



## BenQ Eye-care Technology White Paper

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## A. Human Eye

The human eye is a precise and sensitive optical system, which can adapt to a visual object and change according to different visual environments. The basic structure of the eye is very similar to a camera, including the lens, aperture, and film. A complete optical system projects the image onto the film, which is the retina in our eyes. In order to have a clear image, the light must be able to focus on the retina.

### 1. Cornea – Lens

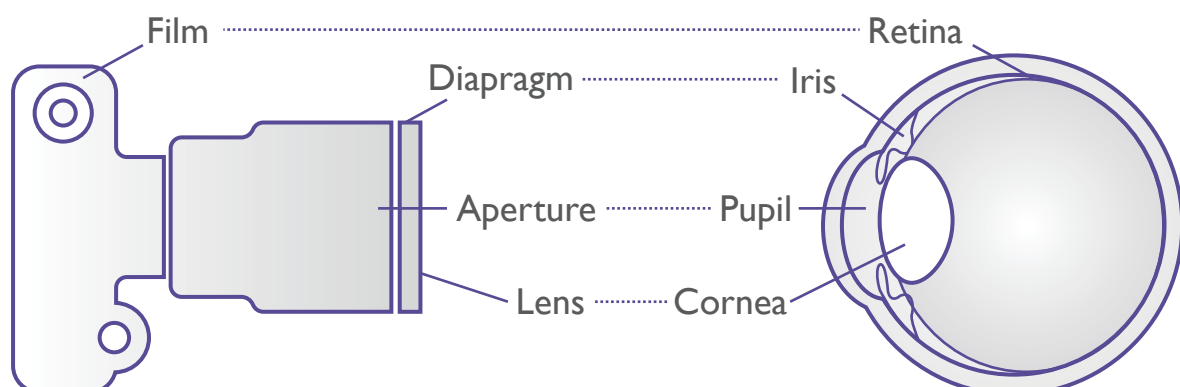
The first element that encounters light entering the eyes is the cornea. Its function is to allow light to enter the eye freely.

### 2. The pupil (iris) - Aperture

After light passes through cornea, it reaches the iris. The iris serves like a camera aperture; it controls the amount of light entering the eye and the center of the hole is called the pupil. The iris is a disc-shaped element and its diameter changes according to the amount of light that enters. In a bright viewing environment, the pupil will contract and in dark viewing conditions the pupil will enlarge. This mechanism controls the amount of light entering the eye and the exposure of the retina (film). Overexposure creates an excess of light interference on the image, but underexposure will result in a very dark, indistinguishable image. Thus, the iris automatically adjusts the size of the aperture to determine the appropriate brightness.

### 3. Retina - Film

The retina functions like a sensor in a digital camera or film in a traditional camera. When the image passes through the lens (refractive element) and shines onto the retina, the optical image will be converted into neural signals and transmitted to the brain.



## B.What Can Cause Computer Eye Strain



As people spend more time on computers, smartphones, tablets, and television. There is a strong correlation between the use of monitors and eyestrain. Monitors displays consist of many dots of light and the frequent flickering, blue light, contrast, brightness and color of the dots can cause the eyes discomfort. If the eyes don't rest enough during the day, it can lead to difficulty focusing, blurred vision, eye strain, and headaches.

## C. Flicker

### i. What is Flicker?

In general terms the human visual system perceives flicker where there is a significant change in the brightness of light reaching the eyes during short time intervals. The frequency of these shifts between lighter and darker light is defined by the number of times per second the change occurs. At around 3 shifts per second (3Hz) the changes in brightness are very noticeable as you might expect. While the very visible flicker of 3Hz may decrease with higher frequencies, visual disturbances are still very problematic up to around 20Hz. Above 20Hz the issues decrease slowly as the frequency is increased, until around 50Hz where the flicker commonly expands into an impression of constant light to the eyes for most users.

The frequency of this transition point is called the flicker-fusion threshold. This threshold may of course vary by person and can also vary in peripheral fields of vision.

Perhaps most significantly, monitor flicker has been attributed to issues with eye strain and headaches when using displays for many years. It is important to understand that monitor flicker in LCD displays is different from older CRT displays. These CRT's refresh at a certain frequency from top to bottom as the cathode ray gun is fired across the screen, with only part of the screen illuminated at any one time.

At low refresh rates the frequency is low enough that it can produce visible flicker for and can commonly lead to issues for the user. A refresh frequency of 72Hz or above is commonly considered suitable to eliminate flicker from CRT's for most users (TCO 92). LCD displays are not refreshed in the same way as their image is constant and updates on a pixel by pixel basis when the image requires the change. While a 60Hz refresh rate on a CRT would be considered problematic to many users when it comes to flicker, most LCD monitors are designed to work at 60Hz but they do not produce flicker in the same way.

Flicker on LCD displays is still a possibility and cause for concern for users, especially those who are using the screen for long periods of time.

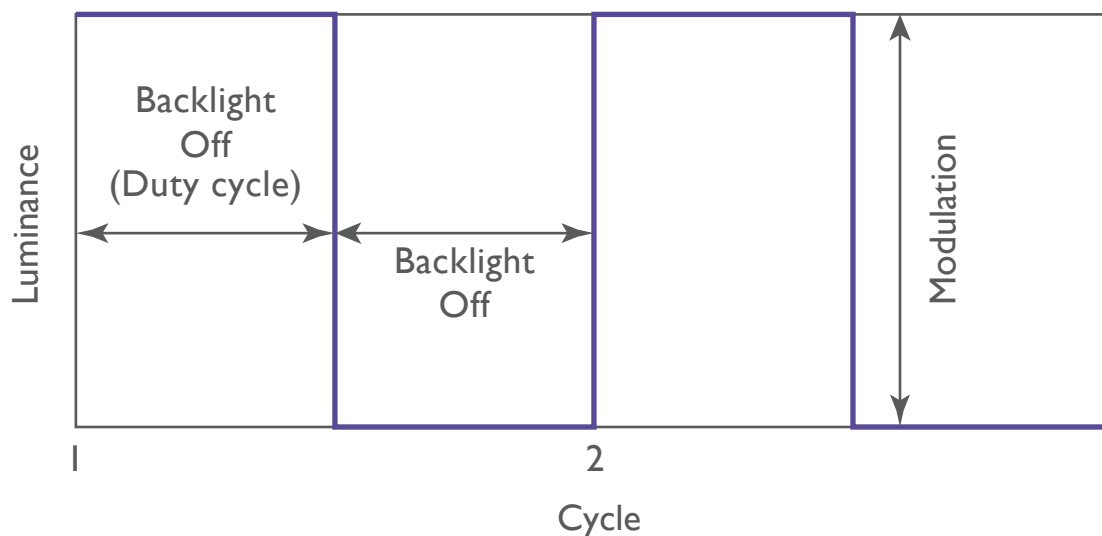


## ii. Causes of Monitor Flicker - Pulse Width Modulation (PWM)

Perhaps the most common, yet not widely understood cause of flicker and related symptoms, is the use of Pulse Width Modulation (PWM) in desktop LCD monitors. This technology is used in the majority of desktop monitors to control backlight dimming, and has been utilized for many years. Nearly all monitors offer the user a direct control over the intensity of the backlight unit through the brightness control in the On Screen Display (OSD), in turn allowing the user to obtain a suitable luminance for their requirements. To achieve this, in simple terms, PWM is a technique used to rapidly turn the backlight unit off and on to simulate a lower perceived luminance for the user, in theory at a level which should be undetectable for the user. At the maximum brightness setting (100%) this technique is not needed and the backlight is illuminated continuously. As the brightness setting is lowered, the luminance intensity is decreased using this PWM technique. Its operation is explained in the following section. This cycling of the backlight off and on is happening all the time, not only in changing images of games and movies, but when viewing static images for general day-to-day use. Word processing, spreadsheets, email and internet browsing with their large bright backgrounds are perhaps most problematic when it comes to issues with PWM backlight techniques.

