
# Why color vision is crucial in outdoor lighting

White paper


# Introduction

We are becoming more urban every day. Humans enjoy living together, in society. Today, more than half of the world's population resides in urban areas, as highlighted in a population and urbanization report by Our World in Data [1]. And this trend is only growing. By 2050, projections indicate that two out of every three people will live in cities.

In a constantly evolving world, human activity never stops—day or night. Light is essential to human beings; it allows us to move around, work, read, and connect with others. We need to see to do almost anything, and we want our lives to remain dynamic even after the sun goes down.

But people don't see well at night. Once sunlight fades, our ability to see diminishes significantly. Under low light, our eyes struggle to distinguish colors, especially those in the yellow, orange, and red spectrum. This reduces visibility, makes it harder to recognize objects and people, and slows our reaction time to potential hazards.

At Signify, we've leveraged our deep expertise in lighting, human vision, LED technology, and artificial illumination to improve visibility and color perception under low-light conditions at night. The result is Philips ColorRevive, an innovative LED lighting solution that enhances visual perception and color representation while maintaining low energy consumption.

# The benefits of enhanced color vision at night

**Our eyes and brain have evolved to see the world in color.**
The ability to distinguish colors has been with humans since the very beginning, helping our ancestors quickly identify ripe fruit or recognize venomous animals based on their color.

In today's society, color perception remains just as crucial:

- A red light signals danger and tells us to stop, while a green light indicates it's safe to go.
- In cities, cyclists and road workers wear high-visibility vests in bright colors so that drivers and pedestrians can easily spot them, helping to prevent accidents.
- Recognizing colors also helps us identify people—we can pick a friend out of a crowd in a busy place—or distinguish objects, such as spotting the taxi we need among all the other vehicles.

**Being able to see colors is just as important at night, even when light levels are kept low to save energy.**
Our vision relies on contrast—the difference between light and dark tones—and color contrast, which is the distinction between different colors, to recognize objects and perceive our surroundings.

**Color helps us differentiate between objects and also between objects and their background.**
That's why color perception provides us with a wealth of visual information. If we're walking down a quiet street at night, we want to be able to see the people around us, recognize their facial expressions to assess if they pose a threat—and we want to do this as early as possible, with enough time to avoid a potentially dangerous situation.

**Our ability to appreciate colors also has a huge impact on our mood.**
We are captivated by the multicolored bursts of fireworks or a vibrant flowerbed in a park. We are moved by the beauty of paintings in a museum and find relaxation in the warm hues of a sunset. On the other hand, dimly lit places where we struggle to clearly see our surroundings make us feel uneasy and on edge.

> Good visibility provides a greater sense of security, making us feel comfortable and more inclined to stay longer in a particular space.

Color perception gives humans an incredible amount of visual information, helping us distinguish objects from each other and from their background.

# Color and object recognition

In human vision, color plays a crucial role in quickly and accurately recognizing complex objects. Our brain processes an object's visual characteristics—its shape and color—combining them into a single neural representation. This information is then integrated with what we already know about the world. If we have a prior representation of a particular object, we can compare it to the new information and quickly determine whether it is similar or different.

For some objects, color is a key identifying feature. For example, we expect fire extinguishers to be red—if they were green or blue, we would have trouble recognizing their functionality.

Various studies have shown that:

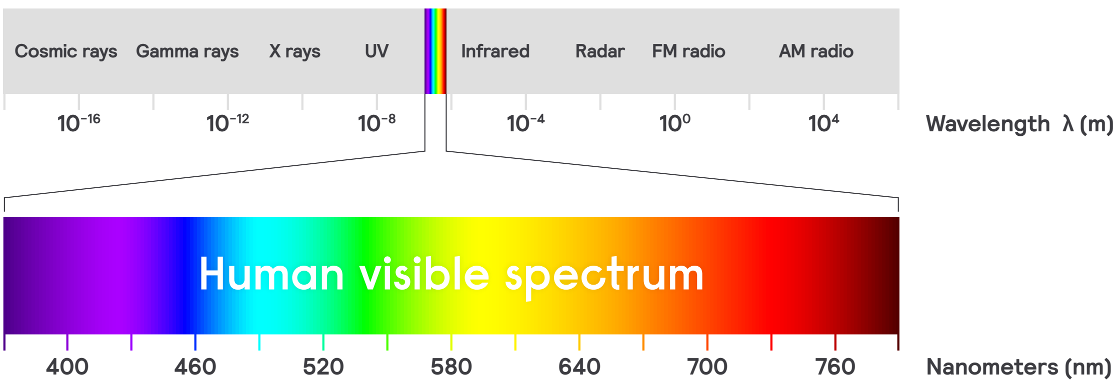
- Color is an important factor in facial recognition [2].
- Color contrast affects the visibility of objects on roads [3].
- Changing an object's standard color or removing its color altogether increases the time needed to recognize it [4].

