



**NANYANG
TECHNOLOGICAL
UNIVERSITY**

SINGAPORE

**ARTIFICIAL LIGHTING DESIGN FOR PAINTINGS IN
INDOOR SETTINGS
WITH SELECTED NANYANG PAINTINGS AS A CASE STUDY**

ONG THIAN CHAI, NICHOLAS
SCHOOL OF ART, DESIGN AND MEDIA

2017

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Abstract

Lighting design for paintings in indoor settings, after having cleared conservation issues, is taking more and more into consideration the illumination parameters related to artist's intentions, curatorial practices, and viewer experiences. Till recently, filtered or diffused natural daylight and incandescent lighting served as the most common lighting means for paintings with significant conservation issues. Today, Solid State Lighting (SSL) has close to no UV radiation resulting in a shift to newer LED lighting for museum use. Thus, lighting designers need to have a specific training to specialize in lighting design for paintings. This thesis started with an empirical investigation of the "Monza Method". It consists of a checklist for lighting design of painted surfaces developed in 2008 by Arch. Francesco Iannone and Arch. Serena Tellini (*Consuline Architetti Associati*, Milan, Italy). Despite positive feedback from a general audience who has experienced lighting designed by the "Monza Method", it is far more subject to the practitioner's "instinctive appreciation of light conditions" rather than to a cogent methodology for standards of illumination related to the interpretation of the viewing audience's appreciation.

This thesis presents the results of an interdisciplinary research project (Physics of Light and Psychology, Art History and Aesthetic) that began in 2015 in the School of Art, Design and Media at NTU Singapore. The aims of the research on LED lighting conditions for paintings in a museum environment (as a key showcase for indoor settings) was to examine how changing values in spectral distribution curves within a fixed intensity and correlated colour temperature can affect preference ratings and perception of a painting under various lighting conditions.

Through surveys conducted in Singapore, in collaboration with and endorsed by the Asian Civilizations Museum (ACM) and the National Gallery of Singapore (NGS), to

1. identify preference with relation to changing relative spectral distribution curves and
2. categorize specific variables that influence the viewers' perceptive impression.

The results of the interpretation of the data generated by these surveys have shown that:

1. individual paintings are viewed best under specific lighting conditions that are related to the painting's medium, i.e. both the type of paint used (e.g., oil, ink) and the base to which it is applied (e.g., canvas, paper);
2. increases in the "Red" wavelengths of the spectral distribution curve correlate with a significant higher chance of altering preference for viewing the paintings as compared to increases in the "Blue" and "Green" wavelengths;
3. despite keeping physical brightness at a constant, perceived brightness changes drastically with the altering of spectral distribution curves (it is an example of a frequently discussed, but not often documented case of how the perception of brightness is not simply proportional to the intensity of the light).

These research findings of human visual perceptions of change in spectral distribution curves, and the related interpretation of viewer behaviour, constitute a proof of concept for the need of a new approach to the standards of illumination in the lighting design for paintings in indoor settings. The lighting designer can be trained to explore more dynamic and science-driven ways to better enhance the empathic relationship of the viewer with the paintings, and show paintings "in new light".

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Glossary

The following glossary of terms, define terms that are used and adhered to within this thesis, unless otherwise stated within the text.

Blackbody radiator

“A temperature radiator of uniform temperature whose radiant output in all parts of the spectrum is the maximum obtainable from any temperature radiator at the same temperature. Such a radiator is called a blackbody because it absorbs all the radiant energy that falls upon it. All other temperature radiators can be classed as non-blackbodies. Non-blackbodies radiate less in some or all wavelength intervals than a blackbody of the same size and the same temperature.” (Rea et al. 2004)

Chromaticity

“The dominant or complementary wavelength and purity aspects of the colour taken together, or of the aspects specified by the chromaticity coordinates of the colour taken together. It describes the properties of light related to hue and saturation, but not luminance (brightness).” (Rea et al. 2004)

Commission Internationale de l'Eclairage (CIE)

The International Commission on Illumination (known as CIE from its denomination in French) is a technical, scientific, and cultural organization based in Vienna and “devoted to international cooperation and exchange of information among its member countries on matters relating to the science and art of lighting.” (Rea et al. 2004)

Coherence

“Coherence relates to our ability to make sense of the environment” (Kaplan & Kaplan 1989) through interpretation, familiarity or experience. If successful,

the environment that is coherent, and the likelihood for preference for the environment is high.

Colour

“1 [*mass noun*] the property possessed by an object of producing different sensations on the eye as a result of the way it reflects or emits light: *the lights flickered and changed colour.*” (Oxford Dictionary of English) It is crucial to understand that this thesis refers to colour as a sensation rather than a physical property.

Complexity

Generally in psychology, a complex is referred to as a core pattern of emotions, memories, perceptions and wishes in an individual's unconscious that is organized around a common theme (Shultz & Shultz 2009). “Complexity in the environment relates to our innate desire to engage, to be active observers with our environment.” (Kaplan & Kaplan 1989)

Contrast

“Also known as luminance contrast, it is the relationship between the luminances of an object and its immediate background.” (Rea et al. 2004)

Correlated Colour Temperature (CCT)

“A specification for white light sources used to describe the dominant colour tone along the dimension from warm (yellows and reds) to cool (blue). Lamps with a CCT rating below 3200 K are usually considered warm sources, whereas those with a CCT above 4000 K usually considered cool in appearance. Temperatures in between are considered neutral in appearance. Technically, CCT extends the practice of using temperature, in kelvins (K), for specifying the spectrum of light sources other than blackbody radiators. Incandescent lamps and daylight closely approximate the spectra of black

body radiators at different temperatures and can be designated by the corresponding temperature of a blackbody radiator. The spectra of fluorescent and LED sources, however, differ substantially from black body radiators yet they can have a colour appearance similar to a blackbody radiator of a particular temperature as given by CCT.” (Rea et al. 2004)

Electromagnetic wave

“A wave composed of perpendicular electric and magnetic fields. The wave propagates in a direction perpendicular to both fields.” (Rea et al. 2004)

Hue

“The attribute of a light source or illuminated object that determines whether it is red, yellow, green, blue, or the like.” (Rea et al. 2004)

Illuminance

“The amount of light (luminous flux) incident on a surface area. Illuminance is measured in footcandles (lumens/square foot) or lux (lumens/square meter). One footcandle equals 10.76 lux, although for convenience 10 lux commonly is used as the equivalent.” (Rea et al. 2004)

Intensity (luminous intensity)

“Total luminous flux within a given solid angle, in units of candelas, or lumens per steradian.” (Rea et al. 2004)

Isotemperature

“A set of coordinates within which all points have the same temperature. In a colour space diagram, isotemperature lines represent lights with identical correlated colour temperatures.” (Rea et al. 2004)

Light-emitting diode (LED)

“A solid-state electronic device formed by a junction of P- and N-type semiconductor material that emits light when electric current passes through it. LED commonly refers to either the semiconductor by itself, i.e. the chip, or the entire lamp package including the chip, electrical leads, optics and encasement.” (Rea et al. 2004)

Luminous flux

“Luminous radiant power, measured in lumens. The overall light output of a lamp or luminaire.”(Rea et al. 2004)

Lux (lx)

“A measure of illuminance in lumens per square meter. One lux equals 0.093 footcandle.” (Rea et al. 2004)

Metamers

“Lights of the same colour but of different spectral power distribution.” (Rea et al. 2004)

Reflectance

“A measure of the ability of an object to reflect or absorb light, expressed as a unit less value between 0 and 1. A perfectly dark object has a reflectance of 0, and a perfectly white object has a reflectance of 1.” (Rea et al. 2004)

Spectral power distribution (SPD)

“A representation of the radiant power emitted by a light source as a function of wavelength.” (Rea et al. 2004)

CHAPTER 1: Artificial Lighting Design for Paintings

1.1 Examining Artificial Lighting Design

Artificial lighting design, or simply lighting design, is a practice that spans across various fields and industries including theatre, architecture, photography, cinema and much more. In problem-based project work, it finds itself at the intersection of several academic disciplines; the physics of light, cognitive psychology, electrical, mechanical and even chemical engineering and the particular field of study it is applied to (e.g., architecture, engineering, art). (Hansen 2013 p.1)

Lighting design deals primarily with the aesthetic appeal, engineering and psychology of illumination. The common denominator across the fields within artificial lighting design is that there is always a structure or an environment to perceptually alter through illumination, be it the painting, a stage, a building or room, or a film-set. Importance in lighting design lies in appreciating that the final assessment of success in lighting is the human response.

Lighting design for paintings in indoor settings is of significance for both observing and appreciating art. Two competing criteria present itself, appearance and damage, this is because the optimal lighting that minimizes irreversible damage is complete darkness, yet in such situations, appearance is non-existent. Lighting design for museums should be concerned with circulation and accentuation of architecture (ambient lighting), and the illumination of the artefact (task lighting). Balancing these criteria includes the “function of many parameters such as the artist’s intention, damage, energy efficiency, viewing experience and understanding, and for commercial galleries – sales. The *Commission Internationale de L’Éclairage* (CIE) has published recommendations to control damage to museum objects by optical

radiation.” (CIE 2004) It recommends designers take measures (1) eliminate all optical radiation below 400nm, (2) “for materials moderately or highly responsive to damage due to optical radiation, maintain illuminance below 50lx, and (3) for materials with low responsivity, maintain illuminance below 200lx. There are also exposure limits measured in lux-hours per year as it is assumed that damage is cumulative. There are no recommendations for correlated colour temperature (CCT) as the CIE is concerned with damage.” (Berns 2010 p. 324)

Moving further with the illumination of paintings, consideration has to be taken towards the medium of the painting. Besides protecting a collection from traumatic damage, the process of light-induced degradation is complex. Within the medium lies information about the visual attributes of the art that has to be revealed and illuminated, thus, advising the lighting design. (Cuttle 2007 p.13)

The conflicting issue for the practice of lighting design for paintings for museums and galleries in its current state, as surveyed in Christopher Cuttle’s seminal survey and text *Light For Art’s Sake* (2007), is that the interaction of light and art media allows for both the visual experience and the degradation of the artwork.

Traditionally, lighting design for paintings in indoor settings was largely constrained by guides for conservation purposes and simple visual matching of light sources to that of traditional incandescent tungsten halogen. For example, the choice of colour temperature was decided by matching light sources to tungsten halogen lamps (3000 – 3500 Kelvin for undimmed lamps). “Low CCT incandescent lighting was preferred because such sources have low shorter-wavelength emission, thereby reducing damage when compared with indirect daylight having much higher CCT.” (Berns 2010 p.324)

There were exceptions, such as the National Gallery in London during the 1990s, 4000K was used to better suit the filtered daylighting coming into some galleries. (Innes 2013 p.1) While most paintings were created under natural daylight, the lighting in which they are viewed in museums are a far cry from which they were created the difference in lighting environments means paintings are rarely seen under conditions which it was created.

However, advances in lighting technology have introduced Solid State Lighting (SSL) and Light Emitting Diodes (LED), that provide close to no UV radiation that is detrimental to the artwork. New breakthroughs such as CoeLUX has even allowed artificially producing the visual appearance of day lighting through skylights. With these advances, “a communal approach is not only logical but also allows the conservation field to address more sophisticated topics of perception and visual performance as well as new technologies in illumination” (Druzik & Eshøj 2007 p.51) of paintings.

In 2007, Kit Cuttle conducted a workshop for the American Institute of Conservation to demonstrate an alternative approach to conservation lighting by blending the light from Red, Amber, Green and Blue (RAGB) LEDs. This allowed chromaticities that matches an incandescent lamp but omitted 44% off the damage potential due to the non-continuous spectrum. The experiment proved that discontinuous white light spectrums were visually acceptable to conservation experts, who showed no preference between tungsten halogen lighting and the RAGB LED source. The RAGB source was designed to match a blackbody source. Since then, LED whites have been designed and engineered to appear on the black body locus.³

Moving onward from Cuttle’s work, Italian lighting designers, Arch. Serena Tellini and Arch. Francesco Iannone from “Consuline Architetti Associati”

(Milan, Italy), demonstrated a new lighting checklist, the “Monza Method” when lighting the Monza Cathedral (Gieselmann 2013)

1.2 The “Monza Method” by Francesco Iannone and Serena Tellini

The “Monza Method” has been developed by Francesco Iannone and Serena Tellini from 2008 till today and serves as a design checklist demonstrating how manipulations of several variables in lighting design for the artwork (such as multiples light sources, intensity, colour temperature and spectra) can produce a more empathic relationship between the viewer and the painting when the lighting for the painting is designed individually. (Iannone 2014)

In the “Monza Method”, the subject matter is taken to be the viewer and artwork is a constant in which the designer manipulates lighting for to evoke a stronger empathic relationship between the subject and the painting¹. (Iannone 2014)

The creators of the “Monza Method” claim that the reason behind it is based on the mirror neuron, “A special class of brain cells that fire not only when an individual performs an action, but also when the individual observes someone else make the same movement” (Perry 2008) and the idea that humans see things with our eyes but “look at” them with our brain (Santini 2012 p.42). However, while there is a database of responses to paintings lit by the “Monza Method” that show a more emphatic relationship between viewer and painting,

¹ In the case of the “Monza Method”, a stronger emphatic relationship is taken to be observed by the viewer taking more time to indulge in observation of the artwork. (Iannone 2014)

the “Monza Method” is essentially still quite subjective to the instinct of the lighting designer to design the lighting.

Monza Method: The Decalogue

Steps		Objective	Process
1	Designing the lighting together with the Authority of Cultural Heritage	Understanding the object for illumination	Working with experts in the object for illumination (the painting) to understand the formal qualities of the object.
2	Discovery of the different types of pigment used by the artist		Understanding the material and physical properties of the object for illumination.
3	True correspondence between the specifications and performance of luminaires	Selection of equipment	Affirming that the equipment specifications are accurate on paper and in reality.
4	Use only high-quality LED and specialized accessories		Use only reliable sources for illumination.
5	Use different spectra together	Task lighting variables	Blending of various light sources of difference spectral distribution curves.
6	Use a minimum of 3 different spectral compositions		
7	Plan the angles of incidence of light		To avoid reflectance and glare from the light source or from the object for illumination
8	Use a different spectrum for the environment	Ambient lighting conditions	Create a distinct difference between the ambient space and the object.
9	The lighting of the whole context must be under control		
10	The real subject is the MAN, not the ARTWORK	Observation	Observe the human response to lighting, instead of human response to the object for illumination.

figure 1.1: The “Monza Method”

1.3 Points of Departure, Aims of The Research Project

Despite substantial neural studies into empathy (Bernhardt & Singer 2012), there are lack credible academic studies into identifying the mirror neuron to having any attribution to the effect of the “Monza Method”. It isn’t the focus of this thesis to identify the neural networks that result in emphatic viewing of paintings, this thesis seeks to strip down, observe and identify, in an academic setting, a means for observing and understanding how specific changes in lighting design for paintings can affect the emphatic relationship when viewing paintings, by taking the components of the “Monza Method” as a starting point for investigation.

The project proposes to build up an experimental methodology employing theories from various academic disciplines and employing a case-study set of paintings to investigate LED lighting conditions for paintings in a museum environment (as a key showcase for indoor settings) to examine how changing values in spectral distribution curves within a fixed intensity and correlated colour temperature can affect preference ratings and perception of a painting under various lighting conditions.

These research findings of human visual perceptions of change in spectral distribution curves, and the related interpretation of viewer behaviour, would ideally serve as a proof of concept for the need of a new approach to the standards of illumination in the lighting design for paintings in indoor settings. The lighting designer can be trained to explore more dynamic and science-driven ways to better enhance the empathic relationship of the viewer with the paintings, and show paintings “in new light”.

Steps		Objective	Concerns to the Thesis
1	Designing the lighting together with the Authority of Cultural Heritage	Understanding the object for illumination	To study properties of eventual case-study paintings.
2	Discovery of the different types of pigment used by the artist		
3	True correspondence between the specifications and performance of luminaires	Selection of equipment	To take into account the spectral and photometric properties of the luminaires used for calculating the properties of variables.
4	Use only high-quality LED and specialized accessories		
5	Use different spectra together	Task lighting variables	Primary concern of the research, studying variables in the lighting design for paintings elicit human responses to the viewing of paintings
6	Use a minimum of 3 different spectral compositions		
7	Plan the angles of incidence of light		
8	Use a different spectrum for the environment	Ambient lighting conditions	Environmental variables to keep constant, and to revisit during discussions after empirical studies.
9	The lighting of the whole context must be under control		
10	The real subject is the MAN, not the ARTWORK	Observation	Data collection comes from the viewer, not the qualitative properties of the painting.

figure 1.2: The "Monza Method" as related to the project.

CHAPTER 2: Project Design

2.1 Framing The Research Project

The project understands that a unique approach to lighting design is required. Stripped down, the concern of the project is to understand the viewing experience of the painting under specified lighting conditions and would require the measure and understanding of human responses to evaluate success and verify theories. Essentially, the project can be considered from a user experience (UX) standpoint. User Experience Design has become highly associated with the digital world. Despite how the term is used now, “User Experience was a term that simply applied to how a person feels about using a system” (Norman 2007)., in this case, the viewing of paintings under artificial lighting.

‘User Experience Design’ was first coined by Don Norman in 1995 while he was the vice president of the Advanced Technology Group at Apple: “I invented the term because thought human interface and usability were too narrow. I wanted to cover all aspects of the person’s experience with the system including industrial design, graphics, the interface, the physical interaction, and the manual” (Norman 2007).

Upon identifying that the research intentions and its experiments can be structured within the framework of a user experience design project, a thorough investigation into the schematics of lighting design the various disciplines that result in the final user experience from needed to be observed.

In professional lighting design, lighting designers make use of a set of tools (luminaries and optics) an apply them to environment to accentuate the spatial qualities by illuminated various features in the environment. They may

study the various materials and components in the environment and try to design a lighting scheme that complements the environment. Over time, with basic principles of design lighting designers develop an intuition of how end users of a space experience space which their lighting designs are applied.

In this process, the lighting designer has, consciously or not, encroached upon a multitude of disciplines, from engineering to design, architecture to material sciences and psychology. Similarly, for this project, a thorough investigation was carried out to explore the various academic disciplines that may shape “Lighting Design for Paintings in indoor settings”.

Firstly, the relationship between light, subject matter and experience was mapped out. While commonly experience would be seen as a result of the interaction between light and painting, the main aims of the research project is to understand why viewers perceive artwork in the manner that they do based on lighting design and light’s influence on experience. As such, experience was called out and the research project would have to dwell within the delicate balance of light, painting and experience.

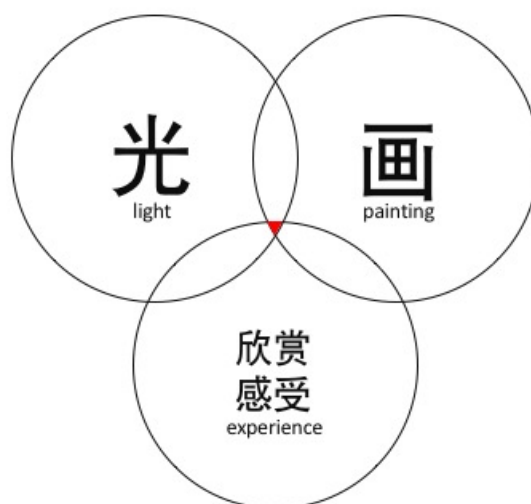


figure 2.1: Relationships between light, painting and experience.

After which, the research explored the current state of knowledge for the following topics, in order to extract and structure what is relevant to design experiments in the field of artificial lighting design for paintings in indoor settings:

1. Physics of Light,
2. Psychology,
3. Art History and Aesthetic.

This theoretical research would allow the experiments to have a foundation base of theories to set the scope of the research upon.

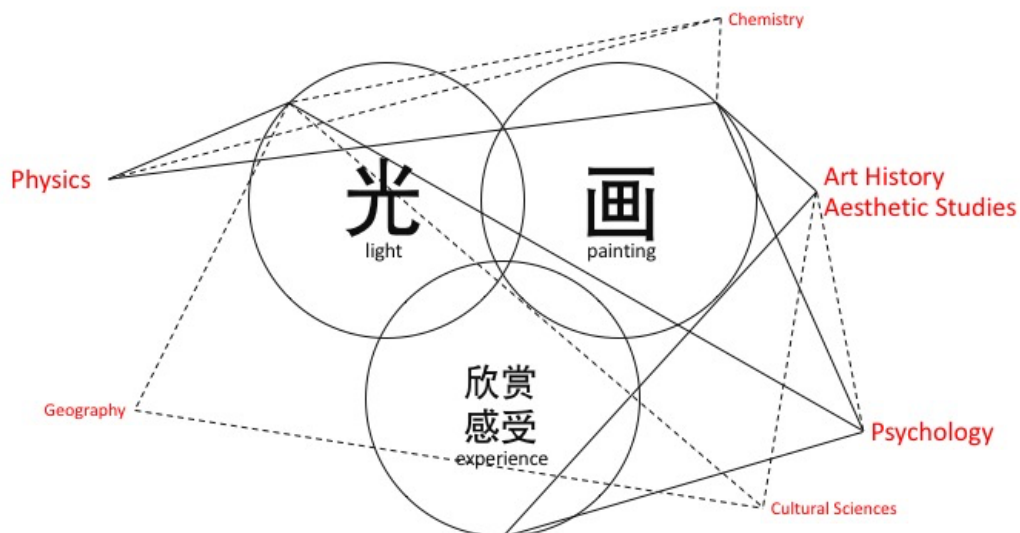


figure 2.2: Academic disciplines affecting the research project.

Physics of light set the stage to identify and isolate variables: prior studies have already examined human responses to variables in lighting for paintings such as the physical intensity of light (brightness in lux) and preferred colour temperatures (Zhai et al. 2015, 2016). Psychology was used to both define the questions to ask to the viewers and participants in experiments, and to interpret their responses (Flynn et al. 1979). Last, but not least, Art History

provided the necessary knowledge about the paintings and the painters, and Aesthetic gave an understanding of the sets of principles used by the painters to make them (Low 2010, Teo 2011).

2.2 Physics of Light

First and foremost, an understanding the science of light is required before any investigation into light can be done. For the purpose of this thesis, light will be used in reference to the portion of wavelengths visible to the human eye of the electromagnetic spectrum, which include “wavelengths of light from 400–700 nm. This is called the visible part of the spectrum between the infrared (with longer wavelengths) and the ultraviolet (with shorter wavelengths).” (Pal 2001 p. 387)

2.2.1 Light as Wave

There are certain phenomena that can characterize light as a wave. As with other waves, light reflects, diffracts and refracts. Light also undergoes interference as well as the Doppler effect, which defines “an increase (or decrease) in the frequency of sound, light, or other waves as the source and observer move toward (or away from) each other” (Oxford English Dictionary). Conceptually and mathematically, light acts in a manner that coheres with a physical understanding of waves.

When waves reach the end of a medium, which it is traveling through, it doesn't just stop. There is a reaction at the intersection of the end of the medium and the beginning of a new one. Light reflects off the surface and transmits into the new medium. The transmission will undergo bending or refraction if it reaches the boundary at any angles other than perpendicular. If the boundary internal to the medium (i.e. it is within the medium), and the obstacle is smaller less sizeable than the wavelength of the wave, the wave will diffract around the obstacle. (Nave 2016)

2.2.1.1 Reflection

Light, just as any other wave will follow the laws of reflection when rebounding off surfaces. This means that the angle at which the wave advances to a flat reflecting surface will be equal to the angle at which the wave leaves the surface. These angles are measured with respect to the normal to the surface (Nave 2016). This is observed with water and sound waves. In the case of light, the most prime example would be how light reflects off a reflective surface resulting in the manifestation of a reflected image.

Reflected light of a scene reaching the human eye is also the reason behind the vision and the perception of colour, which will be explained in later portions of the report.

2.2.1.4 Refraction

All waves refract when they pass from medium to medium. Refraction is taking as the bending of a wave when it enters a medium of a different density, which in turn changes the speed of light (subject to the medium in which light is travelling through). When light enters a denser medium, it finds the fastest way out of the medium by bending to the normal to the boundary. (Nave 2016)

The direction in which the bend steers towards depends on the difference in densities of the two media. A wave will bend to the faster path to exit the media. (Nave 2016) When light travels through a denser to a less dense substance, the light is refracted away from the normal. (Crowell 2010)

While reflection brings light rays to the eye's surface, refraction is the phenomena responsible for image formation by the human eye and by lenses.

In the eye, most of the refraction occurs at the transition between the environment and the cornea, before further refraction in the inner crystalline lenses of the eye. This allows for the eye to focus the scene at the back of the eye where light sensing cones and rods process images. (Nave 2016)

2.2.2 Visible Spectra of Light

Light is an electromagnetic wave. Electromagnetic waves exist within a great range of frequencies known as the electromagnetic spectrum. This section is broken into regions. The region our eyes are sensitized to are a small range within the electromagnetic spectrum known as the visible light spectrum. (Pal 2001 p.387)

Dispersion of visible light produces a continuous spectrum of monochromatic light that is often commonly referred to as the colours of the rainbow, however, the spectrum has no clear boundaries between the different colours. Individual colours can be identified by their respective wavelengths. (Bruno 2005 p.2)

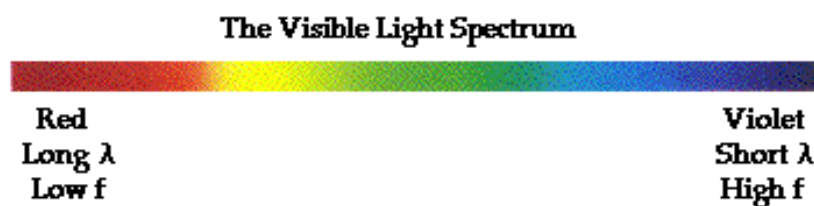


figure 2.3: Visible Spectrum of Light.

