White Paper

Image Perception Survey Results Comparing High Lumen Density (HLD) Projector Light Source to Alternative Solid State Illumination Sources

Written by Chris Chinnock, President, Insight Media

May, 2015

Table of Contents

Table of Figures

Table of Tables

Introduction

Insight Media and Philips Lighting recently collaborated on a survey to evaluate the image quality of four unmarked projectors with an audience of 300 people (mostly from the Philips Lighting Facility and adjoining Open Manufacturing Campus in Turnhout). The survey asked the average consumer to judge the image quality of the four projected images using a series of diverse static pictures. The survey revealed a strong preference for the images produced by a projector that had been modified to accept a newly developed LED-based light source called ColorSpark High Lumen Density (HLD). More will be revealed about the details of this ColorSpark HLD light source in a subsequent white paper.

Philips Lighting is not a projector maker, but a light source provider. The goal of the testing was to benchmark their new ColorSpark HLD light source vs. other solid state light source technologies to hopefully prove there are image quality advantages that projector makers should now consider for integration in next generation projectors.

The results were impressive with 2/3rd of the survey participants preferring the modified Philips image over others (see results section later for details).

Insight Media was involved to help ensure that the testing was as neutral and fair as possible and to provide advice on the set-up, images and questions asked the attendees. There are many options in setting up such a survey, but after witnessing the set up and testing process, we are satisfied it was a good test, given the choices made in the configuration.

Philips chose three other projectors from leading brands to benchmark their new ColorSpark HLD solid state light source against. These were chosen to represent the three different types of solid state illumination sources available in mainstream projection solutions. Commercial, off the shelf projectors representing popular examples of the representative solid state illumination technology were purchased. The brand names of the projectors is not revealed as the testing is not about comparing brands, but in showing that a new solid state light source can make a difference in the way people perceive the brightness, colorfulness and overall image quality of a projector. And, just as importantly, these tests were done in a normal ambient room environment (100-150 lux from top to bottom of the screen) using identically sized images and screens.

The tested projectors were:

A – RGB LED projector
B – Philips modified projector – ColorSpark HLD LED light source
C – Laser phosphor projector
D – Hybrid (LED and Laser) projector

The Philips projector was a prototype of a modified Hybrid projector (same model as projector D) that replaced the hybrid light source with the ColorSpark HLD light source. HLD is an all-LED solution.

The light output levels of these projectors were not matched and it was decided not to try to match them. The idea was to provide a more realistic testing environment that replicates how projectors might actually be evaluated by end users.

In reality, end users purchase a projector and use the projector in one of the pre-set modes. As a result, the projectors need to be run in an out-of-the-box condition for our experiment as well. Philips purchased these projectors on the open market and only set the mode (RGB) for the evaluation. This mode was chosen as this is the mode where color saturation, color accuracy, contrast and overall image quality are supposed to be best represented by the projector.

Test Set Up

To make the survey as unbiased as possible, the four projectors were all concealed under enclosures with only the projection lens side exposed. These projectors were placed on tables with a barrier between the tables and audience chairs to prevent anyone from peeking inside. The projectors were simply labeled A, B, C and D (Figure 1).

Figure 1: Test set up showing the four projectors and screens

Identical matte white screens were used and the distance of the projector from the screen was varied to ensure the images were all the same size (about 80" in diagonal). All featured built-in lenses that were set to their non-zoomed position.

The room where the survey was done has two parts. One area was configured with chairs to encourage the attendees to sit down and carefully consider the images. A large bank of windows was adjacent to the chairs. A set of vertical blinds covered the windows and these were set to a perpendicular position to allow significant light to enter the room. Testing was done on a sunny day.

In front of the chairs was the other section of the room where the projectors, tables and screens were placed. This area is surrounded on three sides by walls and has overhead fluorescent lighting.

It was a test decision to evaluate the projectors in a normal ambient room condition. That is, the goal was to not require projector users to dim the lights or close the curtains in order to see a bright, colorful image with good contrast.

To try to ensure uniform ambient illumination on each of the four screens, measurements were made at the screen surfaces with no projected image. This showed some non-uniformity, which was corrected to a large degree by the placement of a light shield over part of the fluorescent lighting near the screens. This helped ensure that all projectors had the same ambient light exposure for the tests (Figure 2).

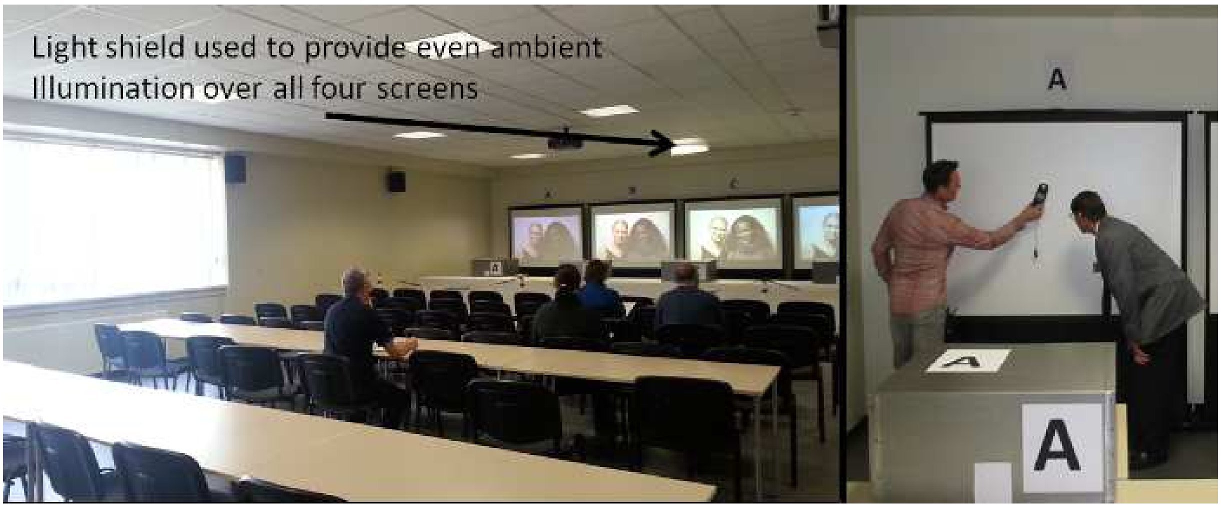


Figure 2: Room set up showing location of windows, projectors and light shield to provide uniform ambient illumination at the projector screens. Photo at right shows measurement of the ambient light levels.