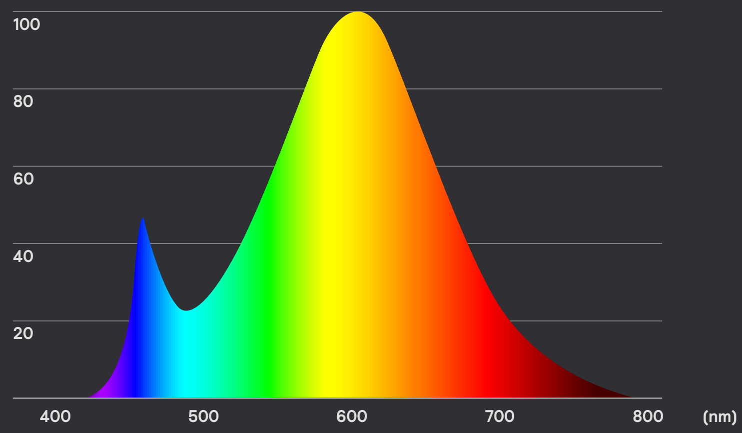
Altering the typical color of a familiar object slows down recognition and, in some cases, may even prevent it entirely.

# Light and Color

The term spectral power distribution (in short: spectrum) refers to the distribution of energy in electromagnetic waves of different lengths. The human eye can only perceive a limited portion thereof, typically between 380 and 780 nanometers (nm). This range is what we call visible light, or simply light.

Light sources emit energy (spectral power), primarily within the range of waves visible to humans. In daylight, our eyes are particularly sensitive to light with a wavelength of around 555 nm. At night the peak sensitivity shifts to 507 nm, that is towards the blue part of the visible spectrum.






Standard white LED spectrum

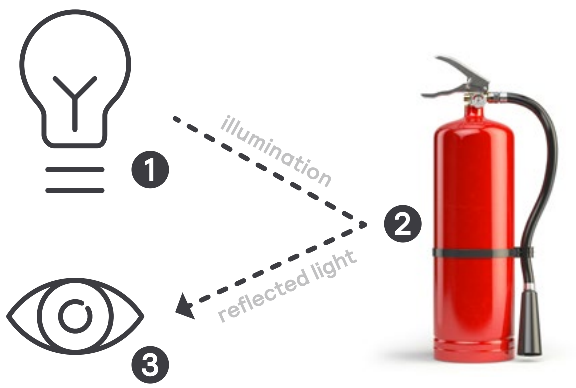
We perceive an image of the world around us because of the light reflected by objects in the visual scene. Just like a light source is characterized by spectral emission, an object is characterized by spectral reflection. This indicates how much of the energy contained in a wave of light is absorbed by the object and how much is reflected by it. Objects appear to have different colors because they have different distributions of energy in the reflected light spectrum.

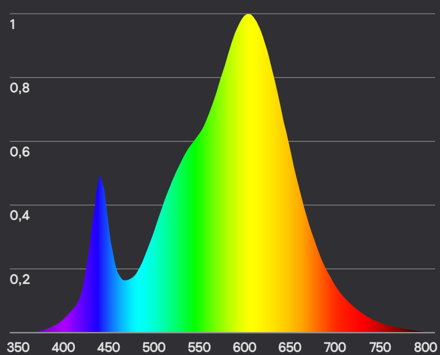
Taking the example of our fire extinguisher again: we see it as red because its surface reflects red wavelengths more strongly than others. If we were to replace the light source with one that does not emit wavelengths in the red part of the spectrum, the extinguisher would absorb all the waves, and it would appear much darker, almost black.