PWM as a technology allows for wide adjustment ranges, helping to offer both high maximum luminance and low luminance control for those who need to use the screen in darker ambient lighting conditions. PWM has been used for many years with success and offers an established, simple circuit design making it a cost-effective and simple route for manufacturers to utilize.

### PWM Operating Parameters



PWM cycling typically occurs at a fixed frequency, and the fraction of each cycle for which the backlight is on is called the duty cycle. By altering the duty cycle the total light output of the backlight is changed.

As a user lowers the brightness setting, the duty cycle typically becomes progressively shorter, resulting in a reduced luminance. As a result, the lower the brightness setting, the longer the “off” periods are, and the more pronounced any flicker may become.

PWM operating frequency determines how many times per second the backlight is cycled on and off, with lower frequencies potentially being more problematic when it comes to flickering.

### iii. Health Concerns of Flicker

Backlight flicker may or may not be perceptible to a given user, but there are still concerns which affect many people. Flicker and the use of PWM dimming methods, even where not directly visible, have been linked to eye fatigue, eye strain, headaches, and nausea. Again, this varies significantly from person to person, but with the increased popularity of LED backlight units it appears to be more of a widespread concern and certainly now better understood in the industry.

Concerns around flicker can affect any user, but may be especially problematic for anyone using a screen for long periods at a time. Web developers, writers, students, office workers, and anyone who needs to sit in front of a screen for a long time may find they are more prone to issues associated with flicker and the use of PWM than casual users.

### iv. How to Test for PWM

Most screens will not list whether PWM is used for backlight dimming and in many cases the manufacturer may not even know. Fortunately there are some simple tests that can be carried out to establish whether PWM is used or not. There are also some more advanced tests used in the industry to more accurately measure PWM frequencies.

Basic Visual Tests—Take a picture of your screen with a camera. This is a simple test may be able to see where PWM is used. The user can quickly perform a basic test for monitor flicker.



## v. Alternative Backlight Dimming Techniques

Other options for backlight dimming do exist, although are not widely used. These include Direct Current (DC) control, which does not cycle the backlight off and on at all, but can be more complicated to implement. In some cases there is also difficulty controlling the colour in darker images and so DC backlight control is less common.

In a study conducted by Kitasato University Japan, School of Allied Health Sciences, it was established that DC resulted in the lowest levels of flicker and eye fatigue, and was overall easiest to view for prolonged working conditions.

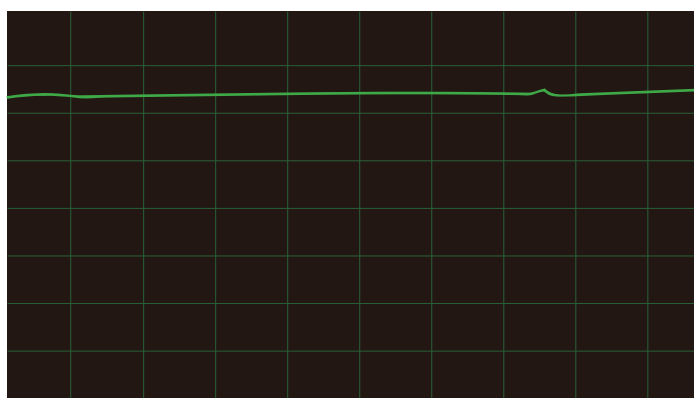
Backlight Dimming Technique	Pulse Width Modulation (PWM)	Direct Current (DC)
<b>Pros</b>	<ul style="list-style-type: none"> <li>• Wide adjustment range for monitor brightness/luminance</li> <li>• Simple and cost-effective circuit design</li> <li>• Established technique used for many years</li> </ul>	<ul style="list-style-type: none"> <li>• No flicker</li> </ul>
<b>Cons</b>	<ul style="list-style-type: none"> <li>• Possible visible flicker for the user</li> <li>• Associated health concerns including eye fatigue, headaches, nausea</li> <li>• Even where flicker isn't directly visibly to the user, PWM may adversely affect the user</li> </ul>	<ul style="list-style-type: none"> <li>• Complicated circuitry</li> <li>• Not widely used and less established than PWM for backlight dimming</li> <li>• Trouble controlling colour in darker images in some cases</li> </ul>



## vi. BenQ Flicker-free Monitor Range

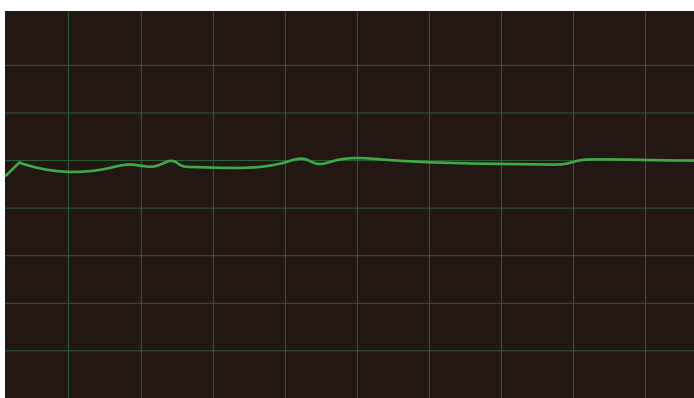
With the increased focus and awareness of monitor flicker and the associated medical concerns, BenQ has introduced a range of flicker-free monitors. These monitors are designed to address user concerns around eye fatigue and other health issues associated with flickering displays. They are based on a Direct Current backlight system where Pulse Width Modulation is not used. As a result, the main cause of monitor flicker is eliminated, making the flicker-free range suitable for even the most demanding users.

Each horizontal grid represents a 20ms period in this scale



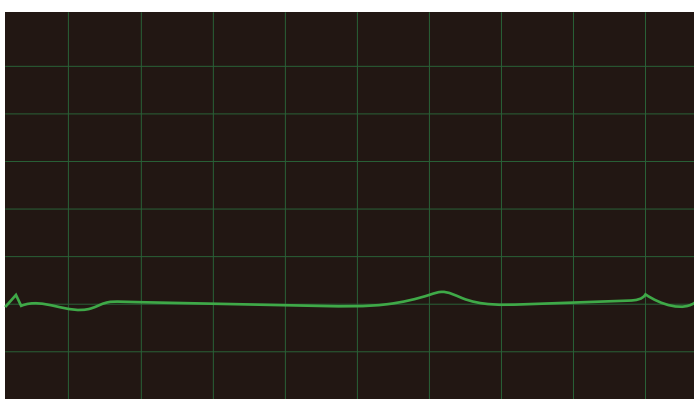
### Brightness Setting = 100%

The straight line indicates a constant backlight illumination at maximum brightness setting as normal.



### Brightness Setting = 50%

When reduced to 50% brightness, the straight line confirms no PWM is being used, and the backlight is not being cycled on or off.



### Brightness Setting = 0%

Even at the lowest backlight setting, PWM is not used and the illumination is constant.

## D. Blue light

### i. What is Blue Light?

Light can be divided into visible light and invisible light. The part that can be perceived by the human eye is called visible light, and comprises wavelength from 420 nm to 780 nm. The colors we usually see, for example, red, orange, yellow, green, turquoise, blue, and violet, all belong to the visible light spectrum. Light having a wavelength longer than 780 nm is called infrared light, and wavelength shorter than 420 nm is called ultraviolet light (UV).

Recent studies have shown that UV light may damage biological tissues, including skin and eyes. People now understand that using sun block products can prevent skin damage. While it is highly unlikely for humans to stare directly at sun light (UV) or infrared light under normal circumstances, chances for infrared light and ultraviolet light damage to eyes are generally quite slim. However, visible blue light is allowed to enter the retina. We can separate visible blue light into two groups - short wavelength blue light (420 nm to 455 nm) and long wavelength blue light (455 nm to 480 nm).

### ii. Effects of Blue Light

#### 1. Short wavelength blue light may cause vision problems

Studies have shown that short wavelength blue light from 420 to 455nm (near ultraviolet range), is considered a potential hazard to the retina and can lead to vision-related problems such as eyestrain and blurred vision. Long-term exposure may contribute to eye-related diseases such as macular disease (AMD) and cataracts.

