WHITE PAPER

Lighting for network video

Lighting design guide

November 2023

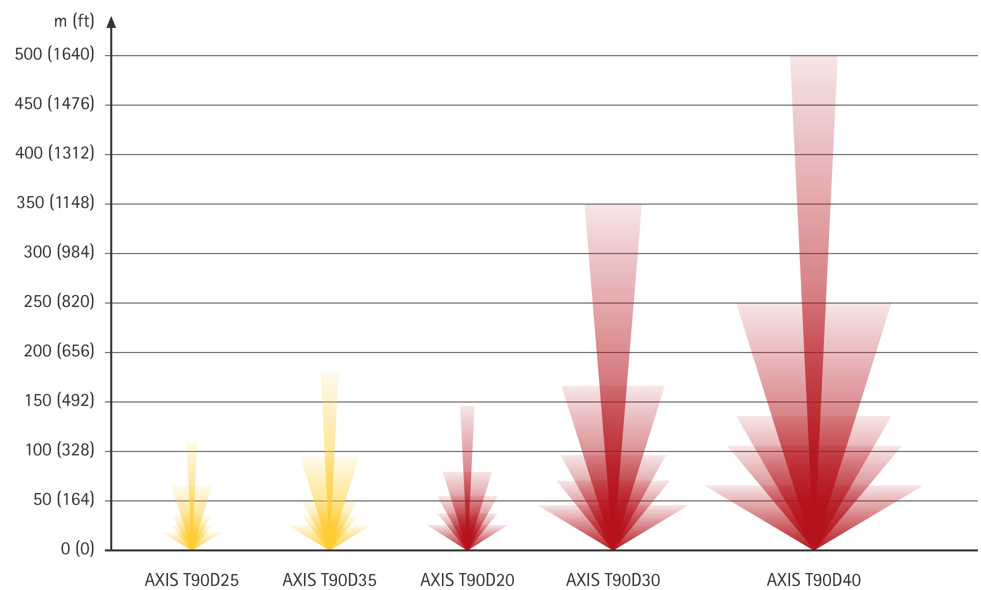
Summary

Selecting a network camera for surveillance involves several considerations and lighting is one such consideration. The view area's lighting source and situation determines the camera's performance and image quality.

Today, light emitting diodes (LEDs) are good lighting solution for most network video systems. They are popular for their cost effectiveness, lasting operating life, and low power consumption. The consideration for day-time surveillance slightly differs from night-time surveillance where there is a need for different types of illumination. For example, a color-corrected illuminator helps to achieve true objects color during night-time surveillance.

There are other light factors to consider, depending greatly on what you want your cameras to perform. They include:

- Light behavior: this relates to the different surfaces light could strike on and the resulting effect on image quality. It can be a diffusing or reflecting material (specular reflectance, diffuse reflectance or retro-reflection).
- Illumination distance and pattern: any lighting system designed for network video surveillance must be able to provide even illumination for good performance. Lighting should not be too narrow or wide for a camera's field of view and there is also a need to consider the distance of the illuminator to the object. Axis illuminators provide flexibility by offering several angles from which you can select the best angle of illumination for your field of view.



These factors among many more are fully explained in this white paper.

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1 Introduction

When selecting a network camera for day or night surveillance, there are several elements impacting image quality that are important to understand. This guide is intended to give an introduction to one of those elements, ‘how lighting affects image’, which is one of the important factors that needs to be taken into consideration for creating favorable lighting in dark environments.

2 What is light?

Light is fundamental to network video. It is the light reflecting from the scene that allows images to be visible to the human eye and to the camera. So the performance of any network video system depends not only on the camera and lens, but also on the quantity, quality, and distribution of available light.

Light is energy in the form of electromagnetic radiation. The light’s wavelength (or frequency) determines the color and type of light. Only a very narrow range of wavelengths is visible to the human eye, i.e., from approximately 400 (violet) to 700 (red) nm . However, network video cameras can detect light outside the range of the human eye, allowing them to be used not only with white light, but also with near-infrared light (715-950 nm) for night surveillance.

