Solid State Light Evaluation In The U.S. Lab Mockup

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Background

This document constitutes the publication of work performed by the Space Human Factors Laboratory (mail code SF5 at the time) at the Johnson Space Center (JSC) in the months of June and July of 2000. At that time, the Space Human Factors Laboratory was part of the Space Human Factors Branch in the Flight Projects Division of the Space and Life Directorate. This report was originally to be a document for internal consumption only at JSC as it was seen to be only preliminary work for the further development of solid state illumination for general lighting on future space vehicles and the International Space Station (ISS). Due to funding constraints, immediate follow-on efforts were delayed and the need for publication of this document was overcome by other events. However, in recent years and with the development and deployment of a solid state light luminaire prototype on ISS, the time was overdue for publishing this information for general distribution and reference.

Solid state lights (SSLs) are being developed to potentially replace the general luminaire assemblies (GLAs) currently in service in the International Space Station (ISS) and included in designs of modules for the ISS. The SSLs consist of arrays of light emitting diodes (LEDs), small solid state electronic devices that produce visible light in proportion to the electrical current flowing through them. Recent progressive advances in electrical power-to-light conversion efficiency in LED technology have allowed the consideration of LEDs as replacements for incandescent and fluorescent light sources in many circumstances, and their inherent advantages in ruggedness, reliability, and life expectancy make them attractive for applications in spacecraft. One potential area of application for the SSLs in the U.S. Laboratory Module of the ISS. This study addresses the suitability of the SSLs as replacements for the GLAs in this application.

Three human factors questions were addressed by the study. First was whether the illumination level provided by the mockup GLAs was adequate for the performance of the visual tasks and whether there was any difference in performance under illumination from SSLs adjusted to a comparable level. The second question addressed the importance of the spectral characteristics of the illumination for the visual tasks being studied. The third question involved whether the astronauts sensed any differences in the way they perceived the US Laboratory Module environment with GLA or SSL lighting.

Experimental Conditions and Apparatus

The evaluation was designed to take a "quick look" from the human factors standpoint at the suitability of SSLs as replacements for the GLAs in the US Laboratory Module working environment. Three visual tasks for the evaluation were selected to broadly represent some of those likely to be encountered in this environment: (1) reading printed text and equipment legends, (2) interacting with computers, and (3) comparing/judging colors. Special attention was paid to controlling the light levels and spectral characteristics during the performance of the visual tasks. Participants were drawn from the pool of astronauts training for ISS missions at the Johnson Space Center.

The environment for the experiment was the US Laboratory Module mockup of the Space Station Mockup Test Facility. Standard lighting for the module is provided by twelve general luminaire assemblies (GLAs). For the experiment, six Sylvania mockup GLAs were installed. A removable temporary Foamcore partition was installed transversely at the midpoint of the module (Figure 1), and the six GLAs above Bay 04 through Bay 06 were replaced with SSLs. This allowed two sets of isolated lighting conditions to be produced simultaneously in the two halves of the module. An access door was constructed in the partition to allow the experiment conductor and participant rapid access to both sides of the partition. Removable work surfaces were fitted to the starboard rack of Bay 02 on the GLA side of the partition (Figure 2) and to the port rack of Bay 05 on the SSL side (Figure 1). The vertical rack surface above and behind the work surface on the GLA side (Figure 2) was covered with Foamcore material to approximate the reflective characteristics of the rack panels

Figure 1. Transverse partition as viewed from SSL side

Figure 2. Workstation, GLA side of partition

adjacent to the work surface on the SSL side. The blue end cone surfaces at the Node 1 end of the Lab Module were also covered with Foamcore (Figure 3) to more nearly match the reflective characteristics of the Node 2 end cone.