#### 2. Long wavelength blue light can boost attention, and reaction efficiency

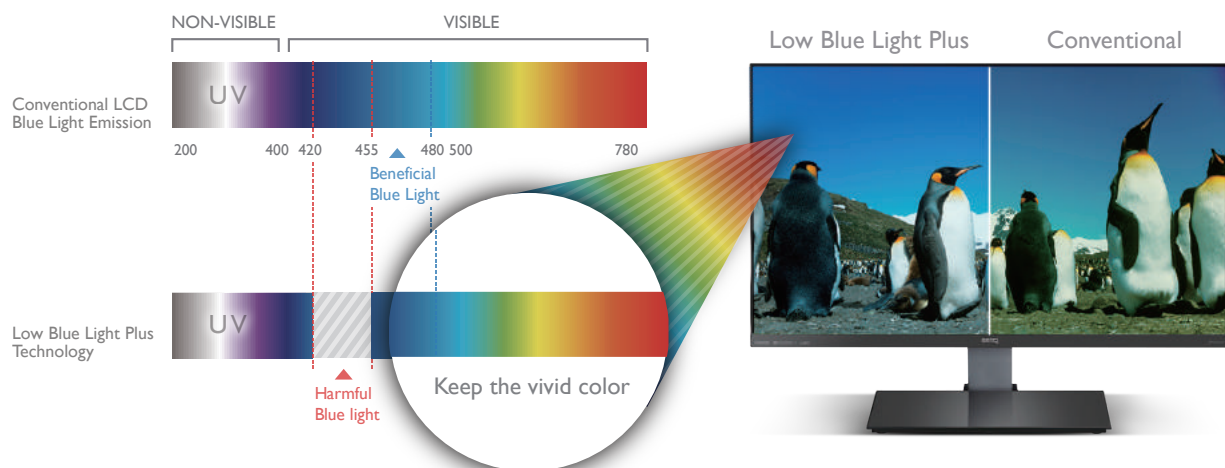
Studies have proven that long wavelength blue light (455-480nm) is beneficial to humans during daytime hours because it can boost attention, shorten reaction times, and positively affect the mood control centers of the brain.

### iii. BenQ New Backlight Module

The LED screens currently on the market use WLED (White LED) backlighting. The working principle of WLED is to use emissions from a blue chip to excite yellow phosphor on chip to produce white light. However, emissions from the blue chip become short wavelength blue light and may cause vision problems after prolonged usage. BenQ Low Blue Light Plus technology utilizes a specially designed blue chip to avoid short wavelength blue light, preventing potential vision problems and providing ultimate image quality.

### iv. BenQ Low Blue Light Plus Technology

BenQ Low Blue Light Plus Technology filters out short wavelength blue light (420 nm ~ 455 nm) emission while retaining the long wavelength blue light (455 nm ~ 480 nm), allowing users to experience the ultimate color reproduction with undistorted colors, high sharpness, and contrast.



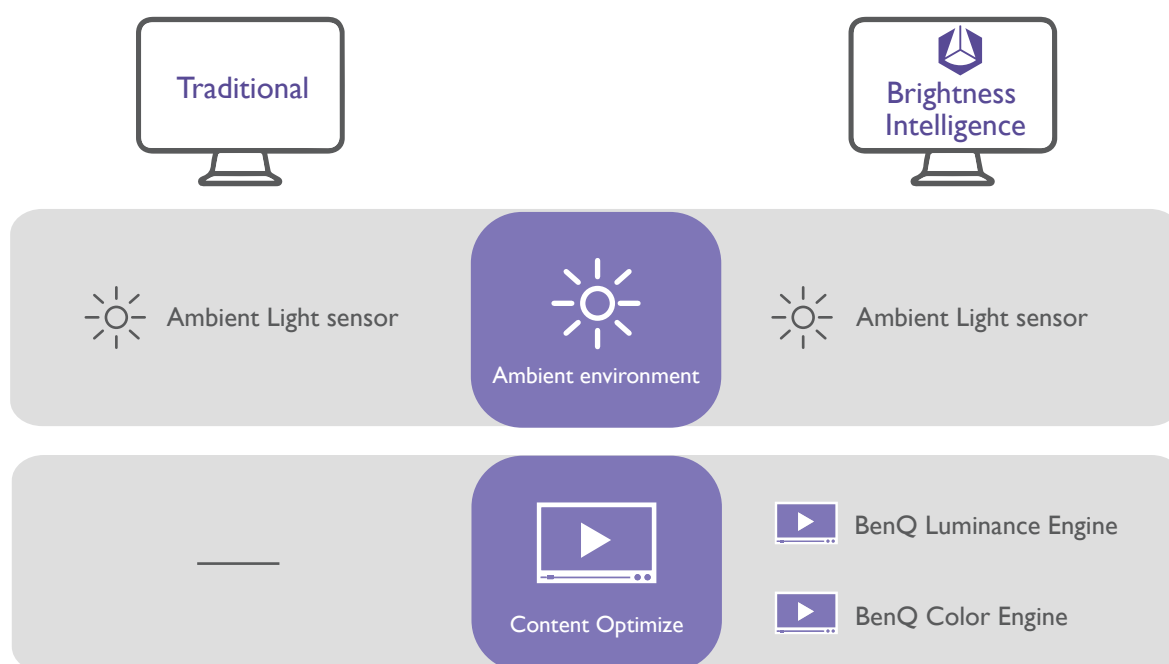
## E. Inconsistent Lighting

### 1. Why Inconsistent Lighting can Damages Eyes?

Shadows and reflections produced by ambient light combined with uneven light from the monitor can cause eyestrain. For example, when using the monitor beside a bright window, eyes will need to work harder to avoid the glare caused by the reflection, resulting in eyestrain. Additionally, strong differences in ambient light and the light from the display can cause eyestrain. For example, if the user has a very bright display in a dimly lit room, his or her eyes need to use more energy to focus. Or, when switching from dark to bright scenes on screen, our eyes need to constantly adjust the pupils to accommodate the brightness difference, which can also cause eyestrain, headaches and blurred vision.

### 2. BenQ Brightness Intelligence Technology

Brightness Intelligence Technology detects the amount of ambient light in the viewing environment and automatically adjusts the brightness for the most comfortable viewing experience possible. Brightness Intelligence Technology also utilizes BenQ Luminance Engine and Color Engine which detect the intensity of the content and adjust the image to ensure that bright scenes don't get overexposed and dark areas automatically adjust to maintain a visible level of contrast, helping to reduce eyestrain.



## i.Ambient Light sensor

When on-screen brightness matches the brightness of ambient light, the eyes don't have to constantly adapt to the difference between dark and light areas.

Brightness Intelligence Technology utilizes the Ambient Light Sensor to detect the amount of ambient light in the viewing environment and automatically adjusts display brightness to the most suitable levels.