The behavior of light varies according to the material or surface it strikes, where it is either reflected, diffused, absorbed or (more commonly) subjected to a mixture of these effects. Most surfaces reflect some element of light. Generally, the paler the surface, the more light it reflects. Black surfaces absorb visible light, while white surfaces reflect almost all visible light. Infrared is not always reflected in the same way as visible light. The way infrared is reflected depends on the nature of the material.

3 What is color?

The processes by which the human eye and brain see color are very complex, so the definition of color presented here is of necessity greatly simplified.

The brain interprets light at wavelengths that are visible to the human eye as colors; from 400 (violet) to 700 (red) nm. Perception of color is done in specialized retinal called cone cells. Cone cells contain different forms of pigments that results in different spectral sensitivities. Human eye contain three types, resulting in trichromatic color vision (red, blue, and green). All other visible colors between these primary wavelengths such as indigo, cyan, yellow and orange are detected as mixtures of the primary colors.

When an equal amount of red, blue, and green is viewed together, these wavelengths appear as white light. The camera collects light and detects color in a similar way. Most digital cameras use Bayer pattern, a color filter that enables color photography using an image sensor. This pattern of color filters is deposited on the sensor after the silicon is complete using the primary colors (red, blue, and green). This pattern is optimized to ease demosaicing, a process that interpolates the missing colors. This pattern imitates the human eye’s sensitivity to different colors by using double amount of green pixels compared to blue and red.

A green leaf looks green because it reflects green wavelengths present in white light. If you look at it under a red light, it will appear black, because the lighting contains no green. The same applies when you buy a colored item of clothing, you might take it to the door or window to check how it looks in daylight. This is because interior lighting contains a slightly different mixture of wavelengths from the light outside, and consequently alters the apparent color of the garment.

The exact same can be said for network video. The color output of an illuminator affects the color seen by the camera, e.g., the yellowish light seen under sodium street lighting. To provide true color network video images, white light illuminators need to provide color-corrected illumination matched to the visible spectrum.

Colored objects reflect light selectively. They reflect only the wavelengths (i.e. colors) that you see and absorb the rest. A red flower, for instance, contains pigment molecules that absorb all the wavelengths in white light other than red so that red is the only color it reflects.

At wavelengths lower than the visible spectrum, the radiation becomes ultraviolet (UV), which burns the skin (tanning) and is therefore unsafe for network video. At wavelengths higher than the visible spectrum, the radiation becomes infrared (IR).

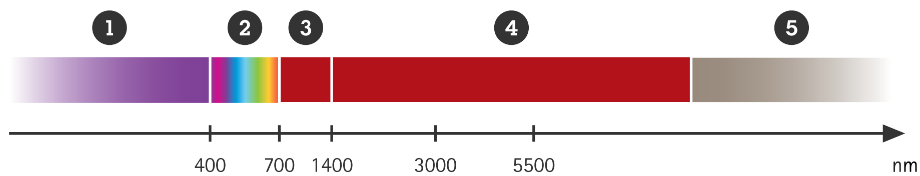

Figure 1. Part of the electromagnetic spectrum, with energy ranges marked in wavelengths (nanometres). The energy ranges from left to right are: (1) Ultraviolet light, (2) Visible light, (3) Near infrared light, (4) Infrared light, (5) Microwave.

4 What is infrared light?

Infrared light (IR) is light with longer wavelength, outside the visible spectrum, thus invisible to the human eye. The infrared light used for network video lighting is at wavelengths slightly greater than the visible spectrum, i.e., between 700 and 1100 nm. This IR range is also known as near-infrared light (NIR). NIR light is detected in all three pixels independent of the primary color filter, so any NIR light is also counted as colored light. This makes color imaging impossible unless the camera is fitted by a IR-filter that blocks all NIR light. This filter is installed at day-time in front of the sensor and removed by an actuator at night-time when there is almost no light, enabling all pixels to collect NIR light (in all pixels) and visible light in each type of colored pixel. To make this image from mixed light usable, it discards the (already destroyed) color information and shows the image in black and white.

As the camera can see some infrared light that is invisible to the human eye, there are various alternatives as to how it is displayed on a computer screen. Usually the image is shown in black and white, with the scene appearing as it would if the human eye could see infrared light. Other false colors can also be used to show the content of infrared light compared to visible light. This is sometimes used in scientific imaging.