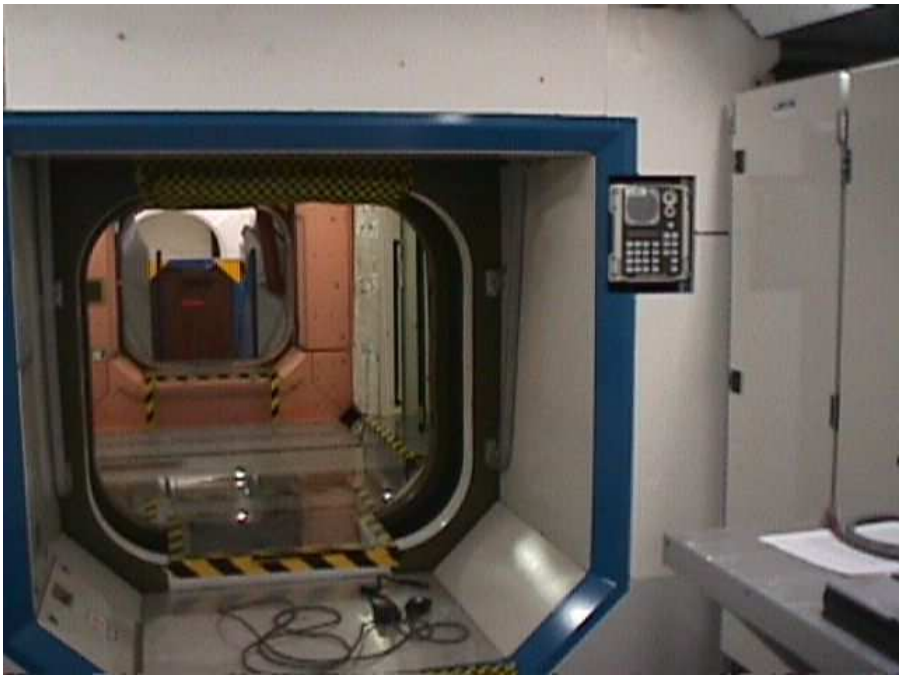


Figure 3. Node 1 end cone surfaces

During the experiment, all individual dimmer controls on the GLAs were adjusted for maximum brightness, and the illumination from the SSLs was adjusted to produce equivalent illuminance readings (22-23 fc) in the centers of the work surfaces on both sides of the partition. Illuminance readings on equipment rack surfaces throughout the module exceeded the work surface values by as much as 10 fc near the “tops” of the racks beneath the luminaires, while readings on the rack surfaces near the floor were as low as 5.6 fc. Ganged control of illumination from the SSLs was effected by adjusting the common DC voltage applied to the SSL luminaires. Time for SSL thermal stabilization was allowed following adjustments in power supply settings to minimize variations in SSL illumination. Electrical current drawn by the SSLs and work surface light levels were monitored throughout the experiment sessions.

A set of filters were constructed for use with the SSLs in the second session of the experiment. These were designed to adjust the correlated color temperature (CCT) of the SSLsto approximate the CCT of the GLAs . The CCT of the Sylvania GLAs was measured to be 4324°K, whereas the CCT of the SSLs was measured to be 6700°K and 4166°K for the unfiltered and filtered cases, respectively. The filter material used was Rosco International Type 3442, a commercial stabilized

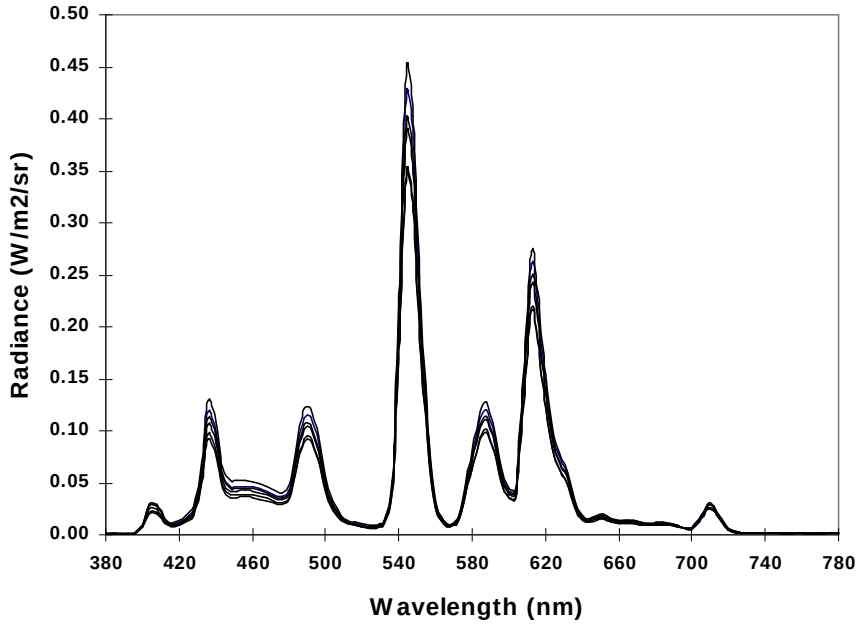


Figure 4. Fluorescent GLA Spectra

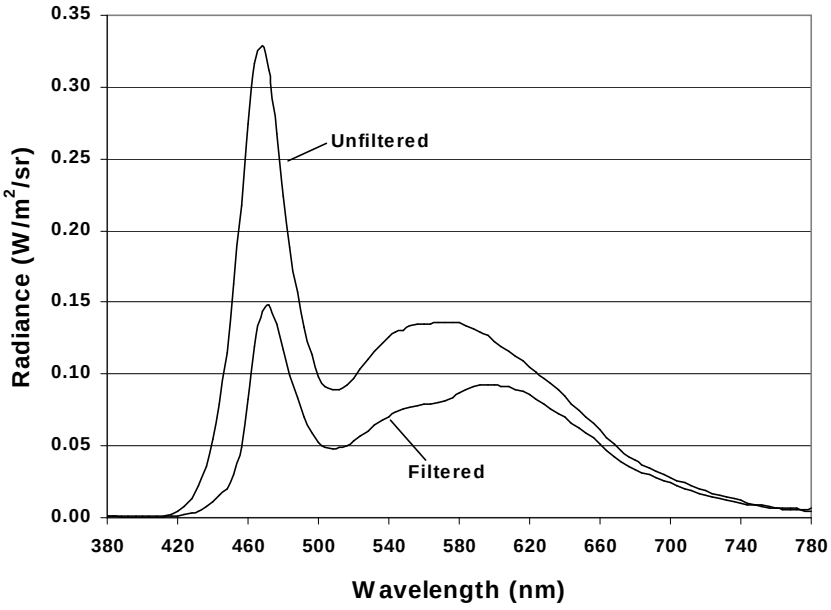


Figure 5. Filtered and Unfiltered SSL Spectra

gelatin stage lighting filter film. Color characteristics of the lights used in the experiment were measured with a Photo Research Model 650 colorimeter. Visible spectra for the lights are shown in Figures 4 and 5.