When all the wavelengths of the visible light spectrum make contact with the human eye simultaneously, white is perceived. The perception of white is arising from the combination of two or more colours of light. As seen above,

light at the longer wavelength end of the spectrum will seem to produce a 'red' sensation and 'blue' at the other end. (Waldman 2002 p.14)

Specific wavelengths represent of different colours. When the light of a certain wavelength makes contact with the retina of the human eye, it is perceived as that specific colour sensation. Pure colours are often defined in wavelengths of light as described and shown above. While, this works for spectral colours at a specific wavelength, many difference combinations can produce the same perception of colour. (Nave 2016)

2.2.3 Colour Temperature of Light

"The colour temperature of a light source is the temperature of an ideal blackbody radiator that radiates light of comparable hue to that of the light source" (Templier 2014). An ideal black body radiator emits electromagnetic radiation which are measured in kelvins, and also serve as the measure of colour temperature. (Stevens 1969 p.51)

When hot surfaces, such as an incandescent lamp, that are not ideal black body radiators are heated, the lamp approximates an ideal black body radiator through thermal radiation. The colour temperature is essentially that of its filament. (MacEvoy 2015)

"Many other light sources, such as fluorescent lamps, or LEDs (light emitting diodes) emit light primarily by processes other than thermal radiation" (Rea et al. 2004), therefore, correlated colour temperature (CCT) is used as a measure of the colour appearance that is closest to that of the chromaticity coordinates to the black body locus.

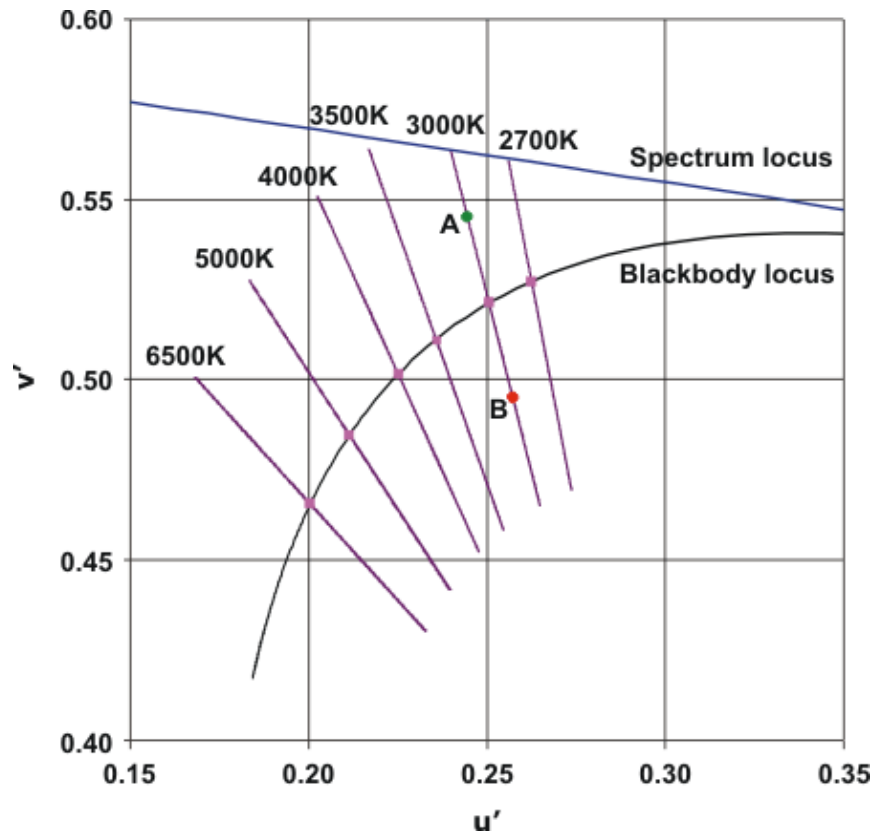


figure 2.4: The CIE 1976 chromaticity diagram with six isotherm lines used by manufacturers to represent light emitted by commercially available fluorescent lamps. (Rea et al. 2004)

“Since it is a single number, CCT is simpler to communicate than chromaticity or SPD, leading the lighting industry to accept CCT as a shorthand means of reporting the colour appearance of "white" light emitted from electric light sources” (Rea et al. 2004). However, as demonstrated above, two sources with the same CCT can have 2 very different SPD, meaning they have very different chromaticity and will look very different to the eye. Therefore, for purpose of this project proper documentation of not just the CCT of the sources used is necessary but also the spectral properties of these sources. (Rea et al. 2004)

2.2.4 Spectral Colour Distribution

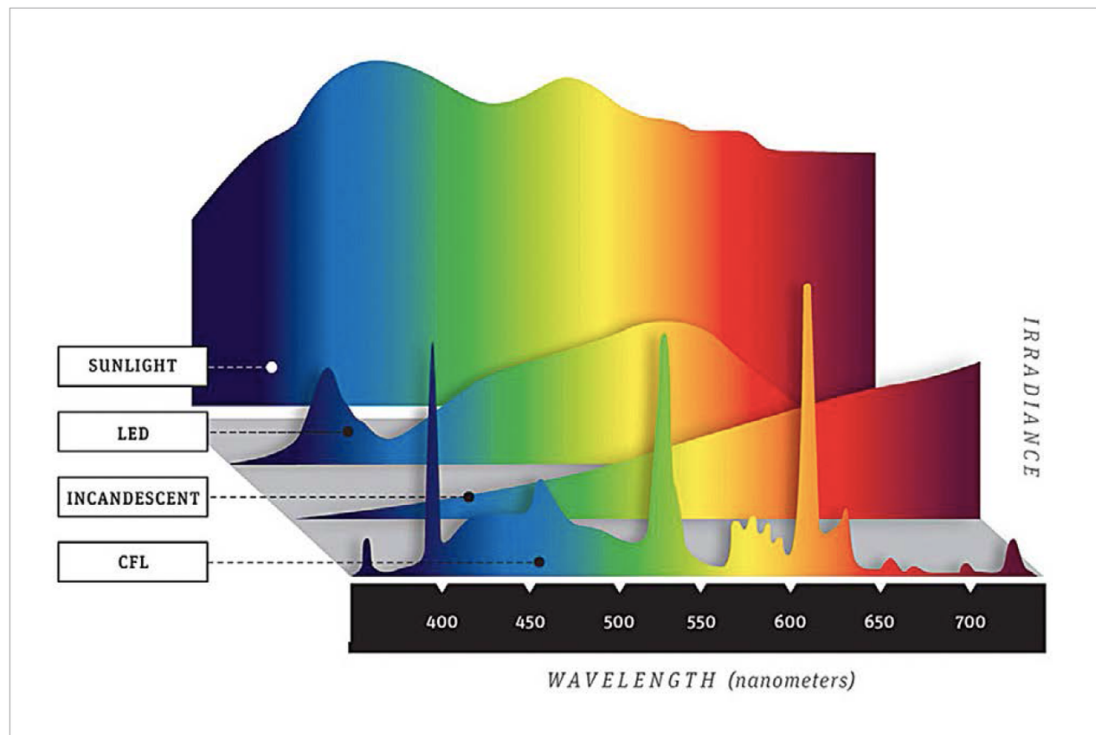


figure 2.5: Comparison of spectra in wavelengths of various white light sources.
(Herman 2015)

Spectral power distribution (SPD) curves display the visual profile of any particular light source by charting the level of energy at each wavelength across the visible spectrum of light.

For example, the SPD diagram for daylight indicates a very balanced source of all wavelengths in almost equal levels of energy, evenness of curves indicate exceptional colour rendering properties.

SPD diagrams are frequently employed to understand how different lamps vary in the composition of their light output.

Two light sources may possess the same chromaticity coordinates and yet have two different SPDs. This explains the allocation of CCTs across lamps of various kinds, from LEDs to Metal Halides or Halogen. Despite similar CCTs, with different SPDs, the perceived colour of subject illuminated by the two distinct light sources will be dissimilar. Reason being, that the colour of an object does not only depend on the properties of the object itself. “Colour is a complex interaction of the spectral characteristics of the light source interacting with the spectral reflectance of the object and finally the spectral sensitivity of the eye.” (Kelly 2012)

2.2.5 Spectral Reflectance of Objects

“An object absorbs part of the light from the light source and reflects the remaining light. This reflected light enters the human eye, and the resulting stimulation of the retina is recognized as the object's ‘colour’ by the brain.” (Konica Minolta 2011)

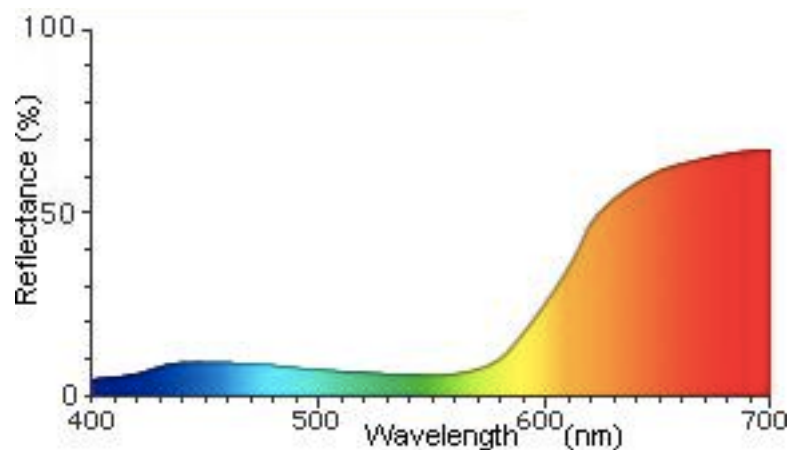


figure 2.6: spectral density curve of light reflected off a red apple.

(Konica Minolta 2011)

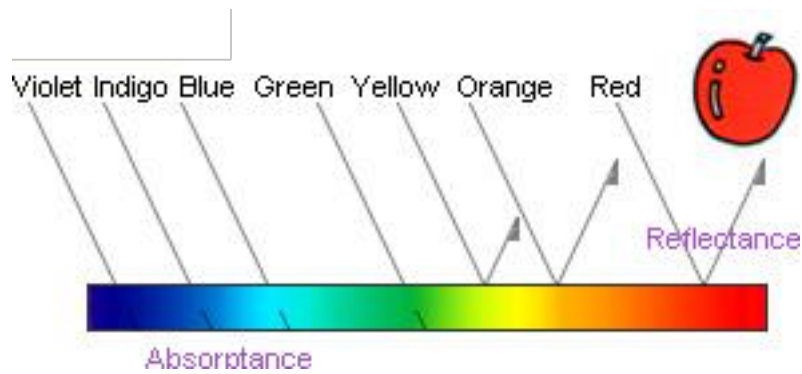


figure 2.7: absorbent and reflecting qualities of a red apple.
(Konica Minolta 2011)

It is the difference in object's absorbent and reflective abilities of the visible light spectrum that makes colours of these objects differ. Concurrently, the colour perceived by the brain will alter when the SPDs of the light source is different as light reflected off the object will be determined by the composition of light shining onto the apple.

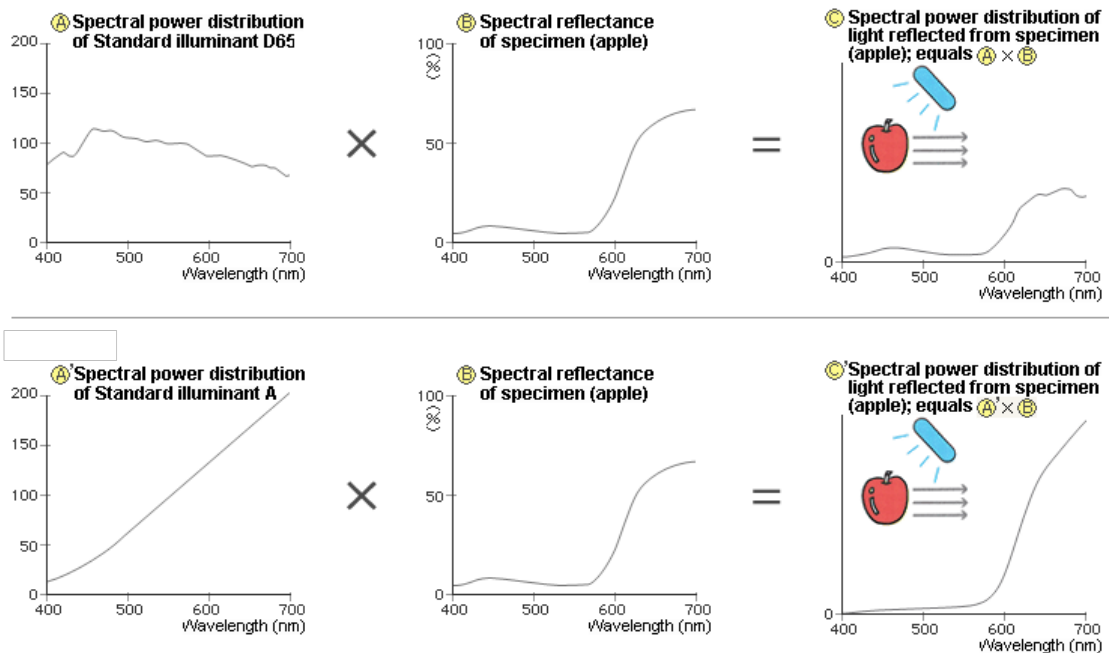


figure 2.8: Spectral power distribution of light reflected off an apple from two illuminants.
(Konica Minolta 2011)

2.3 Light and Vision

As explained earlier, human eyes are sensitive to a very small band of frequencies within the vast range of frequencies of the electromagnetic spectrum referred to as the visible light spectrum.

“Specific wavelengths within the spectrum correspond to a specific colour that’s based on how humans perceive that colour sensation. The long-wavelength end of the spectrum corresponds to light that is perceived by humans to be red and the short wavelength end of the spectrum corresponds to light that is perceived to be violet.” (Nave 2016)

The human visual system, modifies signals received from the retina to produce colours that are perceived. Therefore, colour is more than an intrinsic property of an object itself, but a matter of how it reflects and absorbs light and how the viewer processes and receives this reflected information.

2.3.1 Colour Cones and Human Response to Light

“Colour can be conceived of as a psychological and physiological response to light waves of a set of frequencies impacting upon the eye.” (Nave 2016)

Light enters the eye when light waves come into contact with the retina. Lining the retina are a variety of light-sensing cells known as rods and cones. Mechanism wise, the trichromatic colour theory of colour vision by Maxwell, Young and Helmholtz suggest that there should be three types of receptors in the retina for colour recognition, and are “sensitive to the red, green and blue” (Wyszecki et al. 1982 p.93) segments of the visible light spectrum.

Concurrently, Hering probed the opponent-colours theory of colour vision that included considerations to hues, contrast and vision deficiencies, which provided insight to the manner of colour processing in the visual system.

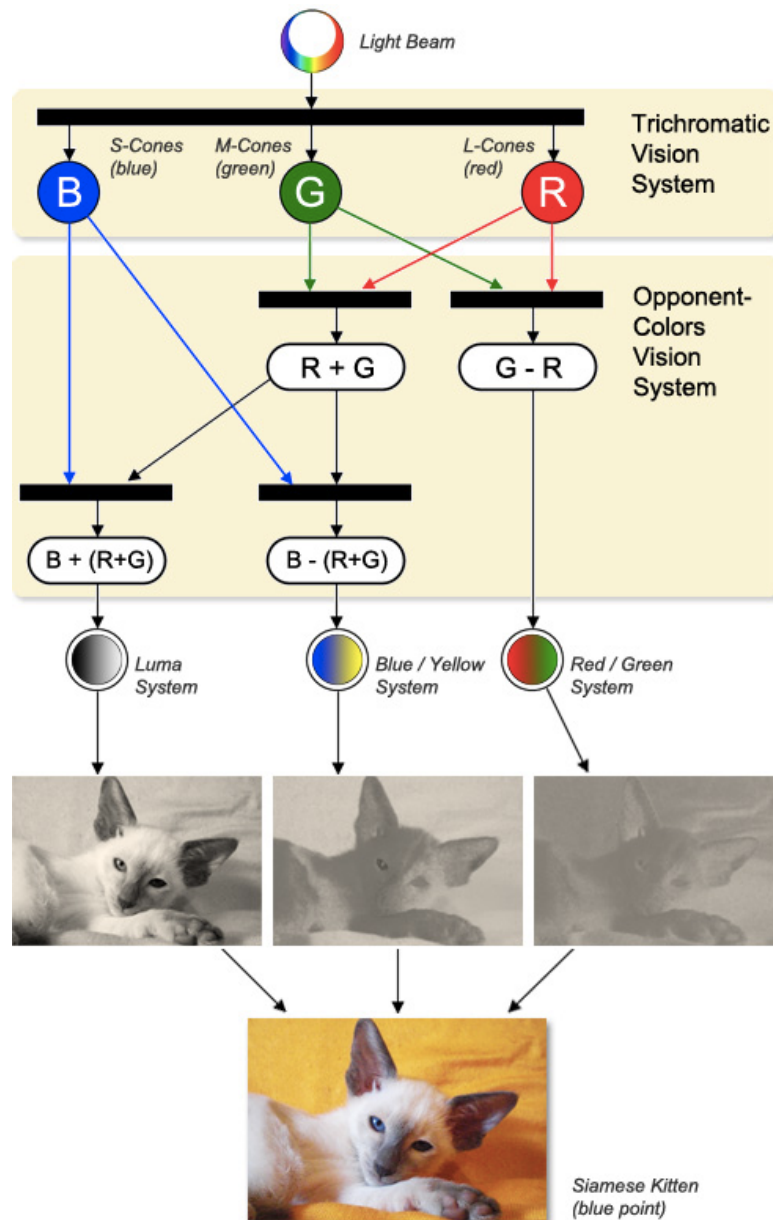


figure 2.9: Mechanisms of colour vision
 (www.workwithcolor.com)

In turn, the cones in the retina are “each sensitive to a range of wavelengths within the visible light spectrum.” (Nave 2016) These are the red, green and blue cones, due to their respective sensitivity to the wavelengths of light in those colours. The graph “below is a sensitivity curve that depicts the range of wavelengths and the sensitivity level for the three kinds of cones.” (Nave 2016)

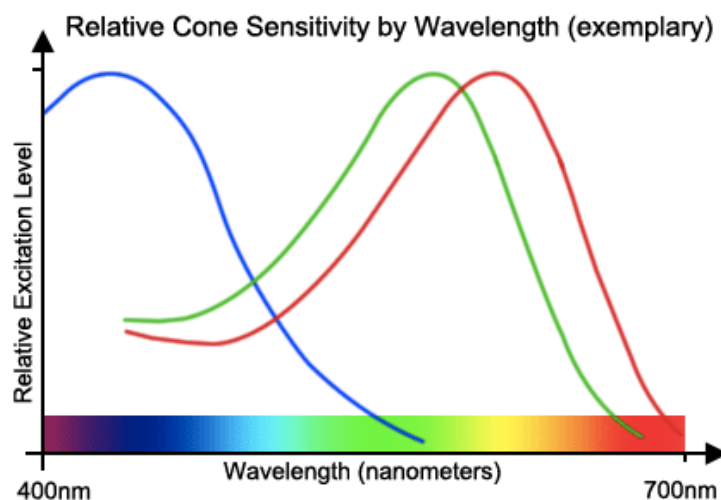


figure 2.10: Cone sensitivity curve.
(workwithcolour.com)

“The cone sensitivity curve shown above helps us to better understand our response to the light that upon the retina. While the response is activated by the physics of light waves, the response itself is both physiological and psychological. Suppose that white light, consisting of the full range of wavelengths within the visible light spectrum is incident upon the retina. Upon striking the retina, the physiological starts by photochemical reactions.” (Nave 2016) The brain detects the electrical messages being sent by the cones and perceives these impulses as a sensation of colour. “Each of the three kinds of cones would be activated into sending the electrical messages along to the brain” (Nave 2016) for white light to be perceived, just as all the wavelengths of the visible light spectrum creates white light physically. The omission of a band of wavelengths within the visible light spectrum, for example, the higher

wavelengths that correspond to red, would allow for perception of a colour that's correspondent to the cones activated, i.e. a blueish-green colour.

2.3.1.1 Retina Function

To further explain how colours are perceived by the human eye, one shall start referring to the cones as the "S" (blue), "M" (green), and "L" (red) cones, which are terms used by visual psychologists, a term that translate directly to the spectrum of wavelengths of visible light. The colours that is perceived by a human are a result of the ratio of responses between the three types of retina cones with regard to a given SPD.

"At the shortest wavelengths when only the S cones are being stimulated we see the colour violet. As the wavelength increases the M cones start to respond in addition to the S cones and violet turns to a deep blue. As the response of the M cones increases further relative to the S cones the colour perceived shifts to a greenish-blue, then to a bluish-green and finally to a pure green when the ratio of the M cones to the L and S cones is at its highest."
(Kelly 2012)

Cones only react when illumination is optimal, under low-light conditions or fluctuating illuminance, the eyes' rod cell take over dominance of vision (Kelly 2012).

2.3.1.2 Metamers

Lighting conditions often affect the way color is perceived, a simple observation for this is recorded in the Retinex Theory² by Edwin Land. While the Retinex Theory is often used in computer vision to understand the human vision's interactions with color, light and the resultant color consistency, it does not explain the full complexity of perceiving colours under different lighting conditions such as metamerism.

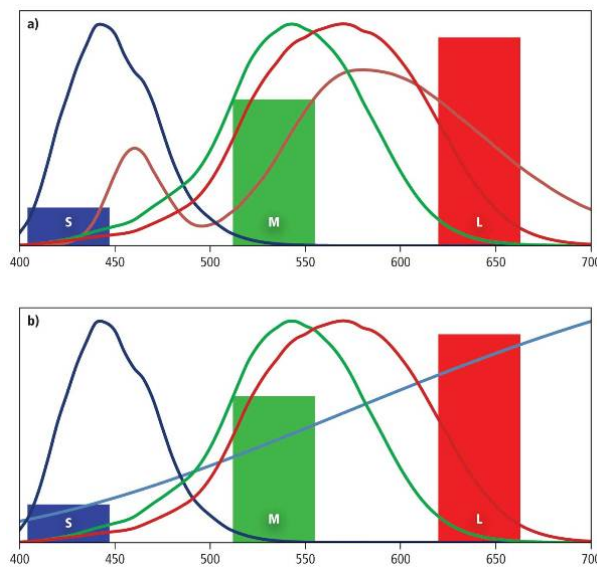


figure 2.11: Two light sources of 3000k with different SPDs which elicit the same response with the eye's colour cones.

(Kelly 2012)

² "Retinex is the theory of human color vision proposed by Edwin Land to account for color sensations in real scenes. Color constancy experiments showed that color does not correlate with receptor responses. In real scenes, the content of the entire image controls appearances. A triplet of L, M, S cone responses can appear any color. Land coined the word "Retinex" (the contraction of retina and cortex) to identify the spatial image processing responsible for color constancy. Further, he showed that color sensations are predicted by three lightnesses observed in long-, middle-, and short-wave illumination. Retinex is also used as the name of computer algorithms that mimic vision's spatial interactions to calculate the lightnesses observed in complex scenes." (McCann 2016)

A metamer is by definition “either of two colours of different spectral composition that appear identical to the eye of a single observer under some lighting conditions but different under others or that under constant lighting conditions appear identical to some observers and different to others” (Merriam-Webster Dictionary).

Metamerism also occurs when different surfaces, due to their physical properties are perceived to be the same colour. Similarly, two light sources with different SPDs could appear to be of the same colour temperature and hue because the eye’s cones react identically. (Kelly 2012)

Metamers are very important in colour science, particularly in colour printing, colour displays, photography, paint matching and in LED illumination. “When a colour is reproduced by a colour display for instance, the display does not have to reproduce the exact SPD of the original colour that is being reproduced. The display only has to produce an SPD that is a metamer of the original SPD. LCDs use three coloured pixels of red, green and blue, generally referred to as the display’s primary colours or primaries. When mixed together in the correct proportions, these primaries produce metamers to a wide range of possible SPDs and their associated colours. The SPD reproduced by a mixture of the primaries only has to stimulate the L, M and S cones in the same proportion as the original SPD does to accurately reproduce the colour of the original SPD.” (Kelly 2012)

2.4 Interactions Between Light and Paintings on a Physical Level

The most prominent concern that museums and gallery owners have for artwork is the chemical degradation of the artwork as exposed to light. Of concern of this project is the physics of lighting design for paintings to best

comprehend how light reacts with the surface of paintings, as pointed out in early chapters that lighting technology has developed to the point where chemical degradation can be brought to negligible levels.

Pioneering the field for the interaction of light and paintings on a physical level is Shoji Tominaga who works predominantly in imaging systems for paintings. Imaging systems have numerous applications across different industries. Creating a “complete imaging system requires the integration of optics, sensing, image processing, and display rendering” (Rea et al. 2004). In the case of this thesis, the work done in digital archiving has quite literally shed some light on the interactions that light has with the surface and materials of paintings, that will be of interest to this thesis.

2.4.1 Lessons From Digital Archiving

Digital archiving seeks to preserve, display and transmit to posterity visual heritage in the digital form. They also allow for seemingly faithful reproduction of artwork across platforms, where high resolution colour calibrated images are photographed from paintings with the assumption that the painting is flat (Martinez et al. 2002). This poses several inaccuracies for archiving, for paintings are 3-dimensional in nature.

In Tominaga’s work, spectral information off the painting is captured with a multiband camera. This surface normals and reflectances are then estimated from this data together with a physical model for describing surface light reflection. These are then “used to render realistic images of a painting under arbitrary conditions of illumination and viewpoint” (Tominaga & Tanaka 2008 p.3).

2.4.2 Reflective Properties of Paintings

In the technique proposed by Tominaga and Tanaka in 2008 for spectral image acquisition, analysis, and rendering for art paintings, the proposal used “multiple lighting directions. It assumed that the painting surface follows a reflection model.” (Tominaga & Tanaka 2008 p.3)

“Painting materials such as oil and water paints are regarded as inhomogeneous dielectric substances.” (Tominaga et al. 2008) When light leaves a point on the surface of a painting, it would have probably taken at least two separate paths. Some light is reflected in a mirror like manner off the surface. And some light leaves the painting after being scattered, refracted and reflected within the painting’s media and medium. (Tominaga et al. 2008 p.1)

However, although theoretically acceptable, it should be noted that Tominaga’s work needs further refinement in order to collect “precise data of surface reflectance and surface shape to improve” (Tominaga et al. 2008 minaga 2001) their archiving of artwork.