Next, the projectors were all set to the RGB mode. This mode is supposed to provide a calibrated sRGB color mode that is significantly lower in brightness than the "bright" or "standard" modes. This mode was chosen as this is the mode where color saturation, color accuracy, contrast and overall image quality are supposed to be best represented by the projector.

Baseline Measurements

The goal of the survey was to test projectors "out of the box" without a detailed calibration. That is why the projectors were set to the RGB mode since this mode is supposed to represent a pre-set calibrated mode. Ideally, the measured x,y chromaticity values should be on the sRGB primary points and the white point tuned to 6500K (D65). As we discovered, this is not always the case, but it was deemed the best configuration for the test as normal users do not calibrate their projectors, but expect them to perform to specification out of the box.

For each projector, measurements taken below were all done in the room ambient light conditions with the projector in the RGB mode (except item 6).

1. Projector off – ambient light levels
2. Projector on (uniform white screen) – peak brightness levels (RGB mode)
3. Checkerboard pattern – Contrast
4. Projector on (uniform white screen) – x, y chromaticity values for white point
5. Projector on (uniform red, green and blue) – x, y chromaticity values for color gamut
6. Projector on (uniform white screen) – peak brightness levels (bright mode)

The result of measurement 1 is shown below in Table 1.

86 -16,+7		96 -5,+5
	119 -1,+2	
144 -24,+20		157 -19,+14

Table 1: Ambient light measurements (in lux) showing the average and range over the four screens

This shows that the average ambient luminance in the centers of the screens is 119 lux with a range of 118 to 121 lux. We find this result to be very good as the center is the most important part of the screen for image evaluation. Average light levels are a bit lower at the top of the screen and higher at the bottom of the screen – a direct result of the location and type of ceiling illumination in the room

The results of measurement 2 are shown in Table 2. This is calculated by taking the full white screen luminance measurements for each projector at the five points and subtracting the ambient light measured with the projector off. As can be seen, all the projectors have moderate to significant non-uniformity with light loss in the corners of the image.

A	-41%		-31%	B	-14%		-30%	C	-29%		-37%	D	-18%		-23%
		100%				100%				100%				100%	
	-19%		-31%		-31%		-11%		-6%		-15%		-31%		-15%

Table 2: Projector Luminance Uniformity less Ambient Luminance

Figure 3 shows the projectors being measured for contrast using a checkerboard pattern. This was done in the same ambient conditions as the survey testing with the projectors in their RGB mode.

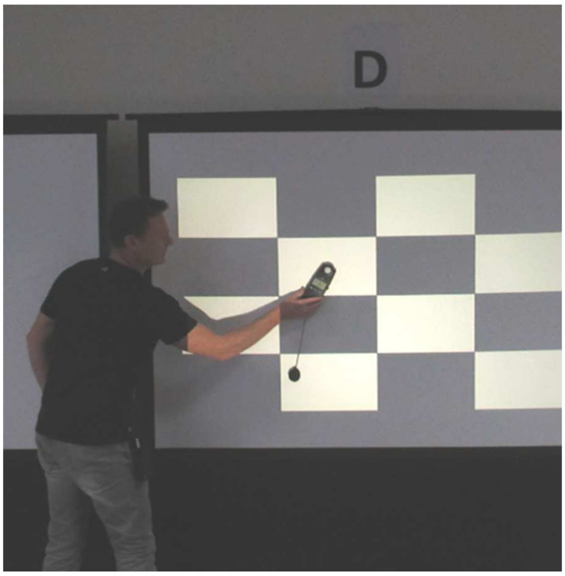


Figure 3: Measuring Contrast

Table 3 shows the results. Since the black levels were all very similar and dominated by the ambient light of the room, the higher luminance projectors will create more contrast

Lux values	With lights on, shades open			
Projector	A LED	B HLD	C Laser-Phosphor	D Hybrid
Black	133	124	123	119
White	431	1030	1330	632
Contrast	3:1	8:1	11:1	5:1

Table 3: Contrast Measurement Results

The results of measurements 4 and 5 are shown in Table 4 and plotted in Figure 4. For the white point, projector B is right on the D65 white point while projector C is very close – just slightly green. The other two are noticeably off the white point with the projector A is a bit purple and projector D a bit cyan. This color shift is very evident in white images. Although we have not shown the line of perfect blackbody radiators, these white points are probably off the line but are clearly hotter than 6500K.

Figure 4 also shows the RGB primaries for the four projectors. It should be noted that none of the four match the sRGB primaries that should be displayed in the RGB mode. For the red primary, all are outside of the sRGB primary specification except the Laser-phosphor (C) projector. For the blue primary, all are outside and very close to encompassing the blue primary spec. The projectors all have green primaries that are more saturated than the sRGB primary, with the Laser-phosphor and HLD projectors not being able to fully show some saturated green and cyan colors, while the LED and Hybrid projectors can display all the colors in the green and cyan region of the sRGB gamut.

Finally, the peak white luminance in the bright mode of each projector was measured. This is summarized in Table 5 below. As can be seen, all measure below their rated luminance levels in the bright mode and much lower in the RGB mode.