Text samples were prepared for the participants to read under the various experimental lighting conditions. These were drawn from current short summaries of technical papers on various topics published in *Science News*. Each article was transcribed and printed on white paper in 10 point sans serif (Arial) font. Transcribed text was single spaced, providing a greater challenge to the reader.

The laptop computer used in the experiment was a Fujitsu Lifebook Model L470 (Figure 6), having a 9-inch diagonal back-lighted LCD color display. The settings for the display brightness and contrast were fixed during the experiment to produce approximately 16.5fL, 11.0fL, 6.7fL brightness readings for the respective white, gray, and black areas of the survey display. All survey prompts were displayed and responses and comments were recorded by means of the computer. Software supporting these activities consisted of a group of Microsoft Excel spreadsheets including option buttons for survey responses and text boxes for comment entries. Spreadsheet contents are represented in their initialized state in Appendix A. Once a selection was made from a group of buttons, it remained active until the end of the session or an alternate button was selected.

Challenges to color rendering under the experimental lighting conditions were explored by having the participants examine a cable with multicolored insulated 22 AWG wires to judge the ease of identifying (naming) colors and the ease of differentiating between the colors.

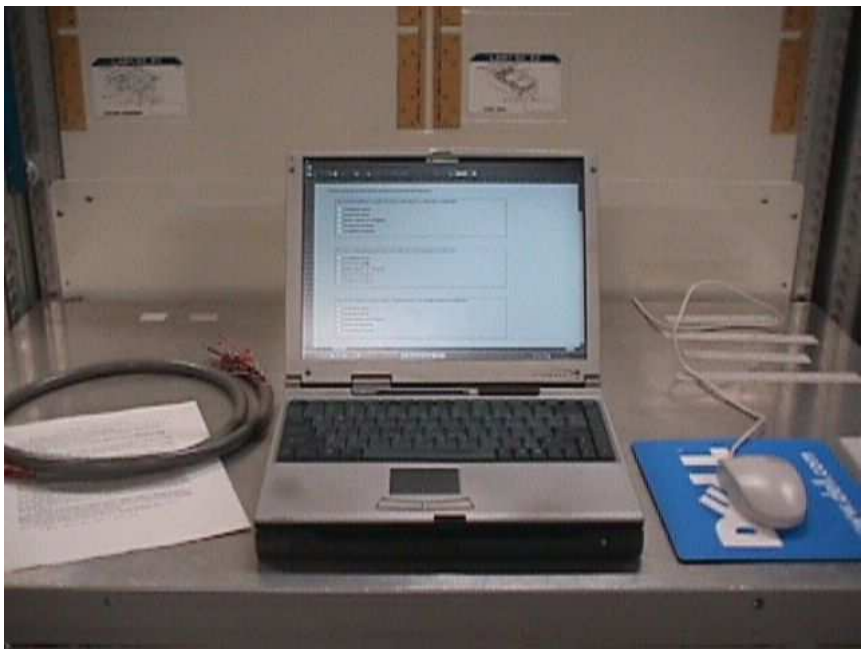


Figure 6. Text sample, wire cable, and computer

Experiment Procedure

The participants performed the experiment in two sessions. In each session responses to one of the forms of the the SSL was examined along with the responses to the GLAs. The SSLs used in the first session were unfiltered, and the second session used the same SSLs fitted with filters to alter the light spectrum to approximate the correlated color temperature of the GLAs. This arrangement precluded complete balancing of the order of presentation of the different lighting conditions, but eliminated the considerable time required to install or remove the filters, thereby reducing the time required of the participants to complete the experiment. Within each session, however, the order of presentation of the GLA or SSL conditions was randomly balanced, with half the participants experiencing each order.

The same sequence of tasks was used for both lighting conditions in each session. First, the participant was provided with a printed page of black-on-white printed text to read. After reading the passage, the participant completed the rating survey on the computer. Following the text reading survey was a second rating survey relating to the ease of computer use in the lighting environment. Once the text reading and computer use surveys were completed, the participant was provided with an electrical cable comprised of wires with multicolored insulation. The participant examined the colored wires and again turned to the computer to complete the last portion of the rating survey, which related to the ease of color judgement and the overall module lighting characteristics.

Results

The use of an Excel spreadsheet for collecting the ratings allowed relative ease in categorizing, counting, and graphically representing the response frequencies. A tabulation of responses to the rating survey items is included as Appendix B.

The survey responses and comments were interpreted to indicate the following results:

- The SSL is a suitable replacement for the GLA.
- The correlated color temperature of the evaluated SSLs is acceptable for the tasks performed.
- Glare in the US Laboratory Module is not significant with either GLA or SSL lighting.
- The availability of higher light intensity than that provided by the current GLA would be beneficial.
- SSL fixtures should be made available for long term evaluations and routine mockup training activities.

Responses to survey items are summarized in Figures 7 through 19. In these charts, the response categories “strongly agree” and “somewhat agree” are combined as “agree”. Similarly, the “strongly disagree” and “somewhat disagree” categories are lumped together as “disagree”.

