper radiation filtration required to protect human vision.

A common light source utilized in welding environments is halogen cycle tungsten filament incandescent. This source produces minimal flicker, and a broad white light spectrum. Table 2 summarizes the efficiency of such a light source with all factors of visual performance and filtering included. The composite low efficacy of the source, combined with the impact of filtering results in just 3.15 lumens delivered to the observer for each 10 Watts of energy consumed. Overall efficacy of the system is 0.31 lumens per watt.

Table 2: Halogen Incandescent System Visual Efficiency

Wavelength nm	Light Source Relative Energy	Per 10 Watts @ 17 lumens/W	Visual Response	Filter Transmission	Relative Transmission
350	5	1.5	0.0%	0.9%	0.00
400	11	3.3	10.0%	0.9%	0.00
450	50	14.9	60.0%	0.9%	0.08
500	83	24.7	75.0%	1.3%	0.23
550	91	27.1	100.0%	6.0%	1.63
600	98	29.2	90.0%	2.8%	0.74
650	100	29.8	70.0%	1.8%	0.38
700	87	25.9	38.0%	0.9%	0.09
750	30	8.9	10.0%	1.0%	0.01
800	16	4.8	0.0%	0.9%	0.00
	571	170		Total Relative Energy	3.15
				Relative Photopic Efficiency	**1.9%**
Watts @ 100lm/W	**10**				
Lumens Delivered	**3.15**				
Effective efficacy	**0.31**	Lumens per watt			

A modern light source utilizing white light LEDs, at 4100 CCT, with a luminaire efficacy of 90 lumens/ Watt provides a significant improvement in raw efficacy, coupled with a narrower overall spectral energy range, as shown in Figure 3. The result is a combination of greater total light reaching the observers eye through the filter for each 10 watts consumed, as shown in Table 3.

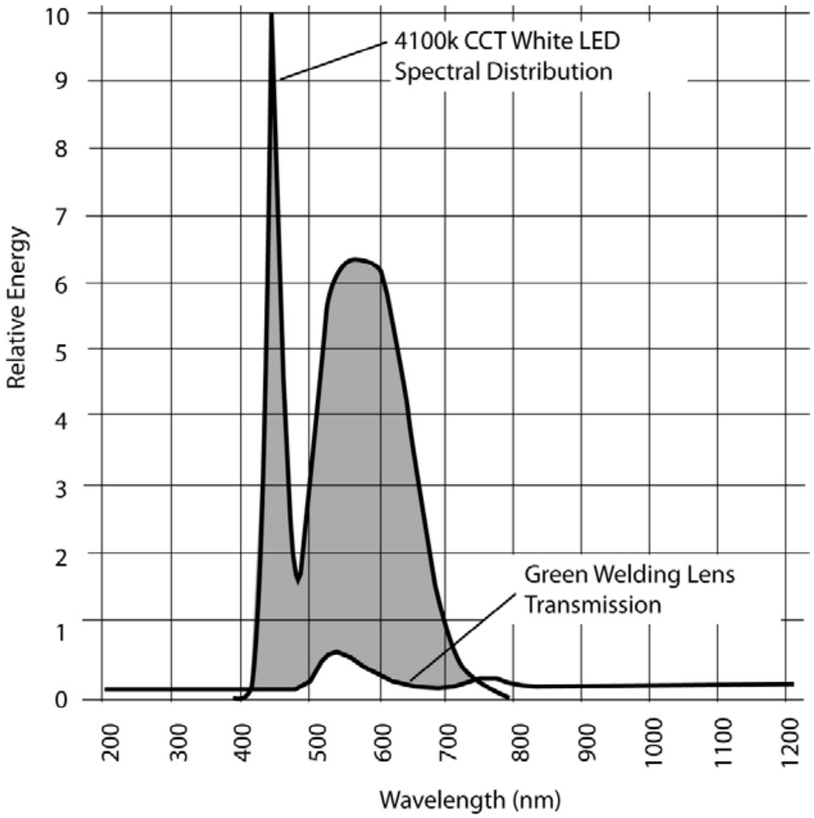

Figure 3: Effect of Spectral Transmission Losses on Light Source Energy Passing Through Filter