A (RGB LED)			
	x	y	
green	0.2831	0.6585	
blue	0.1531	0.0397	
red	0.6862	0.3106	
white	0.3072	0.29	White point shifted 0.03938 from D65
B (HLD LED)			
	x	y	
green	0.3298	0.6459	
blue	0.1508	0.0264	
red	0.6929	0.3051	
white	0.312	0.329	White point is D65
C (Laser-phosphor)			
	x	y	
green	0.322	0.6497	
blue	0.1573	0.0418	
red	0.6315	0.3589	
white	0.3055	0.3391	White point shifted 0.012 from D65
D (Hybrid)			
	x	y	
green	0.2831	0.6585	
blue	0.1531	0.0397	
red	0.6862	0.3106	
white	0.2624	0.2886	White point shifted 0.0648 from D65

Table 4: Chromaticity and White Point Measurements

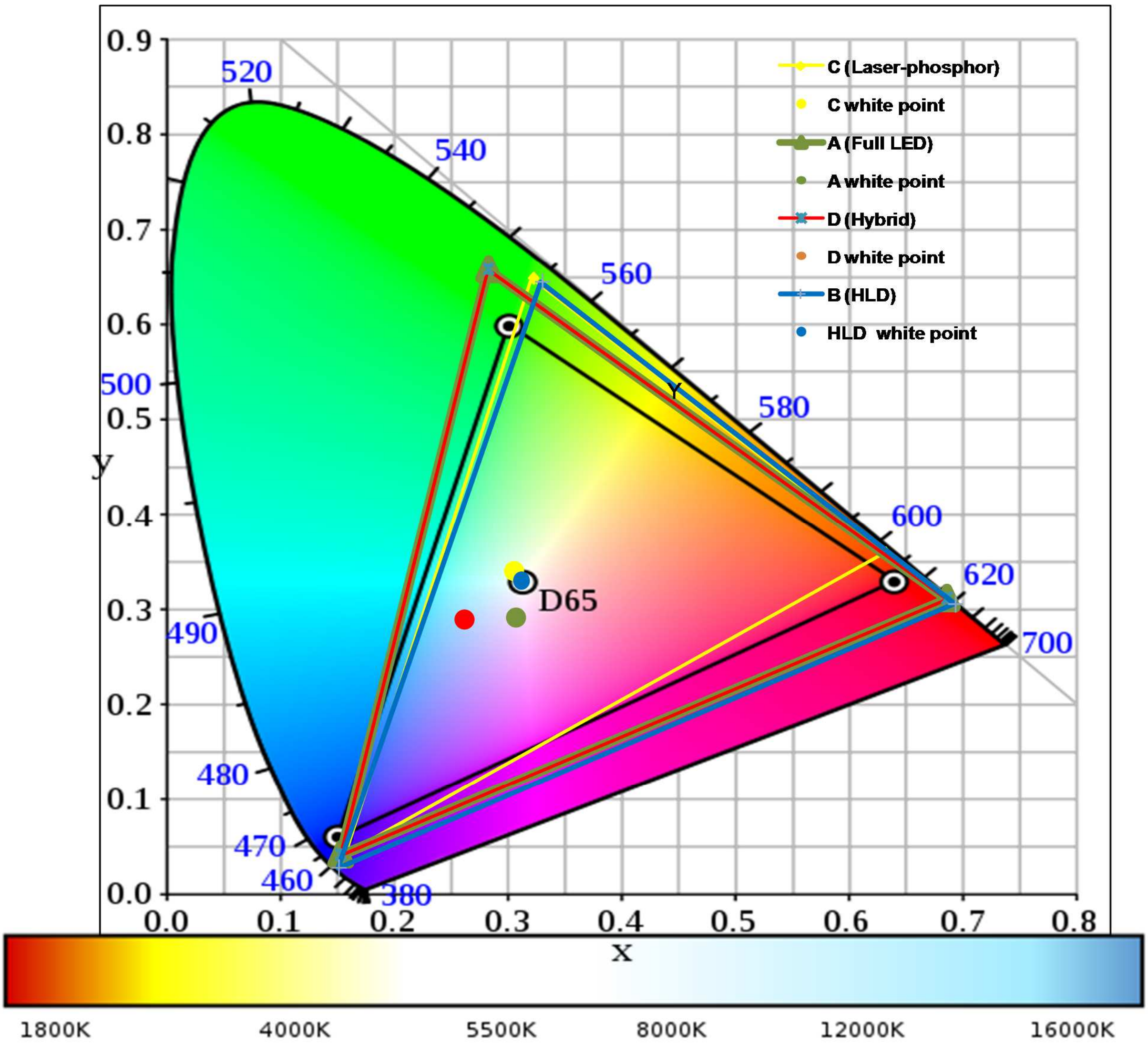


Figure 4: Chromaticity and White Point Measurements Plotted

	A	B	C	D
SSL technology	RGB LED	HLD LED	laser-phosphor	Hybrid
resolution	WXGA	WXGA	WUXGA	WXGA
Commercial Brightness ANSI Lumen	1500		4000	3500
Measured brightness bright mode ANSI Lumen	805	2722	2998	2847
Measured brightness RGB mode ANSI Lumen	358	1213	1742	727
Measured contrast at ambient light conditions	3:1	8:1	11:1	5:1

Table 5: Summary of Peak Luminance Measurements

Test Images

The objective of the tests was to judge how people perceive the picture quality and its individual components such as brightness of images, color accuracy, and contrast of different SSL projector light source technologies. The images that were shown to the test subjects are illustrated in Figure 5 and Figure 6. Each image was displayed for about 10 seconds with the entire sequence playing in a loop.

Static images were chosen over video because we wanted the participants to spend time evaluating the images and videos change images too quickly to allow any serious consideration of image quality.

