When considering light we can look at both the transmittance and reflectance of glass, specifically with the visible region of the electromagnetic spectrum.

THE ELECTROMAGNETIC SPECTRUM

The Sun provides energy across a wavelength region of approximately 150 – 4000 nm, covering the ultraviolet, visible and infrared regions of the electromagnetic spectrum. As a black body, with a temperature of 5778 K, the theoretical spectrum can be determined using Planck's law [1]. ASTM G173-03 [2] provides spectral data for extraterrestrial radiation at the atmosphere and terrestrial solar radiation at the Earth's surface.

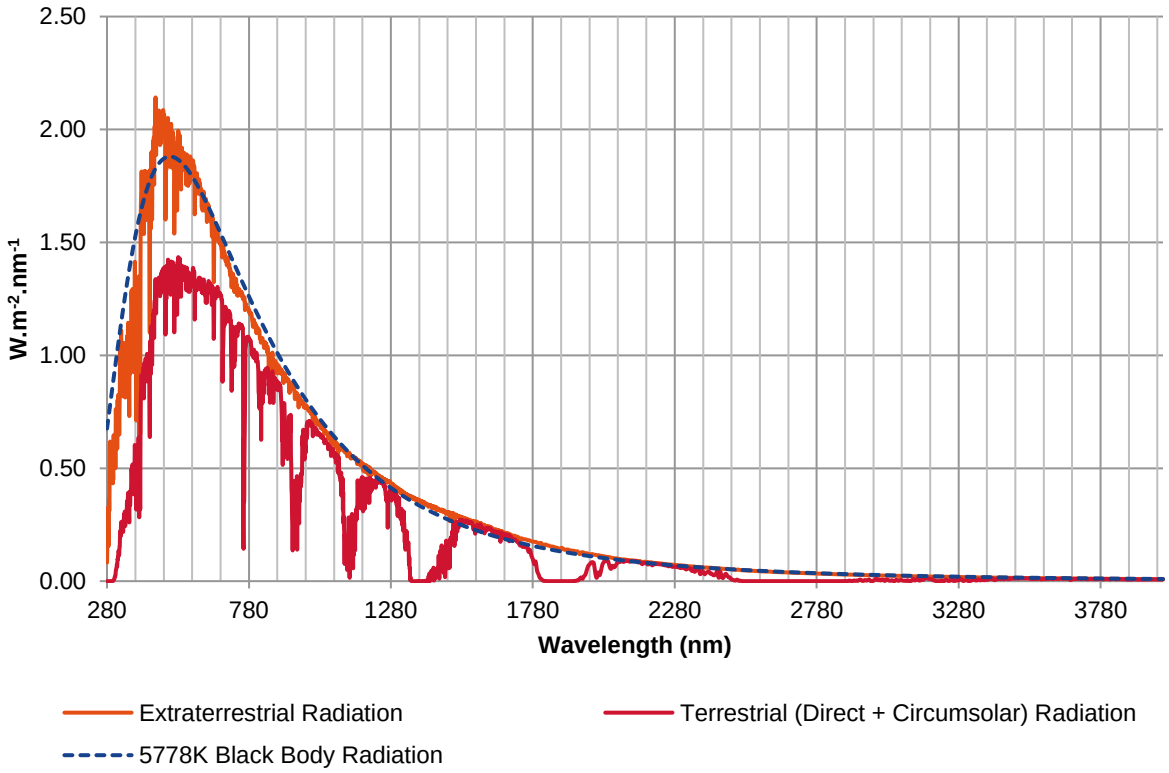

Figure 1 - Electromagnetic spectrum of solar radiation

HUMAN VISION

The human eye can discern electromagnetic radiation between wavelengths of 400 - 700 nm as visible light. There are three types of photoreceptors in the eye; cones, rods and intrinsically photosensitive retinal ganglion cells (ipRGCs).

Each cell type has a specific sensitivity and sensitivity range, which fundamentally determines its function;

- Rod cells are highly sensitive to light, and as such, enable vision at low light levels. When light levels are sufficiently low that cone cells aren't triggered, vision is solely dependent on rod cells, and as such colours aren't perceived.
- Cone function under relatively high intensity light, and as three types exist, each with different spectral efficiencies, these cells enable colour to be perceived. For daytime vision, cone cells are most relevant.
- ipRGCs don't contribute directly to vision but function to influence the circadian rhythm by detecting extremely low levels of light and controlling of the release of melatonin. Simply put, they restrict the release of melatonin, which leads to sleep, until light levels are sufficiently low.