### Without Ambient Light Sensor Control



Light Environment



Dark Environment

### With Ambient Light Sensor Control



Light Environment

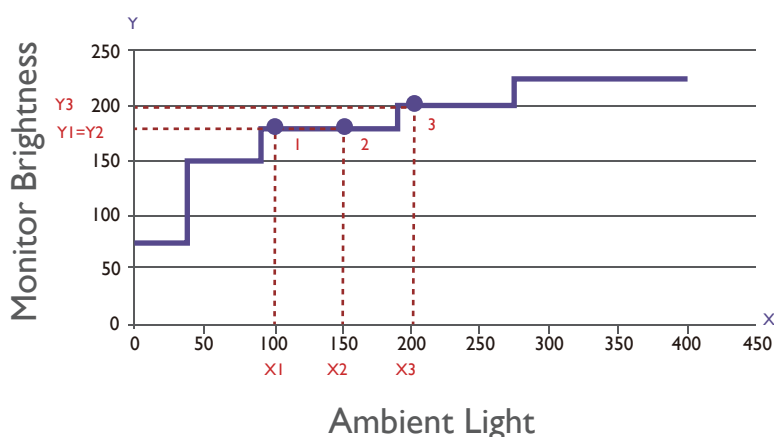


Dark Environment

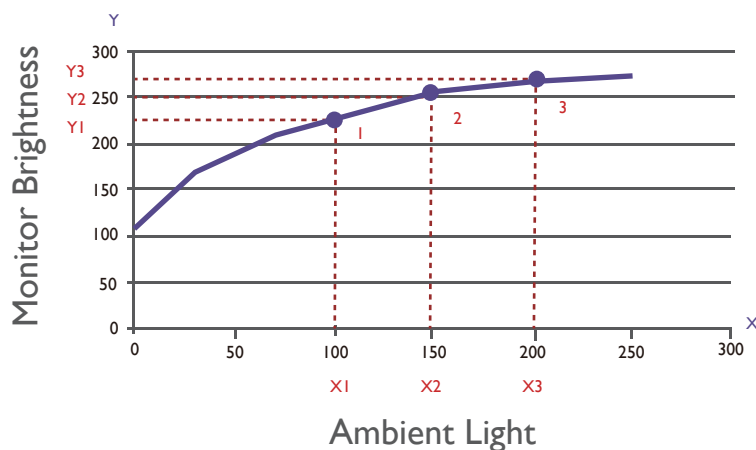
The exclusive algorithm in Brightness Intelligence Technology calculates the appropriate screen brightness for ambient light conditions in real time.

As shown in the following diagrams, X-axis represents the ambient light brightness level, Y-axis represents the screen brightness, X1 corresponds to Y1, X2 corresponds to Y2... and so on. There is a corresponding Y value for every X value, and through unique firmware adjustment, the transition will be smooth and gradual. There will be no flicker ensuring users enjoy smooth transitions.

### General Light sensor



### Brightness Intelligence Technology

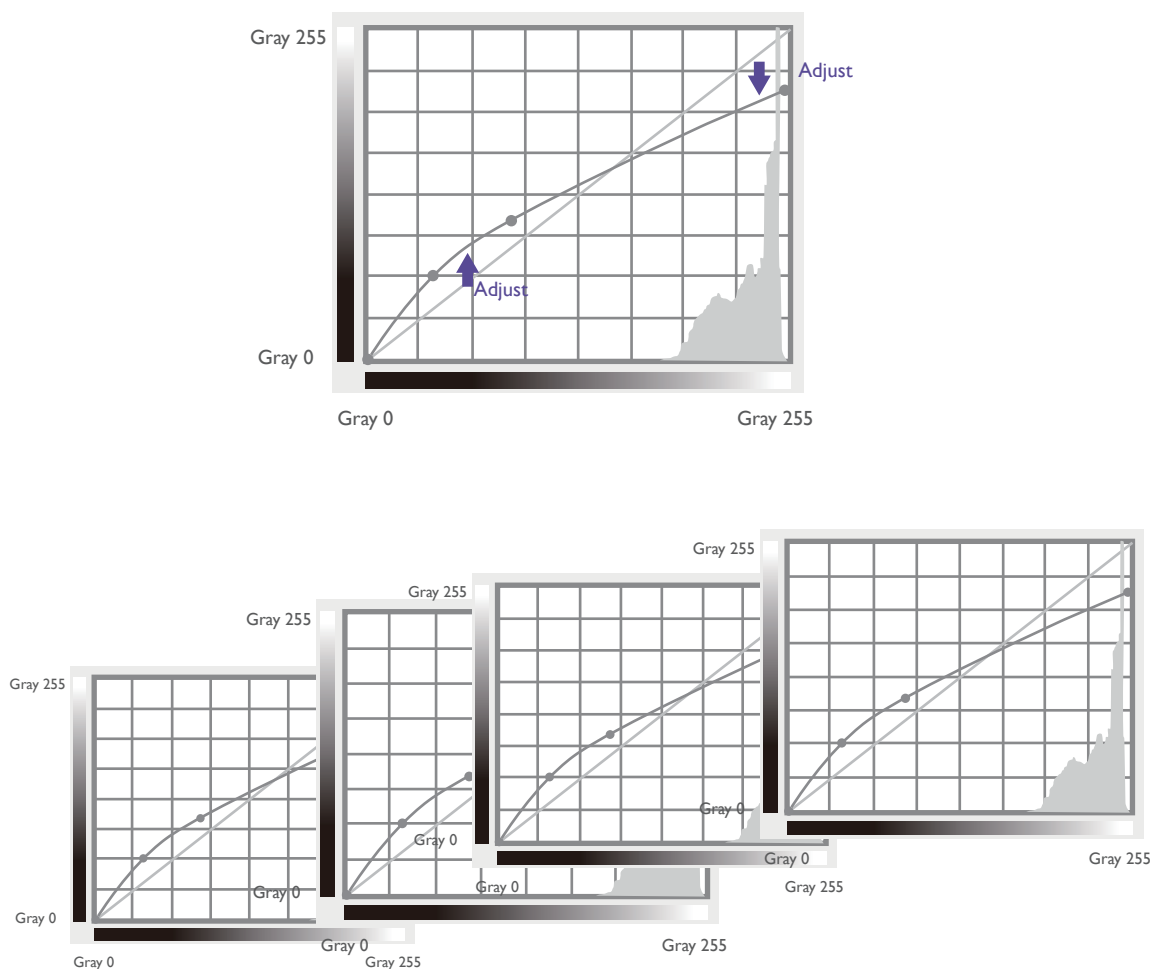


\*Previous generation of Eye Protection function only offers seven kinds of brightness setting for ambient light. New Brightness Intelligence Technology offers more fine adjustment and provides better response (in terms of screen brightness) to different ambient lighting conditions.



## ii. BenQ Luminance Engine

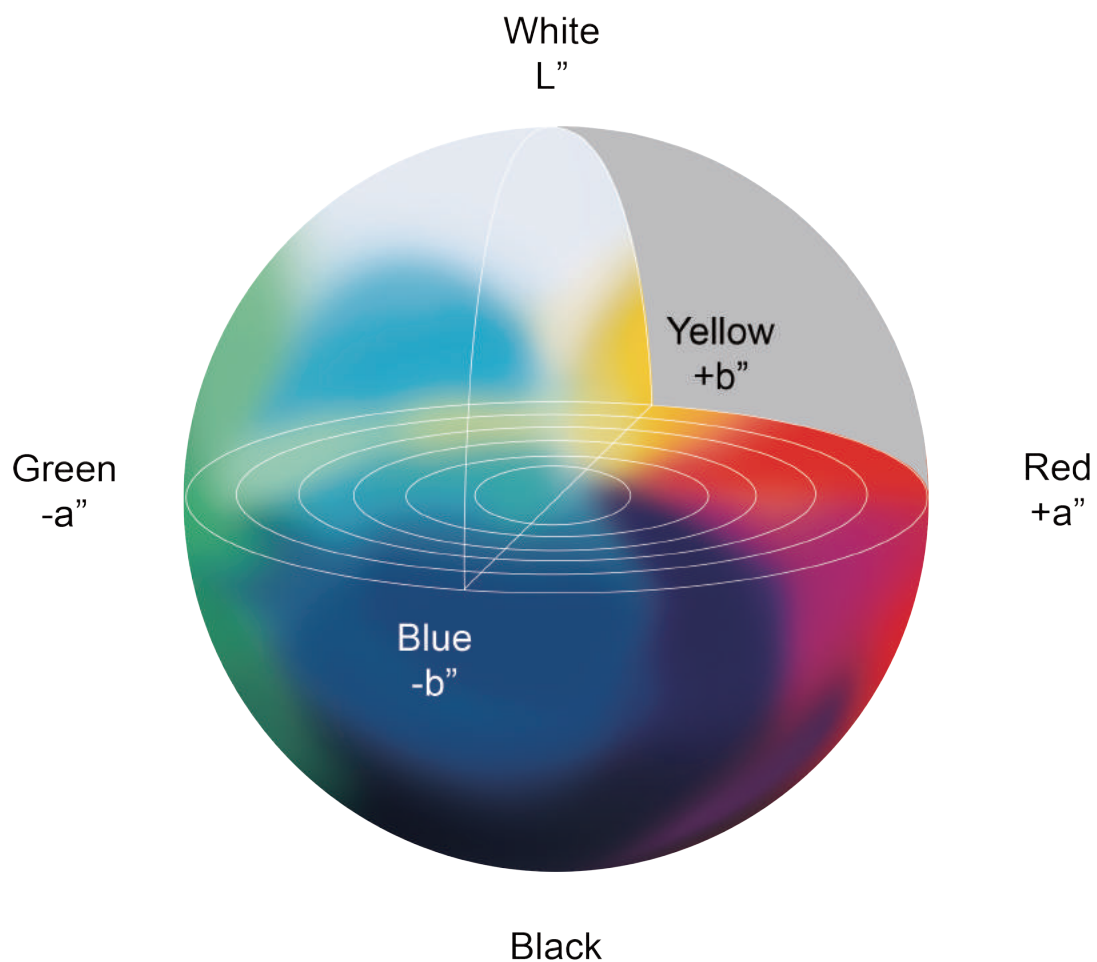
The BenQ Luminance Engine provides the best dynamic adjustment from dark to light and light to dark. The details in dark areas will be revealed without overexposing the details in bright areas. BenQ Luminance Engine sets up a smooth transition curve using multiple corresponding points across different gray level values. Therefore, Brightness Intelligence Technology can provide not only the best screen brightness optimization, but also the best dark to light and light to dark transition adjustments.