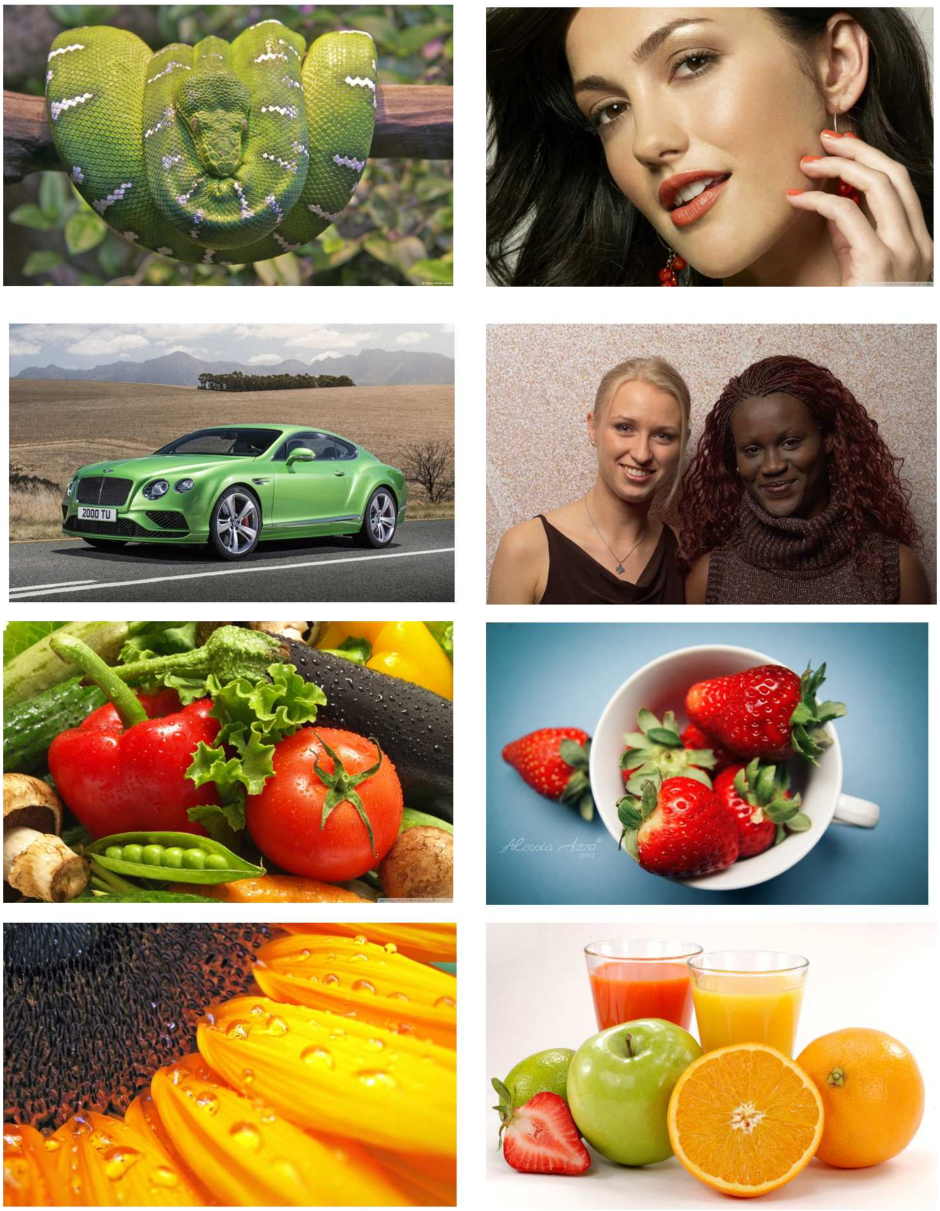


Figure 5: Test Images (1)

Some images were chosen for their saturated colors and colors that have a good reference point with ordinary viewers. This includes fruits like tomatoes, peppers, oranges and strawberries. Several images with deep greens were chosen along with several images that showed flesh tones. Flesh tones seem to be the easiest for people to judge the accuracy of the color rendition.

Other images were chosen for their fine detail and range of contrast. The contrast on the display solution is a key factor in assessing overall image quality.