Table 3: 4100k CCT LED Light Source System Efficiency

Wavelengthnm	Light Source Relative Energy	Per 10 Watts @ 90 lumens/W	Visual Response	Filter Transmission	Relative Transmission
350	0	0.0	0.0%	0.9%	0.00
400	2	5.9	10.0%	0.9%	0.01
450	100	296.1	60.0%	0.9%	1.60
500	25	74.0	75.0%	1.3%	0.69
550	63	186.5	100.0%	6.0%	11.19
600	60	177.6	90.0%	2.8%	4.48
650	40	118.4	70.0%	1.8%	1.49
700	9	26.6	38.0%	0.9%	0.09
750	5	14.8	10.0%	1.0%	0.01
800	0	0.0	0.0%	0.9%	0.00
	304	900		Total Relative Energy	19.56
				Relative Photopic Efficiency	**2.2%**
Watts @ 80lm/W	**10**				
Lumens Delivered	**19.56**				
Effective efficacy	**1.96**	Lumens per watt			

The application of white light LED improves light delivery to the observer by 621%, and an efficacy gain of 632%. However, as can be seen in Figure 3 and Table 3, the production of light in the lowest transmission regions within the filter media results in a significant portion of light from the LED source is absorbed, reducing its visual efficiency significantly, resulting in a total relative visual efficiency just 16% greater than the halogen source.

Invention and Application:

Rather than applying a broad spectrum white light, the invention employs a very narrow spectrum light source or sources with peak emission(s) closely aligned with the peak transmission of the filter media employed, further optimized to match peak human photopic response (as shown in Figure 1). Eliminating energy conversion to produce light in regions where filtering is strongest minimizes energy waste from filtering of light, while high luminance in the region of highest transmission and greatest human visual response creates the greatest visual efficiency. The result is a highly efficient welding light source, with controlled waste from filter spectral reduction. The result is greater visual acuity, enhancing performance of the tasks performed behind the welding mask, greater safety from improved vision of the area surrounding the immediate weld area, and significantly lower energy consumption.

Figure 4 illustrates the desired alignment of light source, filter media peak transmission, and human photopic visual response, resulting in optimized visual performance within the welding task performed with the least amount of energy.

