Full-Spectrum Polarized Lighting: An Option for Light Therapy Boxes

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Abstract
Full-spectrum polarized lighting combines full-spectrum fluorescent lamps with polarized diffusers to provide lighting with the spectral energy distribution and light polarization characteristics of natural daylight. It has been used for interior illumination purposes. However, it can be used for the treatment of Seasonal Affective Disorder. By using full-spectrum polarized lighting in light therapy boxes, there is a substantial reduction in eyestrain, headaches, and fatigue, making the system ideal for this purpose.

Introduction
Since the invention of the incandescent lamp with the filing of Thomas Alva Edisons patent in 1879, lighting designers and engineers have been attempting to duplicate natural daylighting. That goal has finally been achieved with the development of full-spectrum polarized lighting, which combines full-spectrum fluorescent lamps with polarized diffusers to achieve artificial illumination with the spectral energy distribution and light polarization characteristics of natural daylight.

A number of these installations, for general illumination purposes, have been made in a number of municipal and educational facilities on Long Island. These systems have provided glare free, flicker free illumination of excellent colour rendition. The lighting has been found to match natural daylight so closely that one cannot tell the difference between the artificial illumination and any light entering the windows. There is none of the headaches, eyestrain and fatigue typical of conventional cool-white illumination, which drives fluorescent lamps with core coil ballasts in unpolarized fixtures (Karpen, 1991).

Light from the sun is polarized by scattering in the atmosphere. Both visible light and ultraviolet light are polarized; the ultraviolet somewhat more so than the visible. This phenomenon, called Rayleigh scattering, is responsible for the blue colour of the sky.

The recent development of a polarizing material that is able to polarize both the ultraviolet and visible light for use in commercial lighting fixtures should be of great importance to lighting designers. It will eliminate once and for all any glare from unpolarized ultraviolet light.

Much research has been done on full-spectrum lighting. There is a great deal of literature available on the subject. Up until this point, research on the effectiveness of full- spectrum lamps has not looked at the effects of polarizing full-spectrum light sources. New avenues for research on the visible and non-visible effects of light are now possible. One potential application of this new ultraviolet polarizing diffuser would be to light therapy boxes. In theory, polarized lighting, applied to light therapy boxes, should be able to provide a better treatment regime, since one will not get any glare from the system. At the present time, there are no definitive studies of the psychological benefits of polarized lighting, both in the areas of general interior illumination and to light therapy boxes. One company has expressed an interest in developing and marketing light therapy boxes with polarized diffusers.

The remainder of this paper will explain in detail the operation of the multi-layer polarized diffusers and some of the studies done on the visual effectiveness of full-spectrum lamps.

How Polarized Diffusers Work
One of the most infrequently applied methods used to improve the visual quality of a lighting system is to install multi-layer, polarized diffusers in a lighting system. Multi-layer, polarized diffusers suitable for use in commercial lighting fixtures differ from linear polarizers used in sunglasses. First of all, the multi-layer, polarized diffuser is 80 to 90 percent efficient in transmitting light, compared with 28 to 40 percent for linear polarizers, which polarize by absorption. Multi-layer, polarized diffusers polarize instead by means of scattering, internal reflections and refraction.

While it is known that visibility is related to the amount of light present (measured foot-candles), there are other fundamental characteristics concerning vision, task visibility, and lighting which are of equal or greater importance than quantity alone. "Seeing" is not related to the number of foot-candles per se. It is mostly a function of the luminance (brightness) of the task detail and its contrast with the background. The first of these factors is dependent on the task detail reflectance or how much light that reaches a task is absorbed by it and re-reflected so that it can be seen.

The other factor, contrast, is the difference in brightness between the task detail and its background. Gray printing on lighter gray paper can be difficult to see, while black print on while paper is much easier to see. Contrast is very important in "seeing".

The nature of the light and the lighting system can affect both the brightness of the task detail and its contrast. One can see just how much a difference it makes. If one takes a printed object, such as a magazine or book, and places it on a table under a light source located slightly to the front of it, one will notice that the print detail looks "washed out." If one moves around to the side, the print will appear darker. What has happened is that the contrast of the print to the background has increased significantly.

In the first instance, the light bouncing off the task reduced its contrast due to reflected glare, also called "veiling reflections" These reflections are due to light which is reflected from the task without actually obtaining information from it. In the second instance, however, the reflections went off in directions other than to the eye, so they did not wash out the contrast between the task detail and the background.

The "horizontally" polarized portion of the light rays cause reflected glare or veiling reflections. The "vertically" polarized portion of the light penetrates into the task instead of bouncing off the surface, and returns to the eye carrying information about the task, detail, and colour. If therefore one illuminates an object so that the "horizontally" polarized portions of the light is absent; one obtains much higher contrast, and as a result one is able to see detail and colour much better. This is how the multi-layer, polarized diffusers function. They convert the horizontally polarized light rays emitted from the light source to vertically polarized light available to penetrate the task. As a result the reflections are reduced, increasing visual contrasts.