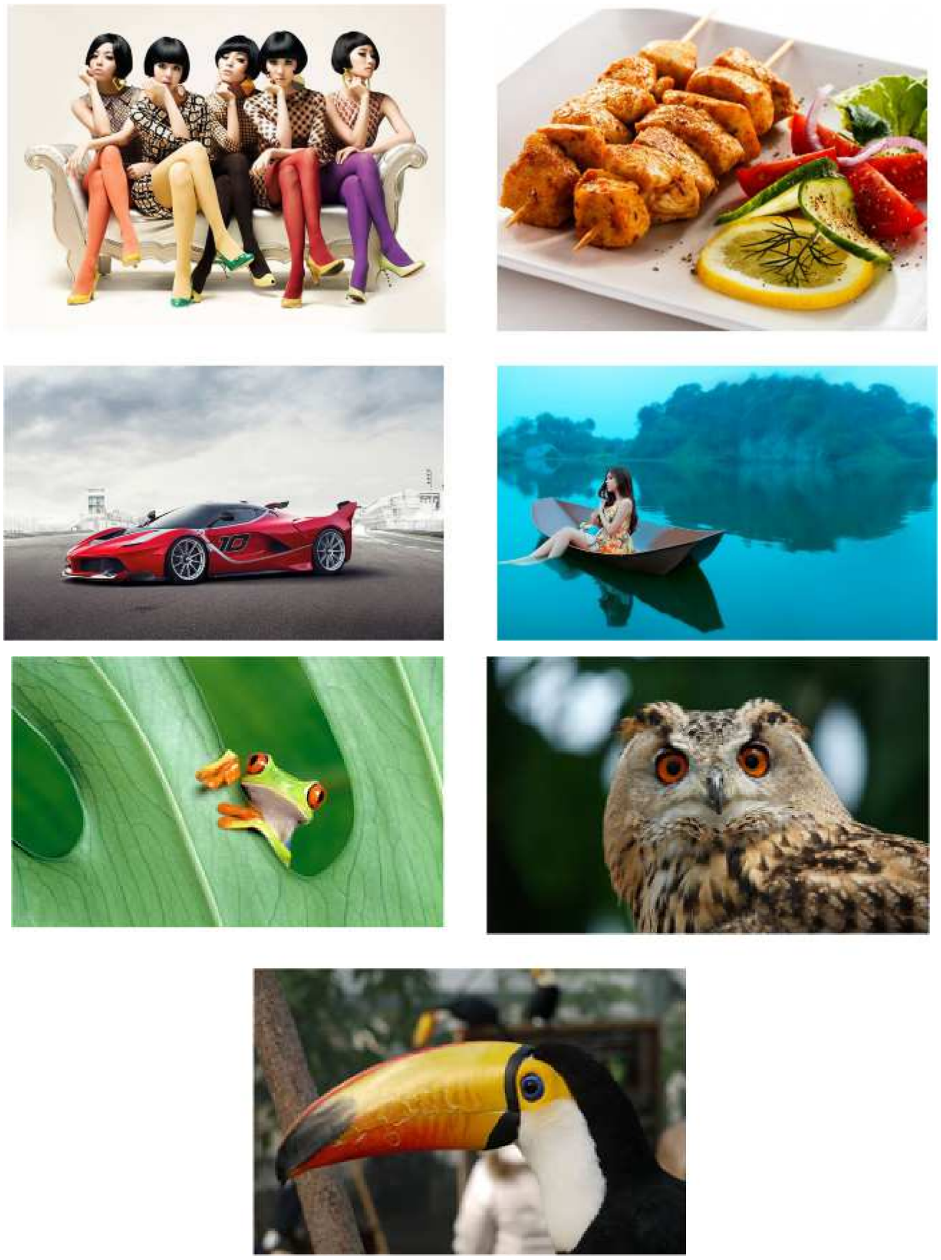


Figure 6: Test Images (2)

Survey Questions

Participants in the survey were recruited from the Philips Lighting Factory as well as several incubator companies located in the same campus. The demo was open from 9:30 am to about 7:00 pm to accommodate workers on two shifts. Attendees were enticed with a free desert coupon, which worked very well. Over 300 people completed the survey!

Participants did not receive any information on the projectors or light sources used. Each subject was given a sheet of paper with 5 questions. They were asked to first sit down and study the images before answering the questions. They were very compliant with the average evaluation time being 3-5 minutes – so they saw the loop 2-3 times before making their judgments. They were also quite studious taking the time to compare images across the four screens.

The question asked were: Please rank the projectors (A, B, C or D) for:

1. Highest apparent brightness
2. Color accuracy (colors are true to life)
3. Most pleasing colors (image looks best with these colors)
4. Best contrast (details are crisp and clear in the darker and brighter regions)
5. Overall picture quality (combination of contrast, colors and brightness)

Upon completion of the survey, subjects were asked if they were color blind and if the questions were clear. Fortunately, only 1-2 people needed some clarification on the questions, so we are confident the instructions were clear.

A notation as to male or female was also made.

Figure 7: Testing in Progress

Survey Results

The results of the 303 people (208 male, 80 female, 15 male color blind) who took the survey are shown below. We will examine each of the five questions below showing four results:

- Upper left – all response
- Upper right – all response but without the color blind subjects
- Lower Left – Male responses
- Lower Right – Female responses

A – RGB LED projector
B – ColorSpark HLD LED light source
C – Laser phosphor projector
D – Hybrid (LED and Laser) projector

Highest Brightness

The answers to the higher brightness question are shown in Figure 8.

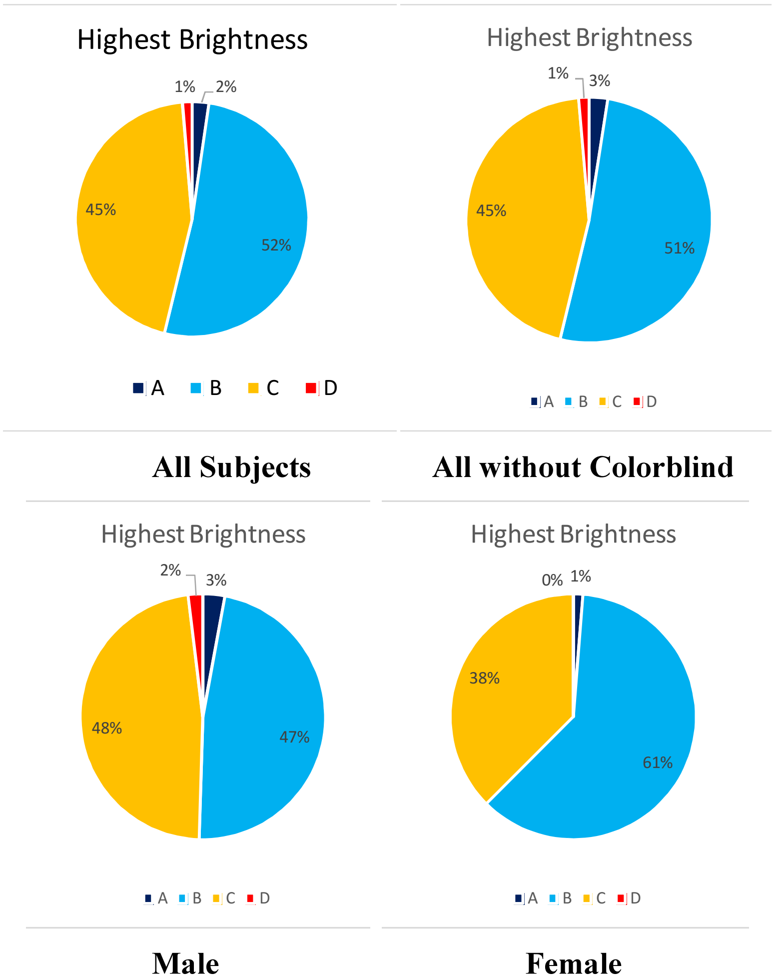


Figure 8: Result of Highest Brightness Question

The result of all responders was a modest preference for B using ColorSpark HLD LED light source over C using Laser phosphor light source. The C result is not surprising as this measured the highest luminance (1742 ANSI lumens). But the strong showing for B is very interesting as the measured luminance was 1213 ANSI lumens.