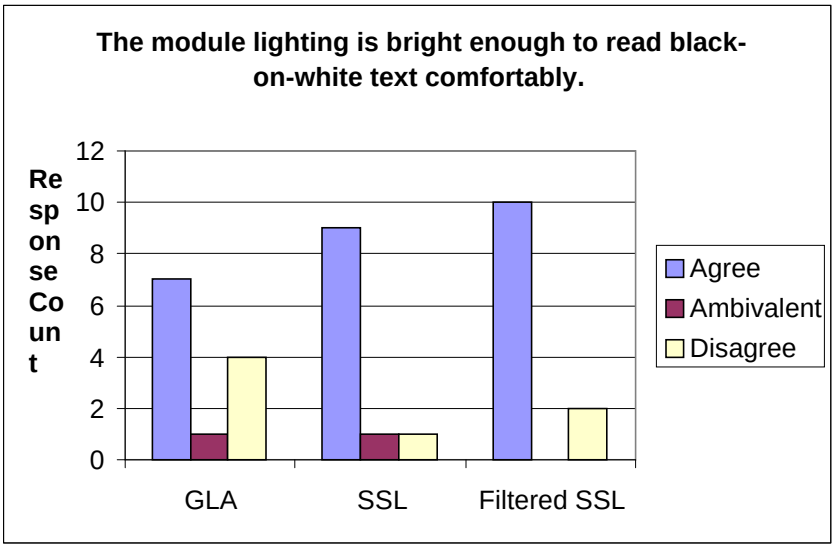


Figure 7

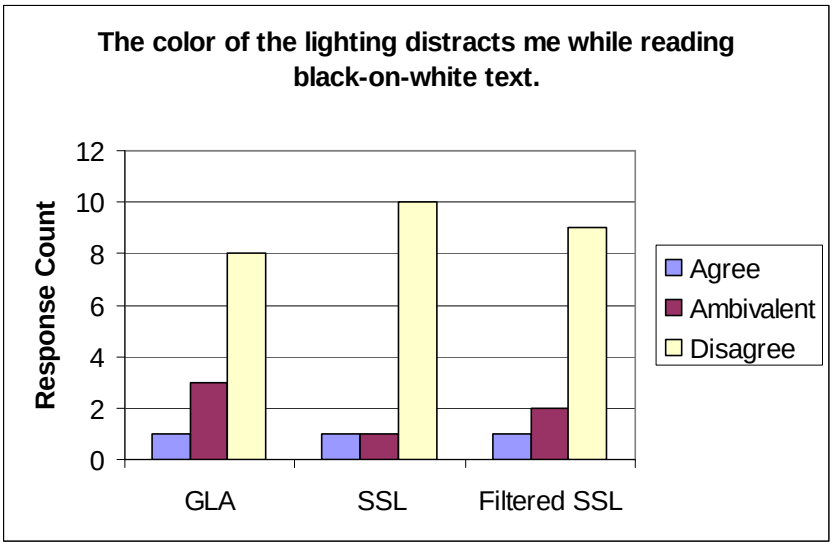
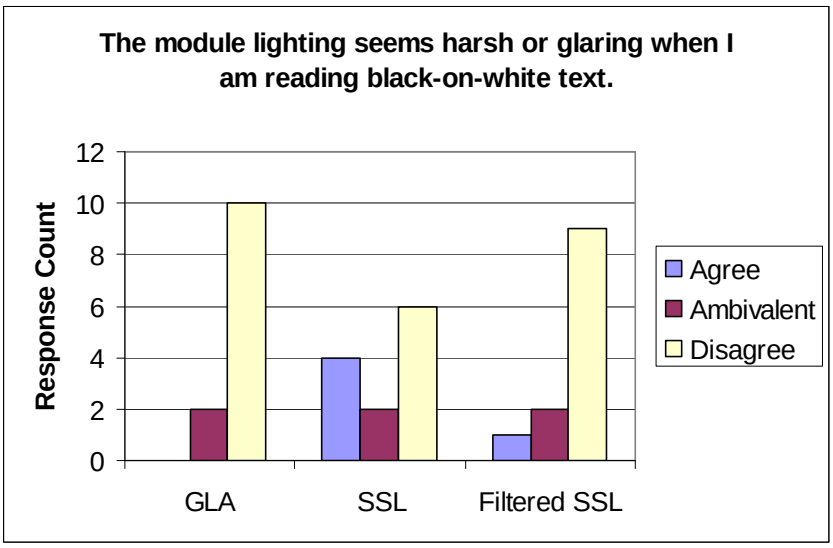


Figure 8



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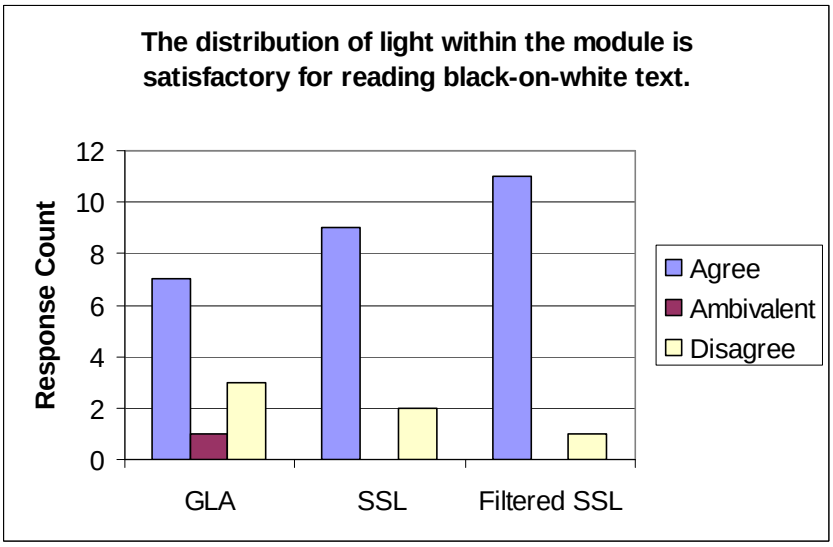