If contrast is improved, then on one requires "less light" to see tasks equally as well. If one improves contrast, then one can reduce the amount of light (measured foot-candles) needed for equivalent visual performance.

Full-Spectrum Lighting

The importance of the colour rendering ability of full-spectrum lighting has been well established for applications where colour identification or comparison is required for inspection purposes. A number of studies have been made to determine the importance of full-spectrum lighting for general illumination purposes. The results of these studies have not yet been incorporated into the Illuminating Engineering Society recommendations for general interior lighting purposes. The practice of combining full-spectrum lamps with multi-layer polarizers will necessitate a complete revision of all IES lighting codes, recommended practices, and handbooks as we now know them.

In this article, a full-spectrum lamp is defined as a lamp having a colour rendering index of 90 or above and a correlated colour temperature of 5,000 degrees or above. These lamps closely match the spectral energy distribution of the overhead sun or sun and sky. Most lamp manufacturers now make lamps with these colour rendering properties.

While full-spectrum lamps have been used for specialized lighting applications, their use has not been widespread for general illumination purposes. One reason is cost. But another reason is that without a polarized diffuser, the full benefits of the full-spectrum lamps are not realized by the user.

A dramatic increase in colour saturation is achieved by using polarized diffusers. Colour saturation or purity improved by decreasing specular reflections. A specular reflection has in effect the physical characteristics of the light source and not the coloured pigment, so specular reflections desaturate colours if the illumination is basically white, and distort colours if the illumination is partially or wholly chromatic (Blackwell, 1962).

Vertically polarized light reduces specular reflections and increases colour purity to a visually noticeable extent. This effect occurs on all surfaces of a room, not just on horizontal surfaces. The increase in colour-purity resulting from polarized lighting is even more striking when polarized diffusers are used in conjunction with full-spectrum lamps.

One of the problems experienced in the past with the use of polarized diffusers is that they are so effective at reducing glare that they give a room a "dull", subtly flat quality by suppressing the specular highlights which harsh lighting has made us expect as visual cues. These effects are especially true for warm-white or cool-white lamps.

The use of full-spectrum lamps with polarized diffusers solves this problem. The result is a space with virtually glare free lighting equivalent to a daylit room. The quality of the lighting is indistinguishable from natural daylight.

Visual Effectiveness

Many lighting designers are turning to tri-phosphor lamps as a way of making some improvements in colour rendition and cutting energy use. Such an approach may not be the most efficient way of reducing lighting electrical usage. Full-spectrum lamps now appear to be more visually effective than tri-phosphor lamps.

There are a number of models which can be used to evaluate the visual effectiveness of various light sources. The earliest models date from the work of Charles Steinmetz at the turn of the century (Steinmetz, 1909). All of these models have a common denominator; sources rich in blue light are far more effective for visual performance at lower lighting levels than sources rich in yellow light. These effects appear to be true for the lighting levels typically found in interior illumination and for exterior street lighting.

Berman's method of examining the visual effectiveness of various light sources is to look at the mean steady state pupil size. He found that at the lighting levels typical of interior office illumination, the pupil size is controlled by the scotopic (night vision) energy content of the ambient lighting. Pupil size significantly affects visual acuity, perceived brightness, and depth of field (Berman, 1992).

Our science (if you can call it that) of illuminating engineering is based on photopic (day vision) illumination, and it is the basis of the lumen measurements of various light sources. Furthermore, the definition of "foot-candle" is tied into the photopic lumen.

What Berman is telling us loud and clear is that our basis of using the "foot-candle" is probably wrong, and what we really should be doing, based on the present state of knowledge, is to base our illumination calculations on a quantity Berman calls "Effective Pupil Lumens", which is derived from a formula that uses both the scotopic and photopic lumens of a light source.

V_λ is the Standard Observer Curve which was established by the International Commission on Illumination. The current basis for measuring the total amount of visually effective light emitted by any source consists of weighting the physical radiant power emitted by the source at each wavelength by a factor representing the sensitivity of the average human eye to light of that wavelength, and integrating this weighted radiant power across the entire visual spectrum. That is the way the number of photopic lumens of a light source is calculated; these values are found in the published catalogues of lamp manufacturers.

The scotopic response curve of the rod photoreceptors of the eye, the scotopic response function V'_λ, differs from the cone spectral response function in that its peak is at 508 nm rather than at the 555 nm peak of the V_λ function. In a sense, the photopic curve has been shifted to the blue side of the spectral energy distribution. There is also a larger bulge in the blue region of the scotopic curve, so the curve is not a simple translation. In between the scotopic and the photopic response curves is an infinite number of mesotopic response curves.