The reason for the preference for projector B using the ColorSpark HLD LED light source could be the Helmholtz–Kohlrausch effect (after Hermann von Helmholtz and Rudolf Kohlrausch), in short HK effect. The HK effect is an entopic phenomenon wherein the intense saturation of spectral hue is perceived as part of the color's luminance. This perceived brightness increase by saturation, which grows stronger as saturation increases, might better be called chromatic luminance, since "white" or a chromatic luminance is the standard of comparison. It appears in both self-luminous and surface colors[1].

In other words, the more saturated the colors the brighter they appear. Our eyes perceive and interpret increasing saturation as part of the colors luminance as well as its chroma. The effect will vary from person to person and also differs per color. The relative strength of the effect is shown in Figure 9, suggesting the effect is weakest for greens and strongest for blues and reds.

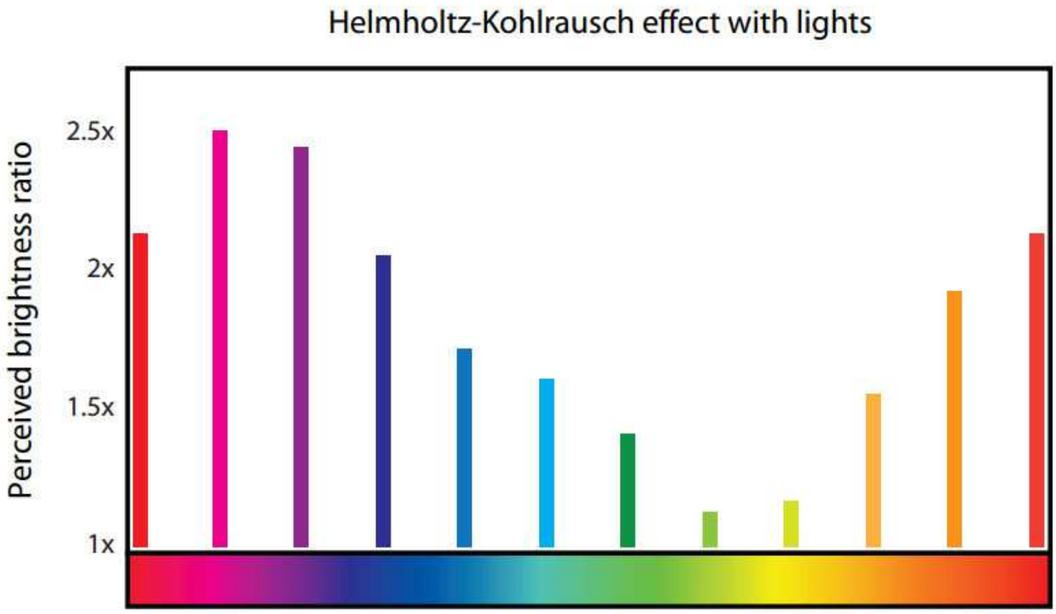


Figure 9: The HK Effect vs. Color (Plot created by Mike Wood based on 1964 data from Sanders and Wyszecki)

As can be seen in Figure 4, the red primary for projector B extends deeper into the red than the red primary for projector C. For red, magenta, pink and blue colors in the triangular region between the B and C primary triangles, projector C will not be able to create as saturated colors

[1] Wikipedia

as projector B can. This might be part of the reason for the increase in perceived brightness of B over C (especially when viewing images with these colors).

What is quite interesting is the difference between the male and female perception of brightness. The males are evenly split between B and C, while the females clearly prefer B over C. The reason of this is not known.

Color Accuracy

The results for the color accuracy question are shown in Figure 10.