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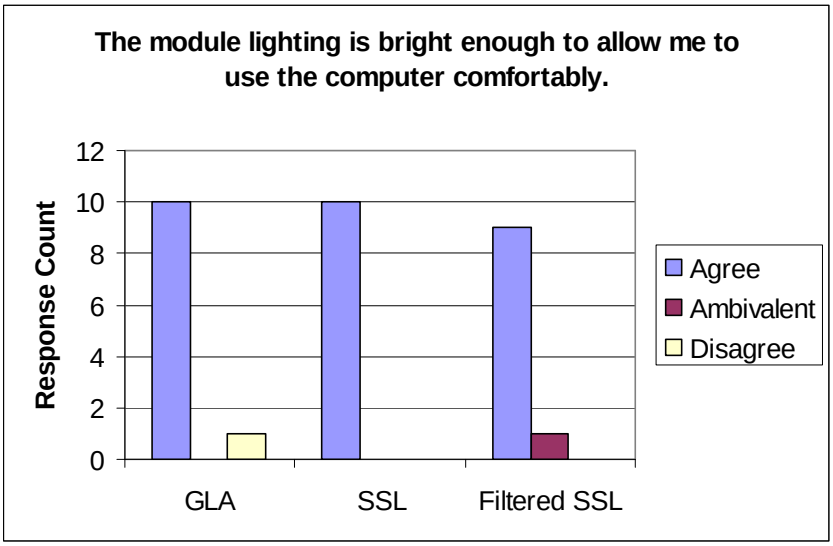

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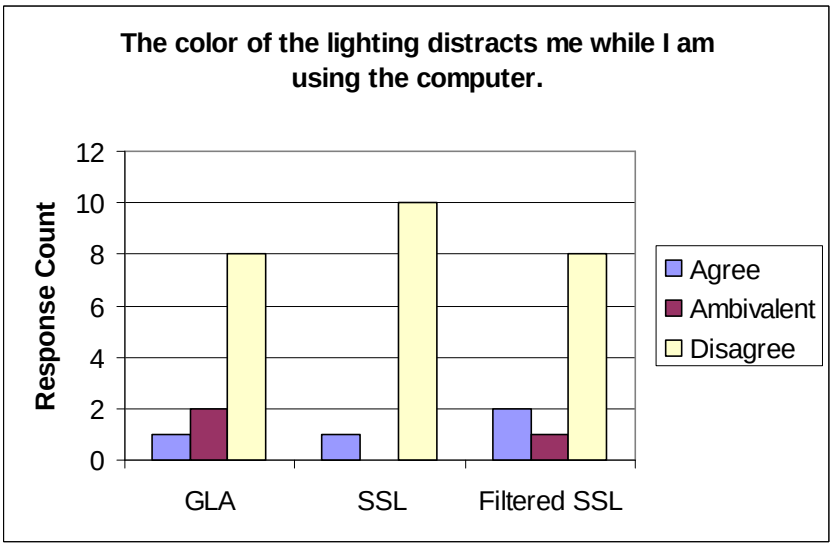
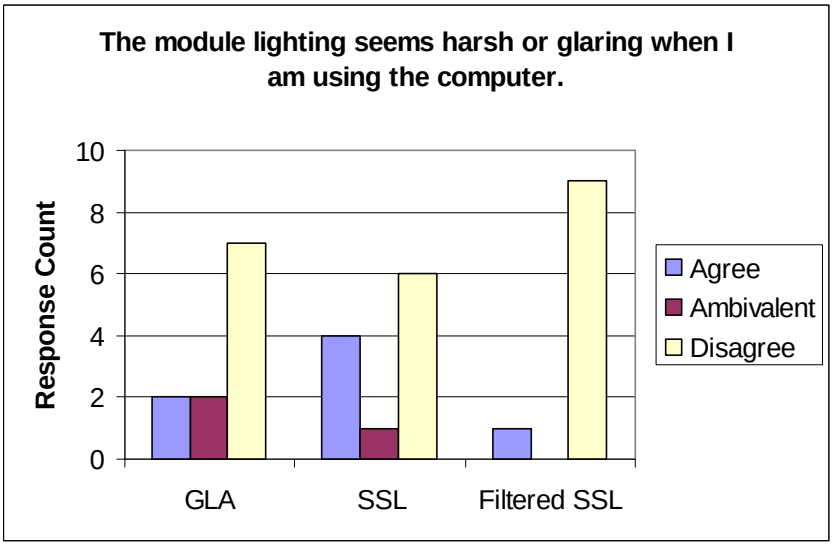


