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Our skies are too grey: Where is the colour?

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The Daylight Illuminant D65, a standardised reference light source in design and research with a colour temperature of 6500 K, is often used to describe the colour of the daylight. However, it represents the colour of an overcast sky, failing to capture the variability and richness of actual daylight, particularly the blue of clear skies. Recent research shows that both sunlight and skylight significantly influence our mood, perception and physiological responses. The colour of daylight is influenced by factors like sun position, weather conditions, as well as geographical location. To address these variations, researchers are collecting worldwide spectral daylight measurements, emphasising the need for localised spectral reference data to appropriately represent daylight in different locations.

Just think for a moment about the last time you enjoyed a sunrise or sunset, with its dark blues and oranges, or the last time you looked up at a clear blue sky admiring its colourfulness. Did it

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lift your mood? Boyce[1] wrote in his opinion piece: Wellbeing, Mood and Uncertainty, that the '*interference from aspects of life other than the visual environment*' should not be neglected when it comes to the impact of lighting on mood. We could not agree more. We are aware that many aspects can play an influential role in our subjective experiences of daylight perception and assessment. Still, imagine those experiences under a grey or overcast sky compared to those under a blue sunny sky. Daylight conditions, its spectral content, intensities and colourfulness, create an emotional, perceptual and physiological difference in many ways.

Yet, when we describe daylight in its spectral characteristics, our most frequently used reference in lighting design, research and application is the benchmark Daylight Illuminant D65. This is a CIE-standardised spectral power distribution with a correlated colour temperature of 6500 K.[2] D65 may represent the colour of daylight under clear sky conditions, particularly when a high proportion of warmer white direct sunlight is combined with a lower proportion of cool white skylight from a clear sky. On the other hand, D65 is also representative for the colour of an overcast, cloudy sky,[3,4] and human perception of daylight mentioned above is largely influenced by the sky vault and its spatial spectral distribution. Thus, the use of D65 will underestimate the potential of a blue sky, not represent the spatial spectral distribution of a dark blue, orange and pink sky at sunrise, for instance, but also overestimate the correlated colour temperature of the sun.

To us, it seems therefore necessary to look at the spectral characteristics of daylight as a whole and as separate components of skylight and sunlight. The colour of daylight and its spectral characteristics influence our mood,[5] the colour appearance of objects and materials,[6–8] the perception of our surroundings[9] and the magnitude of its non-image forming effects.[10–12] This research is recent and upcoming. It indicates that there are several relevant parameters in the macro- and microclimate related to the spectral composition of daylight that might impact our psychological and physiological responses. These parameters are mainly the contribution of the sun to the daylight, the visible portion of the sky, the presence of green trees and the spectral reflectance of room surfaces and furniture.

What is clear is that, when available, the sun's contribution is dominant. Kenny's research highlights this by stating: '*The direct solar component produced a very different result, dominating in both intensity and spectral character but also relatively static in its spectral properties*'.[11] The spectral characteristics of sunlight are well known both from spectral measurements and models, especially those obtained and developed for atmospheric research and by the photovoltaic community. Standardised spectral profiles for the sun are also provided and available from the CIE.[13]

However, the other component of daylight, skylight, can be significantly more blue, pink or orange than CIE's spectral profile for daylight, the Daylight Illuminant D65. Unlike sunlight, various factors influence skylight colour and spectral composition. First and foremost, the variability of the sky colour is primarily due to unpredictable cloud movements and weather conditions. In addition, factors such as the contributing sky region, atmospheric characteristics, seasonal changes and solar altitude impact the spectral composition of skylight. These parameters may partly explain geographical differences in the colour of skylight, which were observed by researchers as early as the 1960s and practically confirmed by Hohnbaum, who travelled around the world in 2006 to find the world's 'best blue sky'; she found, for example, the bluest sky in Brazil.[14]

Various lighting design and research tools are currently being developed and employed to take account of the spectral properties of daylight. These tools often work with *standardised* spectral distributions of daylight on a horizontal plane or a spectral sky using *default atmospheric profiles* in physics-based radiative transfer models. They are either incapable of providing the spatial spectral distribution of skylight or their suitability for localised analyses is posing challenges.

A solid database of measurements is required to draw conclusions about geographical, seasonal and diurnal differences in the occurrence, prevalence and representability of daylight spectral properties and to develop a framework that lighting designers and researchers can work with. For this purpose, a team of researchers are participating in a worldwide measurement campaign as part of CIE Technical Committee TC 3-60 'Spectral Daylight Characteristics'. Within this framework, SKYSPECTRA was launched, an open-source data package with spectral daylight measurements collected from various sources worldwide.[15] An initial analysis of these measurements confirms that geographical differences do not allow a 'one-size-fits-all' spectral sky to reproduce representative or predominant sky colours in different locations.

Some argue whether localised sets of daylight spectra or spectral skies are necessary. Then again, we are used to working with geographical differences in the lighting community, from simple sun position calculations to higher-level approaches. Consider the Perez All-Weather Sky Model,[16] which works with irradiance values for specific sites to describe the luminance distribution of the sky. Also, EN 17037 – Daylight in Buildings[17] uses a differential target daylight factor based on daylight availability in different locations. A transformation from a static generic daylight factor approach to a more dynamic, geographically contextual approach has already taken place. So why would it be different for the colour of the sky?

In line with these approaches, we aim to provide a set of representative local spectral power distributions of daylight tailored to bring more colours into lighting design, research and application. To this end, further work is required to record and analyse measurements of spectral characteristics of daylight globally. CIE TC 3-60 'Spectral Daylight Characteristics' continues to expand its membership as part of a broader initiative to promote international collaboration and to enlarge the dataset on the colours of the sky.

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