Thus, the color we perceive depends on three key factors:

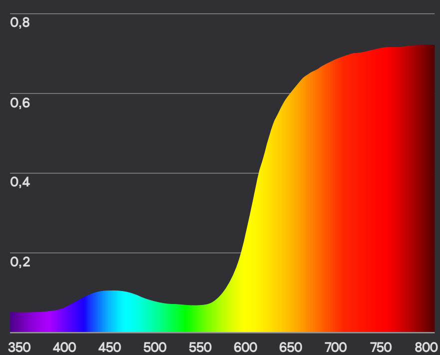
1. The spectral power distribution emitted by the light source.
2. The spectral reflection of the object.
3. The spectral sensitivity of the human eye.

The following image illustrates how the color spectrum that reaches the eye is the result of both, the light source's spectrum and the reflection spectrum of the object.

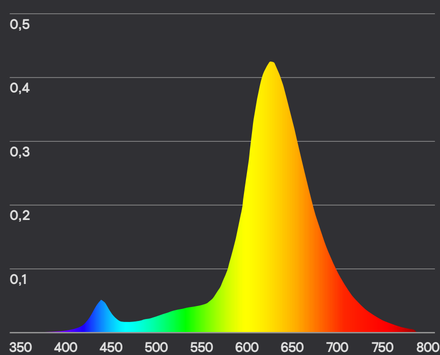



1. Normalized illumination spectrum



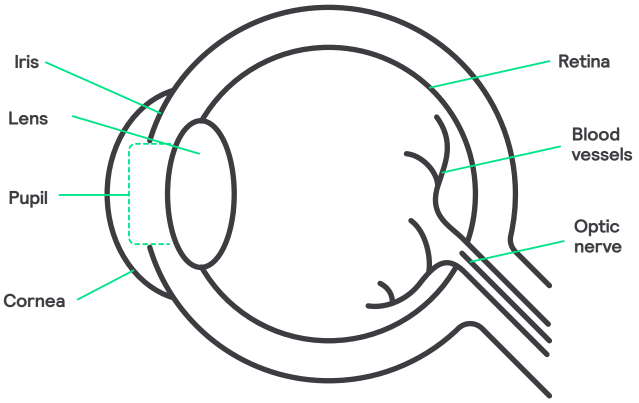

2. Object reflection spectrum

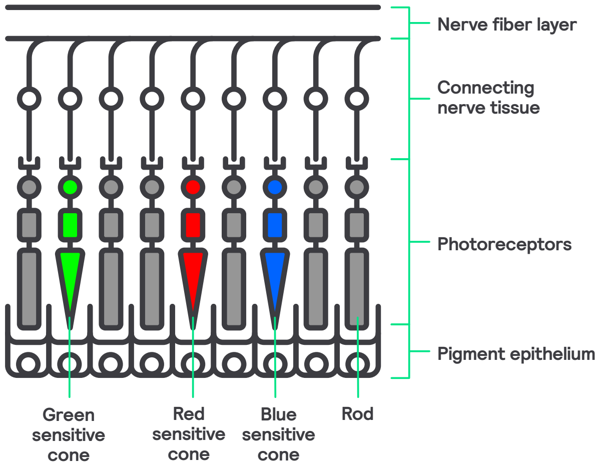



3. Reflected light spectrum

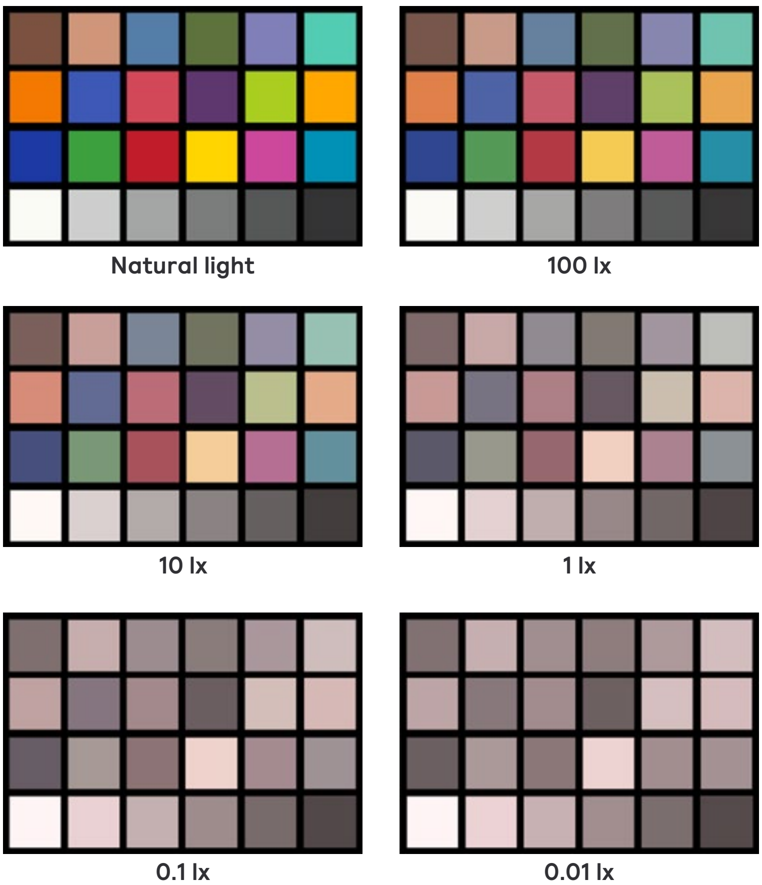