Figure 12



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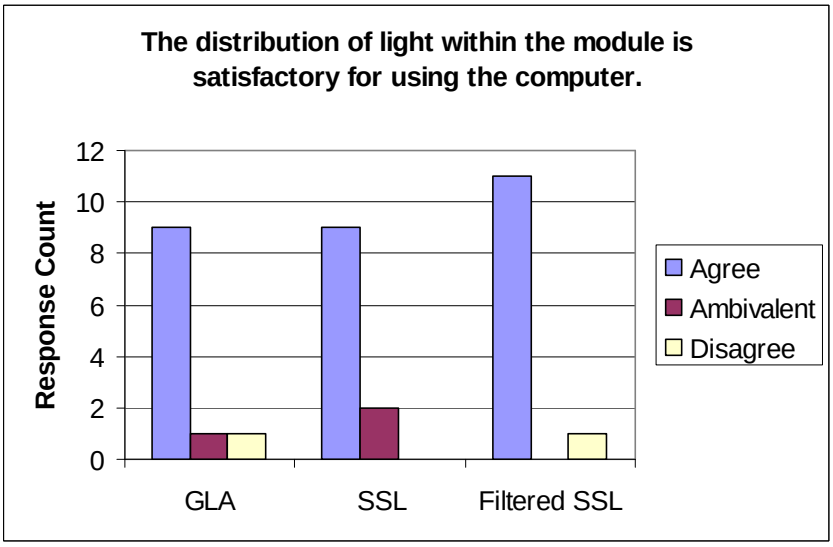
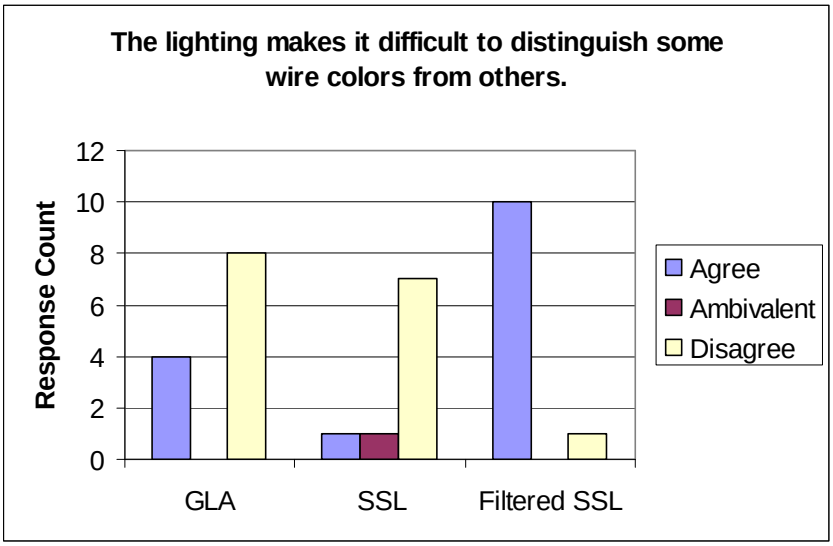


Figure 14



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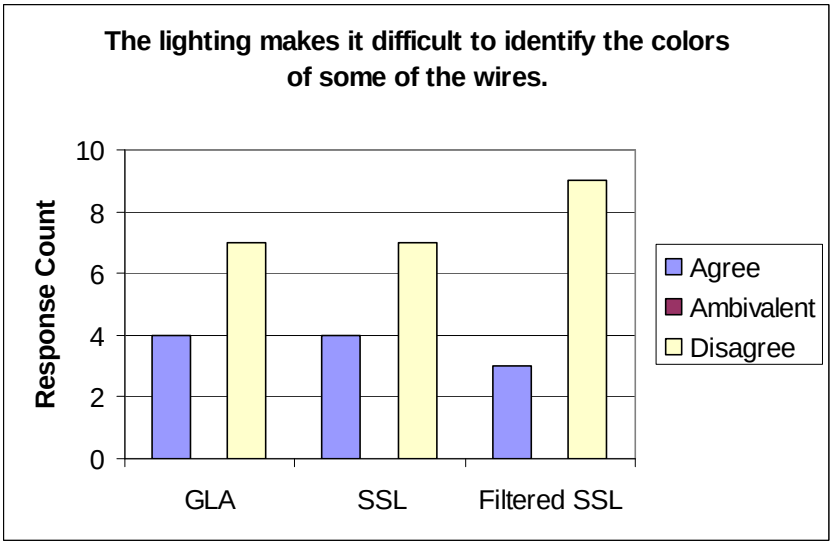