Applications that require covert surveillance, or which must otherwise avoid low levels of visible lighting are ideal for infrared light.

5 Color or monochrome images?

The first decision to make when setting up night-time surveillance lighting is whether to go for color or monochrome images. Color is preferable in many cases, but care must be taken to provide true color, which can be achieved by using a color-corrected illuminator. Consider the yellow light provided by low pressure sodium street lighting. Using incorrect white light can impair performance and lead to inaccurate color rendition and a camera is only as good as the available light.

Infrared should be the method of illumination in all cases where white light would be too intrusive or where covert surveillance is required. Infrared lighting can also illuminate at greater distances than white light at the same power level.

6 Brightness and glare

Brightness is the subjective perception of luminance from a given area. Glare is the result of excessive contrast between bright and dark areas within the field of view. This problem is greater in darkness, when contrast between bright and dark areas make it difficult for the human eye (and network video cameras using infrared) to adjust to changes in brightness.

Diffusion:

A diffusing material scatters light passing through it. The direction and type of light changes as it passes through the material.

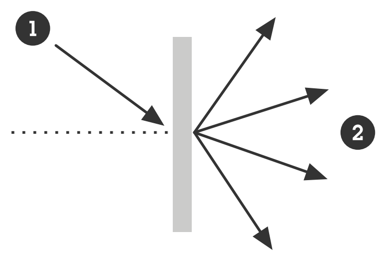

Figure 2. Light diffusion. Incident light (1) and diffused light (2)

Reflection:

When light hits a surface, it can bounce back as a reflection. The quality of the surface affects the type of reflection. Highly textured surfaces scatter light, due to tiny irregularities in the material, while a flat surface such as a mirror provides a more focused reflection.

- **Specular reflectance**:

  If a surface reflects light like a mirror, it is said to have specular reflectance. With specular surfaces, the angle of incidence is equal to the angle of reflectance.

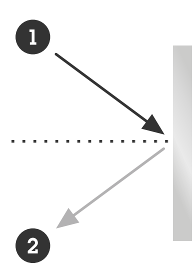

Figure 3. Specular reflection. Incident light (1) and reflected light (2)

- **Diffuse reflectance**:

Diffuse reflection surfaces bounce light in all directions due to tiny irregularities in the reflective surface. For example, a grained surface will bounce light in different directions. A diffuse reflective surface can scatter light in all directions in equal proportions.

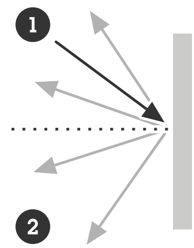

Figure 4. Diffuse reflection. Incident light (1) and diffuse reflected light (2)

- **Retro-Reflection**:

  In this type of reflection, the surfaces bounce light back in the direction it came from. Traffic signs and vehicle number plates have retro-reflective surfaces.

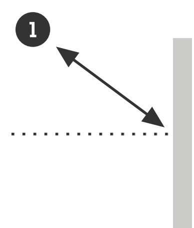

Figure 5. Retro-reflection. Incident light (1)

Reflectance levels:

Reflectivity is a measure of the reflected power compared to incident power. Objects reflect light at different intensities, and energy not reflected is absorbed and converted to heat. Objects with low reflectivity absorb a lot of energy, which is why, for example, a brick wall feels warm in sunlight.

It is important to remember that the camera does not use the ambient light on a scene as detected by a light meter, but instead uses the amount of light reflected by objects in the scene.

Absorption:

Some surfaces absorb light. Colored surfaces absorb some light and reflect the rest, which is why they appear in a particular color. A black surface absorbs most of the light falling on it. The light energy is usually turned into heat, so dark materials heat up easily.

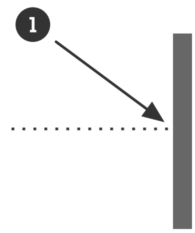

Figure 6. Light absorption. Incident light (1)

7 Light sources

Incandescent lamps (including halogen):

Incandescent bulbs were the first developed bulbs and are highly inefficient, wasting 90% of input energy as heat, making them hot to touch. Halogen bulbs provide a minimal increase in efficiency but still waste up to 85% of the input energy as heat. For network video purposes, incandescent bulb life is limited and they are very inefficient.