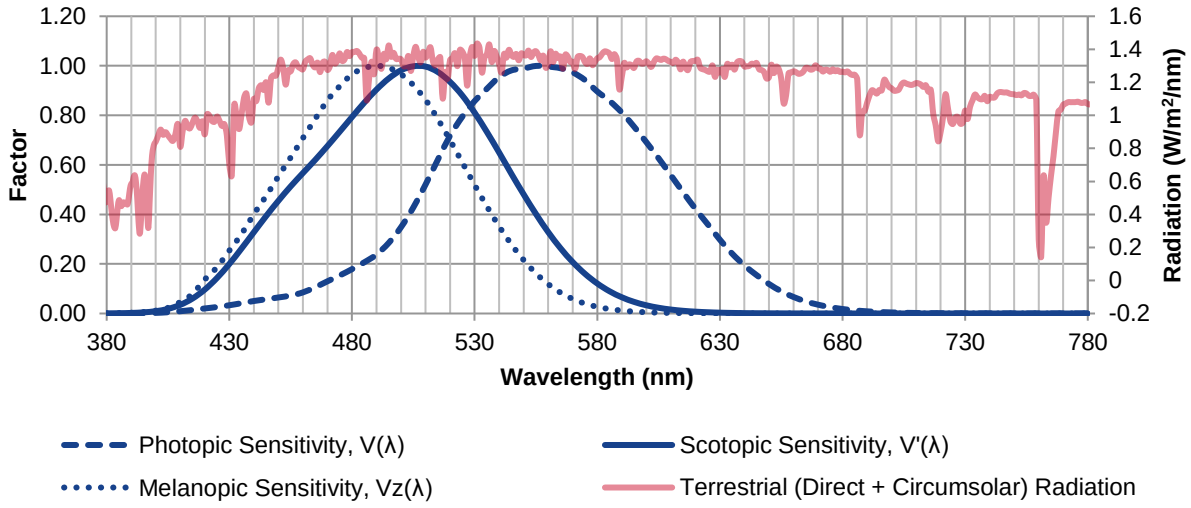

Figure 2 - Spectral sensitivities of cone cells (photopic), rod cells (scotpic) and ipRGCs (melanopic).

LIGHT LEVELS

Light levels are important to allow tasks to be carried out. Light levels are typically measured in lux, which is a measure of the amount of light over a given area. The Sun can provide up to approximately 100,000 lux to the Earth's surface, although the value will be dependent on climatic conditions, such as cloud cover, and the incident angle of the sun throughout the day and year. Typical light levels for both day and night conditions are shown in the following table;

Table 1 - Typical lux levels for specific conditions

Condition	Approx. Illumination (lux)
Sunlight	100,000
Daylight	10,000
Overcast Day	1,000
Twilight	10
Full Moon	0.1
Quarter Moon	0.01
Starlight	0.001