2.5 Cognitive and Emotional Responses to Lighting

Lighting designers deal predominantly with striving to get the right lighting conditions (stimulus) to get a desired response. Traditionally, that meant categorizing visual tasks under different lighting conditions. However, apart from considerations of task lighting, a study into emotional responses to lighting stimuli was required. Lighting can assist navigation and bring about feelings of calm in sacred settings and excitement in areas of recreation. There are few studies into how the human mind processes visual stimulus to produce these emotional responses. (Davis 2012)

The following sub chapters breaks down Davis' white paper on lighting psychology based on the work of John Flynn, Kaplan and Kaplan, and Russell. Davis proposed that lighting practitioners can apply the findings of Flynn and Kaplan with emotional response research to attain "a deeper understanding of the broad range of human responses to the lighting stimulus." (Davis 2012)

2.5.1 Lighting Modes & Subjective Impressions (Lighting Psychology)

Lighting designers often refer to John Flynn's body of work as the go-to text for understanding lighting psychology. In his "Guide To Methodology Procedures for Measuring Subjective Impressions in Lighting", Flynn and his colleagues examined the human response to changes in lighting stimulus with regards to architectural settings. By observing changes in impressions such as spaciousness, visual clarity, privacy, pleasantness, relaxation, complexity, and correlating this back to the nuances in lighting, Flynn demonstrated that architectural lighting plays a pivotal role in human experience besides task enabling (Davis 2012, Flynn et al. 1979).

Of the nuances to lighting conditions that stimulated the responses, Flynn categorized them into 4 "lighting modes", of which each representing a continuum of change between two extremes of which form the basic parameters in which lighting designers design environments around. These are namely, bright/dim, uniform/non-uniform, central/perimeter, and warm/cool. Simply put, changes to these 4 parameters will amount to changes in the responses as mentions in the earlier paragraph. Changes to particular modes, affect attributes to all impressions and are not directly linked.

Changes in these 4 “lighting modes”	Results in	Measurable Impressions
Bright / Dim Uniform / Non-uniform Central / Perimeter Warm / Cool		Spaciousness Visual clarity Privacy Pleasantness Relaxation Complexity

figure 2.12: Flynn’s lighting modes and measurable impressions.

This meant that for lighting practitioners to achieve desired impressions, and yet when there is a need for a constant of one of the “lighting modes” changes to the other 3 can be made. (Flynn 1979)

2.5.2 Making Sense and Being Involved (Environmental Cognition)

Apart from understanding how lighting conditions for paintings stimulate human responses, the project has to understand the factors that drive human preference. Environmental psychology’s basic three elements (De Young 2013): the subject (audience), the object (painting) and the environment (lighting design) are a good conceptual framework to use to study the viewing and display of lighting design paintings as the audience looks into perceiving art through the “knowledge and memory of an environment (that) depend on environmental characteristics that should be stimuli” (Belzner 2006 p.3).

“If an event or thing is experienced frequently and we have learned to react to it smoothly, our reasoning and feeling are not likely to remain actively concerned with it. And yet it is the most common and elementary matters that reveal the nature of existence with powerful directness.” (Arnheim 1974 p.245)

In his paper on the cognitive mapping of human needs to designed environments, Stephen Kaplan proposed that “when we are exposed to a new environment, finding a cognitive match for the environment in our memory is a primary goal, as a way of helping us to interpret and understand the new environment” (Davis 2012).

	Low Complexity	High Complexity
Low Familiarity (Coherence)	Uncomfortable (Low Preference)	Novel Excitement (High Preference)
High Familiarity (Coherence)	Apathetic (Low Preference)	Comfortable (High Preference)

figure 2.13: Kaplan’s model for preference in relation to coherence and complexity.

According to Kaplan, humans have an innate desire to comprehend our surroundings by relating new experiences to existing ones mapped in our cognitive memory, which brings about preference. Preference is also related to the complexity³ and coherence⁴ of the setting (Kaplan & Kaplan 1989).

With regards to lighting, “it is also important that a change in texture or brightness in the visual array is associated with something important going on in the scene. In other words, something that draws one’s attention within the scene should turn out to be an important object or boundary... If what draws

³ Complexity in the environment relates to our innate desire to engage, to be active observers with our environment. (Kaplan & Kaplan 1989)

⁴ Coherence relates to our ability to make sense of the environment through interpretation, familiarity or experience. If successful, the environment that is coherent, and the likelihood for preference for the environment is high. (Kaplan & Kaplan 1989)

one's attention and what is worth looking at turn out to be different properties, then the scene lacks coherence." (Nasar 1992 p.49)

Conversely, while coherence is important, the lack of complexity results in the loss of ample stimulation for human involvement. "We desire coherent environments that we can easily interpret, while at the same time we desire an appropriate level of complexity to keep us interested." (Davis 2012, Levitin 2006)

2.5.3 Pleasantness, Arousal and Control (Emotional Response)

In enacting a framework for the cognitive and emotional responses to lighting, “Flynn gives us a thread of a stimulus described by lighting modes, linked to the human response of subjective impressions of the painting. Kaplan and Kaplan give us a thread of a preference response that appears to be linked to environmental stimuli that are both coherent and complex (i.e. the architectural elements of the gallery) – we can make sense of them and they are interesting enough to elicit our involvement.” (Davis 2013). Davis further proposes that through applying the studies of Flynn and the Kaplans to that of James Russell’s exploration of human emotional development and response.

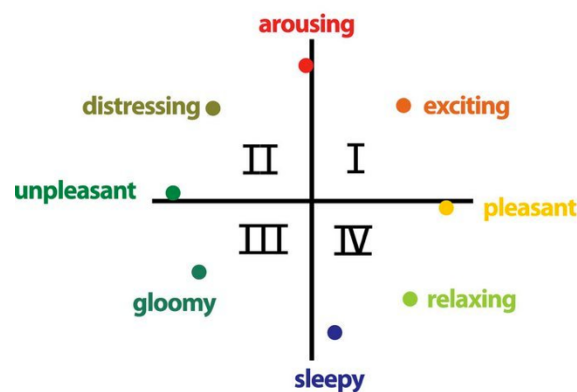


figure 2.14: Russell’s two axes of pleasure and arousal.
(Davis 2012)

Similar to Kaplan & Kaplan’s scales of coherence and complexity, Russell suggests that upon encountering a new environment, humans place the environment within one of four quadrants separated by two axes of pleasure and arousal (Russell 1980).

As such, the project agrees with Davis that a synthesis of the three components above would help to provide a holistic understanding of why

certain lighting conditions result in certain impressions (adapted from Flynn), which therefore results in greater preference as explained by Kaplan. Finally, the project could analyse findings further with Russell's model of emotions to provide an added component for lighting designers to comprehend how lighting paintings can contribute to more an enhanced emotional relationship to the painting.

2.5.4 Other Concepts of Lighting Framed Spaces

With the above in mind, it is necessary to look into concepts of lighting for the stage and theatre, where the experience tends to be more immersive than observing paintings in a gallery. In parallel to artists painting *plein air* (outdoors painting under natural light) and displaying in enclosed galleries, the theatre moved from amphitheatres into “the first major public building type in which daylight was totally omitted” (Spiers & Major 2005 p.34) and that “the environment could be controlled through the location, distribution and manipulation of light” (Spiers & Major 2005 p.34) just as how artist Dan Flavin uses light to build meaning into already meaningful spaces (Skarlatou 2010 p.33), light could be used to add meaning and to paintings steeped with heritage.

A deeper reading into theatrical lighting in an attempt to come to an understanding and make hypothesis on lighting of the scenic space, which is a distinct and divided space used for performance viewing (Skarlatou 2010 p.63), brings us to ‘the McCandless method’ (McCandless 1931, 1932), which is framed eloquently by Roger Edmund Jones in the words “lighting a scene consists not only in throwing light upon objects but in throwing light upon a subject” (R.E. Jones cited in Palmer 1967 p.142). McCandless expresses that with variations in intensity and colour that are complementary to each other,

nature can be imitated. These thoughts are also reflected in architectural lighting research by John Flynn (Flynn et al. 1979).

2.5.5 Prior Studies to Visual Perception of Lighting Design for Paintings

Apart from understanding lighting psychology and laying the foundations to comprehending how lighting design affects human responses and preference, observing previous studies to visual perception of lighting design for paintings helps the project in identifying the areas of task lighting (such as chromaticity, intensity, colour rendering index of the composition of the light sources lateral biasness of the light “spot” on the painting) to focus on investigating deeper.

As leading supplier of museum lighting ERCO states in their website: “Museums attract attention and can alter the perception of whole regions – the best example is the deconstructionist author-architecture of the Guggenheim Museum in Bilbao or the open architecture of the Louvre-Lens embedded in its surroundings. But even smaller galleries and unusual exhibition concepts can open the doors to the world of art. Be it the presentation of modern art in the classic ‘White Cube’ or the interactive exhibition experience revolving around ancient Egypt – few design media direct the attention in exhibitions as precisely and intuitively as light. More than just illuminating art, the exhibition venues themselves are presented in the appropriate light as social meeting points.”

Consideration must be taken towards the medium of the artwork. Within the medium lies information about the visual attributes of the art that should be revealed and illuminated, thus, advising the lighting design. Other than protecting a collection from traumatic damage, the process of light-induced degradation is complex (Cuttle 2007 p.39).

Previous studies examined human response to lighting (Flynn et al., 1979) by studying an array of subjective impressions related to architectural settings through changes in lighting stimulus have revealed that “impressions such as spaciousness, visual clarity, privacy, pleasantness, relaxation and complexity can be created through manipulations in the brightness, uniformity, centrality and colour temperature of lighting.” (Davis 2012)

With regards to lighting design for paintings, thus far, apart from conservation studies, academic studies involving the practice of lighting design in perception for paintings have predominantly been concerned with lateral biases (centrality) (McDine et al. 2011, Sun & Perona 1998). This coincides with the “Monza Method”’s planning (the) angles of incidence of light.

The lateral bias experiments deal with abstract paintings that remove a large possibility of confounding factors that reside in figurative paintings, inclusive of the observers’ interaction with posing biases, and aesthetic biases. The lack of specific forms in abstracts implies that aesthetic preference “is based entirely on the image’s ability to elicit an emotional response, despite the lack of concrete forms. The intended emotional response is not constrained by form and may be tied to colour, line or complexity of a painting” (McDine et al. 2011 p.270).

Mc Dine et al. and Sun & Perona’s studies confirm that there is a central bias toward having the light shine onto the left half of abstract artwork, which is also further explained in his keynote lecture at the 3rd edition of the Lighting Design Forum in 2016 by Prof. Ernst Pöppel that the brain tends to compose objects of importance in paintings in the left side of figurative paintings.

Chapter 3: Nanyang Paintings as Case Study

3.1 Selecting Case Study Material

In practicing lighting design, it is important to understand the object of which the designer is illuminating. As in this research project, a sound and thorough knowledge into the paintings chosen as a case-study is required to investigate the lighting practices for these artworks.

When selecting the case-study material several considerations were suggested before settling on the types of paintings to apply the research to. These were:

1. Accessibility of the physical paintings.
2. Accessibility to experts, scholars and institutions with knowledge on the paintings.
3. Cultural significance to the host university.
4. Cultural significance to the available pool of subjects.

The research project, being conducted at the Nanyang Technological University, Singapore, made a quick survey of established institutions and collections of artwork and paintings in the region.

Of particular interest are the Nanyang Paintings in the “National Gallery Singapore, a visual arts institution that oversees the largest public collection of modern art in Singapore and Southeast Asia, reflecting Singapore’s unique heritage and geographical location.” (www.nationalgallery.sg)

Housed within the gallery is an extensive collection of “Nanyang” artwork which plays a prominent in of Singaporean art history. Apart from being physically able to observe the paintings, there is also access to renowned

scholars on the subject matter such as Mr. T.K. Sabapathy, research fellow at the Centre for Contemporary Art, Singapore (Sabapathy 1979) and Dr. Yvonne Low, an art historian who has written thoroughly on the subject (Low 2010). There is also a wealth of publications housed in national libraries on the subject matter.

Paintings were selected and sourced from museums of the National Heritage Board of Singapore, namely the Asian Civilizations Museum⁵ and the National Gallery of Singapore⁶.

The Nanyang Paintings, are well cherished as national treasures of Singapore and gaining access to them has been a difficult process for the research project. In August 2016, the project presented its status at that point at the Lighting Design Forum 2016 in conjunction with the 'Nightfest' held by the National Heritage Board of Singapore.

Presented were the possibilities of lighting design for the Nanyang Paintings, citing Georgette Chen's *Lotus in a Breeze* as an example. Where through the

⁵ The Asian Civilizations Museum in Singapore works to preserve Asian cultural heritage, with particular interest in the "ancestral cultures of Singaporeans. These include China, Southeast Asia, India, and the Islamic world." (www.acm.org.sg) A museum governed by Singapore's National Heritage Board, the museum strives for a "better appreciation of the rich history that has created Singapore's multi-ethnic society." (www.acm.org.sg)

⁶ The National Gallery Singapore oversees over 8,000 works that chronicle the art history of Singapore and the region from the 19th-century to the present-day. It serves as a Singapore art museum that aims to be the centre for the research, discussion and exhibition of modern Southeast Asian art, the Gallery offers wide access and a fresh understanding of our unique visual art heritage.

research in lighting design, there could be mimicry of Chen’s experience of painting the lotuses across the day and perhaps allow viewers to be in that unique position of viewing the painting as she did the lotuses to “feast(ed) on these delicate white and pink beauties” (Chen 1970).

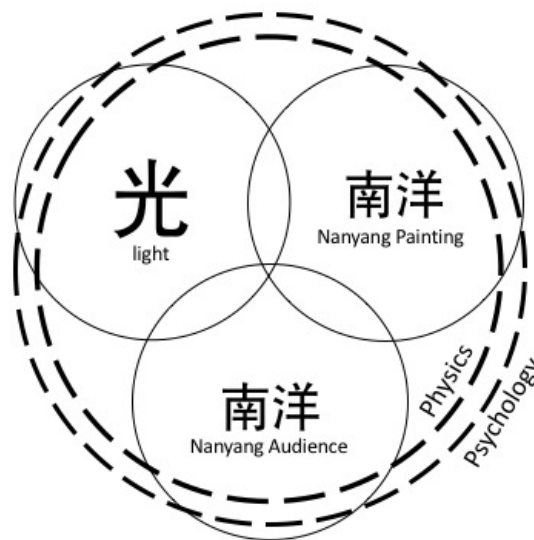


figure 3.1: Knowledge components of the research project.

Having the experiments conducted on Nanyang paintings with participants from the Nanyang region would allow the project to tackle two components of knowledge to balance out to understand how lighting design for paintings can alter perceptions.

3.2 Cognitive Mechanisms for the Sensory Processing of Paintings

Nanyang paintings are a synthesis of painting traditions and styles, and it finds itself at the intersection of both eastern and western art, naturalism and surrealism. This will provide complications for cognitive studies into the viewers' response. A couple of questions arise into how the viewers' response to the artwork in the field of cognitive science: The first being the cultural constraints in Eastern and Western art and the second, the difference in looking at naturalistic and surrealistic pictures.

3.2.1 Cultural Constraints in Eastern and Western Art

Despite anthropological universals that characterize aesthetic and moral judgments, the question remains whether such a framework, there are cultural specifics to aesthetical judgment. When traditional artworks between East and West are compared, the artists from the two extremities tend to use different perspectives for representation. While the Western artists from the renaissance era tend to use geometric perspectives to give distance cues, Chinese and Japanese artists use a reversed perspective where objects closer to the viewer are depicted smaller and, objects that are further are depicted larger. (Pöppel 2013 p.12) Even the orientation of landscapes then to be different, with Western landscapes being wide, and Eastern landscapes being long.

In a study where traditional Chinese and Western paintings were presented randomly for aesthetic evaluation by Chinese and Western subjects, the results showed a reverse pattern of aesthetic preference for typically represented Chinese and Western paintings. While the Chinese subjects gave higher aesthetic scores to the Chinese paintings, the Western subjects gave higher aesthetic scores to the Western paintings. (Bao 2013 p.1) The results suggest that the way artist represent the world influence the way of how

culturally embedding viewers perceive and appreciate paintings, it also suggests that social practice and perceptual habits in daily life across cultures affect aesthetic preferences for the creation of artwork.

Therefore, with regards to the Nanyang paintings, it is important to identify clearly the cultural background of the viewer and subject before carrying on the experiments. Perhaps splitting the subject pool into Eastern and Western subjects for comparison.

3.2.2 Looking at Naturalistic and Surrealistic Pictures

Paintings are either represented in a naturalistic way or abstract and surrealistic forms. Functional magnetic resonance imaging (fMRI) studies using paintings with natural and surrealistic depictions have shown that in naturalistic paintings, an activation pattern indicating stronger feedback signals between the higher and lower cognitive functions, meaning viewing naturalistic images are more of a top-down processing of images. Suggesting that the naturalistic paintings are viewed in a self-related matter which surrealistic paintings do not provide effortless integration of pictorial representations. (Pöppel 2013 p.14) This also suggest that in the synthesis of natural and surrealistic representations in Nanyang art, there are varying modes of processing the image, which could affect the subjects viewing and preference for lighting.

3.3 Nanyang Paintings



figure 3.2: Georgette Chen, Lotus in a Breeze. c.1970. Oil on Canvas.
Singapore, National Gallery Singapore.

“For ten days, the day began for me at 7a.m. and ended at 6.p.m. Under my painting sunshade, I feasted on these delicate white and pink beauties” (Georgette Chen, as quoted on the label of the painting).

When talking about the Nanyang paintings, sometimes confusingly referred to as the Nanyang 風格 (*feng'ge*)⁷ or the Nanyang School of the 1950s and 1960s a great amount of debate comes with what exactly is a Nanyang Painting. Used extensively and freely as a prefix to concepts that span various disciplines, the usage of Nanyang (in art) have not been “critically explained and defined. Consequently, the propriety and scope of their application have not been established.” (Sabapathy 1979 p.43)

⁷ 風格 *fēnggé*, noun: Style. Yet it is important to note that despite translating directly to the word Style. *Feng'ge* refers to the expressed the essence of a thought rather than a formal visual *style*.

This project, through looking at paintings commonly expressed by the lay to be of a Nanyang nature, seeks to establish a keen understanding in the way the term Nanyang has been used in various proprieties and what the term stands for in each of those, while observing the changing usage of *Nanyang* in paintings, and to forge an understanding of the sentiments that make a painting, Nanyang.



figure 3.3: Map of Nanyang Region as defined by Yvonne Low in 2010.

The Nanyang, or Southern Seas is a term originated amongst the ‘Sinosphere’ to refer to “any part or the whole of the island nations situated south of China, including the Philippines, the Indonesian archipelago, the archipelago, the Malayan Peninsular, Singapore and the southern part of Thailand.” (Low 2010 p.230)

Nanyang, geographically, it is a vast and complicated region, charting almost everything south of China, encompassing the entire South-East Asia. In terms

of a means of identity its diasporic roots draw even more confusing concepts of what it means to be a person from the *Nanyang*. Are you a 'sojourner', 'migrant' from China or a 'local'? Even so, 'local' to where exactly in Nanyang?

This crisis in identifying the Nanyang would raise issues to trying to clearly recognize art associated with the Nanyang. Since the first attempt to coin a Nanyang painting in 1979, there has been countless discourse and varied definitions into trying to define the characteristics of a Nanyang Painting.

Yet, what makes a Nanyang painting, Nanyang may not be a lay observation of formal properties but instead a deeper reading of the qualities expressed in the painting. Just at what makes a Chinese man in Singapore, Singaporean, and a Chinese man in China, Chinese, it is the deeper emotional thoughts or sentiments that fills a painting with Nanyang-ness.

To understand the development and inception of a Nanyang aesthetic, a Nanyang state of mind, one would first need to chart course from China, southwards to the Nanyang region. Looking at the paintings commonly known as Nanyang Paintings on a formal glance, there seems to be a synthesis of eastern and western techniques. Is there a degree of syntheses which has to occur in order to make a painting Nanyang, or is it even enough? Is there something more to the blending of techniques that breathes Nanyang-ness into a painting?

3.3.1 The Journey to *Nanyang*

The term *Nanyang*, together with *Xiyang* (Western Seas, referring to the western world) and *Dongyang* (Eastern Seas, with referring to Japan), saw China as the metaphorical center and heart of all bearings.

In the Chinese diaspora to the region of *Nanyang*; Chinese settlers referred to themselves as *Nanyang Huaren* (南洋华人)⁸ or *Nanyang Huaqiao* (南洋护侨)⁹ which indicated that these Chinese settlers or sojourners maintained a “China-oriented identity consciousness”. (Hara 2003)

Apart from referring to themselves and *Nanyang Huaren*, the Chinese in the Region of *Nanyang* also added the prefix *Nanyang* to their enterprises and institutions, for example, *Nanyang Siang Pau* (sweet buns), *Nanyang Technological University* or, of more prominence to this paper, *Nanyang Academy of Fine Arts (NAFA)*.

3.2.2 Prior attempts to define the *Nanyang Style* Paintings.

There have been countless attempts to define the *Nanyang Style*, the first being in 1979 by Redza Piyadza and T. K. Sabapathy. In their attempts to define it obliquely, both scholars tried to skirt the issue by identifying the *Nanyang Artist* first. The artist had to be an affiliate of NAFA and represent local subject matter (still life or scenes which depicted living in the *Nanyang* region) in experimental approaches that are a synthesis of Chinese and

⁸ Chinese in *Nanyang*

⁹ Chinese immigrant in the *Nanyang*.

Western art, using techniques and formal styles derived from Chinese pictorial traditions mainly from the Xinhua School of Art and the School of Paris. (Sabapathy 1979 p.43) It is important to note that the Nanyang Style was never defined here.

In today's situations, the style seems to apply to the paintings of Chinese émigré artists working in the Malay Archipelago between the 1930s and 1960s who's art work synthesizes Chinese and Western art traditions in representing local subject matter to the region of Nanyang. (Teo 2011 p.12) Amongst these émigré artists themselves are, particularly and commonly known as pioneer artists¹⁰ of Singapore, namely Liu Kang, Chen Wen Hsi, Cheong Soo Pieng, Chen Chong Swee and Georgette Chen, made no reference, nor mention of the Nanyang Style in the 1950s. (Kwok 2000)

3.3.3 A Formal Nanyang Style

“In terms of formal characteristics, Chung Cheng San (a Malaysian artist) wrote in 1991 that at its developed phase, the Nanyang Style in its *xiyanghua* (western art) form was characterized by the manners of the Schools of Paris, especially the pictorial forms of Vincent van Gogh, Paul Gauguin, Henri Matisse, and Pablo Picasso, as well as the Balinese wooden figurative form, combined with local subject matters. The Nanyang Style in the ink painting form was characterized by the styles of Shanghai School with life drawing and calligraphic elements, and at times incorporating Western structural forms,

¹⁰These pioneer artists, who had been trained mostly in the Xinhua Art Academy in Shanghai during the 1930s and taught at NAFA during their careers were also greatly exposed or schooled in western techniques from the School of Paris, which is a collective term given to paintings in the styles of Post-Impressionism, Cubism, Fauvism. (Voorhies 2004)

combining with local subject matter.” (Chung Cheng San as quoted by Teo 2011 p.26)

In Teo Lay Khim’s paper a very keen and clear definition is drawn up on how to identify a Nanyang Painting, based on scholarship from Schapiro and Genova. “Schapiro defines style as showing constancy in features, and Genova advocates that style should express meaning. Drawing from these two scholarships, the ‘meaning-expressing’ stable structure, comprising constant elements that characterize the works of early Chinese artists in Nanyang, is developed for defining their style, one commonly described as Nanyang style.” (Teo 2011 p.8)

In accordance to Teo Lay Khim, defining a painting to be Nanyang Style would require 4 elements to be present (Teo 2011 p. 74).

1. Firstly, Nanyang Subject Matter. (still life or scenes which depicted living in the Nanyang region)
2. Secondly, a synthesis of western (School of Paris) and eastern (Xinhua School in Shanghai) art traditions.
3. They should be from the Period of the 1930s and 60s.
4. Artist should have a dominant “Nanyang” identity

However, as seen in examples below and by the description by Chung Cheng San above, the degree of synthesis of eastern and western art traditions is highly difficult to observe due to the wide spectrum in which the two influences collide. And as such it is highly difficult to constrain Nanyang paintings into a distinct formal style.



figure 3.4: Chen Wen Hsi "Gibbons", 1969. Chinese Ink and Colours.
Singapore, National Gallery Singapore



figure 3.5: Liu Kang. Life by the River. 1975. Oil on canvas.
Singapore, National Gallery Singapore

As such, this thesis recognises that the Nanyang Paintings do not conform to any distinct visual look, for formal descriptions, though applicable, sits on a vast scale of interpretations of the guidelines for defining the Nanyang Style in Painting as per Teo Lay Khim in 2011.

Also, with regards to the depiction of Nanyang subject matter and the time period of the 1950s and 60s, It could be too simplistic to simply define paintings to be Nanyang based on these terms alone. One would have to understand the motivations behind the paintings during that period.

3.3.4 Settling in Nanyang

Prior to the 1950s, the Pioneer artists had already been painting with the first two elements of Teo's guideline to defining Nanyang paintings. Synthesizing western and eastern painting traditions due to their global artistic education and portraying the tropics in their subject matter. Yet, these earlier artwork is rarely considered to have a Nanyang essence.

What made all the difference in the 1950s?

To understand this, it is important to look at the political and social climate of that era. The 1950s saw post-war Singapore striving to break free from colonial rule and the 1960s saw the island gain full independence as a country of its own.

Similarly, the once China-centric mind-set of the *Nanyang Huaren* had shifted. Chinese immigrants had settled and undergone western education. In Singapore, the Chinese elites were cultivated to emulate native and colonial elites and tended to cut themselves off from a China-centric sensibility. (Low 2010 p232) The local Chinese community was ready to assume a new national identity, as Chinese leaders sought to have the cultural features of the Chinese community officially recognized as an integral part of a composite national identity. (Cushner & Wang 1988 p4) It is naïve to state that all

Chinese émigré artists had decided to dig roots deep into Nanyang soil. Yet, it is important to note that the Pioneer artist had chosen to stay in Nanyang.