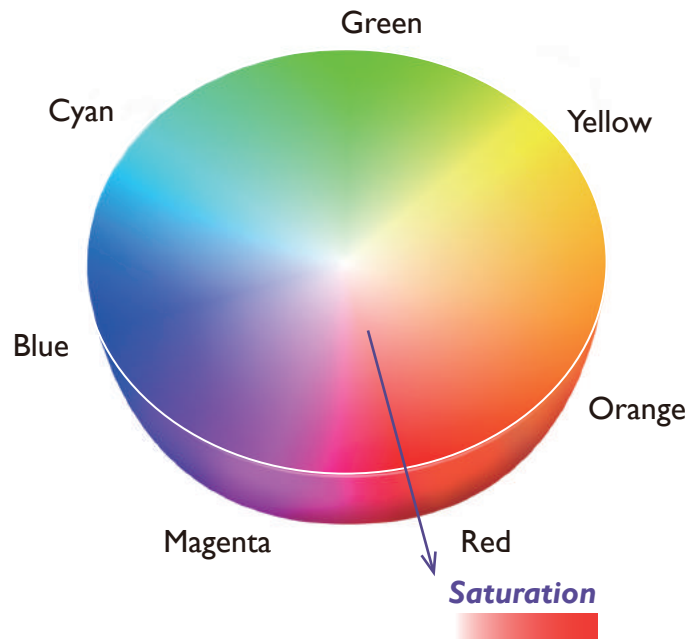
\*BenQ Luminance Engine will provide dynamic brightness adjustment heaps of times for different content in real time.

### iii. BenQ Color Engine

The BenQ Color Engine utilizes six-axis color adjustment technology that allows the hue and saturation to be adjusted independently. With this technology, color reproduction is enhanced and extremely fine intermediate shades of colors can be accurately produced on the display. When the screen brightness is dimmed on a traditional monitor, original colors can become distorted, but with BenQ Color Engine, original colors are retained more often.

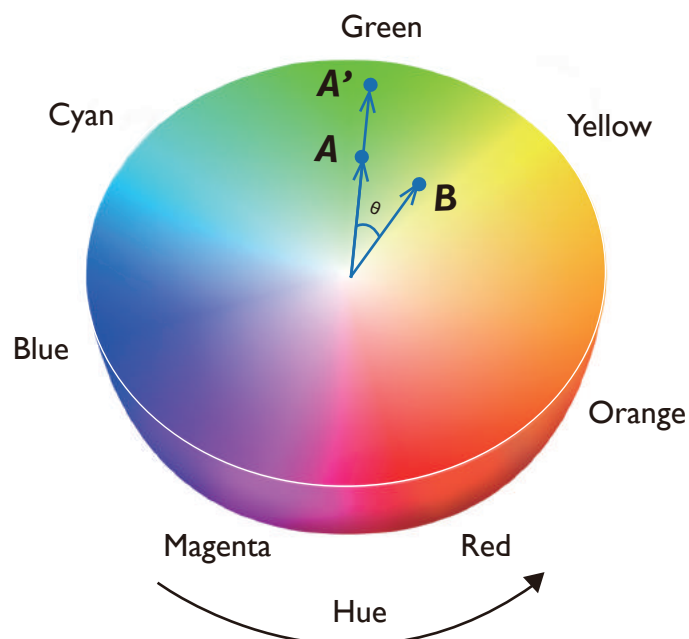


The color map below consists of all the colors the human eye can see and can be divided into 6 color shades: Red, Green, Blue, Yellow, Cyan, and Magenta. BenQ Color Engine allows each color to be enhanced in saturation and hue independently without affecting other colors to improve color accuracy and provide more vivid color.



BenQ Color Engine adjusts colors in a three-dimensional fashion. In the following diagram, Angle  $\theta$  represents the hue angle between two colors. There are two examples shown in the following:

1. Moving from A to A': Enhanced Color Saturation. Green will become more vivid.
2. Moving from A to B: The green hue will move closer to yellow to show a more like yellowish green. This will result in more intermediate shades of between green and yellow.



## F. Brightness Intelligence Plus Technology

### i. Brightness Intelligence Plus Technology Explained

From previous section, we knew that Brightness Intelligence Technology can detect the luminance intensity of the content and adjust the monitor to ensure that bright scenes don't get overexposed and dark areas are automatically adjusted to maintain a visible level of clarity. Now, BenQ has added another great feature to its original Brightness Intelligence Technology, which is able to detect the color temperature in our viewing environment and automatically adjust the brightness and color temperature of the monitor for the best viewing comfort experience. The latest technology is called Brightness Intelligence Plus Technology (B.I.+ Tech.).