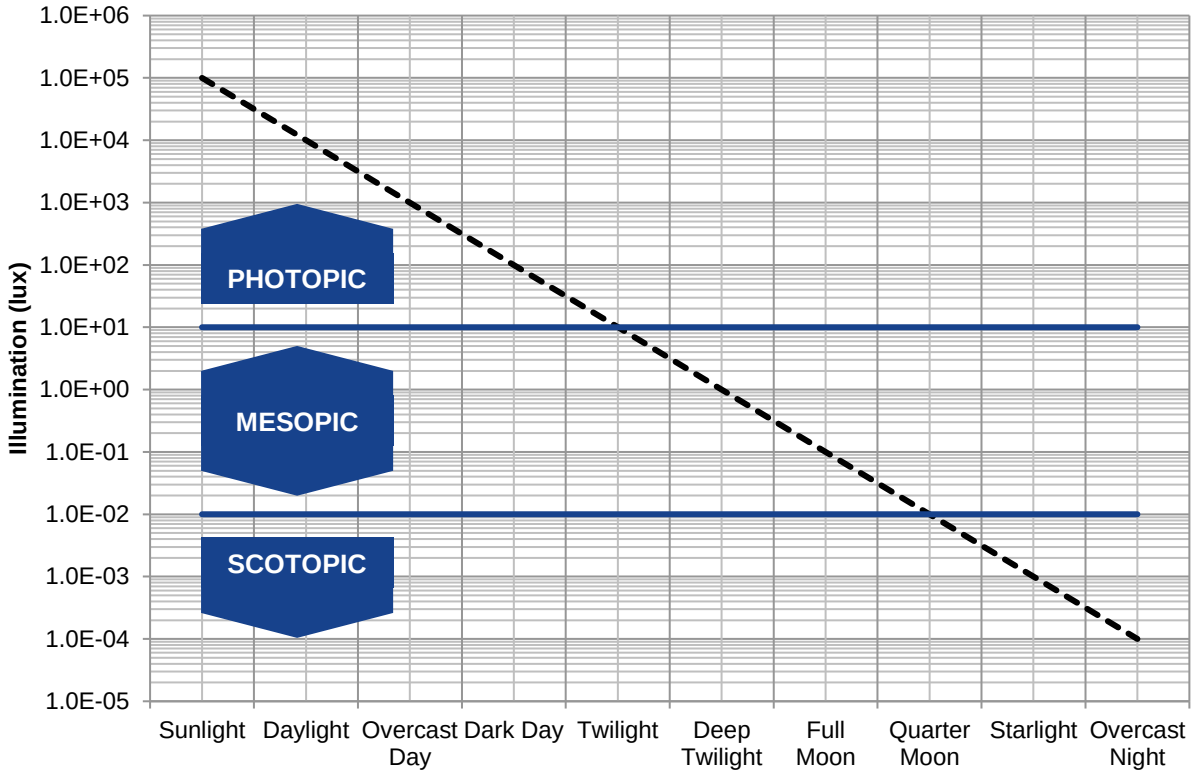

Figure 3 - Lux Levels & Vision Type

Mesopic vision is a combination of photopic and scotopic, and as such, the appearance of colour is changed from purely photopic vision. With photopic/daytime vision, various guidelines exist to provide lighting requirements for buildings, with the below examples taken from EN 12464-1:2002 [3].

Interior Type	Activity	Maintained Illuminance $\bar{E}_m$ (lux)
Offices	Writing, Typing, Reading, Data Processing	500
	Technical Drawing	750
	Reception Desk	300
Operating Areas	Pre-Op & Recovery Rooms	500
	Operating Theatre	1000
Educational Buildings	Classrooms, Tutorial Rooms	300
	Lecture Hall	500
	Sports Halls, Gymnasiums, Swimming Pools	300

PERCEPTION OF COLOUR

As mentioned previously, the cone cells in the eye fall into 3 types, which each have peak sensitivities to different wavelengths of light; short, medium and long, and as such are often referred to as S, M and L cones. These cone cells enable us to perceive colours and the spectral sensitivities of the cell types are shown below. Data adapted from work by Sharpe and Stockman [4];

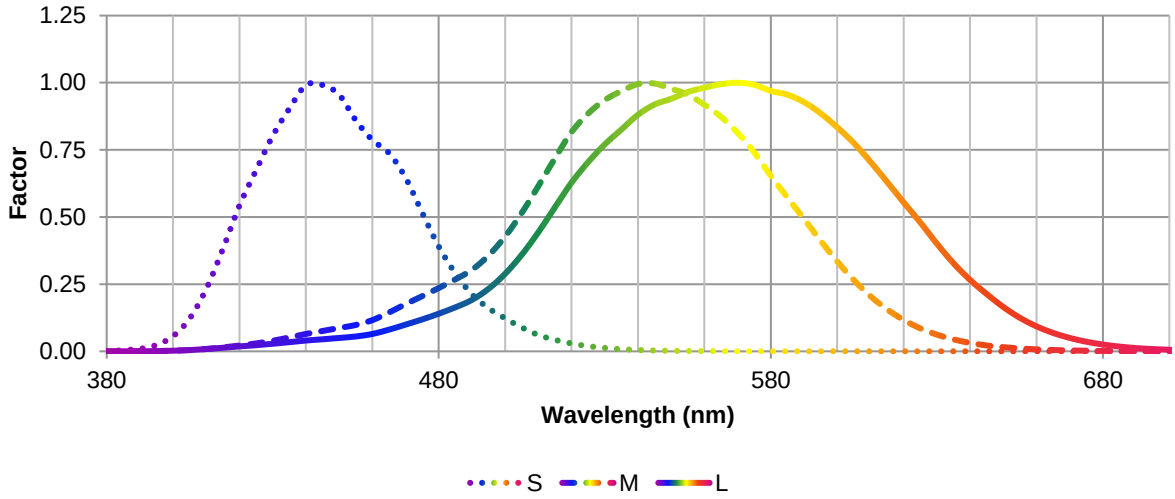

Figure 4 - Spectral sensitivity of S, M and L Cone Cells in Human Vision

As each cone type has a different wavelength sensitivity, or efficiency, when different cells are stimulated relative to the others, different colours are perceived. For example, if the S cone cells are stimulated significantly more than the M and L cone cells, blues will be perceived.

The relationship between colour sensitivity and colour rendering is discussed in Technical Document Solar & Thermal 1B.

REFERENCES

[1] M. Planck, Vorlesungen über die Theorie der Wärmestrahlung, Leipzig: Verlag Von Johann Ambrosius-Barth, 1906.

[2] ASTM, *ASTM G173-03,* ASTM International, 2012.

[3] European Committee for Standardization, *EN 12464-1:2002 - Light and lighting - Lighting of work places - Part 1: Indoor work places,* CEN, 2002.

[4] L. T. Sharpe and A. Stockman, “The spectral sensitivities of the middle- and long-wavelength-sensitive cones derived from measurements in observers of known genotype,” *Vision Research,* vol. 40, no. 13, pp. 1711-1737, 2000.