Fluorescent lamps:

Use of these lamps for network video purposes is limited, due to the "pulse" effect perceived when viewing the scene with a network video camera. These lamps are generally low power and designed mainly for internal fitting. As they have a large diffused source, the light output is difficult to focus and control.

HID (high intensity discharge) lamps:

These are efficient lamps that provide good color rendition and have a long life, up to 12,000 hours. HID lamps could well be used in network video, but they suffer from long start-up times (2-3 mins) and cannot be turned on immediately after being turned off.

LEDs:

Light emitting diodes are the fastest growing lighting solution for network video applications. Their efficiency is typically 80-90%, with the greatest efficiency coming from LEDs producing red light. The LEDs are often chosen in network video applications because of their advantages, which include extremely low electrical consumption, low operating temperatures, and continuity of color throughout the unit's operating life.

Unlike traditional bulbs, LEDs are highly durable, insensitive to vibration, and their hard casing makes them difficult to break. They are also capable of emitting light at a given wavelength without the need for a filter and are quick start devices.

LEDs offer the lowest possible running costs (less than 100 watts for the highest power units) with the longest operating life, up to 100,000 hours (10 years). In comparison, fluorescent bulbs typically last 10,000 hours and incandescent bulbs 1,000 hours. For some LEDs, the driver circuit frequency may not be the same as the local power frequency in use, making it impossible to get a flicker-free image. In the U.S., LEDs always use 30, 60, 120, 240 Hz or higher and in Europe, LEDs use 50, 100, 150, 200 Hz or higher. For a flicker-free video, configure the camera and viewing screen to use the same frame rate.

8 Network video lighting - which wavelength?

White light: A mixture of light at 400- 700 nm provides true white light.

Practical uses:

- Illuminates an area for the network video system
- Improves the overall level of illumination for personnel
- Provides a welcoming environment for authorized personnel
- Deter crime by illuminating a secure area upon intrusion
- Can be used with monochrome, color, and day/night cameras

Infrared:

- 715-730 nm: Overt IR produces a red glow like a red traffic light
- 815-850 nm: Semi-covert IR with a faint red glow
- 940-950 nm: Covert IR, invisible to the human eye

Practical uses of infrared:

- Provides discreet or covert illumination for network video
- Minimizes light pollution
- Provides very long distance illumination
- Can be used with monochrome, day or night cameras

9 Light and safety

White light is visible to the human eye and we have a natural protection against overexposure to white light. The iris and eyelids close to reduce the impact of visible light. If this is not enough, we simply turn away from the light. Our eyes cannot automatically adjust to overexposure to infrared light because we cannot see it. However, infrared light does produce heat which can be used as a safety measure. Do not look at the source of light if you can feel the heat of the IR unit.

10 Beam patterns

The angle of illumination should be adjusted so it can light the whole scene adequately and provide illumination for network video. Modern Adaptive Illumination units allow the angle of illumination to be adjusted onsite, to suit the specific scene requirements. Lighting that is too narrow will produce white-out or glare in the middle of the scene, with some areas not correctly illuminated.

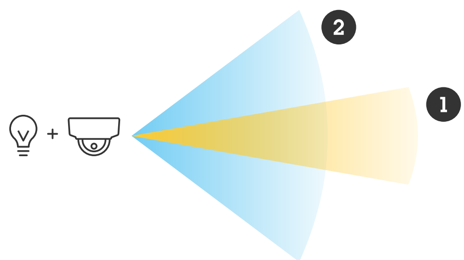

Figure 7. Lighting is too narrow (1) for camera field of view (2)

Lighting that is too wide means "wasted" light and reduced viewing distance.

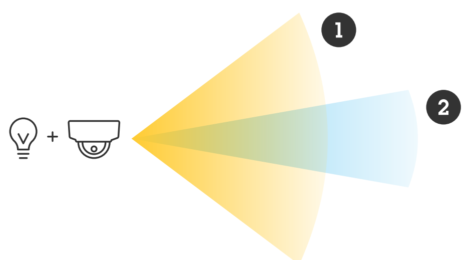

Figure 8. Lighting is too wide (1) for camera field of view (2)

Many installations use varifocal lenses, and ideally, there should be the same level of flexibility as regards lighting, so as to maximize system performance. Flexible illuminators for video surveillance, such as those in Axis' portfolio, offer a range of output angles that allows you to select the angle that covers the exact field of view and provides the best images. Adjustment is quick and convenient, and the available angles are easily selectable.