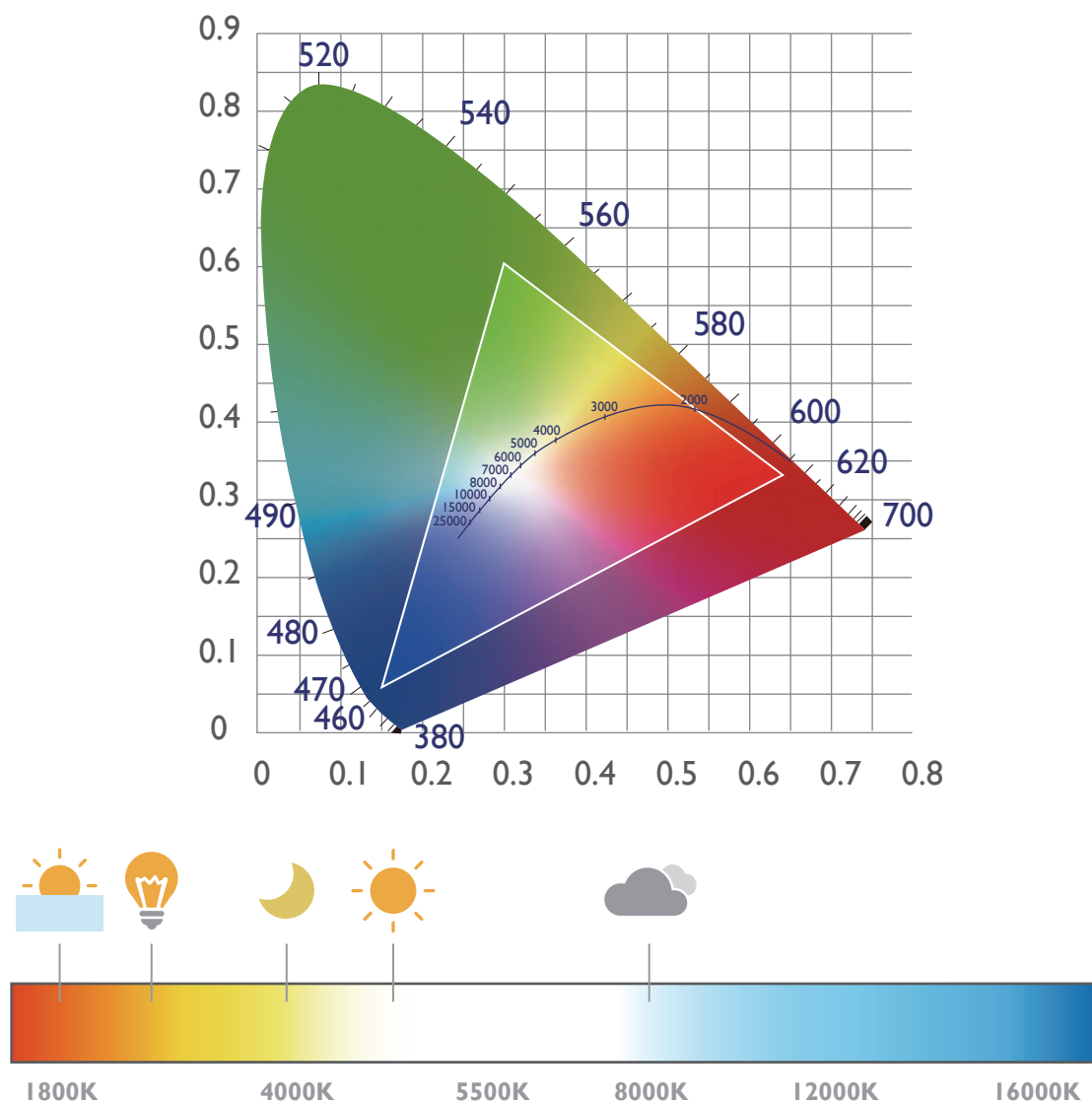
### ii. Color Temperature

#### I. What is color temperature?

For those who are not familiar with color temperature, here is the brief explanation taken from Wikipedia: "the color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of a color comparable to that of the light source." That said, color temperature describes the characteristic of visible light and is stated in units of absolute temperature, known as Kelvin (K). In more simple terms, color temperature was designated to describe the "color" of a light source with a single numeric value. The numeric number is associated with the actual temperature (in Kelvin, K) when the black-body radiator radiates a particular shade of color. For example, the light of tungsten light bulb is designated as 2800K, which means when the temperature of black-body radiator is at 2800K (Kelvin), the radiator radiates the same shade of color as the tungsten light does. Scientists had observed the color changes as the temperature of the black-body radiator goes up, and they had plotted the color shift on the chromaticity diagram. The black curve in Figure 1 shows the observed color shift recorded by scientists, and is called Planckian Locus.

Different color temperatures will deliver different visual and sensation effect. From Figure 1, we can see the higher the color temperature, the more bluish the white light will be. On the contrary, the lower the color temperature, the more reddish the white light will be. This could be explained by a gas burner. When the gas burner burns out a more orange or yellow flame, the temperature is actually lower. But when the gas burner burns out a bluish flame, then the temperature is really high.

Figure 1.: Color Temperature Curve (Planckian Locus)



## 2. Why color temperature matters?

To explain why color temperature matters, first we need to know what values are associated with what kind of light. Figure 2 gives us a better understanding on this topic.

From Figure 2, we could

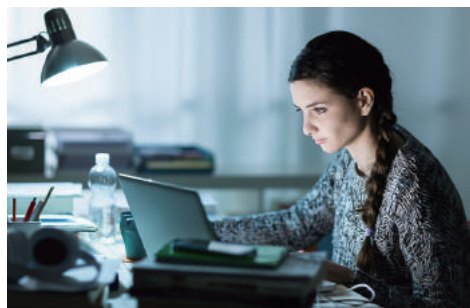
- At the lower end of the scale, from 1800K to 2700K, the light produced is called “super warm white”. Candle lights falls in this category.
- Color temperatures between 3000K and 5500K are known as “warm white”. Most of our light bulbs are in this range.
- Scale from 5500K to 7000K is classified as “natural light”. A good example is our daylight.

Color temperature will greatly affect our mood and color judgment, for example, when we enter a room with low color temperature, we will feel warm and relax, but when we enter a room with high color temperature, we will feel awoken and alert. The reason behind is that our visual system will look for the “white” in scene, and adjust other colors according to the white. Therefore, if the white is consistent in terms of color in a scene, then our visual system will do less work on adjusting colors.

Affects Melatonin to Focus or Relax



Long Working Time Causes Eye Strain



We Can Not Control the Surrounding Color Temperature.





Figure 2.: Color Temperature Values vs Light Sources

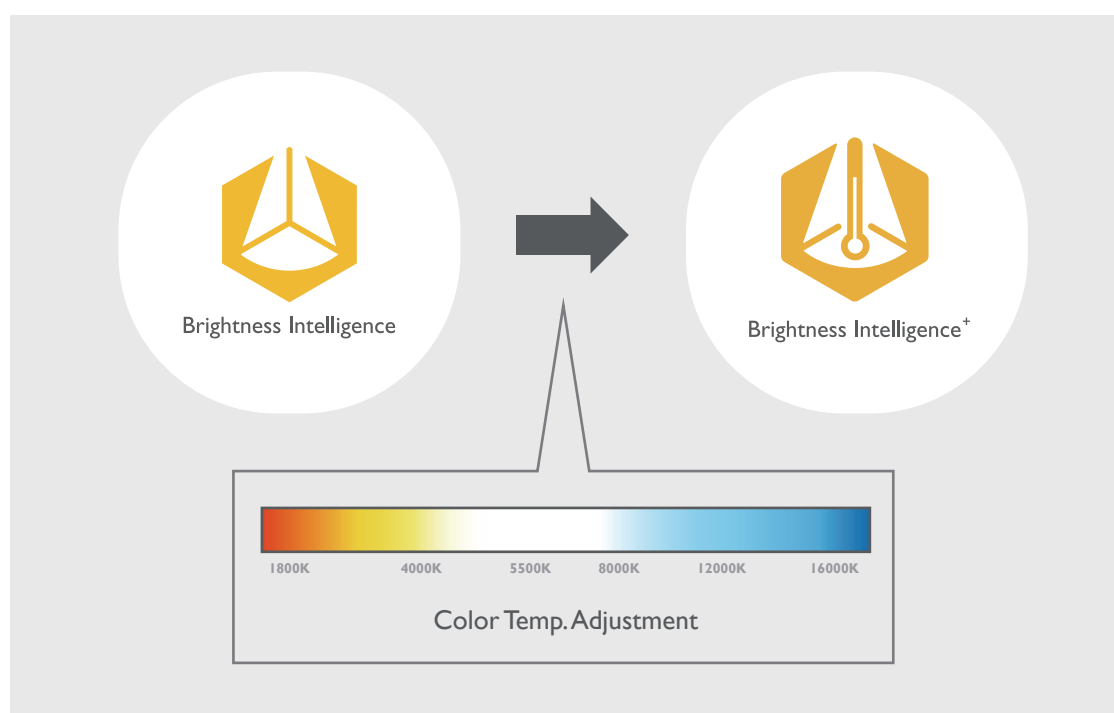
Scenario	Color Temp. (K)	Color of Light
Sunrise / Sunset	1800	Super Warm White
Candle	2000	
Tungsten Filament	2700	Warm White
Halogen Lamp	3000	
Studio Lighting	3000 - 3400	Natural Light
Warm White Fluorescent Lamp	3700	
Moon Light	4000	Day Light
Cool White Fluorescent Lamp	4500	
Day Light	5000	Cool Light
Day Light (at noon)	5200	
Average Day Light	5500	Day Light
Mercury Lamp	5800	
Cloudy Day	6500 - 7500	Cool Light
Sunny Day	8000	
Fluorescent Lamp	9500	

Another important influence of color temperature includes that it affects human's melatonin to focus, relax; as well as causing eye strain.