As art imitates life, painters started to share the “same aim of creating Singaporean Art” despite differences in ‘styles’ as pinpointed by a recent exhibition at the Fukuoka Asian Art Museum that surveyed ‘Nanyang Art’. It is difficult to pinpoint the exact moment where the Chinese identity turned from ‘sojourner’ to ‘migrant’ to ‘naturalized’ and ‘local’, but it is commonly acknowledged that the pivotal Bali trip in 1952 by Chen Wen Hsi, Cheong Soo Pieng, Chen Chong Swee and Liu Kang as the landmark event. (Low 2010 p234)

The Bali trip marked the point where the visual arts made a conscious effort to represent the Nanyang through a Nanyang centric mind, instead of through Chinese Diasporic point of view. In parallel to the trip were Lim Hak Tai’s (founder of NAFA) call for painters to paint the “reality of the Southern Seas and the localness of the place”. (Chia 2002)

Describing Liu Kang in retrospect, and to reiterate the point that the painter had actively sought to promote a unique Nanyang mindset and aesthetic thought, his son has mentioned that “He paid attention and embraced Chinese, Malay, Indian art into his thinking,” he said. “To the extent, he even sent my sister to an Indian dance school when she was young. That was how broad-minded he was, but also how concerned he was in expressing all aspects of the Nanyang environment, in terms of geography, in terms of culture. He was very eager to establish a foothold in the world’s art scene of the art from Southeast Asia.” (Liu Thai Ker as quoted by Othman 2015)

It would then be safe to say that the Bali trip saw the Nanyang Painters coming into a new identity as Nanyang locals, and sought to express their

amalgamation and daily interaction with different cultures their environments in their works. Though still retaining a Chinese identity, they broke away from the China-centric sentiments of Nanyang, Nanyang then stopped being the south, but China became the North. Nanyang became at the core of their bearing.

3.3.5 The Nanyang *Fengge* or Essence.

Nanyang *Feng'ge* (南洋風格), is a term commonly used in Chinese literature on the topic and has since been lost in translation to the term Nanyang 'style', doesn't concern itself with formal styles of paintings but rather the expressed quality that the painting possesses. (Low 2010 p.230)

As such, to clearly identify the Nanyang-ness of a painting is to take a pause from formal styling and to understand and to understand what it resonates with. Low's paper, "Remembering Nanyang *Feng'ge*" claims that "their (the pioneer artist's) success in representing localness lay not in simply depicting 'local' (indigenous subject matter, but in conveying a sense of localness perfected on their individual interpretation of the locality." (Low 2010 p.229) This sense of localness is inseparable from a culture's way of life, which would translate to its own unique *feng'ge* (quality) (Ma 1961).

Nanyang *Feng'ge* remains distinct from western discourse and demands to be understood from a local perspective. It can be understood that the *Feng'ge* grew out of a need for a national identity. "Conceived from a multicultural ideology of the Malayan¹¹ idea-complex that sought to signify a sense of solidarity among the races (and cultures) *vis-à-vis* symbolic representation of

¹¹ Malayan *Feng'ge* and Nanyang *Feng'ge* are sometimes used synonymously (Low 2010)

subject matter or painting techniques in the hope of communication multiculturalism and a Malayan Identity.” (Low 2010 p.229)

Somehow, with the assuming of their new identities as Nanyang locals, the painter’s works seem to be invigorated with a new quality, despite being stylistically varied, filled with the same subtle essence and quality that seemed to radiate with the local Nanyang-ness.

3.3.6 Identifying the Nanyang Paintings

The pioneer artists told “the beginnings of art in Singapore... But as Singapore continues to grow, develop and change, the Nanyang Art Style will never be a fixated one as it was never meant to be.” (Tan 1997 p.88) In parallel through their works, the beginnings of a Nanyang aesthetic or Nanyang 風格 (*feng’ge*), is observed, through a fundamental principal that is required in order to consider works as an authentic representation of Nanyang.

While Teo Lay Khim’s guiding principles in defining Nanyang paintings formally is acceptable, it lacks the sensitivity to identify the Nanyang-ness in the painting. Further to that classifying the Nanyang Paintings to a time space is simplistic, as a look into the socio-political motivations of the time seems to be more applicable rather than dating it. . Thus, revising his definition:

1. Firstly, Nanyang Subject Matter. (still life or scenes which depicted living in the Nanyang region)
2. Secondly, a synthesis of western (School of Paris) and eastern (Xinhua School in Shanghai) art traditions.
3. ~~They should be from the Period of the 1930s and 60s.~~
Lastly, they should be painted with a Nanyang-centric identity.
4. ~~Artist should have a dominant “Nanyang” identity~~

Nanyang 風格 (*feng'ge*), is essentially provided by the painter's paradigm at the point of painting, an honest depiction of the painter's experiences in Nanyang, through a Nanyang-centric mindset. Meaning, the painter should feel a sense of belonging to the region. It is this sense of belonging to the Nanyang, which the artists tried to allow their viewer to experience by observing the Nanyang Paintings, where primary concern of the painting, was to represent the Nanyang to any particular viewing audience.

CHAPTER 4: Experiments

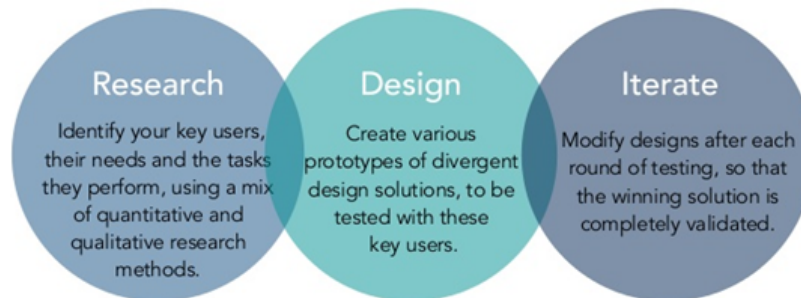


figure 4.1: 3 step process of UX design.
(Fioni 2014)

Similar to the iterative design¹² methodology of UX projects. The research project recognises that theoretical research and experiment design and studies are not separate but are iterative and will constantly inform each other through the review, reflection and re-contextualization of new sets of data to be analysed and interpreted, and new theoretical research for a better understanding of artificial lighting design for paintings in indoor settings.

¹² Iterative design is “based on a cyclic process of prototyping, testing, analyzing and refining a product or” (Nielsen 1993) method. By using results and findings from surveys and tests with latest iterations of the product, refinements can be made to improve the quality and functionality of the design.

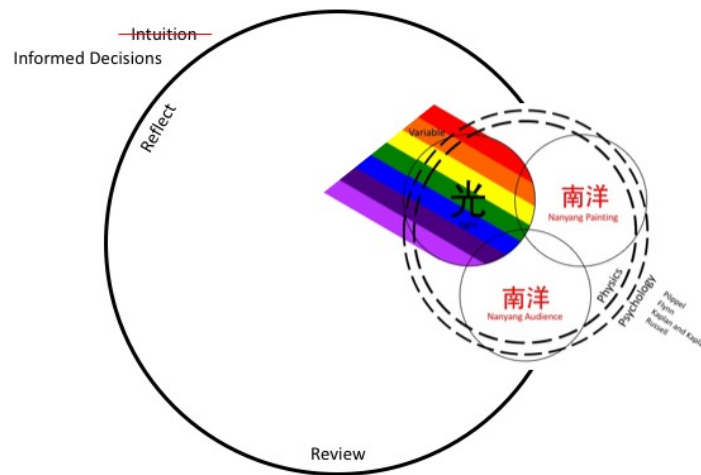


figure 4.2: Cyclic project design process.

This research project adopts a similar process of iterative design with its experiments, where results and discussions from prior experiments inform the next, till a clear trend in data can be found. By doing so the lighting designer's intuition when lighting paintings can be turned into informed decisions.

4.1 Initial Considerations

The project first sought to start by mapping the quantitative qualities of the light source to quantitative spectral data emitted from a painting by charting the painting into tiny pixels and incorporating the archiving research by Tominaga presented earlier.

After-which, a by applying semantic differential rating scales set under standards from the Illuminating Engineering Society's ¹³ guide ¹⁴ to methodology and procedures for measuring subjective impressions in lighting developed by John Flynn into a questionnaire, a second mapping was required to directly relate the initial qualities from the light source to the qualitative responses provided by the subject.

¹³ The Illuminating Engineering Society of North America (IES), part of the PennState College of Engineering, formerly the Illuminating Engineering Research Institute (IERI), is the recognized technical authority on illumination. For over 100 years; its objective has been to communicate information on all aspects of good lighting practice to its members, to the lighting community, and to consumers, through a variety of programs, publications, and services. (www.cire.org)

¹⁴ IERI project 92: "A research methodology for studying psychological and related subjective effects of illumination. In this sense, the study has made note of" (Flynn 1979) the effect of light on subject impression in spatial illumination. These effects can be studied by *scaling procedures*. These scaling procedures were proposed as a "standardized series of test procedures—so that work by various researchers can be compared, and otherwise contribute to a common base of knowledge and information on the subject." (Flynn 1979)

Lighting Condition							
Painting							
Background Colour							
Evaluative Scales		1	2	3	4	5	
General sentiment towards Painting	Pleasant						Unpleasant
General emotional takeaway of the painting	Satisfying						Frustrating
Scales representing Visual Clarity		1	2	3	4	5	
Illuminance of Painting	Bright						Dim
Light Colour	Visually Warm						Visually Cool
Colour of Pigments	Vivid						Dull
Colour of Composition	Distorted						Natural
Scales representing Spatial Modifiers		1	2	3	4	5	
3-dimensionality of Content of Painting	Visually Deep						Visually Flat
3-dimensionality Painting (as a whole) in gallery	Pops out of wall						Blends with wall
Scales representing other influencers		1	2	3	4	5	
Glare	Unnoticeable						Troublesome
Open Ended Questions							
What difference would you prefer to be made to the lighting conditions of the artwork? Eg if it was in a different setting, outdoors or under diffused skylights?							
How do you feel different lighting conditions for paintings have affected the way you appreciate the paintings?							

figure 4.3: Example of questionnaire incorporating semantic differential rating scales.

However, it was to employ spectral band cameras to analyse the paintings at this point of the research would be premature as too much computational data would be required which wasn't logistically viable. Upon archiving the painting, there would be too many variables to account for. There would be the angles of incidence of which the light source shone onto the artwork, which would create too much unpredictability and inconsistency with what the subject sees. Further to that, there was a need to have the painting in question in possession for an extended period of time, of which was financially unviable.

As mentioned earlier, of the 10 steps in the "Monza Method", the project would then focus on the following:

1. Use different spectra together
2. Use a minimum of 3 different spectral compositions
3. Plan the angles of incidence of light

The project had to realize that the subject of investigation was the impressions of the viewer to lighting conditions. Which meant that there was a

need to narrow down to which factor of lighting to vary and before anything, if it elicits a response in the viewer.

In parallel to reviews of existing studies, a minimum viable product¹⁵ (MVP) was required to affirm that changes to the 2 factors (the intensity of the illumination and the spectral composition of the light sources) would display measurable human responses in positive empathic relationships paintings. A small-scale experiment was made with 9 lighting conditions for 9 different paintings of various media and mediums under controlled environments (explained further in the report). The test validated the two factors in question does indeed provide significant differences to the preference between lighting designs for the paintings, regardless of medium. As such, affirming them as significant factors enough to continue the research on.

4.2 Minimum Viable Product

Overview

Experiments were conducted in a dark room with viewing conditions set to be as close to that of museum galleries. 9 paintings were selected for the experiments. There were 9 phases of illumination for each painting. Intensity of all 9 phases of illumination were kept at a constant of 100lux.

¹⁵ A term commonly used in entrepreneurship. In the product development phase of a business, “the minimum viable product (MVP) is a product with just enough features to gather validated learning about the product and its continued development.” (Ries 2011)

Illuminants

Paintings were hung close to as they would be in galleries. The paintings were hung against a photographic background roll, Savage Widetone Seamless Background Paper (#27 Thunder Grey, 107" x 36'). Observers were seated 1.5 meters away from the images and had their eyes parallel with the center of the image, this was to simulate viewing paintings behind boundary lines at museums.

A track-light comprising of 3 Reggiani Lighting's Yuri lighting system is shone at a fixed angle throughout the experiment and the total lux value of light hitting the artwork is kept at a constant despite mixing of 3 different sources, with different colour temperatures. was suspended at a height of 2400mm from the ground and at 1500mm away from the walls in which the paintings were hung. All 3 lamps were used to create each of the 8 viewing conditions per painting. There were 9 phases of viewing conditions per painting,

Paintings

Stimuli, original paintings of various media and mediums (4 water colour on water colour paper, 3 Oil on Canvas, 2 Acrylic on Canvas) were presented. The paintings varied in style and technique and were painted by both amateur and professional artists. Paintings varied in style, as they were not Nanang paintings, no formal studies were made into these paintings.



figure 4.4: paintings used for minimum viable product.

- a) Andrew Duffy. Untitled painting of Heliconia. Circa 2010. Acrylic on Canvas.
- b) Andrew Duffy. Untitled painting of Bird of Paradise. Circa 2010. Acrylic on Canvas.
- c) Andrew Duffy. Untitled painting of Angkor Thom. Circa 2000. Watercolour on Paper.
- d) Andrew Duffy. Untitled painting of Blue Mosque. Circa 2000. Watercolour on Paper.
- e) Joan Kelly. Untitled. Circa 2010. Oil on Canvas.
- f) Ng Woon Lam. Singapore Botanical Gardens. Circa 2016. Oil on Canvas.
- g) Ng Woon Lam. School of Art Design and Media, Night. Circa 2016. Oil on Canvas.
- h) Ng Woon Lam. Colonial House. Circa 2016. Watercolour on Paper.
- i) Joan Kelly. Untitled. Circa 2010. Oil on Canvas.

Observers

A total of 9 observers (4 male, 5 female, mean age=26 years) were selected through a call for observers. The observers had normal or corrected to normal vision and had perfect colour vision. The Institutional Review Board at the Nanyang Technological University approved all procedures.

Observers were from a varied background in art education. According to similar experiments by Luo et al. 2014, there were no difference in results regardless of education background.

Observers were all native or naturalized to the Nanyang region. The Nanyang, being geographically along the equator in South East Asia, receive more sunlight all year round compared with those in higher latitudes of the hemispheres. As the case study paintings were Nanyang paintings, it was imperative that the observers were culturally Nanyang to avoid cultural differences in perception of art. (Pöppel 2013 p.12)

Observers had English as their first language and were all effectively bilingual.

Observers were asked to go through a briefing session prior to experiments. The briefing introduced them to the terms used in the questionnaire and the proper procedure of filling in the questionnaires.

Due to logistical constraints, experiments were conducted both between subjects with each observer only viewing 1 lighting condition for each painting.

Observers were tested individually.

Questionnaire Motives

Observers were asked to fill in a questionnaire. The motives of the questionnaire were to determine whether there is a difference in the reception and preference of viewing paintings under different lighting conditions.

Scales

Observers preferences for a lighting condition was measured on a Likert scale for likability.

Procedure

Observers viewed different paintings under 9 different lighting conditions. Observers were to rate on a scale of 1 to 5 how pleasing the lighting condition was for appreciating the painting. Paintings varied in media from various artists.

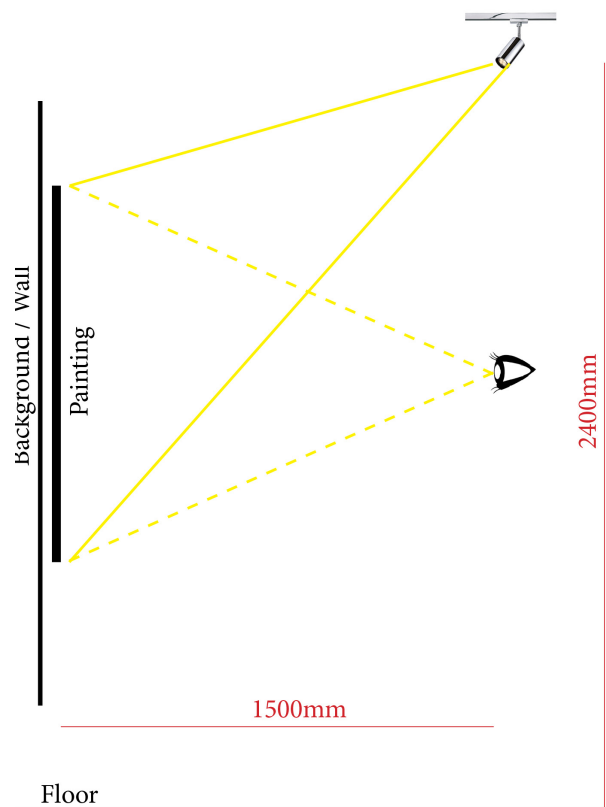


figure 4.5: experiment set up and positions

After filling in and acknowledging consent, the observers completed brief questionnaire to familiarize themselves with how to fill in the actual questionnaires for the study. Observers were then told to observe the various paintings and fill in the questionnaires regarding to their preference and the details obtained from the paintings under the varied lighting conditions.

As the experiment was arranged in a between subject manner, no randomizing of viewing conditions was needed.

Results

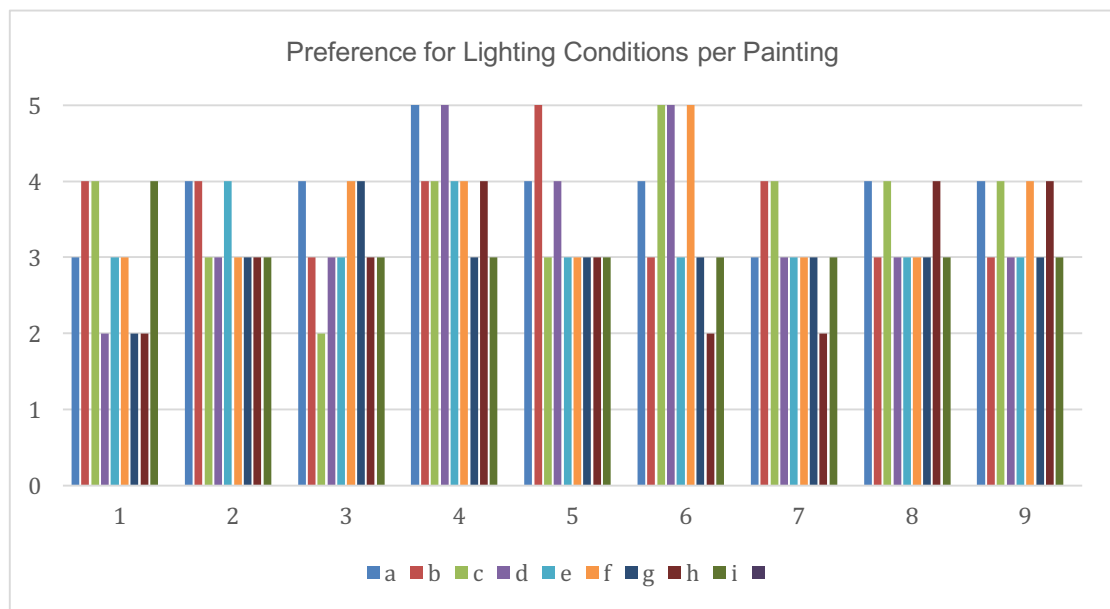


figure 4.6 Preference for Lighting Conditions per Painting

The MVP revealed the following:

- Stronger preference for lighting of mixed sources
- Stronger preference for warmer correlated colour temperature for paintings with warmer undertones and vice versa for paintings with cooler undertones
- A presence of cooler correlated colour temperature is preferred for paintings with white space.

However, the MVP exposed following flaws:

- Rating scales had to be widened in order to see a significant peak in preference.
- Specific information about SPDs required.
- Observer pool had to be larger to find a consensus on preferred schemes.
- Experiment was logistically cumbersome, where too much time was spent to gather data.

Reviewing the areas of concern in the “Monza Method”, the project was to focus on the following:

1. Use different spectra together
2. Use a minimum of 2 different spectral compositions

After validation from the MVP that varying and mixing the colour temperature, and as such the spectral qualities of the light shining on the painting, this project further narrowed down its focus on the nuances in spectral conditions of blending 2, not 3 light sources.

The reduction of 3 to 2 is so as to narrow down the variables to better comprehend how stronger empathic relationships to paintings are affected by the intensity of illumination from the mixing of 2 different light sources to illuminate the painting, before attempting to introduce a 3rd.

4.3 Digital Pilot Experiment.

A streamlining of the MVP was required in order to identify more clearly the preferences for lighting conditions of paintings. The observer base needed to be expanded in a shorter amount of time. Also, the range of colour temperatures can be significantly increased via digital means to see if there are drastic differences in preferences. Experiments to an online survey of 5 Paintings under rendered lighting conditions.

Digital surveys at this phase of the research at this juncture would be a lot more efficient and avoid the logistical cost of physical experiments to obtain data from larger sources.

The focus here is to find a tipping point in the nuances of lighting conditions in which the preference turns from dislike to like, in accordance of identifying a preferred means of lighting Nanyang paintings.

Overview

Experiments were converted into a digital survey. The survey was set up using web application Survey Monkey. Viewing conditions were varied, and subject to that of the observers' decision as to where they participated in the survey. Observers viewed 5 different Nanyang paintings under 11 different lighting conditions. Observers were to rate on a scale on how satisfying the lighting condition was for appreciating the painting. Observers were also asked to give feedback as to which lighting conditions were satisfactory or not.

Illuminants

The experiment was a digital one, as such, no luminaires were used. Digital images were rendered in Adobe Photoshop with virtual luminaires.

3 digital “spotlights” were created by visually matching the visual output from the Lumileds Luxen 30302 LED chip in a photo editing software.

Paintings were rendered to an approximated illuminance to that of their display at the National Gallery Singapore.

Paintings

5 paintings were selected for the experiment. All 5 paintings were Nanyang Paintings, which are on display in the National Gallery Singapore. Paintings selected varied in size, medium and subject matter.



figure4.7 : Paintings used in digital experiments.

- a) Georgette Chen. Lotus in a Breeze. 1970 Oil on canvas.
- b) Liu Kang. Life by the River. 1975. Oil on canvas.
- c) Cheong Soo Pieng. Bali Beach. 1955. Gouache on cardboard laid on masonite board.
- d) Chen Wen Hsi, Herons. 1991. Chinese ink and colour on paper.
- e) Landscape. Chen Chong Swee. 1968. Chinese ink and colour on silk.

Singapore, National Gallery Singapore

As the experiment was conducted digitally, digital images of the paintings were required. Images were downloaded from the National Gallery Singapore's website. Considerations were taken with regards to the paintings being represented in digital format and digital colour space.

Observers

A total of 166 observers (82 male, 84 females, mean age= 34.8 years) were selected through a call for observers. The observers had normal or corrected to normal vision and had perfect colour vision. The Institutional Review Board at the Nanyang Technological University approved all procedures.

Observers were from a varied background in art education. According to similar experiments by Luo et al., 2014, there were no difference in results regardless of education background.

Observers were all native or naturalized to the Nanyang region. The Nanyang, being geographically along the equator in South East Asia, receive more sunlight all year round compared with those in higher latitudes of the hemispheres. As the case study paintings were Nanyang paintings, it was imperative that the observers were culturally Nanyang to avoid cultural differences in perception of art. (Pöppel 2013 p.12)

Observers had English as their first language and were all effectively bilingual.

Observers were asked to go through a briefing session prior to experiments. The briefing introduced them to the terms used in the questionnaire and the proper procedure of filling in the questionnaires.

Observers could participate in the surveys at their own discretion and in an environment and platform of their choice.

Questionnaire Motives

Observers were asked to fill in an online questionnaire. The observers were asked to indicate their preference for each viewing condition for each painting on a 7-point Likert scale ranging from 1 (very satisfied) to 7 (very dissatisfied).

The questionnaire also asked the observers to comment on how satisfied they were with the viewing conditions.

Scales

The observers were asked to indicate their preference for each viewing condition for each painting on a 7-point Likert scale ranging from 1 (very satisfied) to 7 (very dissatisfied).

Procedure

After acknowledging consent, Observers were then told to observe the various paintings and fill in the questionnaires regarding to their preference and the details obtained from the paintings under the varied lighting conditions. The instructions were simple to avoid presenting them with external hints regarding the preference of lighting scenes for the various paintings. All observers went through all 5 paintings under 11 different lighting conditions for each painting. These conditions were broken into 2 sets, 1 with only one light source of a single colour temperature and 2nd set with a blended light source; this is due to the findings of the pilot study which indicated that blended light sources were generally preferred.

Understanding Digital Colour Space

In colour perception, The LAB¹⁶ colour space model caters for all colours perceivable to the human eye, unlike the Red Green Blue (RGB) and Cyan Magenta Yellow Black (CMYK) colour models. The LAB model is also device independent¹⁷; meaning that the LAB colour space is optimal for denoting colours across different devices and screens.

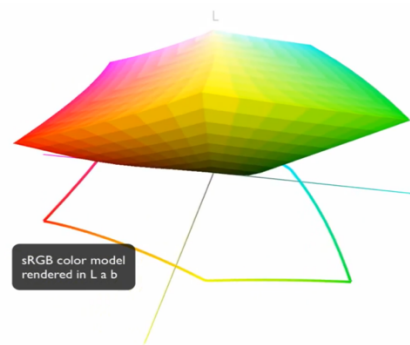


figure 4.8: 3D display of sRGB colour model rendered in LAB.

¹⁶ “A LAB colour space is a colour-opponent space with dimension L for lightness and a and b for the colour-opponent dimensions, based on nonlinearly compressed coordinates.” (eprints.uwe.ac.uk)

¹⁷ Device Dependent refers to the CMYK gamut a printer/press can print to – it’s behavior. All printers/presses print differently, therefore they have Device Dependent profiles, or colour gamuts. Basically, CMYK values for one device will print differently on another CMYK device. In contrast, Device Independent refers to the LAB Colour Space. LAB values (50,0,0 – neutral gray) are absolute values that have a known colour value. This is the colour sensation that are eye processes and how spectrophotometers communicate colour values between devices. In contrast, device independent refers to colours staying true despite screens or print.

However, in digital rendering, most screens will render images in RGB colour models in an additive colour. In the figure attached, the volume of the colours reproduced from this additive colour model. Since sRGB models are often used in projected images, the colours in the model are highly saturated and bright.

A survey where colours are rendered on digital screens will mean that a painting that is normally perceived by the human eye in LAB will be rendered in sRGB, which consists of a smaller set of colours that actually perceivable by the human eye. As such, considerations had to be taken when analysing results that the colours presented to the participants are different from when viewing paintings in real life.

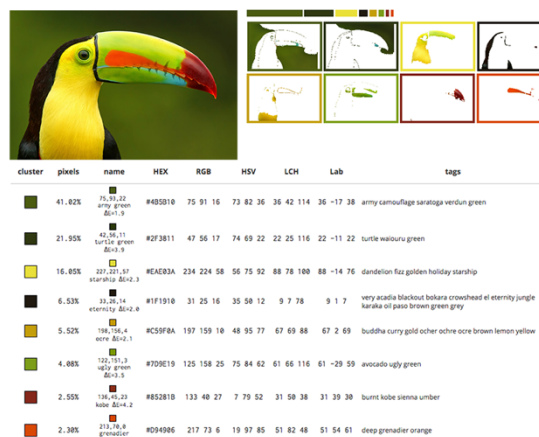


figure 4.9: Analysis of image colour composition.