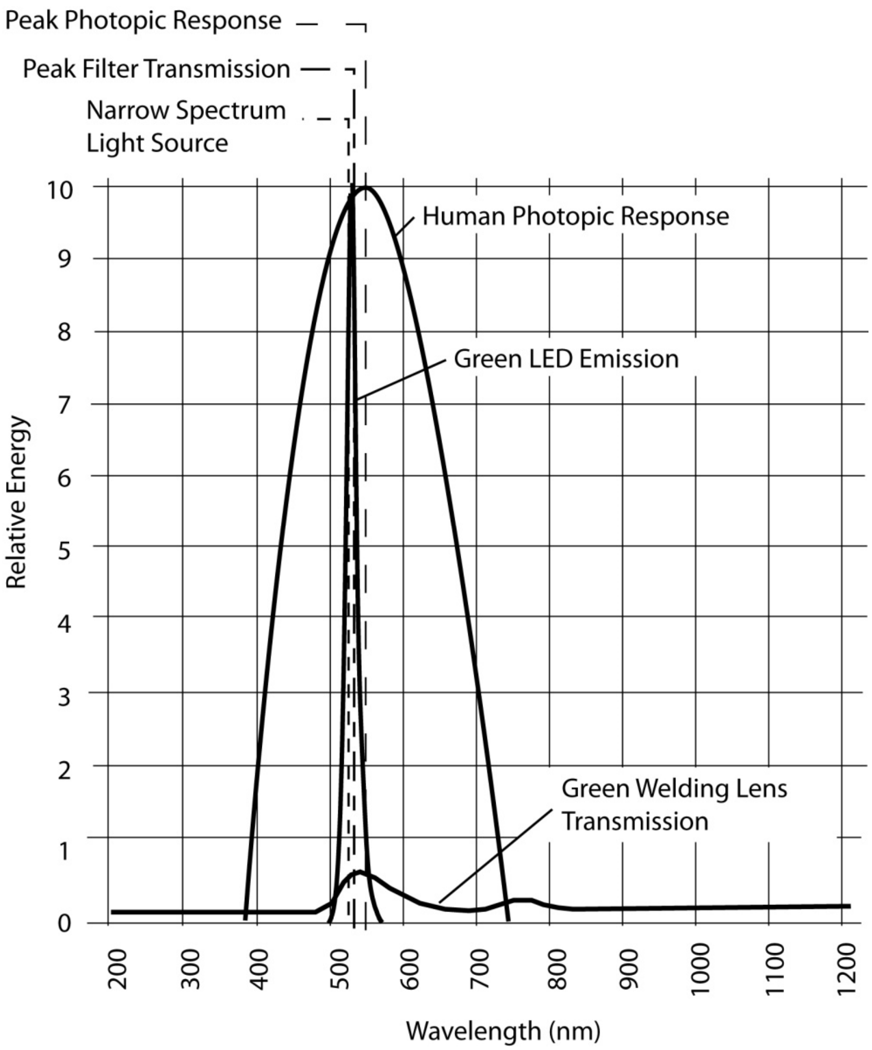

Figure 4: Alignment of Light Source, Visual Photopic Response and Filter Media Peak Transmission

The light source illustrated in Figure 4 is a standard 530nm Green LED. Other light sources may be applied with similar narrow spectral power distributions, including special metal halide, plasma, fluorescent, or Organic LED. Other factors of desired focal intensity, overall optical control, and total power desired may dictate selection of light sources. Further, development of filter media aligned with a specifically tuned light source is possible to further advance efficiency gains.

Table 4 summarizes the effect of using a common dark green filter with a 530m Green LED, relative to the comparison of white LED and halogen lamp performance.

Table 4: 530nm Green LED System Visual Efficiency

Wavelengthnm	Light Source Relative Energy	Per 10 Watts @ 65 lumens/W	Visual Response	Filter Transmission	Relative Transmission
350	0	0.0	0.0%	0.9%	0.00
400	0	0.0	10.0%	0.9%	0.00
450	0	0.0	60.0%	0.9%	0.00
500	2	12.4	75.0%	1.3%	0.02
550	100	619.0	100.0%	6.0%	6.00
600	3	18.6	90.0%	2.8%	0.08
650	0	0.0	70.0%	1.8%	0.00
700	0	0.0	38.0%	0.9%	0.00
750	0	0.0	10.0%	1.0%	0.00
800	0	0.0	0.0%	0.9%	0.00
	105	650		Total Relative Energy	6.09
				Relative Photopic Efficiency	**5.8%**
Watts @36lm/W	**10**				
Lumens Delivered	**37.73**				
Effective efficacy	**3.77**	Lumens per watt			

The use of a 530nm green LED produces an improvement of 1,197% over the halogen system, and a relative photopic efficiency gain of 98%. This approach also produces an improvement of 93% over the 4100k CCT White LED system, and an improvement in photopic efficiency of 263%. These gains include the loss of source efficacy creating a difference in luminaire efficancy between the white light LED of 90lm/W to 65 lm/W for the green narrow spectrum LED system. This is incurred do to the lower source efficacy of green LEDs over phosphor converted InGaN LED packages.