# Less light, Less color

Our eyes perceive light through photoreceptors called rods and cones. To see in color, our cones— which have evolved to see properly in daylight—are divided into three types: those sensitive to the red, green, and blue parts of the spectrum. At night, as natural light levels decrease, the sensitivity of the cones also diminishes, reducing our ability to perceive colors.




Schematic representation of the human eye, with the rods and the three types of cones.

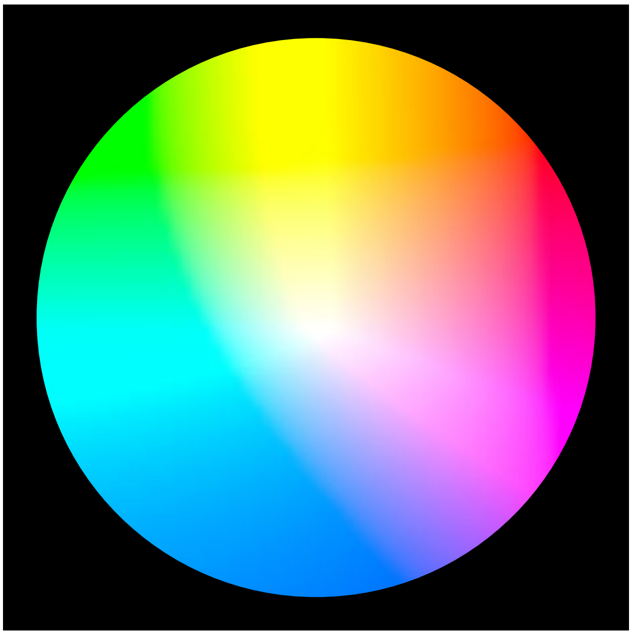


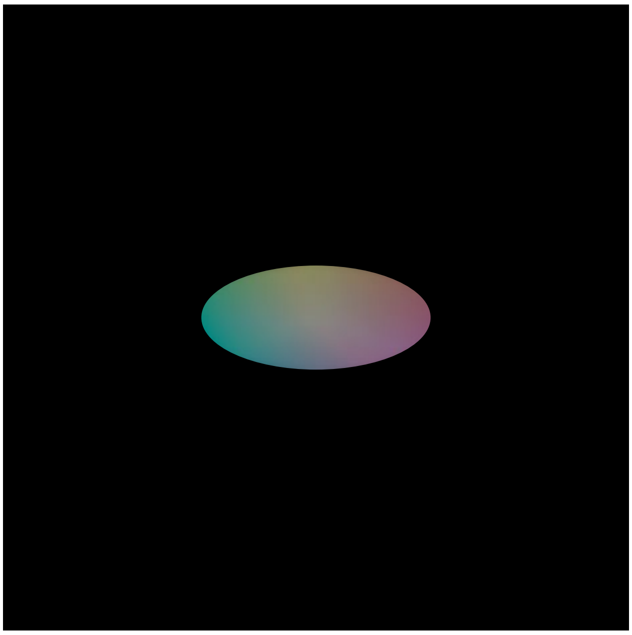

Simulation of reduced color perception as light levels decrease, based on Dr. Shin's study [(5)].