(Image Colour Summarizer, <http://mkweb.bcgsc.ca/color-summarizer/>)

By first summarizing a digital image into its colour composition, it would be possible to calculate the percentage of “colour” that make up the image in the various colour systems. Though the images are viewed in RGB colour on screen, these images could be reverse engineered to attain the LAB colours that the eye processes and thus relate this to the spectral information that is

hitting the image from our lights, and in doing so, find patterns in preference, perception, colour and light.

Results

Results were calculated using repeated measures¹⁸ ANOVA¹⁹ with 2 within-subject factors (painting with 5 levels; light with 11 levels) and 2 between-subject factors (gender with 2 levels; sight with 2 levels).

The repeated measures ANOVA allows for a detection of effects between the lightning conditions and paintings (within-subject effects), effects of gender or normal/impaired sight (between-subject effects), and effects of interactions between those factors.

The following table indicates the statistically significant results for within-subject effects that have significant effects. Within-person (or within-subject) effects represent the variability of a particular value for individuals in a

¹⁸ Repeated measures design uses the same subjects with every branch of research, including the control.

¹⁹ Analysis of variance (ANOVA) is an analysis tool used in statistics that splits the aggregate variability found inside a data set into two parts: systematic factors and random factors. The systematic factors have a statistical influence on the given data set, but the random factors do not. Analysts use the analysis of the variance test to determine the result independent variables have on the dependent variable amid a regression study.

(<http://www.investopedia.com/terms/a/anova.asp#ixzz4ieux8SQ6>)

sample. In this case, it is a measure of how much an individual's preference then to vary with each factor.

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	
painting	Sphericity Assumed	61.24	4	15.31	4.177	0.002	0.031
	Greenhouse-Geisser	61.24	3.259	18.789	4.177	0.005	0.031
	Huynh-Feldt	61.24	3.43	17.853	4.177	0.004	0.031
	Lower-bound	61.24	1	61.24	4.177	0.043	0.031
light	Sphericity Assumed	253.98	10	25.398	12.256	0	0.086
	Greenhouse-Geisser	253.98	4.657	54.532	12.256	0	0.086
	Huynh-Feldt	253.98	4.963	51.173	12.256	0	0.086
	Lower-bound	253.98	1	253.98	12.256	0.001	0.086
painting * light	Sphericity Assumed	67.604	40	1.69	1.659	0.006	0.013
	Greenhouse-Geisser	67.604	22.027	3.069	1.659	0.028	0.013
	Huynh-Feldt	67.604	27.318	2.475	1.659	0.017	0.013
	Lower-bound	67.604	1	67.604	1.659	0.2	0.013
painting * light * Gender	Sphericity Assumed	59.601	40	1.49	1.462	0.03	0.011
	Greenhouse-Geisser	59.601	22.027	2.706	1.462	0.076	0.011
	Huynh-Feldt	59.601	27.318	2.182	1.462	0.057	0.011
	Lower-bound	59.601	1	59.601	1.462	0.229	0.011

figure 4.10: within subject effects of digital experiments

This indicates that there changes in lighting illicit a large response in the human reaction and preference for viewing the paintings, lending to the notion that different lighting conditions can perhaps alter the way humans perceive a painting.

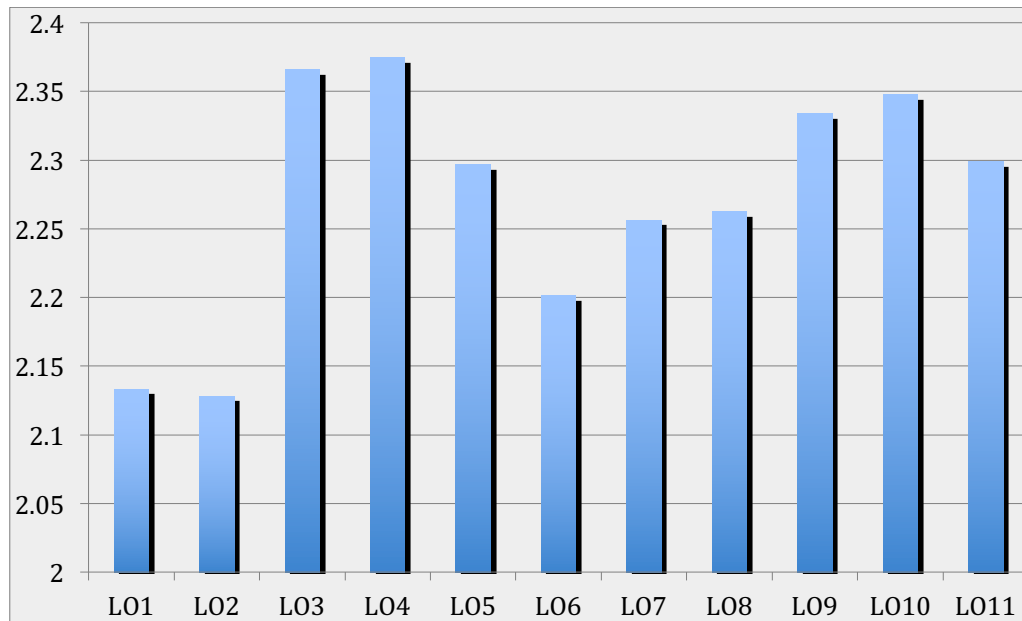


figure 4.11: Preference of lighting conditions across all 5 case study paintings in the digital experiment

When preference for all 11 lighting conditions were averaged across all 5 paintings, despite the spikes indicating a trend towards a particular lighting condition, the statistical difference in between the most favoured lighting condition and the least appears to be insignificant with a rating point of only 0.2 points difference. This suggests that lighting design for paintings is not independent to the painting and that individual paintings should be lit specifically.

Though the statistical difference in preference was favourable for the research across paintings, when observed for individual paintings, the results also showed a statistical insignificance in preferred lighting conditions across all 5 paintings. This suggests that there could be improvements to be made to the survey scale.

Out of the 166 observers that completed the survey, the general trends are as follows:

- For Set 1, where lights are of a single-colour temperature, Colour temperatures of 5000k and above are significantly preferred.
- For Set 2, similarly, lighting conditions 1 to 3, which are of 50% 3000k colour temperature (warmer) tend to be less preferred. However, there isn't a significant spike in which lighting condition is preferred.

At this point of the research, further exploration into understanding the data collected is required to determine any further action. However, following the current studies, several observations for amendments are required to obtain certain specific information before making the move from digital studies to actual physical experiments, of which will include:

- Increasing statistical significance
- Incorporating spectral data into digital experiments
- Controlling the environment
- Cognitive science in perception of case study material.

Iterations fo Increasing statistical significance

The current preference is charted on a 7 point scale, by reducing the scale to a yes/no choice, there would be prominent demarcation between the preferred lighting condition and the ones that are not, allowing for a clearer statistical analysis of preference. This is taced in later experiemtns by reducing the scale to 4-points, creating larger variation in responses.

Iterations for Incorporating Spectral Data into Experiments

Currently the experiments use a matching of correlated colour temperature from digital rendering to actual sources. As sources of the same correlated colour temperature may have different spectral densities, further experiments will need to digitally simulate the effects different spectral information instead of matching digital CCTs to that of a physical one. This could be done by lighting physical paintings or replicas and using photographs for the digital experiments rather than renderings. In later experiements with real paintings, lightng conditions were measured carefully to incoporate spectral data for analysis

Iterations for Controlling the Environment

There are also limitations to this current study where, the screens, which the tests were conducted, were not uniform, and as such colour calibration of the monitors may be slightly off tune. As the study was conducted online, and without a controlled environment, there may have been distractions to the observers at the point of the study. Later experiments were conducted under strict conditions as outlined in later sections of the thesis.

4.4 Experiments with Real Paintings

Overview

Experiments were to be conducted with viewing conditions close to that of museums galleries. As such experiments were held in collaboration with, and on actual paintings displayed in the galleries of the Asian Civilization Museum and the National Gallery Singapore. 4 paintings were selected for the experiments. Original task lighting for the paintings in the gallery were turned off, while house lighting remained. There were 8 phases of viewing conditions per painting, which were divided into 2 sets of 4. Set 1 had 4 viewing conditions lights that measured at 4000k CCT and set 2 had 4 viewing conditions lights that measured at 3500k CCT. The intensity of the viewing condition was kept at the museums' conservation guidelines at 150 lux for oil on canvas paintings and 50 lux for ink on paper paintings.

Illuminants

Paintings were hung in their original galleries, allowing the viewing environment to be just as it would be when viewing paintings in museum galleries. Background walls and frames were as they were in the original setting of the paintings. The viewing angle kept as the paintings were in their original setting.

A track-light comprising of 3 Philips Hue LED GU-10 lamps was suspended at a height of 2400mm from the ground and at 1500mm away from the walls in which the paintings were hung. All 3 lamps were used to create each of the 8 viewing conditions per painting. There were 8 phases of viewing conditions per painting, which were divided into 2 sets of 4. Set 1 had 4 viewing conditions lights that measured at 4000k CCT and set 2 had 4 viewing

conditions lights that measured at 3500k CCT. The intensity of the viewing condition was kept at the museums' conservation guidelines at 150 lux for oil on canvas paintings and 50 lux for ink on paper paintings.

The lamps were connected to a Philips Hue Bridge Gen 2 via a closed wi-fi system and controlled by a Philips Hue application on a Samsung Galaxy S7 mobile phone.

Paintings

4 paintings were selected for these experiments. Of which 2 were from the Asian Civilizations Museum (1 Oil on Canvas and 1 Chinese Ink on Paper) and 2 from the National Gallery Singapore (1 Oil on Canvas and 1 Chinese Ink on Paper). Paintings selected varied in size, medium and subject matter. 2 paintings provided by the National Gallery Singapore were Nanyang Paintings, while 2 paintings provided by the Asian Civilisation Museums were similar to the Nanyang paintings with the exception by the thesis' definition that it was not painted with a Nanyang-centric identity.

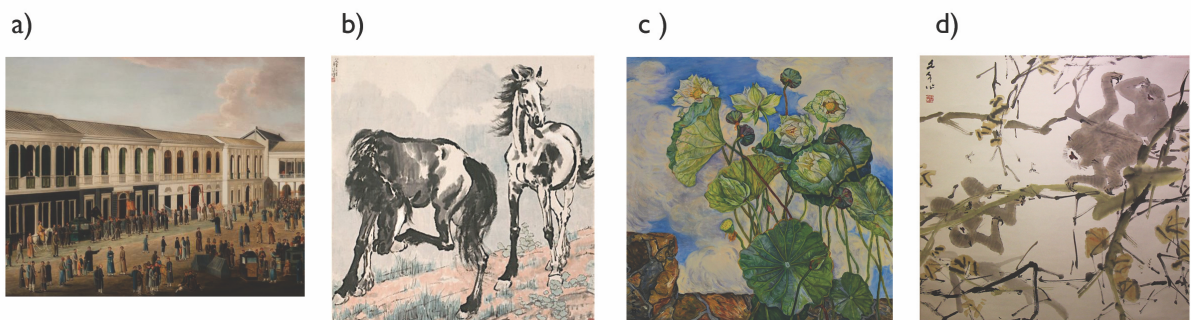


figure 4.12: Paintings used in experiments with real paintings.

- a) Officials assembling for a trial at the hong of Canton. C. 1807. Oil on canvas.
- b) Xu Beihong. A Pair of Horses. 1940 Ink on paper
- c) Georgette Chen. Lotus in a Breeze. 1970 Oil on canvas.
- d) Chen Wen Hsi, Gibbons. 1987. Chinese ink on paper.

Observers

A total of 20 observers (10 male, 10 female, mean age=26 years) were selected through a call for observers. The observers had normal or corrected to normal vision and had perfect colour vision. The Institutional Review Board at the Nanyang Technological University approved all procedures.

Due to logistical restraints, two separate calls were made for 2 lists of 20 observers with 1 list participating in experiments at the Asian Civilizations Museum and the other participating in the experiments at the National Gallery Singapore. There was some overlap in the observers in both lists.

Observers were from a varied background in art education. According to similar experiments by Luo et al., 2014, there were no difference in results regardless of education background.

Observers were all native or naturalized to the Nanyang region. The Nanyang, being geographically along the equator in South East Asia, receive more sunlight all year round compared with those in higher latitudes of the hemispheres. As the case study paintings were Nanyang paintings, it was imperative that the observers were culturally Nanyang to avoid cultural differences in perception of art. (Pöppel 2013 p.12)

Observers had English as their first language and were all effectively bilingual.

Observers were asked to go through a briefing session prior to experiments. The briefing introduced them to the terms used in the questionnaire and the proper procedure of filling in the questionnaires.

Paintings were observed in groups of 5. Observers were discouraged from comparing results.

Questionnaire Motives

Observers were asked to fill in a questionnaire. There were two questions for each viewing condition for each painting. The motives of the questionnaire were to

1. identify preference with relation to changing relative spectral distribution curves and
2. categorize specific variables that influence the viewers' perceptive impression.

Scales

The observers' preferences are indicated by either a Like or Dislike. Preference was not measure on a scale to avoid responses on the middle ground.

Concomitantly, a method of categorical judgment²⁰ was used to test the observers using word-pairs recommended by the Illuminating Engineering Society's methodology for studying psychological and related subjective effects of illumination. The word pairs used were Bright/Dim, Clear/Unclear, High-Contrast/Low-Contrast, Colourful/Dull. These 4 categorical word pairs were based on the better performing factors prior factor analysis on similar experiments done by Yoshiwara et al. (2012), Luo et al. (2014) and Zhai et al. (2015) and were found to be effective categories in identifying factors that are affected by lighting conditions.

²⁰ Proposed by Torgerson, 1958 based on the principles of Thurstone's law of comparative judgement. It suggests that an individual's psychological continuum can be divided into a specified number of ordered categories and ideally should provide a scale with equal intervals for psychological measurement. (Roeckelein, 1998)

Each word pair were measured on a measured on a Likert scale from -2 (very dissatisfied) to 2 (very satisfied). Scores 1 to 2 and -1 to -2 represent the extent of the positive and negative perceptions respectively.

Procedure

Observers were assessed to fill in a questionnaire on a printed sheet. Each observer participated in 2 sessions. Each of these sessions took 10 minutes. Observers participated in groups of 5 per session.

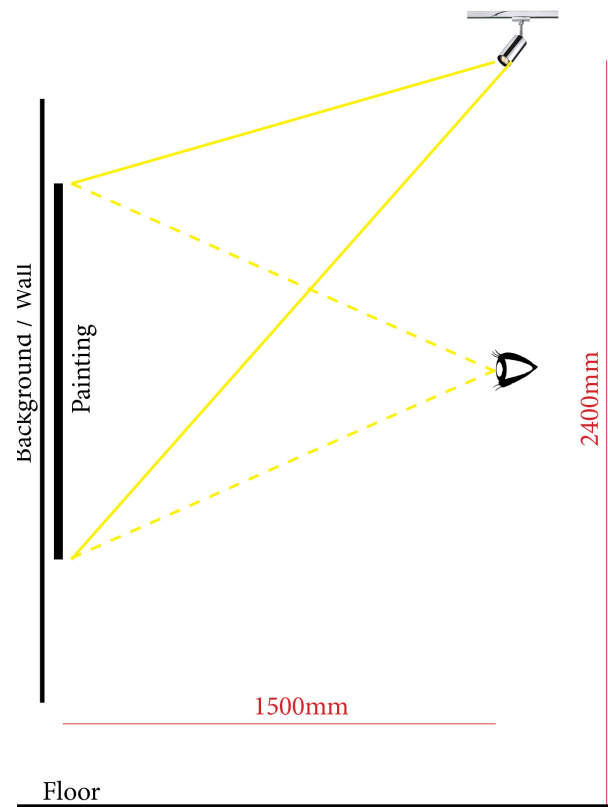


figure 4.13: : experiment set up and positions



figure 4.14: illuminants set up, gallery view.

In the experiment, the observers were first briefed on the definitions and proper means of filling the questionnaire with an example. Observers were then walked to the gallery and observed the paintings under the 8 phases of illumination for each painting. Observers were allowed 1 minute of adaptation for every change in viewing condition before they evaluated the viewing conditions in their questionnaires. Upon completion of all 8 phases, they were brought to a holding room for a 45-minute interval before the next session.

The sequence of illuminated viewing conditions were randomised in every session.

Results

Inter-observer variation

“The inter-observer variability was investigated in terms of the difference between each observer and the average observer. All the categorical scores (-1 to 2) were transformed into a positive number (1 to 5) before applying the inter-observer variability test. The STRESS (the Standardized Residual Sum of Squares) was calculated for the experiments on both paintings.” (Zhai et al. 2014)

A “residual sum of squares is used to help decide if a statistical model is a good fit for your data. It measures the overall difference between your data and the values predicted by the estimation model” (www.statisticshowto.com) (a “residual” is a measure of the distance from a data point to a regression line²¹). The residual sum of squares indicates how much of the dependent variable’s variation the used model did not explain. The smaller the residual sum of squares, the better the used model fits the data and vice versa.

Higher STRESS values would indicate that there is more of a variance between the observers. Any STRESS value above 30 would mean a 30% disagreement between the datasets. Out of 20 observers, 3 questionnaires were in complete and not included in calculations.

The STRESS tests indicated below show that the residual squares are all below 15. “These results imply that observers in the experiments performed

²¹ Regression analysis is process for estimating the relationships among variables when the objective is to observe relations between dependent and one or various predictors

consistently and the results can be used to report on the impact of different paintings and different lighting parameters.” (Zhai et al. 2014)

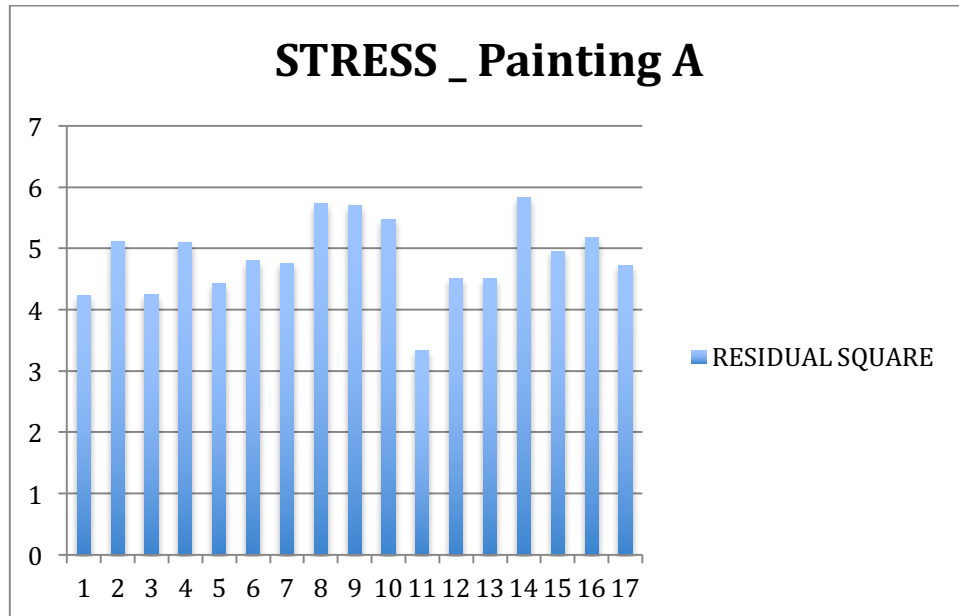


figure 4.15: STRESS chart for Painting A

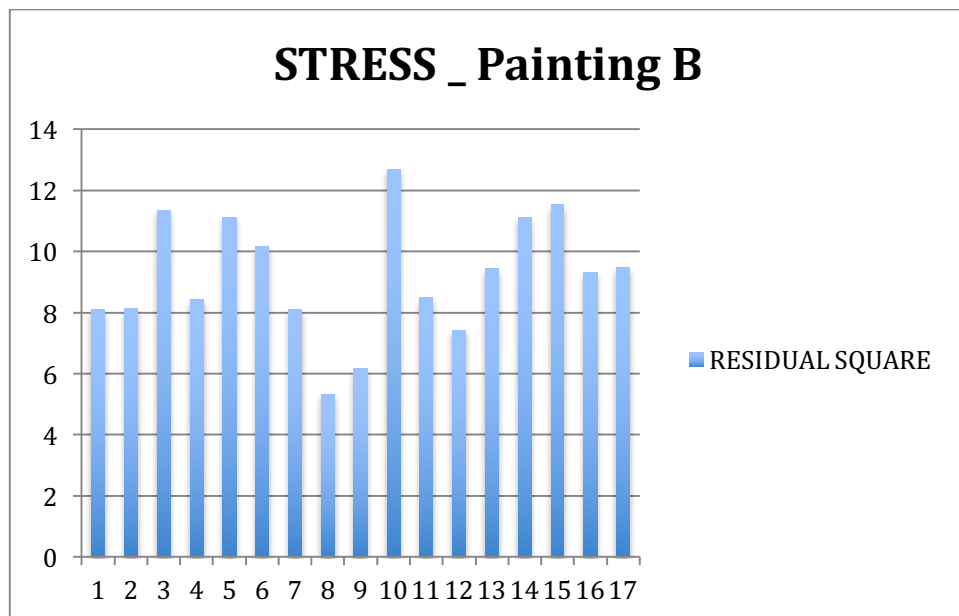


figure 4.16: STRESS chart for Painting B

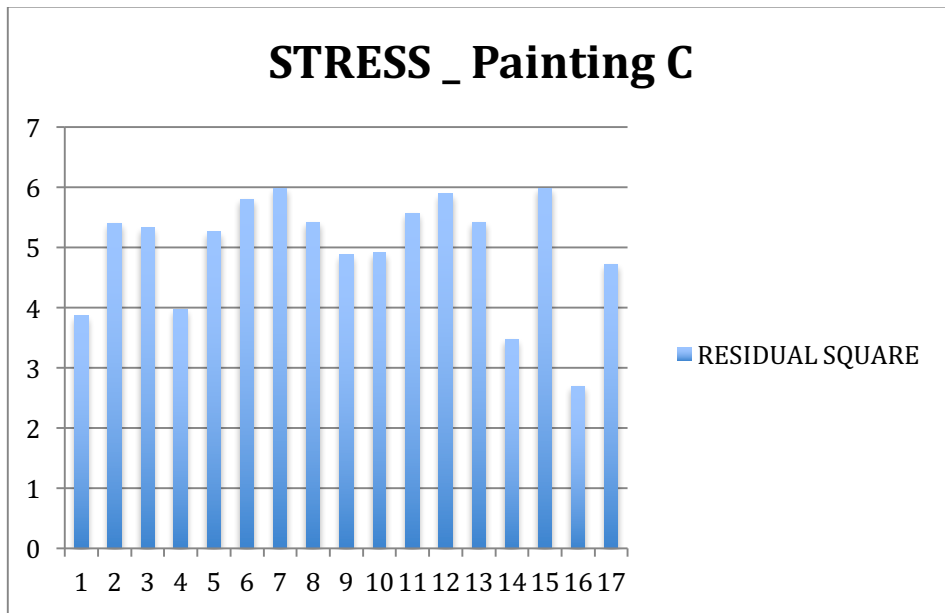


figure 4.17: STRESS chart for Painting C

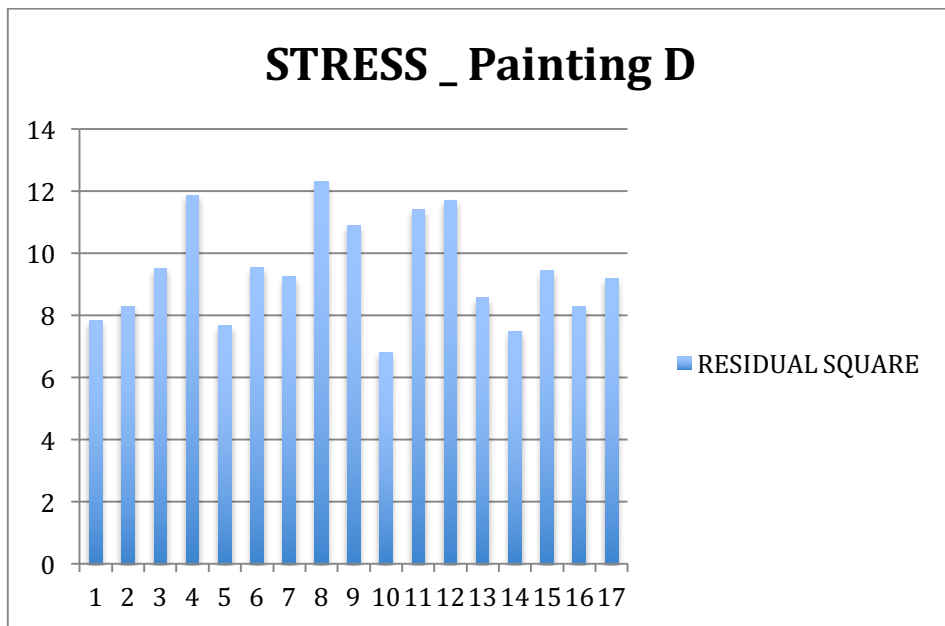


figure 4.18: STRESS chart for Painting D

Binary Logistic Regression of Preference with changes to Relative Spectral Distribution Curves

In the experiment, r, g and b values for the lighting conditions were varied within the same CCT. This means that for the 8 lighting conditions of which 4 were measured at 3500k and 4, 4000k, were metameric.

Binary Logistic Regression allows for the calculation of the extent in which multiple variables contribute to the probability of a preference to the lighting condition for the paintings. Since r, g and b values were taken as dependent variables, the co-efficient of the values following the regression would indicate that changes in the relative value of r, g or b in the SPD would result in a certain percentage of preference for viewing the painting under that lighting condition.

However, notice must be taken to the p-value. The p-value indicates how statistically significant the study is. If the p-value is less than 0.05, the study rejects the null hypothesis that there's no difference between the means and conclude that a significant difference does exist.

For painting A, the data set is taken to be statistically insignificant and results are viewed as a null hypothesis. This shows that there across the changes to the SPDs and thus, the lighting conditions, there is not much of a perceptible difference for the preference of viewing the painting under the 8 lighting conditions. Painting 3, like painting 1 reports a statistically insignificant data set.