### iii. Brightness Intelligence Plus Technology

To enhance Brightness Intelligence Technology, BenQ has added another powerful weapon to its original technology - Color Temperature Adjustment. This new technology is called Brightness Intelligence Plus Technology (B.I.+ Tech.).

Figure 3.: Brightness Intelligence Technology



Color Temperature Adjustment works by using a color sensor to detect the color temperature and illumination level of the surrounding light. And then adjust the monitor to display the corresponding color temperature and brightness level for best viewing comfort experience.

#### iv. Benefits of Brightness Intelligence Plus Technology

Besides all the benefits from Brightness Intelligence Technology, there are two additional benefits from B.I.+ Tech:

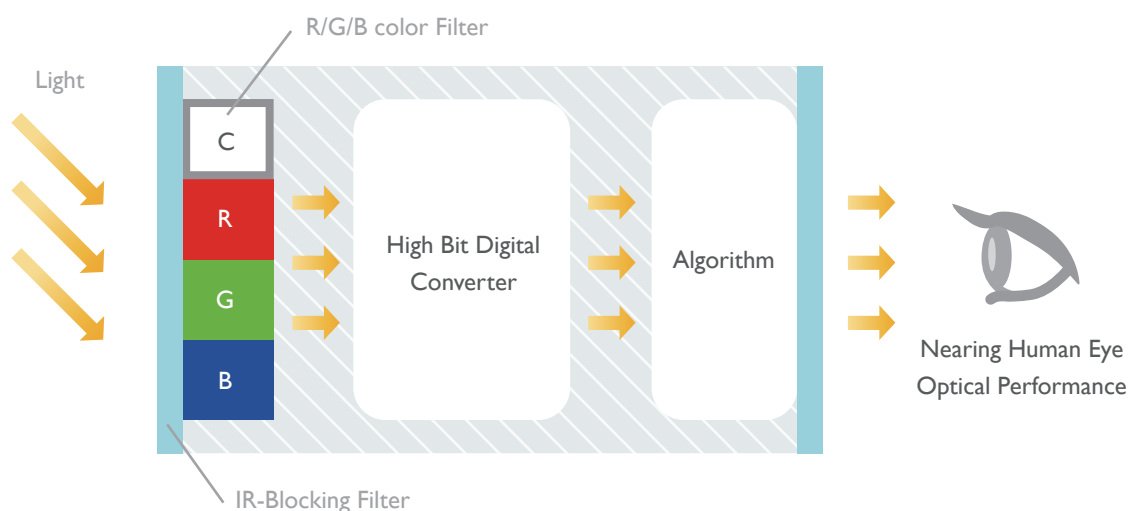
- Reduce Eye Strain in any Lighting Environment- detects ambient light levels and the color temperature in the environment. It adjusts both brightness and color temperature of the monitor to provide the most comfortable human viewing experience.
- Colors Stay Original for a Picture Perfect Content- enhances the hue and saturation of colors while ensuring a smooth color gradation so that colors stay true to original with vibrancy.

#### v. Color Sensor:

But how could the monitor know what kind of lighting it's under? There is not secreting: a color sensor does all the job. But how does the color sensor work? Figure 4 shows the structure of the color sensor. And we have summarized the functionalities in the following:

- Contains red, green, and blue filtered photodiodes, and clear photodiodes to deliver near-photopic response mimicking human visual system. This sensor array design provides superior optical performance for color sensing.
- IR Blocking filter minimizes the interference from IR spectral component to provide precise reading on RGB and color temperature values. The ambient temperature will not affect the RGB readings from the sensor.
- Four powerful analog to digital converters rapidly and accurately convert the amplified photodiode current to high bit digital value for color sensor system.
- Advanced algorithm to offer near human visual system performance from sensor readings.

Figure 4.: Color Sensor Structure

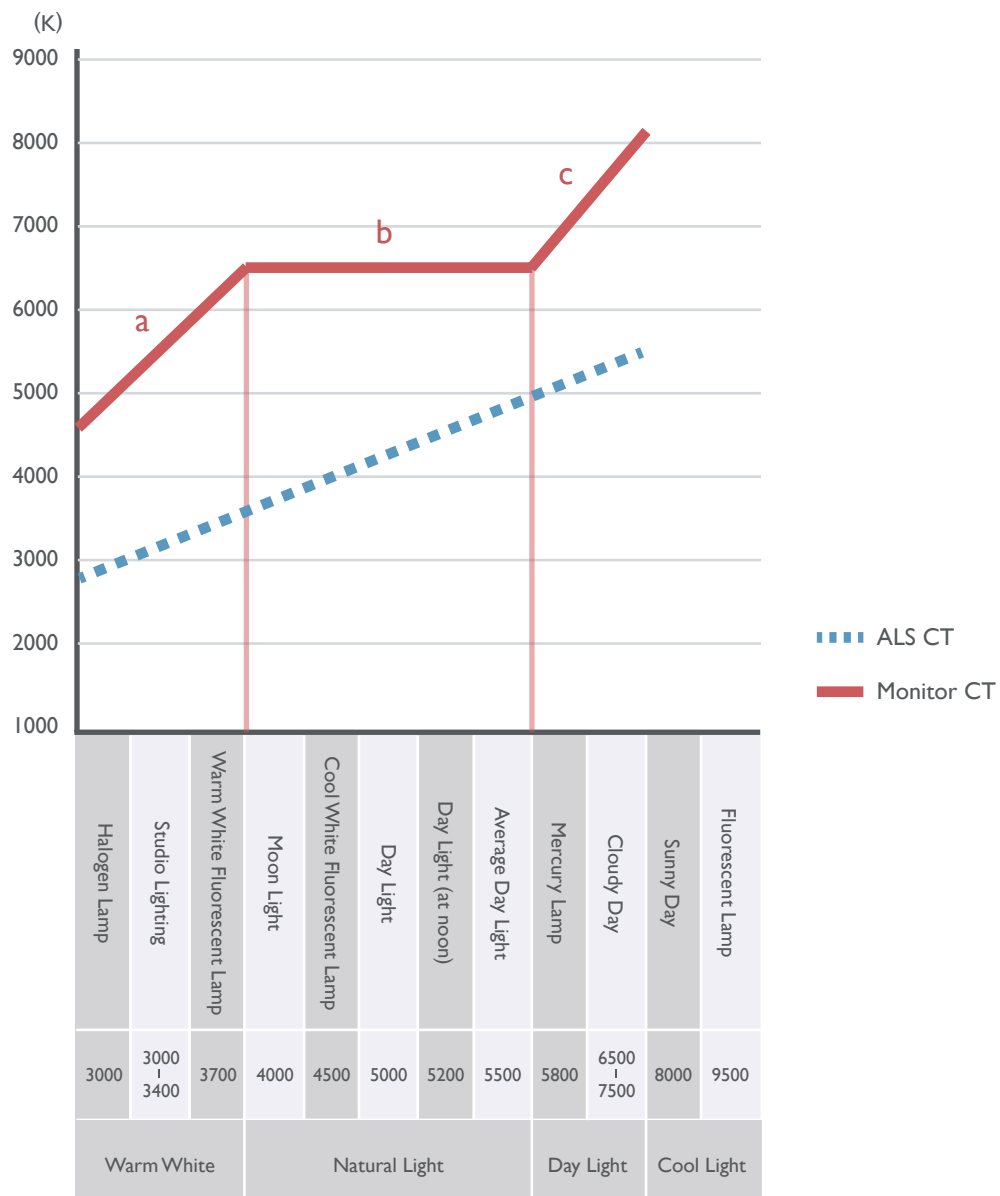


## vi. Ambient Light Sensor (ALS) Color Temperature vs. Monitor Color Temperature

From Figure 5, we can see the relationship between ALS Color temperature and Monitor Color Temperature.