Table 5 summarizes the resulting comparison between white light sources and a narrow spectrum light source, showing the total energy required to attain the illuminance values required to deliver a luminance ratio of 20:1 in the visual field. For purposes of this comparison, all light sources are assumed to have identical optical distributions of 30 degrees FWHM, located 18” from a 50% reflective work surface.

Table 5: Energy Use Comparison

Weld Brightness in Footlamberts	Light Level (Fc)	Energy Required (Watts)		
		Halogen	White LED	Green LED
1,250	126	14.5	2.3	1.2
2,500	250	28.4	4.5	2.3
5,000	500	57.0	9	4.7
10,000	1000	113.4	18	9.4
20,000	2000	226.8	36	18.8
40,000	4000	453.6	72	37.4

The reduction of energy required to attain the desire luminance result produces a benefit of lower energy cost and reduced heat generated into the work space. Further, for LED systems requiring thermal management components, a reduction in luminaire component size is realized due to the lower thermal dissipation requirement.

Further optimization of the system may include use of multiple light sources multiple spectral distributions to match filter media characteristics, light sources employing special phosphors, nanocrystal, and/or quantum dot photoluminescence to achieve a desired spectral power distribution optimized to align with human visual response and filter media transmission to fine tune efficiency of the composite system or system components.

Other Applications:

In addition to the examples presented here to illustrate the use of this approach to welding filters, the approach is applicable to other applications, such as glass molding and fusing, lampworking, casting, metal foundry and smelting, and materials processing facilities where filtering of harmful light is necessary to protect human health (such as UV curing), while a simultaneous need exists to produce a high degree of visual acuity in order to facilitate task performance or enhance safety. In each specialty application, the combination of filter media and selection of light source spectral distribution will result in similar results to the gains represented in the welding lens examples.

Practical Limitations:

This approach is limited to availability of appropriate light sources to suit the filter media employed, within the human visual response regions, including photopic, scotopic and/or mesopic, which supports use of source luminous efficacies that produce gains over high efficacy white light sources. For example, bright red LED sources present low source efficacy, and minimal photopic efficiency. The resulting combination may produce lower performance and higher energy use than an available white light source. The most effective uses of this approach are those that employ filter media whose peak transmission is aligned with the human visual response curve, where light sources of high efficacy are available, to deliver the combined gains in system performance.

Claims:

1. A light source employing single color LEDs alone or in combination, and/or other selective spectrum light sources chosen to align with the specific spectral transmission of a filter media applied to protect human health, and/or human visual response in photopic, scotopic, mesopic, or any combination therein to reduce light lost in filter media employed.
2. A light source that employs LEDs, and/or other selective spectrum light source, in combination with phosphors, nanocrystals, quantum dots, or other photo luminescent conversion, remote or integral to the light source package, to create a spectral power distribution output of a lighting system aligned with the spectral transmission of a filter media and/or human visual response in photopic, scotopic, mesopic, or any combination therin to reduce light lost in filter media employed.
3. Filter media matched in spectral distribution transmission developed in conjunction with a chosen light source described in claims 1 and 2, to align spectral transmission with light source spectral power and/or human visual response into optimize visual performance photopic, scotopic, mesopic, or any combination therein, to maximize lighting system efficiency
4. A reactive electronic control system combining changing filter spectral transmission to control the balance of light output from a light source described in claims 1 and 2, or lighting system utilizing light sources described, to optimize lighting performance in response to automatically darkening filter systems, including incorporation of white light general task lighting for use when spectral filtering is shut off during setup or preparation to perform tasks where harmful light is present during task execution.
5. An automatic or manually activated control for initiating the narrow spectral distribution light source upon initiation of a harmful task, including photo-reactive relay, foot operated control, equipment relay control relay or interface, a hand switch, and/or pressure switch to activate the components employed in claims 1, 2 and 4.

References:

(1) Barton, H. and Byrne, K. *Introduction to Human Vision, Visual Defects & Eye Tests* (March 2007), p. 22.