However, for painting B, the p-value scores are considerably below 0.05 and close to 0, indicating that there is great statistical significance in the dataset for the experiment on painting B. This implies that for the changes in the SPDs and thus, the lighting conditions, viewers recorded a very perceptible

difference with their preference for viewing the painting under the 8 lighting conditions. Namely, for changes in the reds, there is a 14.2% change that there will be a liking to the lighting for the painting and so forth as recorded in the below chart.

	coeff b	p-value
Painting A Logistic Regression		
Intercept	-7.833476209	0.07328352
b	2.484840026	0.121389679
g	-0.277965259	0.847915108
r	5.934467517	0.108521746
Painting 2 Logistic Regression		
Intercept	-22.30006223	0.000218678
b	6.823359048	7.29348E-05
g	5.531262977	0.001320682
r	14.17249893	0.00192847
Painting C Logistic Regression		
Intercept	-30.4452459	0.147828974
b	1.726487135	0.288991775
g	-1.377061012	0.383787227
r	29.8497114	0.143616253
Painting 4 Logistic Regression		
Intercept	-115.1356276	0.001022405
b	0.053324225	0.971416923
g	3.174362312	0.011876746
r	113.6969116	0.00096439
	This column indicates the likelihood (in percentage) for a person's preference for a viewing the painting when the respective R,G or B values in the lighting is altered.	This column indicates how statistically significant the study is. If the p-value is less than 0.05, the thesis rejects the null hypothesis that there's no difference between the means and conclude that a significant difference does exist.

figure 4.19: Logistic regression coefficients and p-values.

A similar trend is seen in painting D, where p-values scores for the green and red variables indicate a high significance. However, both the coefficient score and the p-values for the blue variable are insignificant at close to no change in

perception for changes in the blue values. This could imply that for painting D, there is no observable change in perception with varying intensities of the blue wavelengths.

Factor Analysis

To further understand the preference for lighting conditions, a factor analysis was run across the 4 categorical word pairs to understand which factors contribute to the preference for their perceived preference for the viewing the lighting conditions for the painting.

Despite the lux levels for the various lighting conditions remaining the same across conditions due to conservation demands, it was observed that the lean towards preferring any lighting condition for the paintings are greatly tilted towards the perceived (and not actual) brightness of the painting due the alterations of the relative SPDs. This indicates that the alterations in r, g and b despite allowing for metameric perceptions in the viewers with regard to colour also allow for perceptions of brightness which is not physically manifested.

Chapter 5: Discussion

5.1 Trends in Data

The results of the interpretation of the data generated by these surveys have shown that:

1. individual paintings are viewed best under specific lighting conditions that are related to the painting's medium, i.e. both the type of paint used (e.g., oil, ink) and the base to which it is applied (e.g., canvas, paper);
2. increases in the "Red" wavelengths of the spectral distribution curve correlate with a significantly higher chance of altering preference for viewing the paintings as compared to increases in the "Blue" and "Green" wavelengths;
3. despite keeping physical brightness at a constant, perceived brightness changes drastically with the altering of spectral distribution curves.

5.1.1 Specific Lighting Conditions for Individual Paintings

The paintings used in the penultimate experiment, were of different media and visual language. Though all 4 were arguably figurative in nature, the ink on paper paintings had more abstraction in form as well as in the pigments used. Results have also shown that the degree of effect on perception is greatly observed with the ink on paper paintings as compared to the oils.

A plausible reason for this is that the ink on paper paintings are visually different from the scenes that is often seen in the natural world, and thus allowing for a higher visual discomfort, in turn activating more neurons in to process this image (Wilkins 2015).

Given that the human vision has been adapted to processing natural images, a painting that differs would evoke a relatively large oxygenation of the visual cortex. Wilkins further proposes that this could be a cause of either high

colour contrast in the image being processed that causes visual discomfort and more effort to process this image, further to contrasts in the image, visual discomfort is also associated with randomly disposed dots and lines (Juricevic et al. 2010). as such perhaps making the viewer more critical to the changes in viewing conditions.

It is with reasonable grounds to deduce from Wilkins and Jurivecic's statements as well as the data collected that due to the composition and formal properties of paintings that lean towards a more traditional Chinese-ink painting style, nuances in lighting properties would impose great effects on the perception of these paintings.

The findings here also reiterate Davis' (2012) white paper on lighting psychology where lighting conditions which result in certain impressions (adapted from Flynn 1979), which therefore results in greater preference as explained by Kaplan & Kaplan 1989.

5.1.2 Differing Spectral Distribution Curves result in different perception

5.1.2.1 Red Wavelengths

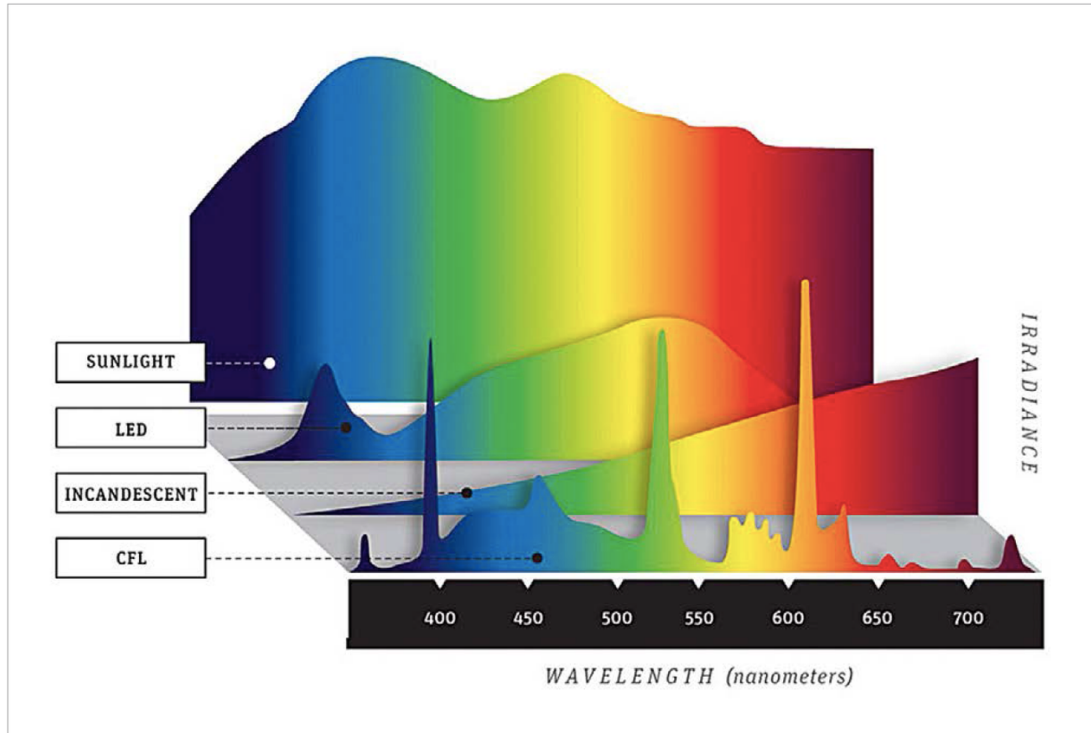


figure 5.1: Comparison of spectra in wavelengths of various white light sources.

Image credit: Herman 2015

Colour contrasts are, after all, affected by the spectral power distribution of the lighting and could be a responsible for visual discomfort. Both the chromaticity of the light source, and the colour contrasts in the image processed affect visual discomfort. However, they do so individually. Light sources and large surface areas with strongly saturated colour (particularly red) can trigger headaches (Barbur et al. 1979 p.308). In the experiments conducted by this research project, observers were found to have greater alterations in their perception and preference for paintings when the “red” end of the lighting condition’s chromaticity were altered.

This could possibly be due to a familiarity to the SPDs of daylighting and incandescent lamps that were the predominant means of museum lighting prior to LEDs. There could be an existing coherent SPD that has been mapped into our cognitive memory as suggested by Kaplan & Kaplan 1989, and Russell 1980 which results in the likelihood of preference for the lighting condition.

5.1.2.2 Perceptions in Brightness

The participants were also recorded to have perceived paintings to be lit brighter for certain lighting conditions despite the physical lux levels maintained constant. These phenomena is recorded as the Helmholtz-Kohlrausch (HK) effect, where when two colour stimuli have the same luminance but different chromaticity in a certain hue, allowing for perceived brightness by the two stimuli to be different (Shizume et al. 2014 p. 558)

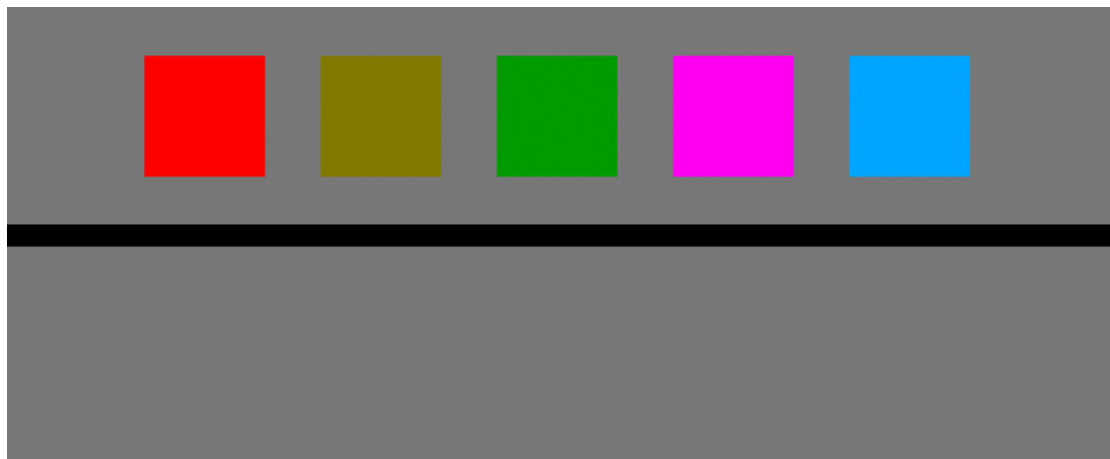


figure 5.2: the above colours have been rendered with the same luminance level yet are perceived to be different in brightness, when converted to grayscale, they appear the same.

Stimuli that are more saturated would appear to be brighter. Similarly, stimuli that are red or blue appear brighter than yellow and green stimuli that have the

same luminance. (Corney et al. 2009 p.1). As colour, perceived is directly dependent on the SPDs of light illuminating the object, there could be means for editing SPDs of luminaires to allow for greater perception of brightness in paintings.

“The perceived colour at each point in a visual scene depends on the relationship between light signals from that point, and light signals from surrounding areas of the scene. In the well-known phenomenon of simultaneous colour contrast, changing the overall brightness or hue of an object's surround induces a complementary shift in the perceived brightness or hue of the object's colour. Colour contrast is thought to contribute to colour constancy with changes in illumination.” (Brown and MacLeod, 1997 p.844)

The trends observed in this research reiterates the HK effect as an example of a frequently discussed, but not often documented of how perception of brightness cannot be a simply be proportional to the intensity of the light. This could plausibly be due to the varying sensitivity of the eye's cones to specific wavelengths. In lay, “red and blue spectral stimuli appear brighter than equiluminant yellow and green stimuli, and more saturated stimuli appear brighter than less saturated stimuli” (Brown and MacLeod, 1997). In turn, perceived brightness of points in a visual scene is dependent on the physical qualities (saturation, reflectance) of its surrounding point.

As a whole, colour appearance of the scene in paintings, are dependent on the distribution of the colours about the mean colour of the painting. (Brown and MacLeod 1997). With specifications to these experiments, paintings could appear to be more vivid and perceived brightness could be further dependant on how spectral properties of the varying lighting conditions interact with the frame or the specific qualities of the background in which the painting is hung on.

5.2 Limitations

5.2.1 Repeating the project in a different cultural context

As suggested by Pöppel 2013, viewers of different cultural upbringing would mean a difference in what is coherent and therefore result in a difference in what is preferential (Kaplan & Kaplan 1989 p.5). Repeating the project with an viewers of a different cultural and geographical background (apart from Nanyang) could result in a difference in findings and results. As such, the project recognizes that the findings are, after all, specific to Nanyang and Nanyang paintings, a wider survey on a variety of painting styles and viewers would allow for comparisons and further discussions in preferences for lighting design for paintings.

This would be highly useful for museum authorities, particularly with travelling shows and for exhibitions targeted at specific target groups and decided by museums.

5.2.2 Chromatic adaptation

The project held experiments over digital screens and in galleries as it is. The degree of chromatic adaptation to the environment, such as background colour and spatial qualities of the galleries were taken to be negligible in this study.

More controlled environments for the surveys would mean having paintings brought out of their existing galleries and into a lab where the environment is in full control of the researching team. This would allow for a more precise determination on the effects of task lighting for paintings.

5.2.3 Neural Adaptation

“When the same visual stimulus is repeatedly presented with a brief interval, the brain responses to that stimulus are attenuated relative to those at first presentation” (Noguchi et al. 2004) In studies by Noguchi et al. in 2004, Visual Neural Adaptation (NA) can be dissociated into 3 dimensions, activation strength, peak latency and temporal duration of neural response. Their study indicated that visual responses repeated stimuli shows significant “reduction in both activation strength and peak latency but not the duration of neural processing”. This implies that for the experiments conducted for this dissertation, consideration had to be taken in order to ensure that the neural adaptation was not dominant in the responses. Therefore, the research looked to prior studies that were similar in nature and adapted their experiments. (Zhou et al., 2004, 2005, McDine et al. 2011, Sun & Perona 1998)

Furthermore, the results obtained from the experiments conducted for this research were randomized, the variation in results between and within subjects indicated that there was negligible adaptation to the varying lighting conditions for the painting stimuli. Steps were also taken in the randomization to ensure that adjacent lighting conditions were spectrally different to avoid NA being dominant in responses.

5.3 A new light

These research findings of human visual perceptions of change in spectral distribution curves, and the related interpretation of viewer's responses, constitute a proof of concept for the need of a new approach to the standards of illumination in the lighting design for paintings in indoor settings. The lighting designer can be trained to explore more dynamic and science-driven ways to better enhance the empathic relationship of the viewer with the paintings, and show paintings "in new light".

The research also serves as a documented case of the complexities of human visual perception of brightness in a scene, in particular, how changing spectral densities can alter the processing of brightness in the human brain.

The thesis started off as a means to identify which specific parameters of lighting for paintings leads to an effect in emphatic relationships between viewer and painting. The research results provide new skills associated with lighting design for paintings. Arising in new manners of looking at paintings, allowing museum visitors to view paintings under different lighting conditions, and in turn, allow viewers of paintings to observe hidden details within paintings that they may never experience under generic lighting with the altering of light spectrums.

Altered spectrum lighting may also be particularly useful when curating museum exhibitions for particular target audiences, for example an older more geriatric audience may benefit from altered spectrum lighting that may increase contrasts within paintings and allow for an easier viewing of masterpieces.

For museum practitioners and conservationists: altering the lighting spectrum has proven to allow for a brighter perceived painting that is physically lit (i.e., a painting lit at 50lux is viewed to be 150lux), this opens a whole platform for discussion on archaic conservation standards such as the dyed blue wool test which informs the current standards for conservation. The research allows for paintings to be lit at a lower lux level while maintaining the perceived brightness, therefore maximizing the lux hours for exposure and extending the display life of the painting, allowing such masterpieces to be conserved and appreciated for generations to come.

Further applications of the research could also lead to more efficient lamps, with the discovery of enhanced perception of brightness with different SPDs, could mean that lower wattage lamps could be employed in everyday situations, allowing for more energy savings and in the long run cost savings and environmental benefits

Appendix A) Studies on Nanyang paintings

Lotus in a Breeze, Georgette Chen



figure a.1: Georgette Chen. Lotus in a Breeze. 1970 Oil on canvas.
Singapore, National Gallery Singapore.

Lotus in a Breeze, is one of Chen's larger works. She wrote of her fascination with painting lotuses: "For ten days, the day began for me at 7am and ended at 6pm. Under my painting sun shade, I feasted on these delicate white and pink beauties..." This is a classic example of a Nanyang School artist using European pictorial techniques to depict local subject matter. (Siew, 2012)

Rendered figuratively, the lotus in frame are set against a cloudy sky, despite the surrealistic nature of which the lotuses are rendered, the entwined stems of provides hints of an Art Nouveau education.

Artist Biography

Georgette Chen Li Ying (1906-1993) was born in the Zhejiang Province, China. She had received her art education in several cities, namely, Paris, New York and Shanghai. Chen's artistic oeuvre can be divided into three phases, French Period (1927-1933); China-Hong Kong Period (1934-1948) and Penang-Singapore Period (1949-1980).

Chen was greatly inspired by her surroundings and she produced still-lives, portraits and landscapes from each phase of her artistic career. In 1954, she settled in Nanyang, Singapore and taught at the Nanyang Academy of Fine Arts till retirement. (Creamer 2002)

During the Penang-Singapore Period (1949-1980) of her career, she was regarded as as a Pioneer Artist of Singapore who developed the Nanyang Style (of which she was awarded the Cultural Medallion in 1982). At this juncture of her career, her paintings were painted distinctively Nanyang, with strokes and colours in her paintings that were strongly influenced by the Impressionist painters, Georgette Chen enjoyed working outdoors to capture the fleeting light a possible trait that could have been adopted during her time in France, and painting *plein-aire*. and yet subject matter that were Nanyang in nature.

Life by the River, Liu Kang



figure a.2: Liu Kang. Life by the River. 1975. Oil on canvas.
Singapore, National Gallery Singapore.

Life by the River features the casual aspects of a typical Nanyang village lifestyle. Painted in with bold colours and faceless figures, it reflects a semi-abstract style which fuses eastern and western art techniques. By using a Chinese landscape method of composing the picture in separate perspectives and positioning the figures next to a meandering river, Liu manages to evoke a sense of movement and vibrancy within the composition of the painting. (Virtual Collection of Asian Master Pieces 2013)

Artist Biography

Born in China and raised in Malaya, Liu spent most of his childhood shuttling between Nanyang and Shanghai for his art education. In the 1920s he travelled to Paris, France where he was greatly influenced by postimpressionism. (Tan & Creamer 2016)

As one of the pioneer artists of the Nanyang paintings, he made the defining trip to Bali in 1954 in pursuit of creating a Nanyang painting style that has been characterized by a union of eastern and western art techniques and thought.

Bali Beach, Cheong Soo Pieng



figure a.3: Cheong Soo Pieng. Bali Beach. 1955. Gouache on cardboard laid on masonite board. Singapore, National Gallery Singapore.

Painted with a very matte and opaque casein emulsion (Tay 2010), the paintings depict a pair of Balinese women dressed in sarongs. The women are rendered long and slender that are reminiscent of Balinese shadow puppetry. Bali Beach reflects the rich culture and the vitality of the Balinese people.

Artist Biography

Cheong Soo Pieng was a pioneer Nanyang artist who “was a very open-minded (artist), wh0 only one with this mind set (of exploring new materials and supports); other artists of his time were more conservative” (Tay 2010)

Stylistically, a lot of influence on his paintings themes came from trips to Bali and Sarawak, characterized by the use of bright unmixed colours with various degrees of impasto. He layered paint on graciously on his supports and would sometimes scrap the paint off for finer details such as wrinkles in skin or for marking contours, resulting in heavily textured paintings. (Lobon 2014)

Hérons, Chen Wen Hsi



figure a.4: Chen Wen Hsi, Herons. 1991. Chinese ink and colour on paper.
Singapore, National Gallery Singapore.

With clear influence from Cubism and Fauvism and Chinese painting techniques, Herons captures Chen's obsession with the bird. Sharp and angular brushstrokes result in elongated abstract forms that suggest the movement of birds fluttering in the sky. With overlapping bodies and beaks, Chen has added a layer of dynamism and movement in the painting. Fragmented neutral earthy tones that are paired with stark white pockets create visual depth and an interplay of light and shadow. (Sotheby's 2013)

Artist Biography

Chen Wen Hsi (1906-1991) was born in the Guangdong Province, China. In 1928, he pursued a full-time fine art education at the Shanghai College of Art, following dissatisfaction would have him transferred to the Xin Hua College of Art in Shanghai, where he became acquainted with Chen Chong Swee and Liu Kang, who were, together with Chen Wen Hsi, become known as Singapore's Nanyang Pioneer artists.

Chen arrived in Singapore in 1948, and though intended to stay for a short 3 months, ended up settling in Singapore and proceeded to teach art at the The Chinese High School (1949–1968) and the Nanyang Academy of Fine Arts (1951–1959). Chen travelled to various places in Southeast Asia to collect drawing materials and was greatly inspired by Balinese culture and Art.

Chen was well trained across a variety of mediums; however, his most exceptional works are rendered in Chinese ink. His inclination to Gibbons as a subject matter came from early Chinese literature, deeming gibbons the “gentlemen” (jūnzǐ, 君子) of the forests. He was also highly influenced by gibbons painted by Southern Song painter Muxi had Muxi’s skill for rendering nature through close observation of faunae (active in the 13th century), “Awestruck upon viewing this 13th century image, he desired to emulate his ancient mentor and commenced a lifelong pursuit of depicting these noble, human-like animals in an impeccable manner.” and started his own collection of the animals for observation. (Sotheby’s, 2016)

Landscape, Chen Cheong Swee



figure a.5: Landscape. Chen Chong Swee. 1968. Chinese ink and colour on silk.
Singapore, National Gallery Singapore.

The landscape in question here depicts a fishing village and is an amalgamation of South-East Asian and Chinese elements. With landscapes

that appear to be Chinese, yet figures in traditional Malayan dress are seen in the foreground. (Wang 2015)

Though composition wise, predominantly Chinese, the application of colour is influenced by western watercolours, yet executed with techniques that are often used by Chinese landscapers. The coast and seas are left to reveal of the support medium, a predominantly Chinese technique of using negative space in paintings.

Artist Biography

Chen was born in Chenghai, China in 1910. He studied painting in Xinhua Arts Academy in Shanghai, where he was exposed to western art and ideas. In 1932 he travelled to Penang, Malaysia and eventually moved to Singapore in 1934, where in 1951, he headed the Chinese painting department at the Nanyang Academy of Fine Arts. He is considered as a pioneer Nanyang artist who made the defining trip to Bali in 1954. (Tan 2014)

With a training in Chinese-ink and calligraphy, he merged western realism to his landscapes, with the firm believe that art should incorporate “Truth, Goodness and Beauty” (Kwok 1996)

Officials assembling for a trial at the hong of Canton.



figure a.6: Officials assembling for a trial at the hong of Canton. C. 1807. Oil on canvas.
Singapore, Asian Civilizations Museum.

“The buildings of the Western traders at Guangzhou frame a busy square filled with Westerners and Chinese. The painting represents a specific event when seamen from the British ship Neptune were tried for the death of a Chinese man.

The trial is well-documented and some figures in the painting can be identified. The painting was made by a Chinese artist, presumably for a foreign trader.

The event shows that Chinese law governed foreign activities, a principle that would shift after the Opium Wars of the mid-19th century.” (Asian Civilizations Museum, 2017)

Artist Biography

Artist unknown.

Pair of Horses, Xu Bei Hong



figure a.7 Xu Beihong. A Pair of Horses. 1940 Ink on paper
Singapore, Asian Civilizations Museum.

Xu, a well-known patriot, painted hundreds of horses, during a time where China was subjected to Japanese occupation. His horses, were filled with bravery and valiant grace imbued with a sense of nation and aggression against territorial disputes with Japan. “The horses have expressive poses. Some are standing, some are galloping, or drinking water by the river,” (Carmen Ip quoted by Blanc 2014)

The pair of horses here, are defined rather than “with calligraphically energized outlines, he sketched it impressionistically, integrating light and dark washes and un-inked areas of paper to suggest light and shadow.” The

chiaroscuro modelling of its form is more subjective than scientific, but the horse's accurate anatomy and the convincing foreshortening of its body reflect Xu's solid grounding in Western academic art.

Artist Biography

Xu Beihong (1895-1953) was born in the Jiangsu province of China. He attained great reputation for his Chinese-ink paintings of horses and birds. A patriot, he is one of the pioneering Chinese artists to express a need for a 20th century China to be reflected in paintings. He is also a pioneer in creating Chinese themed paintings in oil, and was highly skilled in both western and eastern painting techniques.

Xu began his training as an artist with calligraphy under instruction from his father. In 1915, he moved to Shanghai and proceeded to Tokyo to study art. After which he thought at the Peking University's Art School before continuing his art education at the the École Nationale Supérieure des Beaux-Arts, in Paris, France where he studied oil painting and drawing. During World War 2 he travelled to Nanyang to exhibit his artwork and to fund Chinese causes in the war.

"Xu had an immense influence on the development of Chinese painting in the 20th century because he championed an expansive realism that included Romanticism and Expressionism," said Kwok Kian Chow, director of the Singapore Art Museum in 2008.

Xu was held in high regard and a mentor and peer by founding Nanyang artists such as Chen Wen His and Chen Chong Swee. During his stay in Nanyang, his process of close observation of nature and inclination to inject realism and western perspectives to Chinese painting. In his efforts to create a new form of national art, he combined Chinese brush and ink techniques

with Western perspective and methods of composition. He integrated firm and bold brush strokes with the precise delineation of form.

Xu's work and paintings during his time in Nanyang had a lasting impression and influence on the development of Nanyang paintings. Xu has applied western scientific methods in applying proportions and a fixed-point perspective in his work, combining them with a formal Chinese-ink painting style. (Chow, 2008)

Gibbons, Chen Wen Hsi



figure a.8: Chen Wen Hsi, Gibbons. 1987. Chinese ink on paper.
Singapore, National Gallery Singapore.

“After moving to Singapore, I chanced upon a gibbon similar to the one in Muxi’s painting in a pet shop one day and bought it immediately. Later on, I added another six or seven in grey, white and black to my collection. For years I would often study their movements, expressions, habits and physical characteristics.” – Chen Wen Hsi

The painting depicts a trio of Gibbons frolicking in the branches. The gibbons play with each other, with the limbs interlocking with the branches and twigs around them. Due to their tendency to glide through the branches of towering canopies, wild gibbons are elusive beings that are difficult to catch a glimpse of. The painting here, however, portrays an ephemeral moment of these dignified creatures frozen in time. (Sotheby's 2016)

Chen maintained a personal philosophy to colour, "a lot of blue to depict leaves and the sky, as it can signify serenity... a mixture of yellow and red becomes orange, which signifies passion. Red speaks of courage, warfare or bloodshed... Another point is that green speaks of life. Leaves are painted in green. A mixture of blue and red yields purples, which enhances unusual shapes." (Sotheby's 2016)

The present painting shows the subject matter a sanguine palette against an unpainted white background. The gibbons are earthy in tone, with similar colours used to render their surroundings.