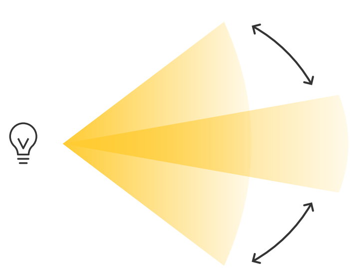

Figure 9. Adaptive illumination to cover many angles of view

11 The inverse square law

The amount of light available at a particular distance is inversely proportional to the square of the distance from the light source. As light obeys this inverse square law, we'll now look at how this law is applied.

As light travels away from the point source, it spreads both horizontally and vertically, with less light at greater distance. In practice, this means that if an object is moved from a given point to another point twice as far from the light source, it will receive only ¼ of the light ((2 x distance)^2 = 4).

Taking this further, if an object 10 m from a light source receives 100 lux, moving the object to 40 m from the source means it will receive only 1/16th of the light ((4 x distance)^2 = 16) resulting in the object receiving only 6.25 lux. The inverse-square law applies to both white light and infrared light in the same way.

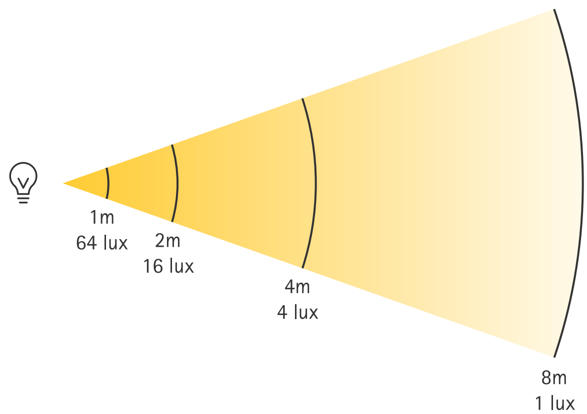

Figure 10. The inverse square law

12 Illumination distances for Axis products

The figure shown below is a guide to selecting an appropriate Axis infrared illuminator for the illuminator's distance to the object. Note that the solid area denotes optimum usage and the shaded area denotes less-than-optimum usage. Also, the lens you select determines the angle and illustrated light cone you will get. For example, AXIS T90D20 IR-LED has standard lens (10°) and diverging lenses (35°, 60°, 80°, 120°) which you can select from.