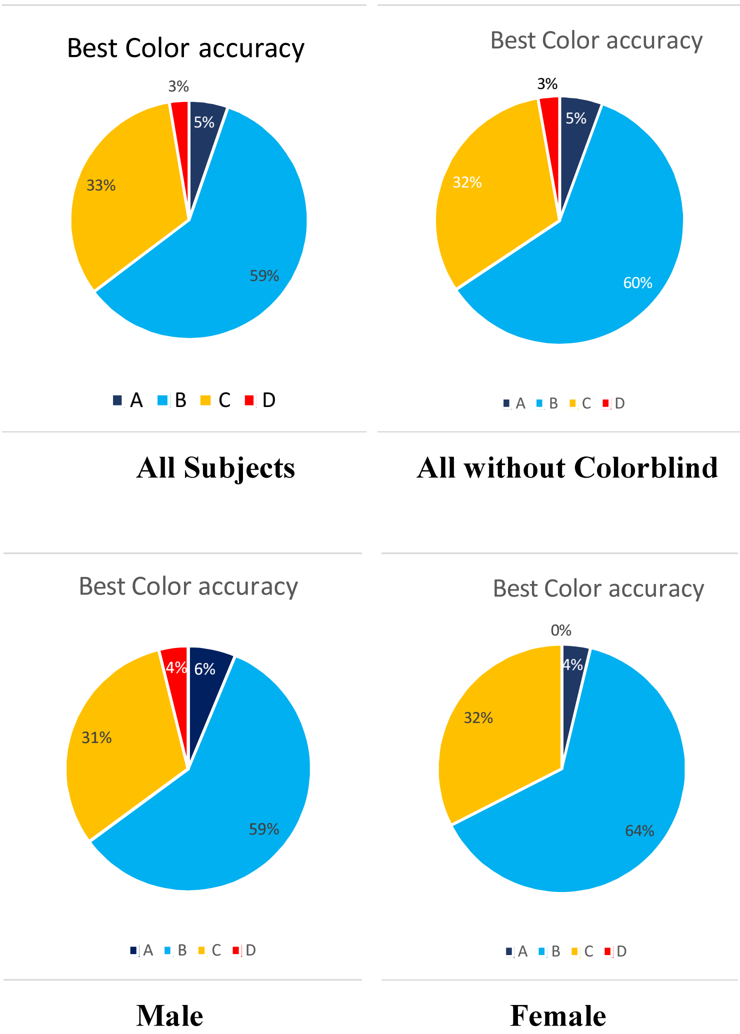


Figure 10: Results for Color Accuracy Question

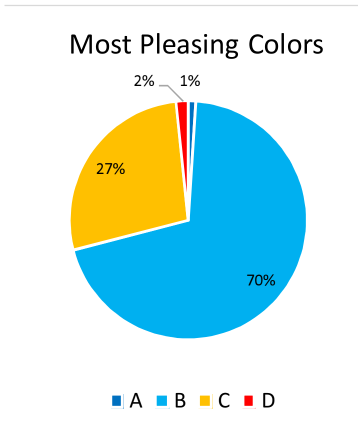
Again there is a 2:1 preference for B over C for all subjects, for the male subjects and for all without the color blind people.

Females prefer B over C a little more than males, but not very significantly.

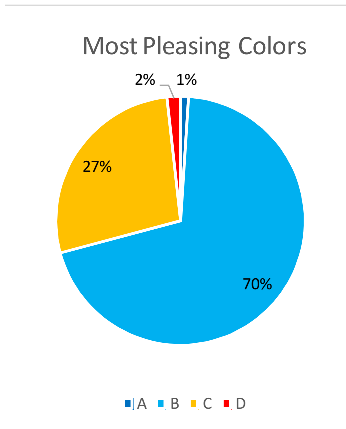
For projector A using a RGB LED light source this is its best scoring question with 5% of participants rating A as having best color accuracy. The limited brightness of projector A, inherent to the RGB LED light source impacts the participants perception of color accuracy.

Most Pleasing Colors

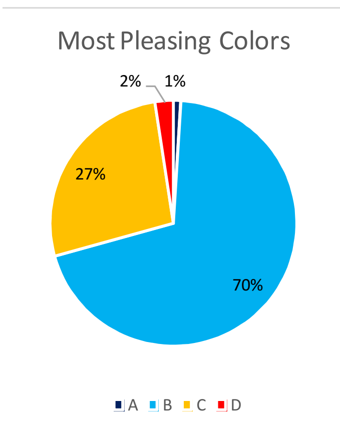
Figure 11 shows the results to the question about most pleasing colors. This question was inserted to try to see if there was a difference between what people liked and what they thought was correct or accurate.



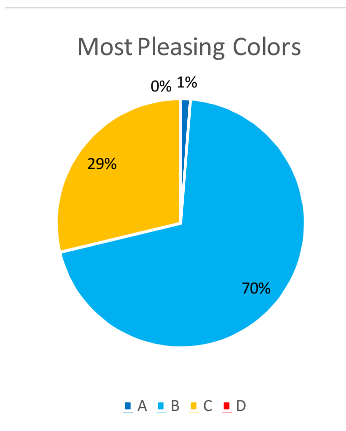
All Subjects



All without Colorblind



Male



Female

Figure 11: Results of Most Pleasing Colors Question

These results are incredibly consistent across the four categories below. 70% prefer B, with 27% preferring C (a few more women prefer C than total population).

This 70% preference is higher than the 60-64% who thought B was the most accurate with colors. This might seem to suggest there is a small effect where people may like the colors of an image even if they think it may not be accurate colors.

Best Contrast

Figure 12 shows the results to the best contrast question. As expected, there is no difference between the full survey group and the group without the color blinds included. But there is a small difference between the men and women with the women preferring B 69% to the men preferring B 64%.

This result is a bit surprising as the contrast measured using the checkerboard pattern was largest for C, followed by B.

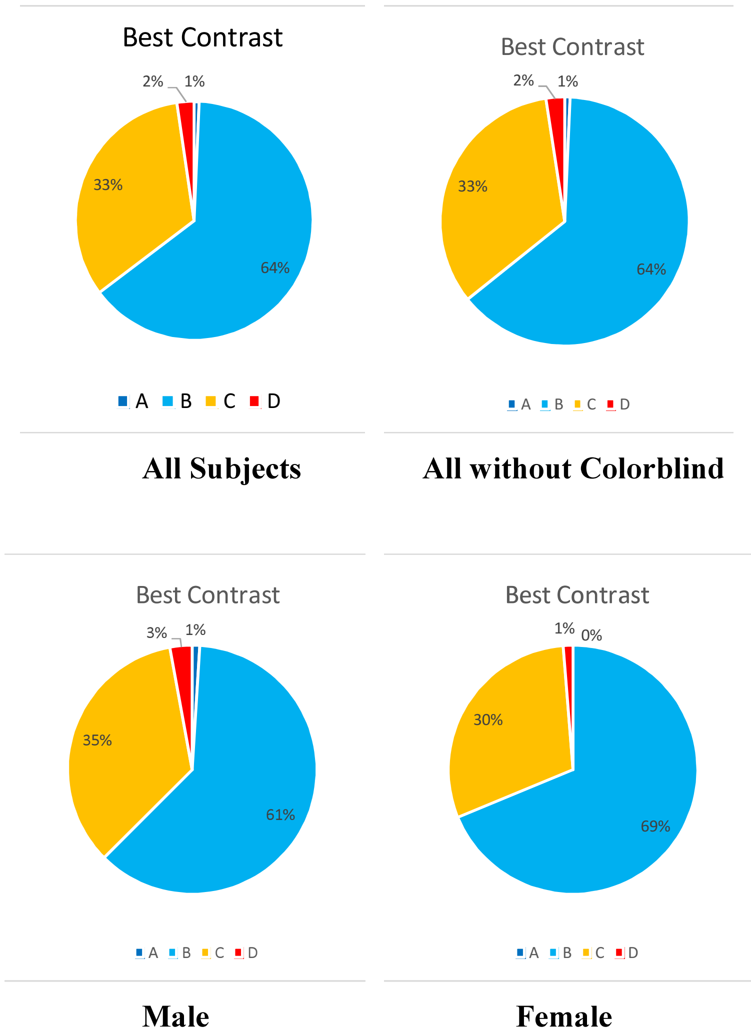


Figure 12: Results of the Best Contrast Question

Best Picture Quality

Not surprisingly, B was preferred overall by 68% over C at 30%, with D and A getting a very poor 1% each. The results only differed slightly when removing the color blinds.