Figure 16

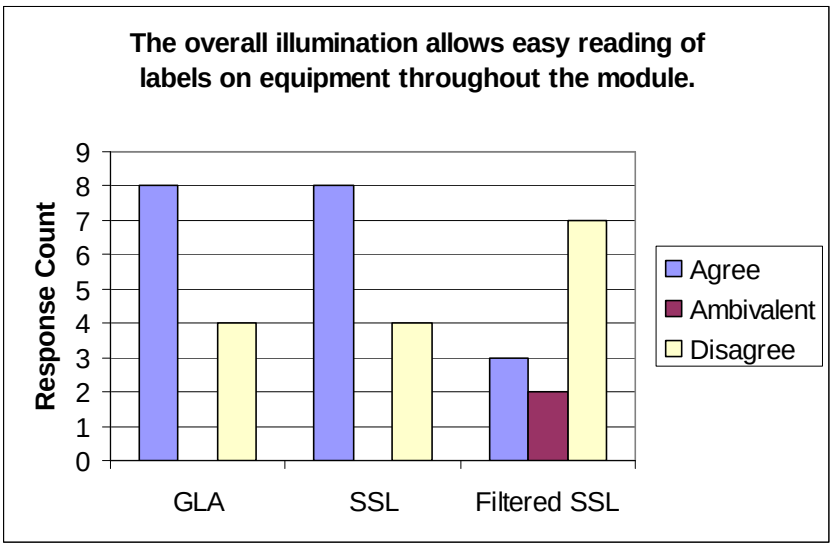

Figure 17

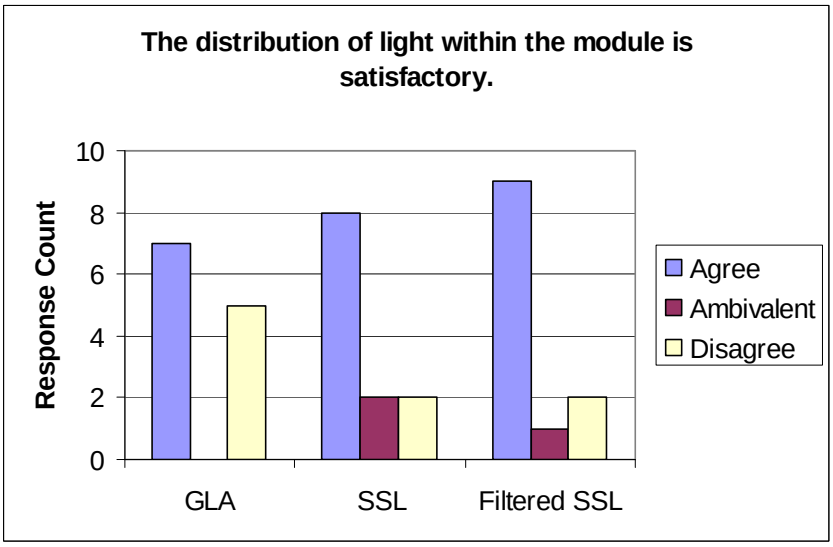

Figure 18

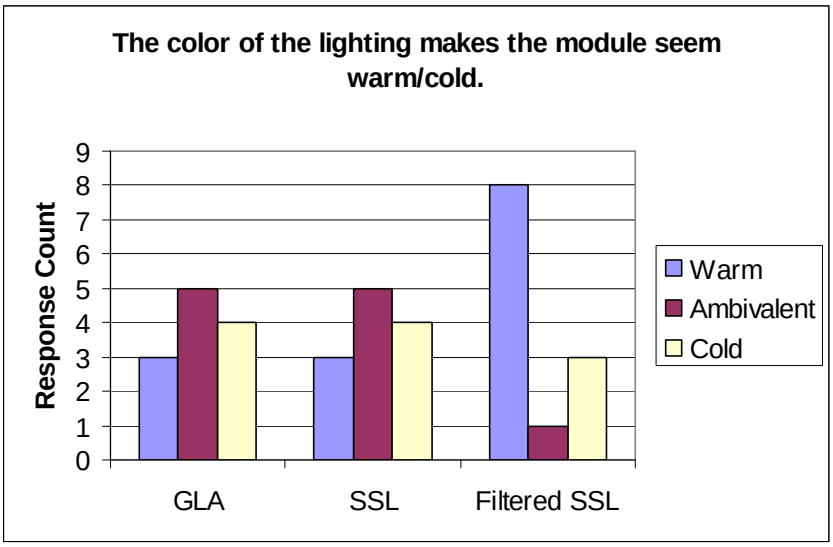
The color of the lighting makes the module seem warm/cold.
Response Count
9
8
7
6
5
4
3
2
1
0
GLA
SSL
Filtered SSL
Warm
Ambivalent
Cold

Figure 19

Appendix A. Response Worksheets

Please read the printed article and then answer the following questions:

The module lighting is bright enough to read black-on-white text comfortably.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The color of the lighting distracts me while I am reading black-on-white text.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The module lighting seems harsh or glaring when I am reading black-on-white text.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The lighting conditions for reading black-on-white text are uniform throughout the module.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

Comments regarding reading black-on-white text:

The module lighting is bright enough to allow me to use the computer comfortably.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The color of the lighting distracts me while I am using the computer.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The module lighting seems harsh or glaring when I am using the computer.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The lighting conditions for computer use are uniform throughout the module.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

Comments regarding computer use:

Please perform the wire matching task and then answer the following questions:

The color of the lighting makes it difficult to distinguish wire colors.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The overall illumination allows easy reading of labels on equipment throughout the module.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The difference in brightness between lighter and darker areas in the module is satisfactory.