Both segment a and c are linearly adjusted as the surrounding color temperature changes. The goal is to provide consistent color temperature between monitor and the surrounding to reduce the eye strain from changing color temperature. But in segment b, the color temperature from the monitor maintains at standard color temperature of 6500k to provide the best viewing experience.

Figure 5.:ALS CT vs Monitor CT



## G.Color Weakness Mode

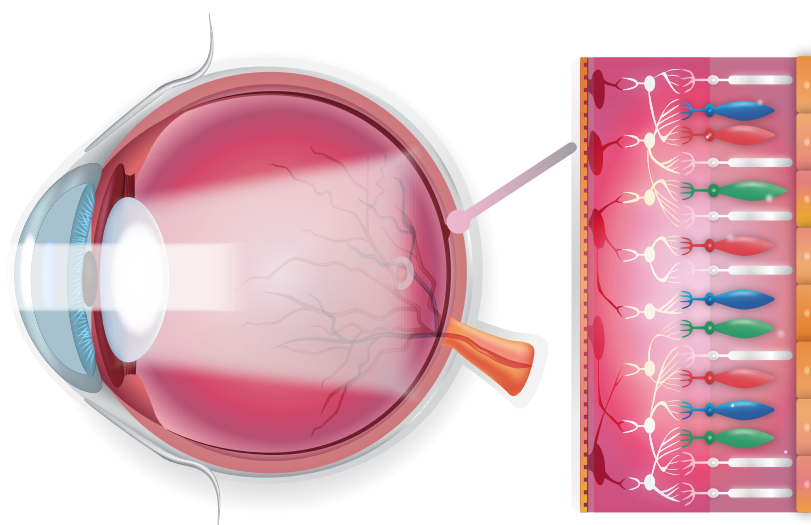
Color Weakness, also known as color vision deficiency (CVD), is the decreased ability to distinguish color or differences in color. To know what color weakness is, it's essential to understand how human eye perceives color.

### i.How Human Eye Perceives Color?

The structure of the human eye projects light and images onto the retina, and the retina is made up of what are called Rods and Cones. Rod cells are the lightness detectors. Cone cells are the color detectors. Rods allow you to see in dim light or at night, whereas cones ensure that you can see in detail and distinguish colors.

### Different Types of Cone Cells

There are three different types of cone cells. Each of the cones is responsible for detecting one of three different colors— red, green and blue – and reacts differently on colored light sources. For each of this three types there exists a specific color absorption curve with peaks at different points in the color spectrum. Mixing together the information of those three different types of cones makes up our color vision. When you look at an object, light enters your eyes and stimulates the cone cells. Your brain then interprets the cone cells, allowing you to see the color of the object. The red, green and blue cones all work together to allow you to see the whole spectrum of colors. For example, when the red and green cones are stimulated to a certain level, you will see yellow.

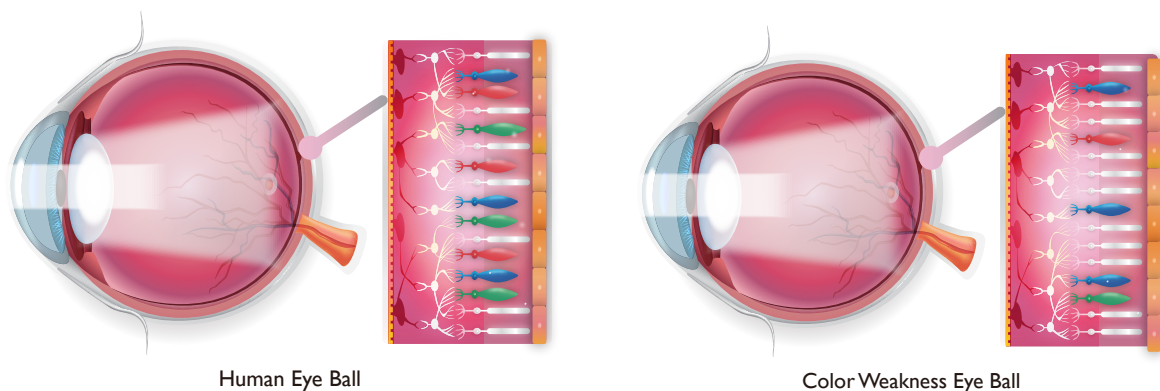


Human Eye Ball

## ii. What is color weakness?

Most people with color weakness are able to see things just as clearly as the rest of the population, and the difference is their inability to distinguish red, green, or blue light.

Color Weakness is a condition in which the retinal cone cells respond to light differently than normal; that's because one or more of the cone types are faulty or missing. In everyday life, people with color weakness can usually still see colors but have color confusions or see certain pairs of colors so similarly that they cannot tell them apart and have trouble distinguishing between some shades of red, yellow, and green. For example, if the red cone is missing, you will not be able to see colors which mix the red color clearly.



The most common types are the red and green color weakness. Sufferers mix up all colors which have red or green as part of the whole color. Those affected by Protan color blindness are less sensitive to red light, whilst sufferers of Deuteranomaly (green-weak) have the same problem with green. For example, a person with Protanomaly (red-weak) will confuse blue and purple because they can't recognize the red element in the color purple. The third type of color deficiency, Tritanopia, is the least common one; they are people who struggle to distinguish blue or yellow light.

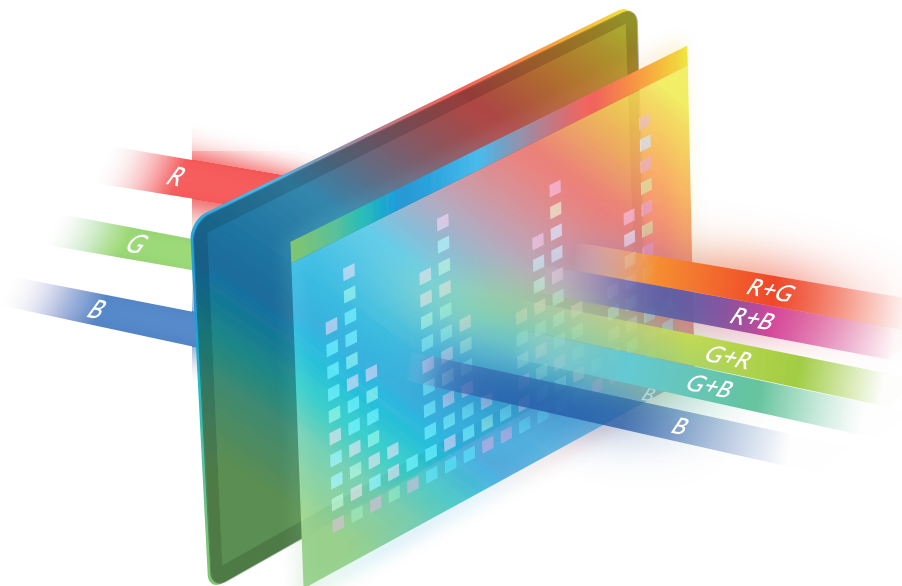




For those who inherit color weakness, daily tasks are made more difficult than people with color blindness. Driving can be a problem as the red and green colors on a traffic light will be in the wrong position. And when it comes to career choices, people with color weakness might have to avoid some professions, such as graphic design, which require accurate color perception.

### iii. BenQ Color Weakness Mode

BenQ has developed Color Weakness Mode which applies additive color mixing for those with the Deuteran (green) and Protan (red) inefficiencies. It mixes varying proportions or intensities of two or three additive primaries to create intermediate colors and can thus offer a color filter that enables its users to distinguish colors more easily when they study the photos, maps or statistic charts on the monitor.



By interviewing people with color vision deficiency, BenQ has developed 2 kinds of color filters for the color weak by fine-tuning and enhancing color on the display based on these findings. Both the red and the green filters are adjustable according to varying degrees of the color vision deficiency and people with color vision deficiency can pick out the settings from 0-10-20 to offer a better viewing experience.