By using the V_λ and V'_λ functions, one can calculate the photopic and scotopic lumen ratings for a number of light sources. Berman then calculates "Effective Pupil Lumens" from the formula $P(S/P)^{.78}$, where P and S are photopic and scotopic lumen ratings of the lamps. The ratio of the scotopic to photopic outputs of the lamp is referred to as the S:P ratio.

Table 1 below shows the scotopic and the photopic lumen ratings for a number of light sources, the Effective Pupil Lumens, the relative power level for equal pupil sizes, and a calculation of the Effective Pupil Lumens per watt.

Table 1
Lumen Ratings of Selected Fluorescent Lamps

Lamp	Photopic Lumens	Scotopic Lumens	Effective Pupil Lumens (Calc.)	Relative Power Level for Equal Pupil Sizes	Effective Pupil Lumens Per Watt
F40/T10 5500 K, 91 CRI	2,750	6,023	5,042	85	126
F40/T12 Warm White 34W	2,750	2,750	2,727	136	78
F40/T12 Cool White	3,150	4,630	4,254	100	106
F32/T8 4100 K Tri-phos	2,850	4,389	3,991	85	125
F40/T12 Vital Care 7500 K	2,868	7,198	5,900	72	148

Sources: R. Clear, personal communication, Dec. 15, 1992 and Table 5 in Berman, 1992.

The above table is most instructive. It shows that on the basis of Effective Pupil Lumens, the lamp designated as F40/T12 Vital Care 7500 Kelvin is the most visually effective 4 foot fluorescent lamp available. It is 40 percent more visually effective than a cool-white lamp. On a lamp for lamp basis, it is 48 percent more visually effective than the F32/T8 4100 Kelvin tri-phosphor lamp now being recommended for many retrofit projects. This lamp approaches the efficiency of the hypothetical, scotopically rich, narrow band lamp proposed by Berman (1992).

It would be possible to save an enormous amount of additional energy, beyond what is presently being done on many retrofit situations, by installing the Vital Care lamps in place of the 4100 K T8 lamps. It should be noted that the 3000 K T8 lamps are much less visually effective than the 4100 K lamps.

The Role of the Ultraviolet Light

The importance of ultraviolet light to human vision has not been given sufficient attention. There are old references in the literature to the response of the eye to ultraviolet light; for example, see some of the work of Wald (1945). Recently, Brainard, Beacham, Hanifin, Sliney, and Streletz (1992) have shown that there is a visually evoked response in young children to 340 nanometre wavelength ultraviolet light. Yet it is commonly thought that the visual spectrum ends at 380 nanometres.

Nature gives us polarized ultraviolet light. Why is the sky blue? It is blue because of the Rayleigh scattering of light in the atmosphere. The scattering is dependent upon the wavelength of the light. The amount of scattering-goes up as the fourth power of the frequency. What you see is gloriously blue polarized light. It should also be pointed out that the ultraviolet light is scattered even more than the blue; it is extremely highly polarized. To match natural daylight, one should polarize the ultraviolet light as well. That is the purpose of the ultraviolet polarizing diffuser.

It should be pointed out that the V_λ curve is based on non-polarized illumination. A major basic research project that should be funded and undertaken by the lighting industry should be to redefine the visual response curve in terms of polarized illumination. In 1924, when the V_λ curve was established by the International Commission on Illumination, it was impossible to artificially polarize the light in a large room, since the only polarizers known at the time were crystals of calcite, tourmaline and other minerals.

The work to be done should include an examination of the effects of polarized illumination through the entire visual spectrum and into the ultraviolet as low as 313 nanometres. While some information is available about the response of the human eye to ultraviolet light, almost nothing is presently known about the response of the eye to polarized ultraviolet light. The human eye contains an internal polarizer; it is not know at all if this polarizer is effective in the ultraviolet, although on should suspect that it should be the case. It would appear that an ultraviolet transmitting polarized diffuser would be of great benefit to a designer of lighting systems since it would eliminate the glare from unpolarized, ultraviolet light once and for all and solve one of the greatest problems in illuminating engineering.

An ultraviolet polarizing diffuser would appear to provide an increase in contrast when reading printed materials. It is well known that manufacturers of paper and textile materials put optical brighteners in their products to make them fluoresce under ultraviolet light and appear brighter. If black print absorbs all incident radiation, and paper fluoresces under ultraviolet light, then the paper appears brighter and there is an increase in contrast between the paper and the print. The Marks (1959) equations clearly show an increase in contrast under polarized light compared to unpolarized light. The Marks equations are true regardless of the wavelength of light as long as it is small compared to the objects being seen. Therefore the Marks equations should be true in the ultraviolet range as well.

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