- ○ Completely agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Completely disagree

The color of the lighting makes the module seem:

- ○ Warm
- ○ Somewhat warm
- ○ Neither warm nor cold
- ○ Somewhat cold
- ○ Cold

Comments:

Appendix B: Rating Survey Responses

			Response Frequencies					
Light Type	**Question Category**	**Question**	**Comp. agree**	**S'what agree**	**Ambiv.**	**S'what disagree**	**Comp. disagree**	**No Resp.**
GLA	**Text Reading**	Bright enough?	5	2	1	3	1	0
		Color distracting?	0	1	3	1	7	0
		Harsh or glaring?	0	0	2	2	8	0
		Brightness ratio OK?	4	3	1	3	0	1
	Computer Use	Bright enough?	8	2	0	1	0	1
		Color distracting?	0	1	2	2	6	1
		Harsh or glaring?	0	2	2	3	4	1
		Brightness ratio OK?	5	4	1	1	0	1
	Color & Overall	Color distinguishing problem?	2	2	0	3	5	0
		Color naming problem?	2	2	0	3	4	1
		Easy to read labels?	5	3	0	4	0	0
		Brightness ratio OK?	4	3	0	4	1	0
		Warm (agree)/cold?	1	2	5	3	1	0
SSL	**Text Reading**	Bright enough?	6	3	1	0	1	1
		Color distracting?	0	1	1	2	8	0
		Harsh or glaring?	1	3	2	1	5	0
		Brightness ratio OK?	7	2	0	2	0	1
	Computer Use	Bright enough?	7	3	0	0	0	2
		Color distracting?	0	1	0	3	7	1
		Harsh or glaring?	0	4	1	1	5	1
		Brightness ratio OK?	6	3	2	0	0	1
	Color & Overall	Color distinguishing problem?	0	1	1	2	5	3
		Color naming problem?	0	4	0	1	6	1
		Easy to read labels?	4	4	0	4	0	0
		Brightness ratio OK?	4	4	2	2	0	0
		Warm (agree)/cold?	2	1	5	3	1	0
SSL with Filter	**Text Reading**	Bright enough?	6	4	0	1	1	0
		Color distracting?	1	0	2	3	6	0
		Harsh or glaring?	0	1	2	4	5	0
		Brightness ratio OK?	5	6	0	1	0	0
	Computer Use	Bright enough?	8	1	1	0	0	2
		Color distracting?	0	2	1	3	5	1
		Harsh or glaring?	0	1	0	6	3	2
		Brightness ratio OK?	5	5	0	0	1	1
	Color & Overall	Color distinguishing problem?	5	5	0	0	1	0
		Color naming problem?	0	3	0	2	7	0
		Easy to read labels?	0	3	2	1	6	0
		Brightness ratio OK?	4	5	1	2	0	0
		Warm (agree)/cold?	3	5	1	3	0	0

Appendix C. Contrast Sensitivity and the Perception of SSL Glare

Glare is predicted when a light source or reflective surface in the observer's field of view exceeds the surrounding brightness by a ratio of 12:1 or more. An additional factor not usually considered in predicting glare is the human contrast sensitivity function. This characteristic, shown in Figure 20, relates the sensitivity of the human visual system to periodic spatial variations in contrast (brightness). The graph of Figure 20 shows that humans respond most strongly to variations in contrast in the spatial frequency range from about two to four cycles per degree of visual angle.

When considered from the standpoint of contrast sensitivity, the periodic spacing of rows of LEDs arrayed in an SSL may conspire with the interior dimensions of a habitable structure such as the US Laboratory Module to exacerbate the perception of glare from the luminaire. The visual angle, α, between two points S distance apart from one another and viewed from a distance D is calculated as $\alpha = 2\tan^{-1}(S/2D)$. For example, assuming that the spacing between rows of LEDs in the SSL is 0.3 inch (similar to the row spacing in the SSLs used in this experiment), and that viewing distances range from two to seven feet, the row spacing in terms of visual angle occupies from 0.205º to 0.716º. Since the fundamental spatial frequency corresponding to the LED spacing, f_s, is the reciprocal of the visual angle α, the range of fundamental spatial frequencies corresponding to this range for α in cycles per degree (~/°) is $\{1.4 \sim /^\circ \le f_s \le 4.9 \sim /^\circ\}$. The range for f_s in this example thus brackets the peak of the contrast sensitivity function, possibly increasing the likelihood of the perception of glare. The spacing of point source illumination elements in arrays to form luminaires might well be considered in relation to the dimensions of the space in which they may be viewed when designing for increased visual comfort.

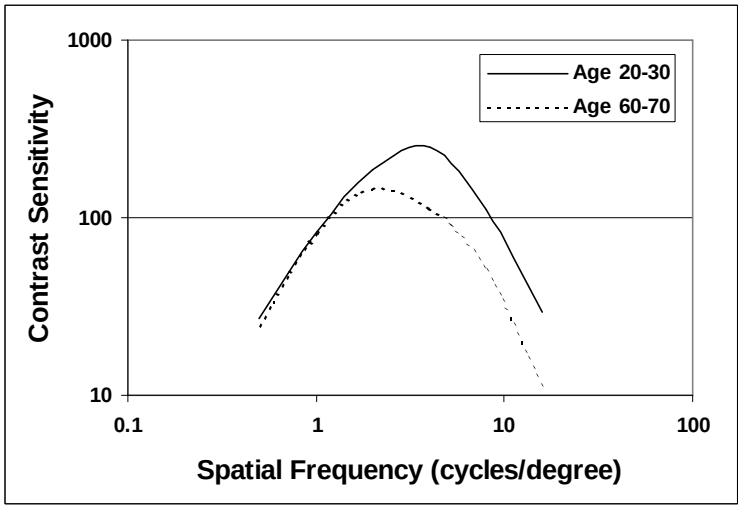

Figure 20. Human contrast sensitivity function

Reference:

Owsley, Cynthia, Robert Sekuler, and Dennis Siemsen (1983). Contrast sensitivity thoughout adulthood. *Vision Research* 23(7), 689-699.