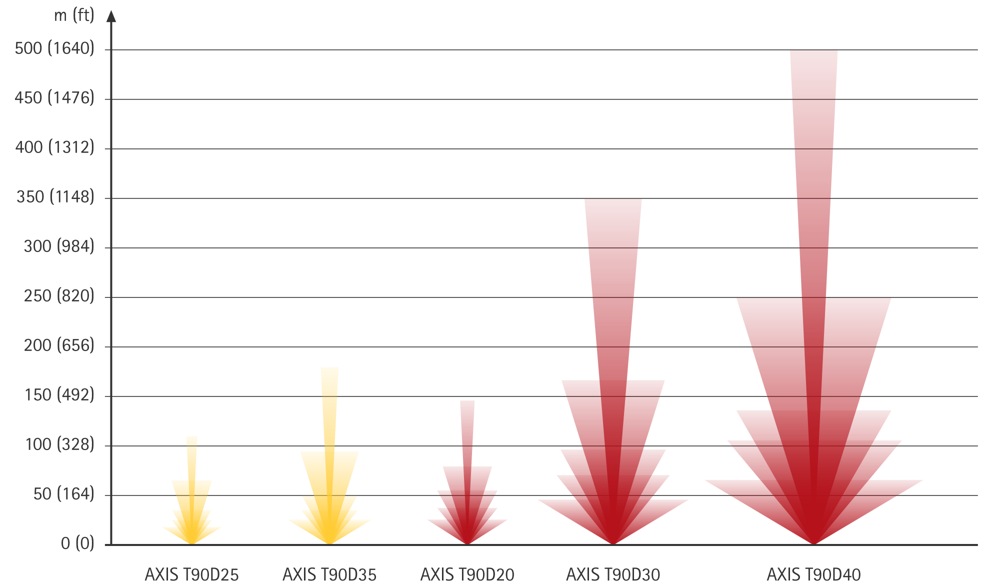

Figure 11. IR Illuminator selection chart

13 Using multiple illuminators

The inverse-square law explains how the amount of light drops over distance, but it can also be used to calculate how many additional illuminators are needed to achieve specific increase in distance.

If the distance from a single illuminator is doubled, then the amount of light is reduced to 25%. To illuminate at twice the distance possible with one illuminator (keeping the same power at the scene), four illuminators will be needed ($2^2 = 4$). Similarly, to achieve three times the distance of one illuminator, nine illuminators will be required ($3^2 = 9$).

The inverse square law can also be used to calculate the effect of using multiple illuminators, by taking the square root of the change in available light at source. For example, using four illuminators will produce a twofold increase in distance ($\sqrt{4} = 2$), and using 25 illuminators will result in a fivefold increase in distance ($\sqrt{25} = 5$).

It is not always necessary to use multiple illuminators to achieve increase in distance. Illuminators with narrower angles or more powerful illuminators may provide the required additional increase in distance.

If you only need to illuminate a particular object at a particular distance, using e.g. a zoom lens, you can place a small illuminator close to the object. An example is a gate or door at a site perimeter, relatively far from the site's buildings and other infrastructures.

Table 13.1 Distance increase with number of illuminators

No. of illuminators	Distance multiplier
1	1
2	1.4

Table 13.1. Distance increase with number of illuminators (Continued)

3	1.7
4	2
5	2.2
6	2.4
7	2.6
8	2.8
9	3

Doubling the illumination distance requires four times the power. Doubling the number of illuminators provides a 1.4 times increase in distance.

14 Measuring light

White light:

White light is measured in lux, the International System of Units (SI) of illuminance, which also takes into account the area the light is spread over (1 lux = 1 lumen per square meter). The foot candle is still widely used as a unit of measurement: 10 lux ≈ 1 foot candle. White light at the scene can be measured by the simple use of a light meter. Typical lux light levels are:

Table 14.1 Light intensity for various scenarios

Bright sunny day	10,000 – 100,000 lux
Overcast day	1,000 – 10,000 lux
Twilight	1 – 100 lux
Street lighting	5 lux
Full moon	0.1 lux
Bright, clear starlight	0.01 – 0.0001 lux

Infrared Light:

As lux is a measurement of visible light, and by definition, infrared produces invisible light, then lux cannot be used to measure infrared light. The most common form of measurement for infrared light is mW per square meter, a simple statement of energy output from a light source over a given area.

15 The need for even illumination

The most important aspect in designing any lighting system is achieving even illumination. Both the human eye and network camera or lens need to handle differences in the amount of light within a field of view.

When driving at night on an empty road, you can clearly see using only the headlights from your car. However, when a car approaches from the opposite direction, although the light on scene actually increases, your night vision will be impaired, as there is now a very strong light around the centre of the scene causing the iris in your eye to close. The same thing happens with a network video camera, a bright spot within the image will cause the lens to close and reduce night-time performance. To achieve the best images at night, the illumination must be evenly distributed using lighting products designed for this purpose.

OptimizedIR:

Axis OptimizedIR provides even illumination for a camera's field of view. It is specifically tailored to fit each camera. For example, the IR beam of an Axis pan-tilt-zoom (PTZ) camera with OptimizedIR automatically becomes wider or narrower when the camera zooms in or out, to achieve even illumination.

Cameras with OptimizedIR use high quality LEDs and provide good heat management, in addition to evenly illuminating a scene.

16 Specifying the correct camera

Sensitivity:

This describes a camera's sensitivity to light and essentially measures the minimum light level needed to produce acceptable images, although this value is very subjective. An image may be acceptable to one person and totally unacceptable to another.