Artificial lighting in our cities allows us to extend our active hours, enabling good enough visibility. However, the light levels from artificial outdoor illumination are much lower than those of natural light, especially nowadays, as we focus on reducing energy consumption. As a result, standard urban lighting does not allow us to perceive colors as well.

This reduction in color perception can be represented within a scientific color space [6]. The more color we perceive, the larger the area covered in the color space. In this way, a light source's ability to enhance color vision can be represented by the size of the area within the color space.

The following image is a representation of the difference in the covered area at high and low light levels. On the right, we see how the perceptible color area shrinks significantly compared to the left and loses color intensity. In addition, the vertical axis (yellow-blue) shrinks more than along the horizontal axis (green-magenta) due to the different sensitivity of the three types of cones at low light level.





Representation of how the perceptible color area changes from high light levels (left) to low light levels (right).

# LED lighting that enhances color vision

We have analyzed the importance of color perception for humans, the impact of light levels on color visibility, how a light source's spectrum affects our perception of color, and the growing need for artificial lighting to be more energy-efficient.

A natural question that arises from these factors is: How can we improve color visibility without increasing energy consumption?

As we have seen, by adjusting the spectral distribution (spectral power), we can enhance the color saturation of certain objects without increasing the amount of light. For example, yellow, orange, and red colors fall within the 560 to 800 nm range. If we modify a light source's spectrum to emit more energy within this wavelength range, objects in these colors will reflect more light, making them appear more vivid to our eyes. This can help people identify stop signs in urban areas more quickly and from a greater distance, improving road safety.

In essence, we can stimulate all three types of cones in our eyes by using spectral distributions that enhance the color range to which they are most sensitive.

Philips ColorRevive technology expands the color gamut based on the sensitivity of the human visual system at night, creating an enriched white light spectrum without increasing brightness levels.

Compared to ordinary urban lighting sources optimized for energy efficiency, our ColorRevive spectrum offers two major benefits:

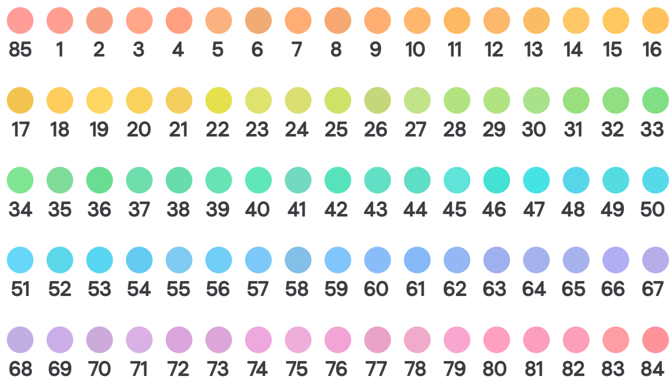
- At the same light level, ColorRevive provides an expanded color gamut, making it easier to distinguish subtle differences between similar colors.
- With only a slight 2% increase in energy consumption, the color gamut area expands by a factor of 1.46.

# Color contrast and Gamut Area

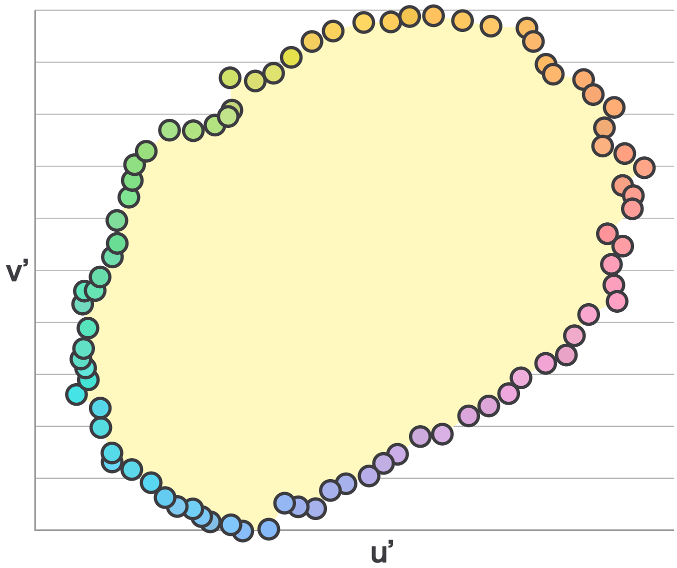
To quantify the effect of ColorRevive, the Farnsworth-Munsell Hue Test [7] was used. It is a standardized color ordering test used to assess someone's color discrimination ability and detect color blindness.