With sweeping strokes to paint vigorously defined lines of the tree branches, added a degree of geometry to the composition, which hints at a cubist nature, but within a figurative nature and doesn't stray too far into abstraction.

Painted upon observation of his own pet gibbons, Chen managed to capture the essence of the animal by studying their mentality and movements to a level of minutiae. Careful consideration would have been taken to the balance of the apes' limbs in motion, resulting in a true capture of the spirit of the Gibbon and not simply the appearance of a Gibbon.

Appendix B) Spectral Density Curves for Lighting Conditions on Nanyang Paintings.

Digital Experiments

Refer to following page inserts.



Cluster colors, sized by number of pixels:

cluster	pixels	name	HEX	RGB	HSV	LCH	Lab	tags
	19.12%	152,149,141 half friar grey $\Delta E=0.8$	#9A968F	154 150 143	40 7 60	62 4 91	62 0 4	aquashield archive delta fern friar half quarter sandstone silver stonehenge tapa taupe grey
	18.07%	141,144,148 voltage $\Delta E=1.0$	#8B8F95	139 143 149	214 7 58	59 4 263	59 0 -4	amber bay clouded exponent mist mountain neutral oslo voltage blue grey
	17.11%	69,99,75 gecko $\Delta E=3.2$	#476854	71 104 84	143 32 41	41 18 156	41 -17 8	finlandia gecko ozone pasifika stromboli style whirlpool
	13.41%	120,134,107 camouflage green $\Delta E=2.1$	#76826A	118 130 106	91 18 51	53 15 129	53 -9 11	ash camouflage flax grove limed ranger smoke spanish willow xanadu green
	9.40%	75,77,74 cathedral $\Delta E=1.2$	#494D4B	73 77 75	140 5 30	32 2 156	32 -2 1	armadillo blast cathedral gravel ironsand quarter ship silver streak thunder grey
	8.58%	93,119,71 dingley $\Delta E=3.8$	#687C4D	104 124 77	86 38 49	50 29 125	50 -16 23	army barmy dingley
	8.15%	78,127,158 wedgewood $\Delta E=1.5$	#527F9E	82 127 158	204 48 62	51 22 252	51 -7 -21	slate moderate air cornflower force greyish rackley steel stormy waterfront wedgewood blue
	6.16%	113,93,71 tobacco brown $\Delta E=0.7$	#745E48	116 94 72	30 38 45	41 17 71	41 5 16	bandit bean coffee double nullarbor pastel pickled roman soya tobacco triple brown

IMAGE CLUSTER PARTITIONS

Pixels of the image assigned to each cluster. The border is the color of the cluster as calculated by the average value of its pixels.

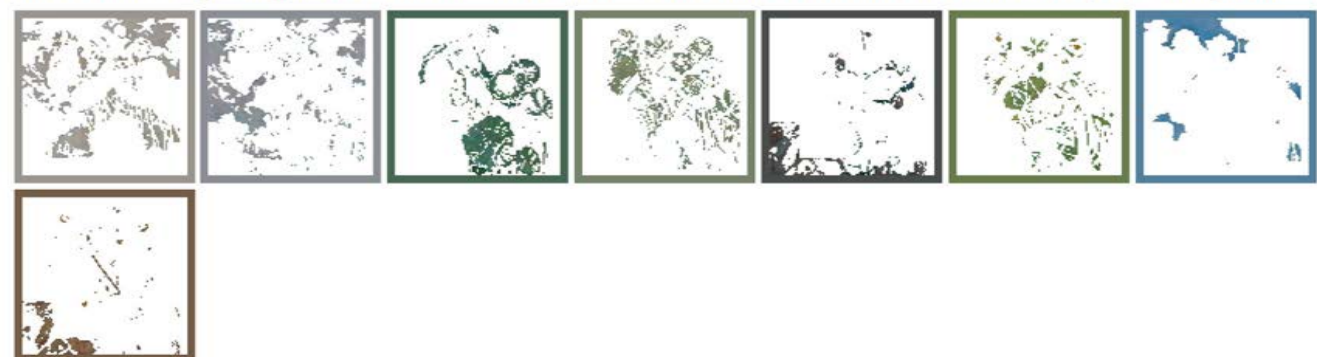
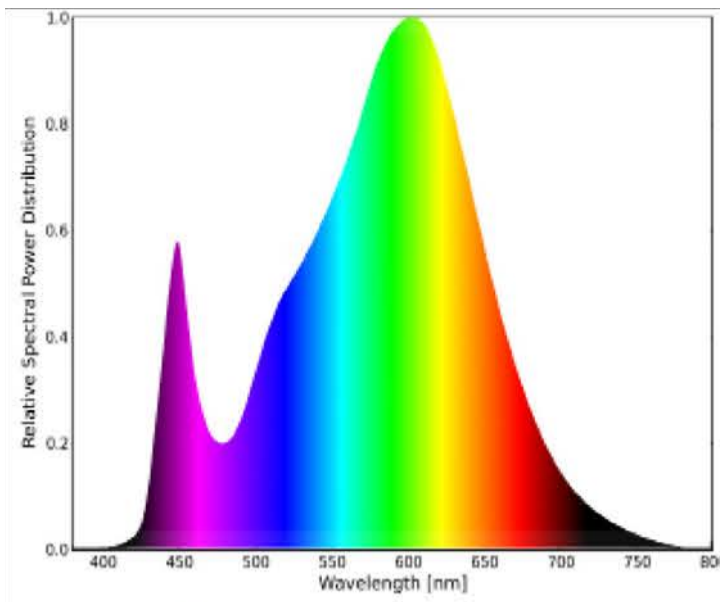


figure b.1: Lotus in a Breeze in sRGB color space.

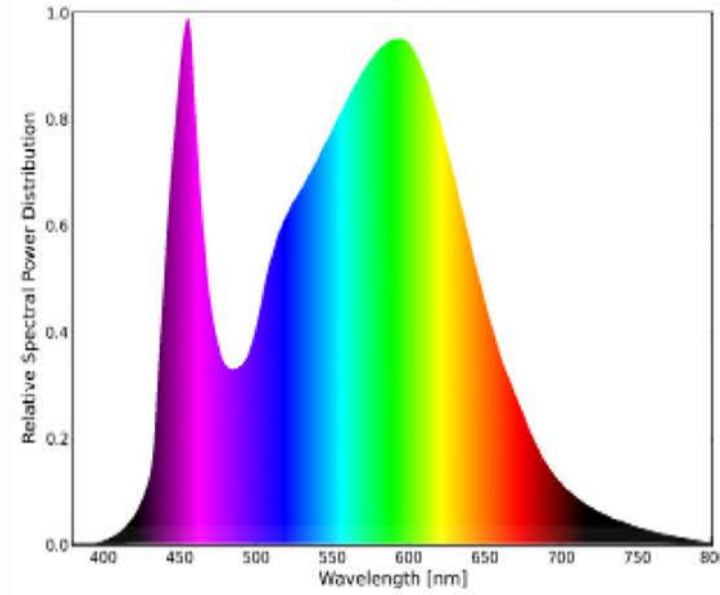
Lighting Condition 1:

Equivalent to
Lumileds Luxen 30302D LED Chip, 3000K
at 100% intensity and 150lux on image.



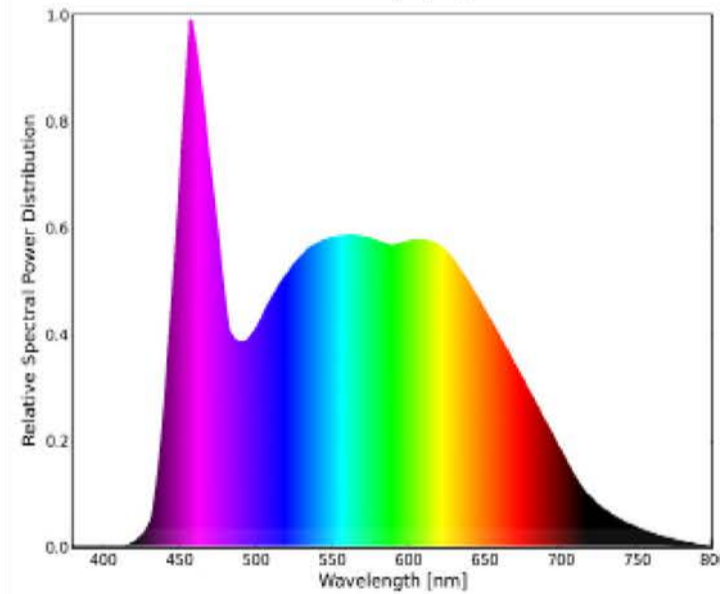
Lighting Condition 2:

Equivalent to
Lumileds Luxen 30302D LED Chip, 4000K
at 100% intensity and 150lux on image.



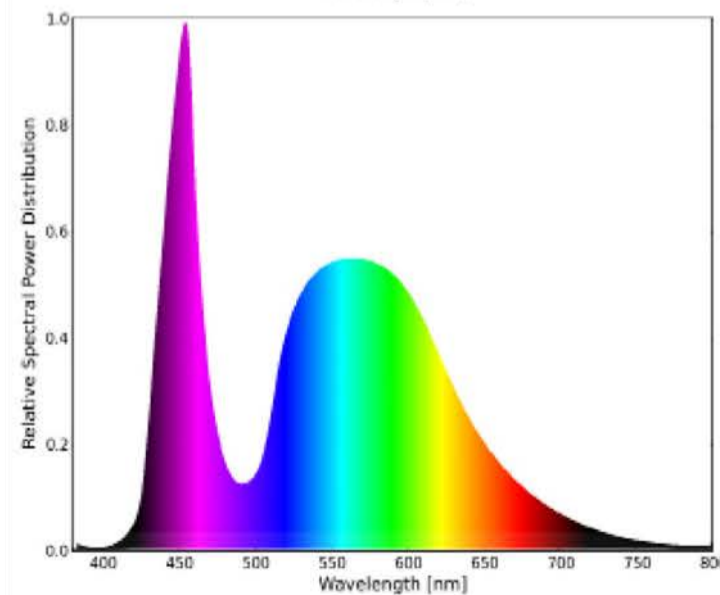
Lighting Condition 3:

Equivalent to
Lumileds Luxen 30302D LED Chip, 5000K
at 100% intensity and 150lux on image.



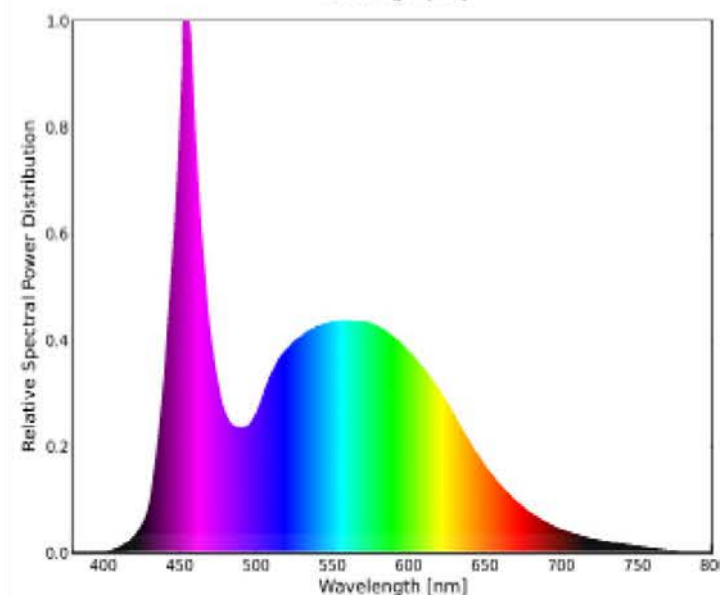
Lighting Condition 4:

Equivalent to
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



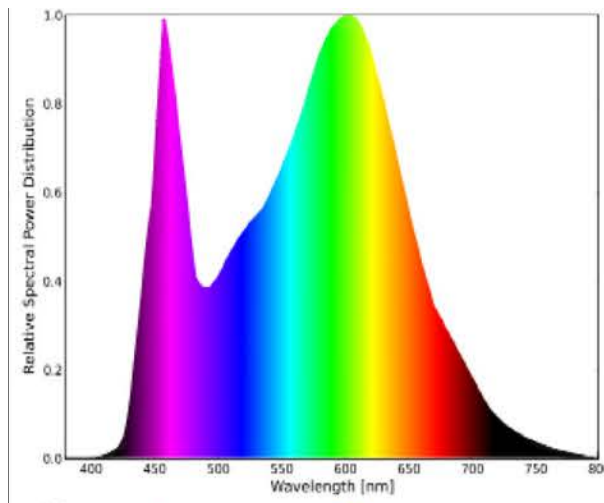
Lighting Condition 5:

Equivalent to
Lumileds Luxen 30302D LED Chip, 7000K
at 100% intensity and 150lux on image.



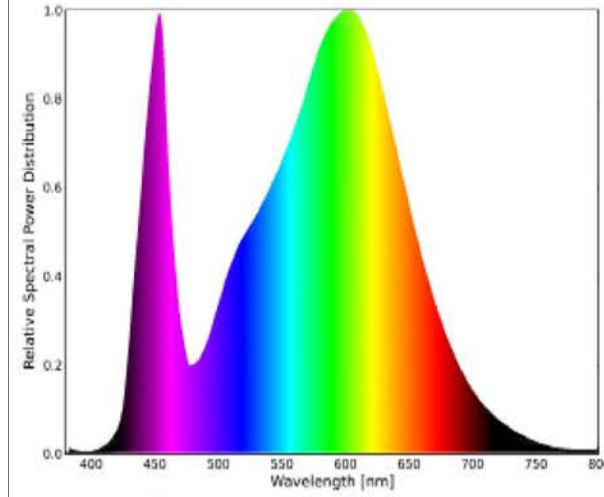
Lighting Condition 6:

Equivalent to 3000K and 5000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



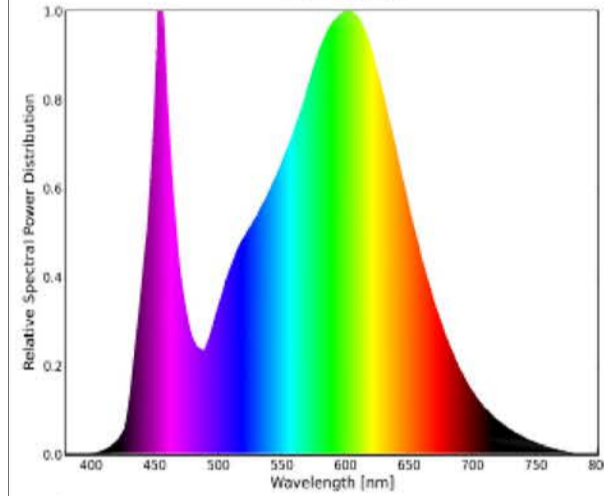
Lighting Condition 7:

Equivalent to 3000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



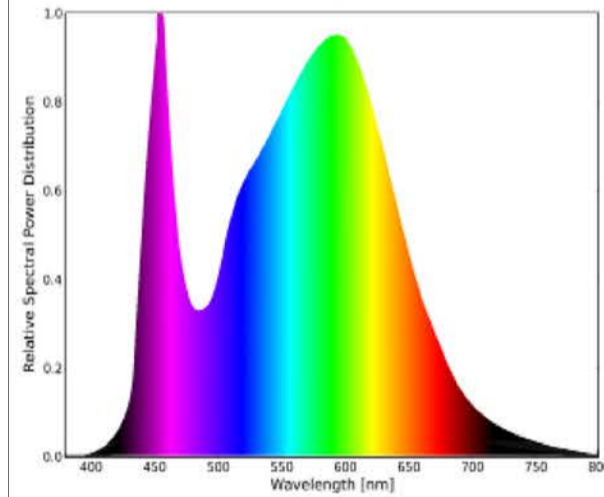
Lighting Condition 8:

Equivalent to 3000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



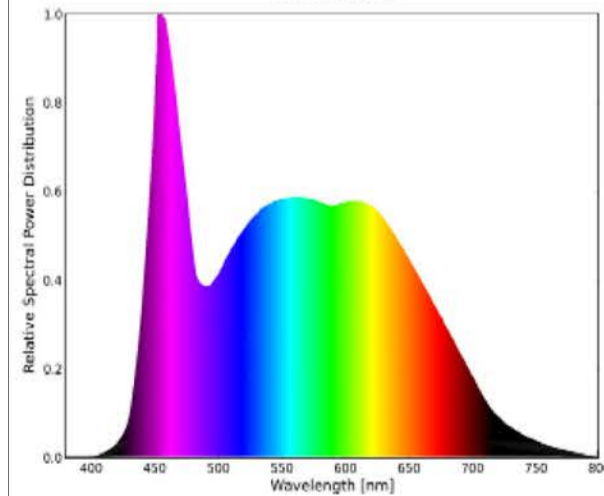
Lighting Condition 9:

Equivalent to 4000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 10:

Equivalent to 5000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 11:

Equivalent to 4000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.

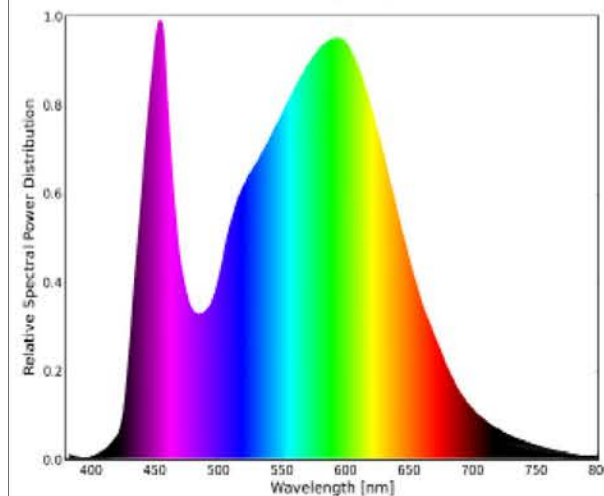


figure b.2: Spectral density distribution curves and effect on Lotus in a Breeze (digital)
for 11 different simulated lighting conditions.



Cluster colors, sized by number of pixels:

cluster	pixels	name	HEX	RGB	HSV	LCH	Lab	tags
	17.56%	100,89,119 covert $\Delta E=4.0$	#646081	100 96 129	246 25 51	42 20 297	42 9 -18	covert high society
	16.44%	114,75,67 lumberjack $\Delta E=3.3$	#68463C	104 70 60	14 43 41	33 18 43	33 13 12	dark very cioccolato copperhead double lumberjack spice brown
	15.31%	95,49,42 red sienna $\Delta E=2.6$	#5D2C28	93 44 40	4 56 36	25 25 30	25 22 13	dark buccaneer cajun caput hukanui mortuum ochre point reddish scarlet sienna tan tipping brown red
	14.18%	135,97,79 lone ranger $\Delta E=1.4$	#896553	137 101 83	20 39 54	46 20 53	46 12 16	dark beaver leather lone mix pastel ranger spicy tangelo brown
	13.74%	61,38,34 hot chocolate $\Delta E=2.1$	#3F2726	63 39 38	3 41 25	19 13 27	19 11 6	dark chocolate digeridoo earth havana hot jon mahogany maroon pasifika style toorak brown crimson
	9.41%	129,66,44 nutmeg $\Delta E=1.8$	#814330	129 67 48	14 63 51	36 34 43	36 25 23	canyon clay copper desperado fawn kwila mule nutmeg paarl peanut salmon scorched teranova warm
	7.64%	168,109,74 moderate tangelo $\Delta E=1.9$	#A46A46	164 106 70	23 57 64	50 35 57	50 19 30	moderate beech cape double earth kalgoorie palliser sands sepia sugar tangelo brown red
	5.72%	175,147,125 sandrift $\Delta E=2.6$	#B39784	179 151 132	25 26 70	64 16 63	64 7 14	del double grayish joss mushroom rickshaw rio sandrift brown

IMAGE CLUSTER PARTITIONS

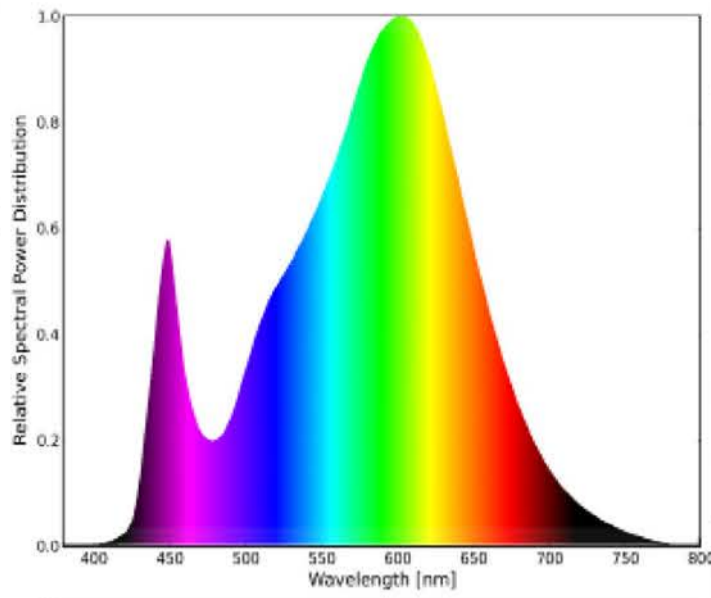
Pixels of the image assigned to each cluster. The border is the color of the cluster as calculated by the average value of its pixels.



figure b.3: Life by the River in sRGB color space.

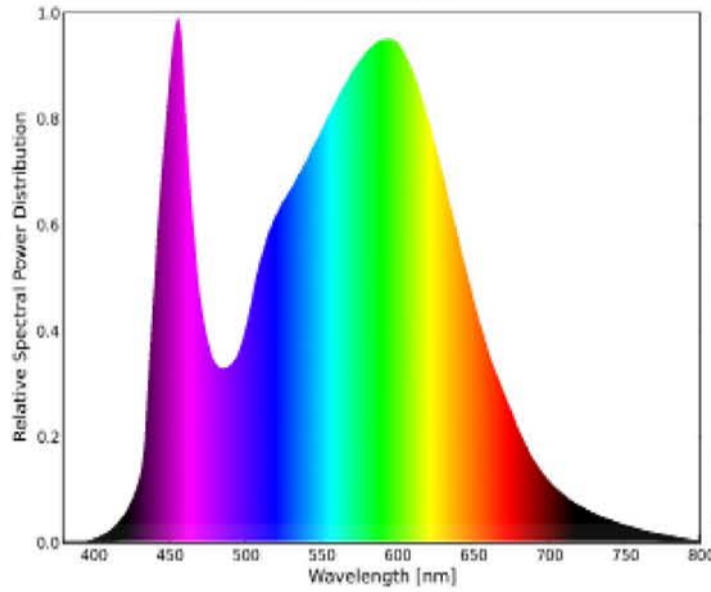
Lighting Condition 1:

Equivalent to
Lumileds Luxen 30302D LED Chip, 3000K
at 100% intensity and 150lux on image.



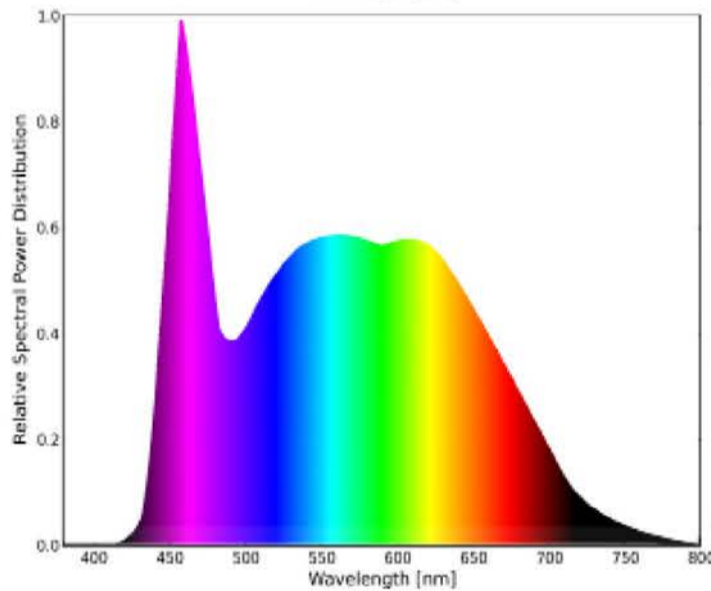
Lighting Condition 2:

Equivalent to
Lumileds Luxen 30302D LED Chip, 4000K
at 100% intensity and 150lux on image.



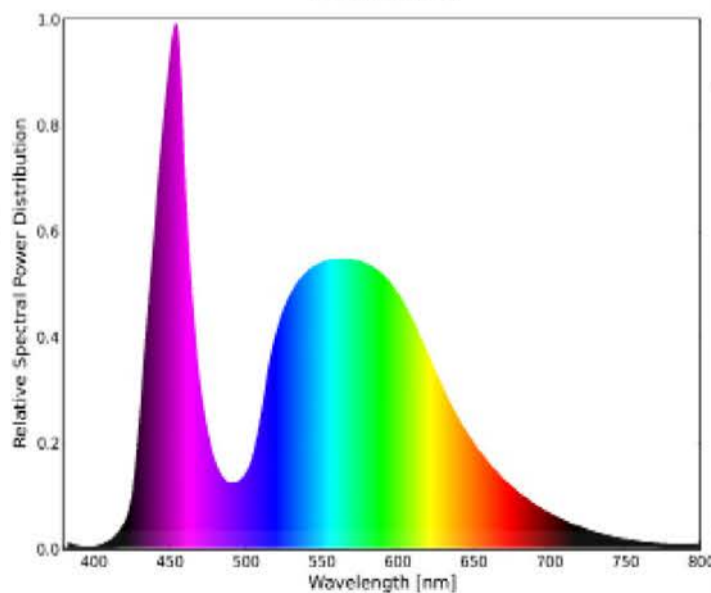
Lighting Condition 3:

Equivalent to
Lumileds Luxen 30302D LED Chip, 5000K
at 100% intensity and 150lux on image.