Axis Lightfinder technology takes away noise and produces well-detailed images when there is low light. Therefore, cameras with Lightfinder will capture fully colored images and videos even in dark areas.

Sensitivity is typically measured in lux, with camera manufacturers stating the minimum lux level needed to provide acceptable pictures. However, this statement does not usually specify if the minimum lux figure represents the minimum light on scene, at the lens, or at the camera chip. For Axis cameras, this value always applies to the light on scene.

Although lux claims tend to be overstated, and although minimum lux only describes a camera's performance with visible light, this lux value is still one way to measure a camera's sensitivity, if the minimum illumination is subjectively compared in the same way.

There is no such thing as a zero lux camera, every camera needs light to produce high quality images. Even the most light-sensitive cameras will produce higher signal and lower noise pictures when there is more light. The exception is thermal cameras, which create images based on the heat that radiates from a vehicle or person, allowing the cameras to also produce images in complete darkness. Some cameras add a near-infrared (NIR) emitter to claim zero lux, but such cameras lose color wavelengths, making all objects look the same in black and white.

For more information about light sensitivity, you can refer to Axis' white paper, **Lightfinder**, available at *White paper | Axis Communications*

17 Specifying the correct lens

F-stop:

The f-stop (aperture) of a lens determines how much light passes through it to the camera chip. In simple terms, the lower the f-stop, the more light passes through the lens, although the lens' manufacture and quality also affects the amount of light that can pass through it. The table shows the impact of using different aperture lenses in a network video system (• = a full f-stop):

Table 17.1 F-stops and light levels required to achieve 1 lux at the sensor

F/number	Light passed in %	Amount of light needed to achieve 1 lux at sensor
f/1 ·	20%	5 lux
f/1.2	15%	7.5 lux
f/1.4 ·	10%	10 lux
f/1.6	7.5%	13.3 lux
f/1.8	6.25%	16 lux
f/2 ·	5%	20 lux
f/2.4	3.75%	30 lux
f/2.8 ·	2.5%	40 lux
f/4	1.25%	80 lux

For most camera sensors, the lower the f-stop of a lens, the more light will pass to the sensor. For a zoom lens, the best f-stop is only achievable at the wide setting. As the lens is zoomed, the aperture closes. This affects how much light is needed on scene to produce good images at low light levels.

Transmission:

The efficiency of a lens is measured by its transmission. Passing through the lens, some of the light will be lost as a result of the lens material, thickness, and coating characteristics. A lens with a higher efficiency will pass a higher percentage of the light. Whilst the f-stop of a lens describes how much light the lens will pass, it is not a measure of its overall efficiency.

The transmission of a lens changes with wavelength. For example, one lens may pass 95% of visible light and 80% at 850 nm infrared, while another may pass 95% of visible light and 50% at 850 nm infrared. When specifying the lens, consider the wavelength of light it will be used with. Also note that glass lenses tend to be more efficient than plastic lenses.

Corrected lenses:

- Infrared corrected lenses:

  Infrared corrected lenses are designed to remove the problem of focus shift between day and night light, using specialist glass and coating technology to minimize light dispersion. Focus shift is caused by the different wavelengths of light. Each individual wavelength focuses at a different point after passing through the lens.

- Color corrected lenses:

  Light sources, including the sun, produce a broad spectrum of lighting. White light is simply the range of the lighting spectrum visible to humans. As a result, a lens must control which light passes through to the camera, so as to create an image accurate to the images perceived by the human eye. Many cheap lenses do not efficiently match their color passing with the visible spectrum, so they provide inaccurate color images. Color corrected lenses pass only visible light and focus each individual color at the same point, providing true color and sharp images.

  Most color corrected lenses are not suitable for use with infrared lighting, although there are some exceptions.

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About Axis Communications

Axis enables a smarter and safer world by creating solutions for improving security and business performance. As a network technology company and industry leader, Axis offers solutions in video surveillance, access control, intercom, and audio systems. They are enhanced by intelligent analytics applications and supported by high-quality training.

Axis has around 4,000 dedicated employees in over 50 countries and collaborates with technology and system integration partners worldwide to deliver customer solutions. Axis was founded in 1984, and the headquarters are in Lund, Sweden