It features 85 test samples, ensuring an accurate measurement of ColorRevive's color contrast enhancement. Each color sample in the test corresponds to a point in color space, which varies depending on the light source illuminating it.

The gamut area of a light source is calculated as the enclosed area formed by all test samples. The larger this area, the greater the contrast between colors, making it easier to differentiate between them.




The larger this area, the greater the contrast between colors, making it easier to differentiate between them.




Color samples from the Farnsworth-Munsell 100 Hue Test (top) and their distribution in the CIE 1976 u'v' color space under daylight illumination (bottom).

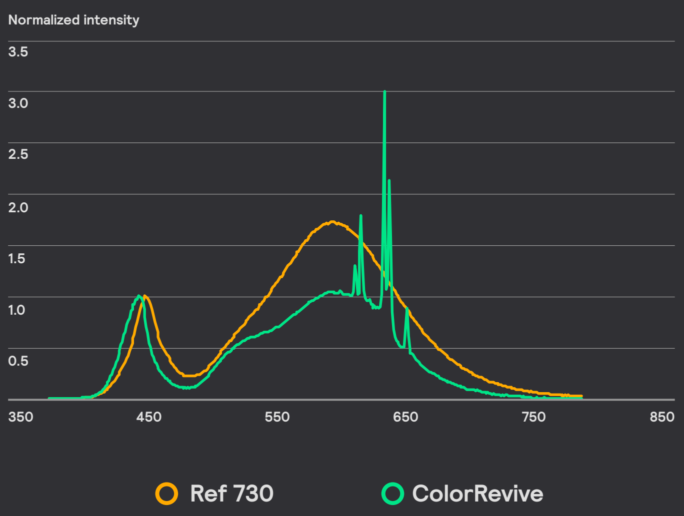
# Enhancing color by expanding the Gamut Area

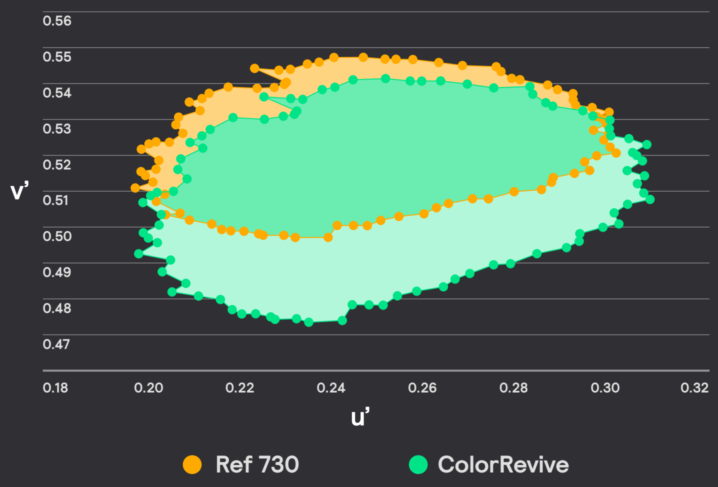
ColorRevive is an outdoor LED lighting solution that enhances color perception compared to a standard 730 and 830 solution. 730 is one of the most commonly used colors for outdoor lighting applications. Therefore, it is used as a reference. In addition, it is also of interest to compare ColorRevive to a solution with equal CRI – in this case 80 – to provide a like-for-like comparison.

The latter comparison reveals that LED lighting solutions with identical CRI and CCT can result in different color perception and visual experience. In fact, a laboratory experiment using the FM hue test showed a 25% reduction in color ordering errors under ColorRevive compared to a standard 830 light at 20 lux.

Using the same light level, our solution achieves a gamut area that is 43% larger than the reference 730 LED. The following image illustrates the parameters defined in the study.

Spectral power distribution of Philips ColorRevive and the reference LED 730 (left) and the associated gamut areas in the CIE 1976 u'v' color space (right).