And, as was seen earlier, women prefer B slightly more than men 70% to 66%.

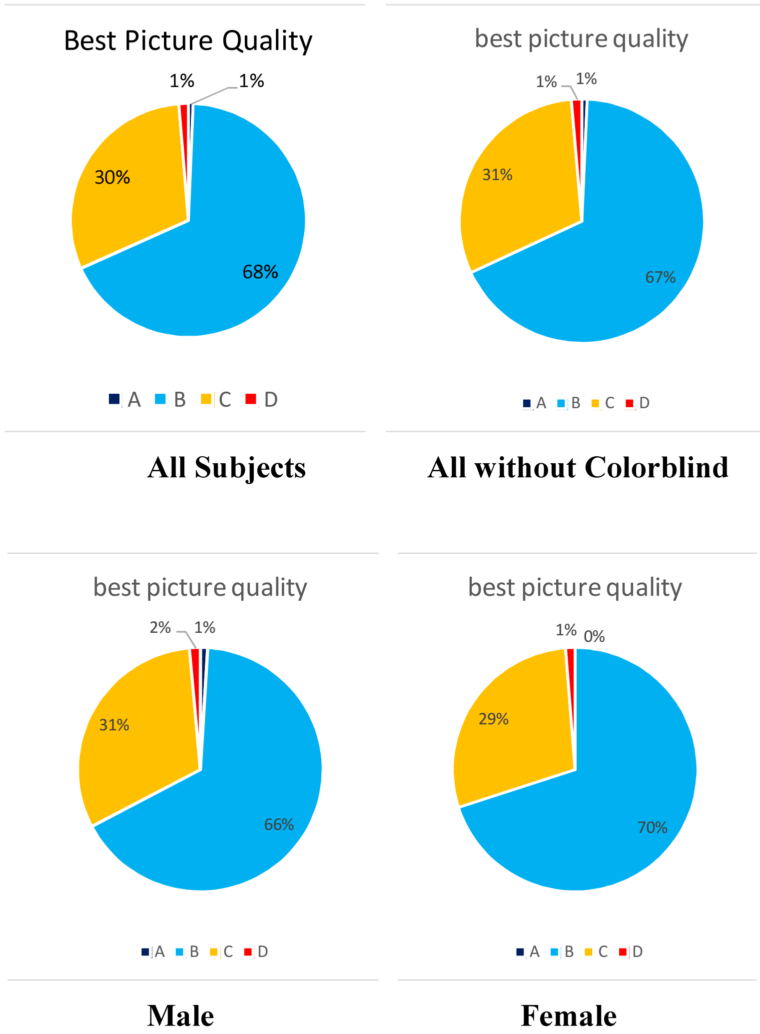


Figure 13: Results of Best Picture Quality Question

Conclusions

Over 300 people participated in a survey to evaluate the image quality of four unmarked projectors. The survey asked to judge the image quality of the four projected images using a series of diverse static pictures. The goal of the survey was to benchmark Philips new ColorSpark HLD LED light source vs. other solid state projection light source technologies in an ambient lit room.

	A	B	C	D
	RGB LED	HLD LED	Laser-phosphor	Hybrid
Commercial Brightness ANSI Lumen	1500		4000	3500
Measured brightness bright mode ANSI Lumen	805	2722	2998	2847
Measured brightness RGB mode ANSI Lumen	358	1213	1742	727
% of participants perceiving highest brightness	2%	52%	45%	1%
% of participants perceiving most accurate colors	5%	59%	33%	3%
% of participants perceiving most pleasing colors	1%	70%	27%	2%
% of participants perceiving best contrast	1%	64%	33%	2%
% of participants perceiving best picture quality	1%	68%	30%	1%

Table 6: Summary of Results

The results showed that for the best picture quality the ColorSpark HLD LED light source was preferred overall by 68% over the Laser-phosphor projector at 30%, with the RGB LED and Hybrid projector getting a very poor 1% each. The results, see table 6, also indicate that in RGB mode the projector with ColorSpark HLD LED light source having a lower measured brightness than the projector with Laser-phosphor light source is perceived by 52% of the participants as brighter than the Laser-phosphor projector in a normal lit environment. By breaking through the 1000 ANSI lumen barrier in RGB mode and 2500 ANSI lumen in bright mode, ColorSpark HLD LED technology can compete with and even outperforms Laser-phosphor and Hybrid projectors with a commercial brightness specification of 3500 to 4000 lumens.

Discussion of Results

Great care was taken to try to ensure a fair comparison between Philips ColorSpark HLD light source and the other types of SSL illumination technologies. The ColorSpark HLD LED light source can be used in any projection architecture (LCOS, 3LCD or DLP) and by any brand. The objective of the perception test was to see if the HLD light source offered advantages over other solid state light sources.

These tests are certainly not exhaustive and have revealed surprising results. On all aspects of perceived picture quality, including brightness, color and contrast the ColorSpark HLD LED light source outperforms the other SSL technologies, although the measured values for brightness and contrast of the projector using ColorSpark HLD LED are much lower than those of the high end projector using a Laser-phosphor light source.

It is clear that Philips proved that the ColorSpark HLD LED technology can create compelling images with 68% of all participants choosing the projector with ColorSpark HLD LED technology. All projector makers should seriously evaluate the ColorSpark HLD LED technology as this will bring mainstream projection lighting to a next level of picture performance and color enhancement in any normally lit environment. Philips ColorSpark HLD-LED technology enables a brightness and color performance based on full led light sources that is perceived superior to Laser-phosphor and Hybrid picture quality performance.