This table provides the full spectral specifications of ColorRevive LED compared to the LED 730 and LED 830 references.

| LED | Reference 730 | ColorRevive | Reference 830 |
|---|---|---|---|
| CCT | 3000K | 3000K | 3000K |
| CRI (Ra) | 70 | 80 | 80 |
| R9 | -30 | 22 | 11 |
| Color gamut area | 100% | 143% | 98% |

# Improved visibility or reduced energy consumption

Based on the results in the table above, ColorRevive offers enhanced color perception compared to the reference LEDs 730 and 830.

However, this is not the only possible approach. As shown in the table below, another perspective focuses on energy consumption. With ColorRevive, we can theoretically match the color gamut area of the reference LED while reducing light levels from 5 lx (reference) to 3.5 lx with ColorRevive—resulting in a 27% energy savings while maintaining the same color appearance. The relationship between light levels and color appearance was previously discussed in the section “Less light, Less color” [5].

| LED | Reference 730 | ColorRevive | Reference 830 |
|---|---|---|---|
| Lux needed for same color visibility as 730 | 5 lx | 3.5 lx | 5.1 lx |
| Electrical energy usage at same color visibility as 730 | 100% | 73% | 109% |

# Global objectives and the impact of Lighting

In 2015, United Nations member states established 17 Sustainable Development Goals (SDGs) [8] to protect the planet, combat poverty, and promote equality.

The International Commission on Illumination (CIE) fosters cooperation and knowledge exchange in topics related to light and lighting, color and vision, photobiology, and imaging technology. In September 2023, the CIE updated its research strategy, incorporating SDGs and outlining how outdoor lighting can enhance urban environments—making them more attractive and inviting, encouraging social interaction, improving visibility, and fostering a sense of security.

According to CIE criteria, lighting can contribute to achieving the following UN SDGs:

- Better visibility and a safe, pleasant environment encourage walking and cycling, promoting healthy lifestyles (SDG 3).
- Stimulating nighttime activities and facilitating pedestrian and vehicle mobility in outdoor spaces after dark (SDGs 8 and 11).
- Efficient outdoor lighting helps to reduce energy consumption (SDG 12).
- Proper LED optical design minimizes light pollution and protects local wildlife habitats (SDGs 14 and 15).

At Signify, we prioritized these considerations—aligned with CIE's strategy—during the development of ColorRevive technology.


# Summary

For humans, the ability to clearly perceive colors is extremely important. That's why it's a crucial factor when illuminating urban and residential spaces.

As we've seen, proper lighting helps create inviting and pleasant environments, encouraging people to spend more time outdoors, promoting tourism, and driving economic growth. Good lighting also enhances navigation and movement, improves the visibility of objects and facial features, and increases the perception of safety—helping to reduce accidents and crime.

At the same time, lighting must become increasingly efficient—reducing energy consumption, ensuring easy installation and maintenance for long-term performance, lowering operational costs, and offering a long lifespan to minimize replacements, reduce waste, and support a more sustainable, environmentally friendly world.

Philips ColorRevive technology enhances color perception without increasing light levels, or maintains the same color appearance as reference LED 730 while significantly reducing energy consumption. Both options align with the sustainability goals of the United Nations and CIE strategies.

# Literature


(1) https://ourworldindata.org/urbanization#what-share-of-people-will-live-in-urban-areas-in-the-future

(2) Color helps in face recognition, research shows. MIT News - Massachusetts Institute of Technology, July 31, 2002.

(3) Assessment of the Impact of Color Contrast in the Detection and Recognition of Objects in a Road Environment. Travis N.Terry, Ronald B. Gibbons - Virginia Tech, Dec 16, 2011.

(4) The Influence of Object-Color Knowledge on Emerging Object Representations in the Brain - PMC (nih.gov), Aug 26, 2020.

(5) A Color Appearance Model Applicable in Mesopic Vision. Jae Chul Shin, Naoki Matsuki, Hirohisa Yaguchi, Satoshi Shioiri. Optical Review Vol. 11, No. 4 (2004).

(6) CIE Colorimetry 15 (Third edition). CIE. 2004.

(7) Farnsworth, Dean. "The Farnsworth-Munsell 100-hue and dichotomous tests for color vision." JOSA 33.10 (1943): 568-578.

(8) https://www.un.org/sustainabledevelopment/