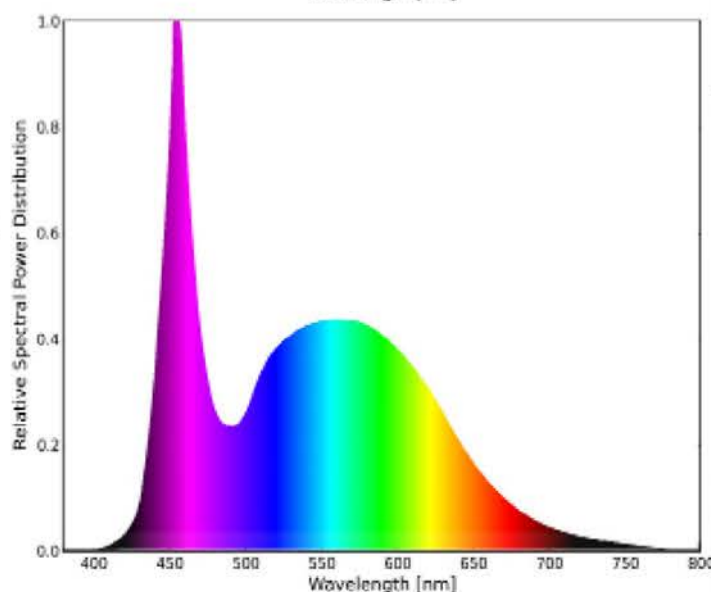
Lighting Condition 4:

Equivalent to
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



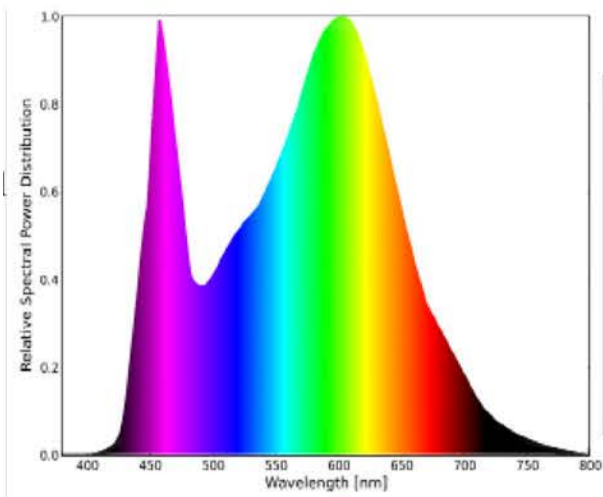
Lighting Condition 5:

Equivalent to
Lumileds Luxen 30302D LED Chip, 7000K
at 100% intensity and 150lux on image.



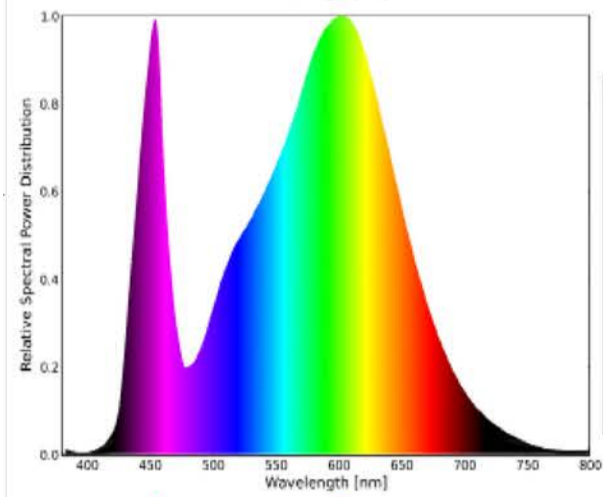
Lighting Condition 6:

Equivalent to 3000K and 5000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



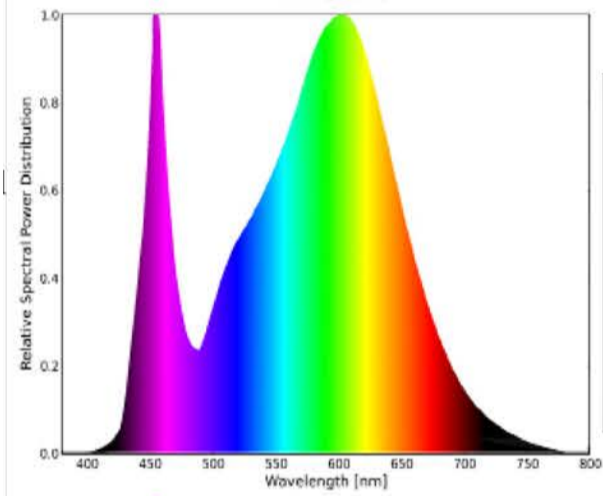
Lighting Condition 7:

Equivalent to 3000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



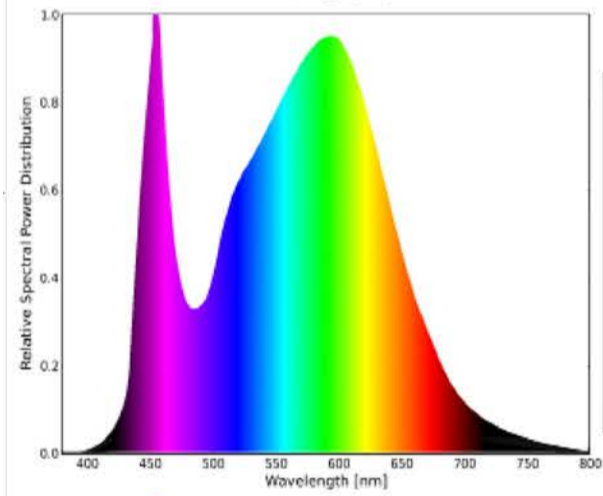
Lighting Condition 8:

Equivalent to 3000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



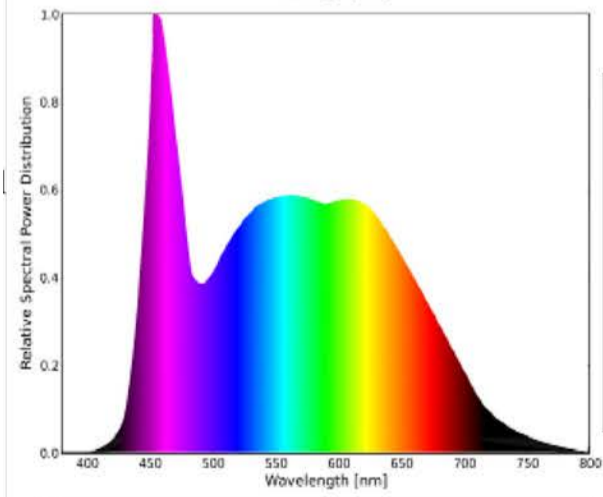
Lighting Condition 9:

Equivalent to 4000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 10:

Equivalent to 5000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 11:

Equivalent to 4000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.

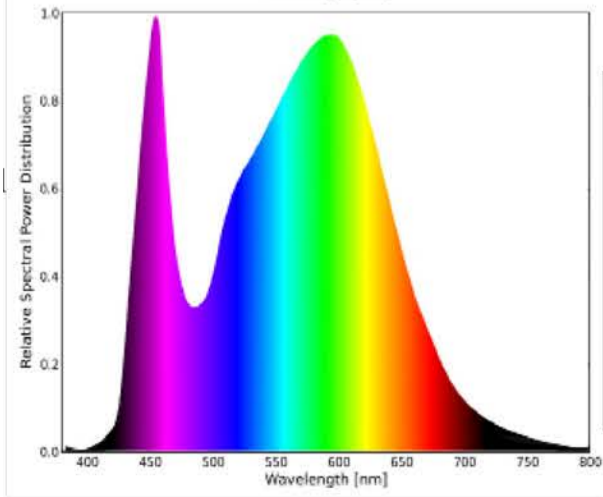
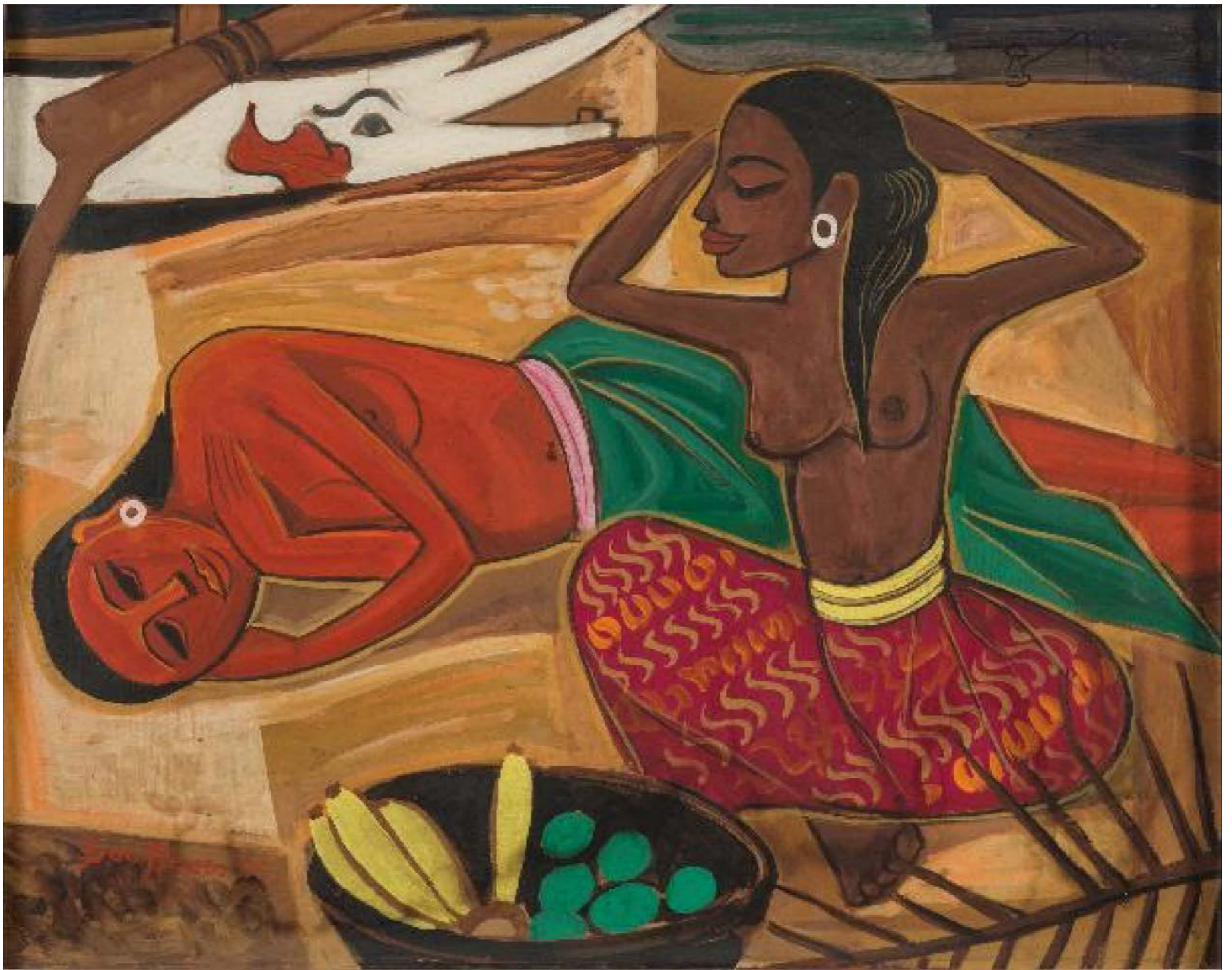


figure b.4: Spectral density distribution curves and effect on Life by the River (digital)
for 11 different simulated lighting conditions.



Cluster colors, sized by number of pixels:









cluster	pixels	name	HEX	RGB	HSV	LCH	Lab	tags
	21.19%	100,67,47 drumbeat $\Delta E=1.3$	#66422F	102 66 47	21 54 40	32 22 54	32 13 18	dark bracken brownie coffee drumbeat irish jambalaya nutmeg points quincy rimu spice
	17.53%	183,128,56 noosa $\Delta E=5.6$	#BA8447	186 132 71	32 62 73	59 43 71	59 14 40	noosa
	14.16%	136,89,49 natural $\Delta E=2.4$	#8C5D37	140 93 55	27 61 55	44 33 63	44 15 30	clay mckenzie natural potters sugar triumph brown
	13.75%	55,49,43 dark ebony $\Delta E=0.9$	#38312B	56 49 43	28 23 22	21 5 69	21 2 5	burnt dark acadia bean bushtrack coffee cuban ebony filmpro marlin monkey pepper tan treehouse umber black
	11.10%	136,53,49 totem pole $\Delta E=1.7$	#8A352F	138 53 47	4 66 54	34 42 32	34 36 22	apple coaster crab dawnbreaker el erica pole prairie roller salva sand tabasco thunderbird totem vixen
	9.30%	158,54,35 brownish red $\Delta E=3.4$	#A83E27	168 62 39	11 77 66	41 56 41	41 43 37	brick brownish chinese cognac mexican prairie sand wave red
	6.65%	195,176,145 indian khaki $\Delta E=2.3$	#C6AE91	198 174 145	32 27 78	72 19 76	72 5 18	coral doeskin dough half indian khaki peachpuff puff soul sour tabby vanilla peach
	6.32%	39,89,64 dark spring green $\Delta E=2.2$	#265D42	38 93 66	150 59 36	35 27 158	35 -25 10	dark alfresco kaitoke leprechaun mid pea sea spring green

IMAGE CLUSTER PARTITIONS

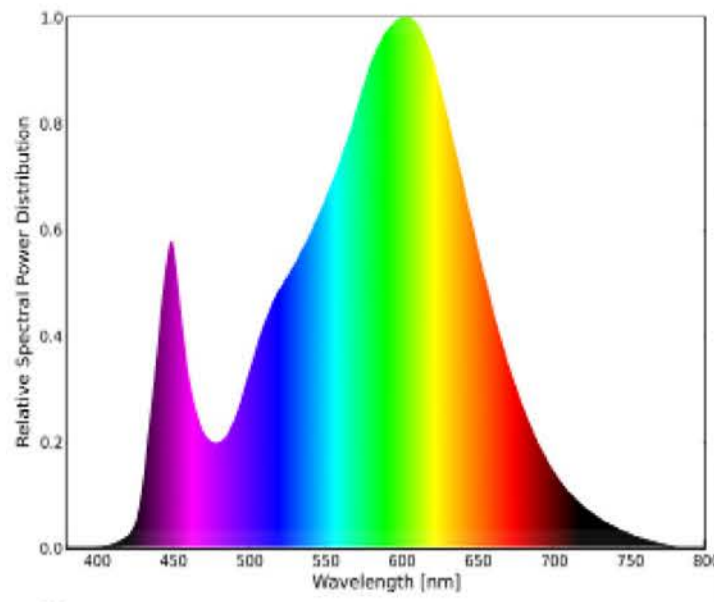
Pixels of the image assigned to each cluster. The border is the color of the cluster as calculated by the average value of its pixels.



figure b.5: Bali Beach in sRGB color space.

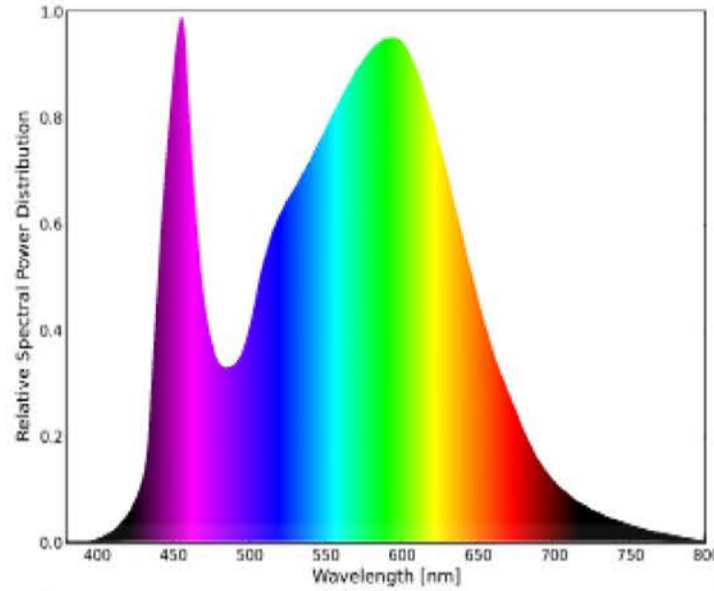
Lighting Condition 1:

Equivalent to
Lumileds Luxen 30302D LED Chip, 3000K
at 100% intensity and 150lux on image.



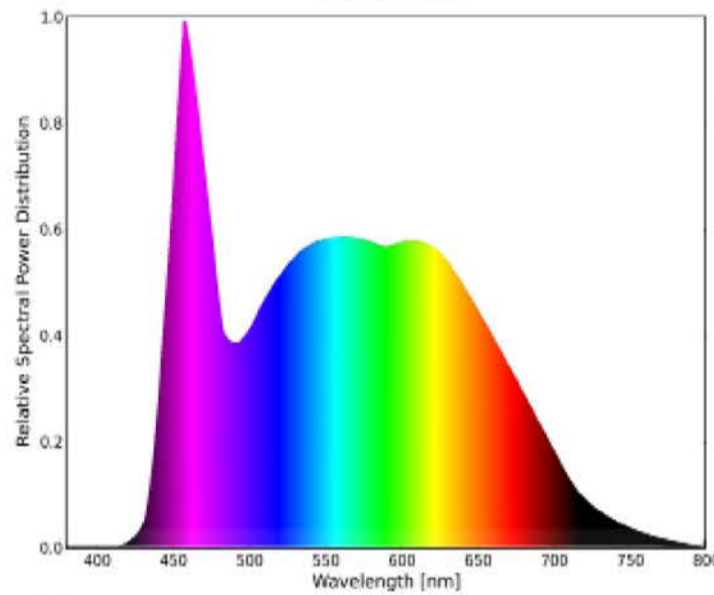
Lighting Condition 2:

Equivalent to
Lumileds Luxen 30302D LED Chip, 4000K
at 100% intensity and 150lux on image.



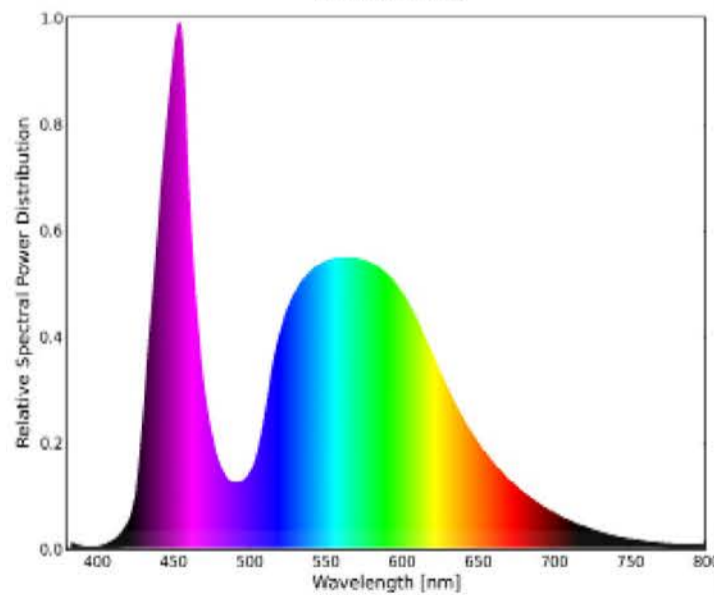
Lighting Condition 3:

Equivalent to
Lumileds Luxen 30302D LED Chip, 5000K
at 100% intensity and 150lux on image.



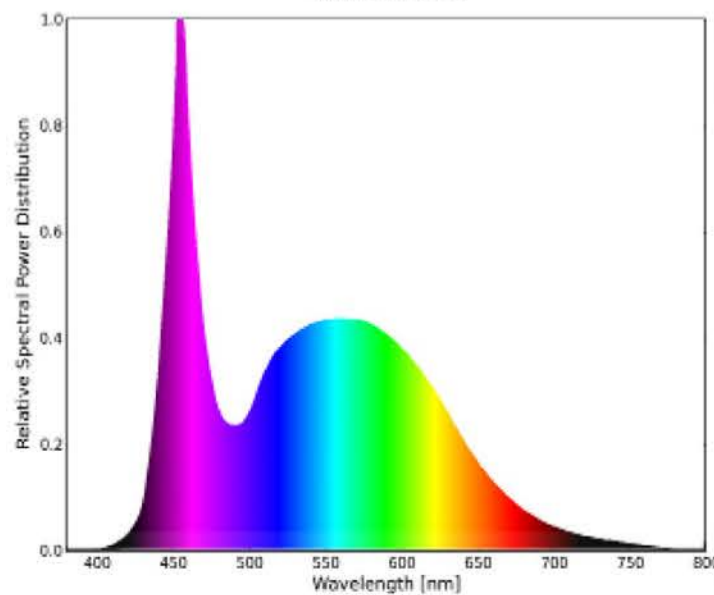
Lighting Condition 4:

Equivalent to
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



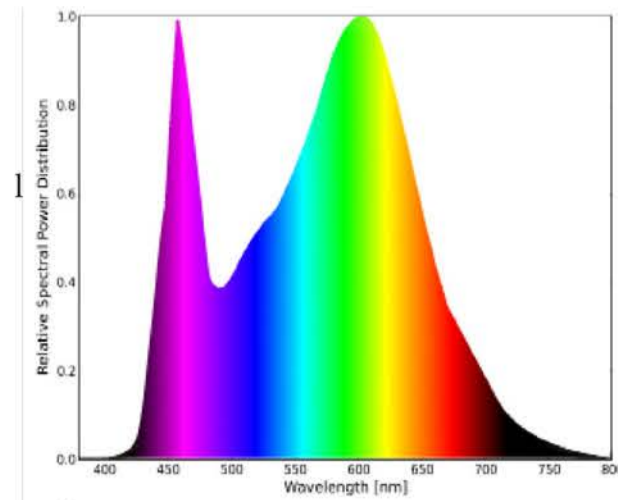
Lighting Condition 5:

Equivalent to
Lumileds Luxen 30302D LED Chip, 7000K
at 100% intensity and 150lux on image.



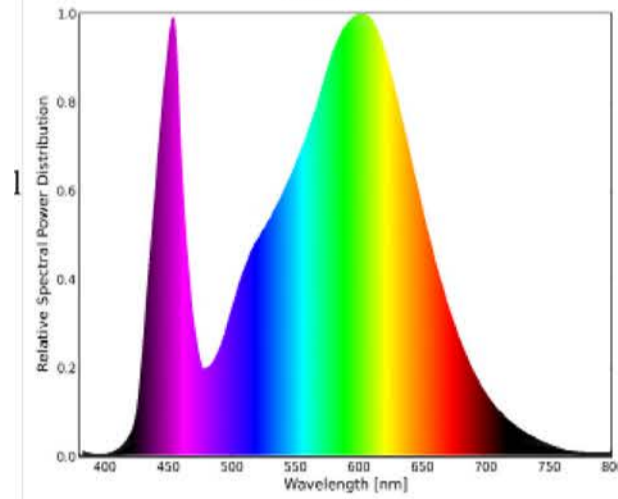
Lighting Condition 6:

Equivalent to 3000K and 5000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



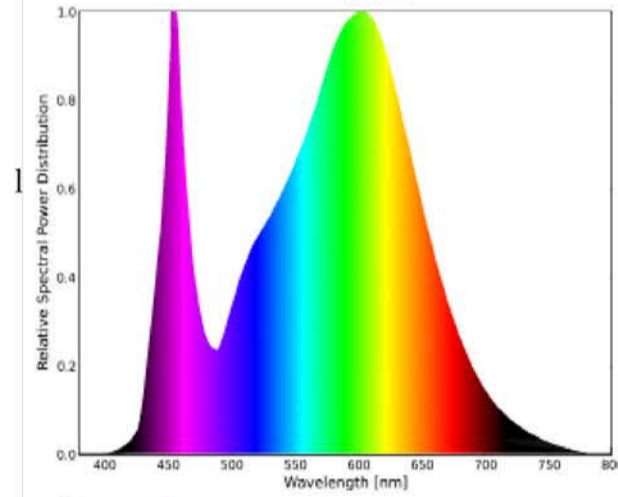
Lighting Condition 7:

Equivalent to 3000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



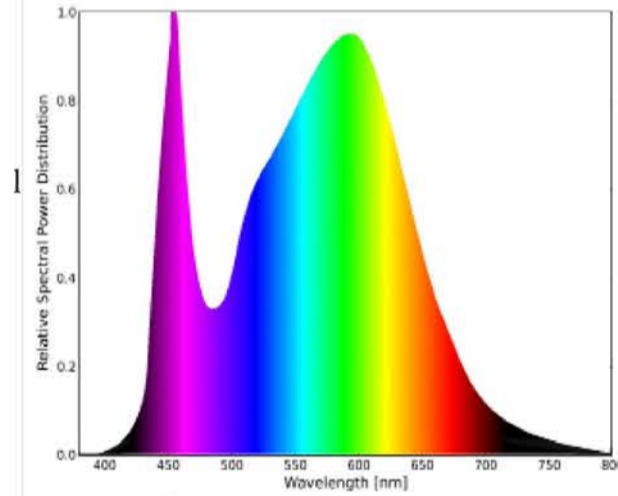
Lighting Condition 8:

Equivalent to 3000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



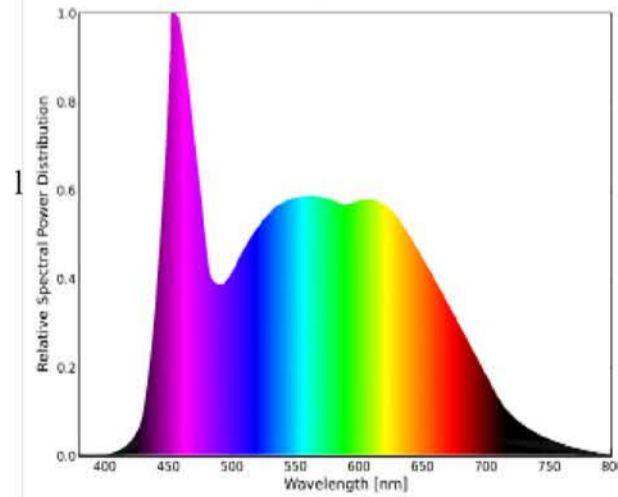
Lighting Condition 9:

Equivalent to 4000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 10:

Equivalent to 5000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 11:

Equivalent to 4000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.

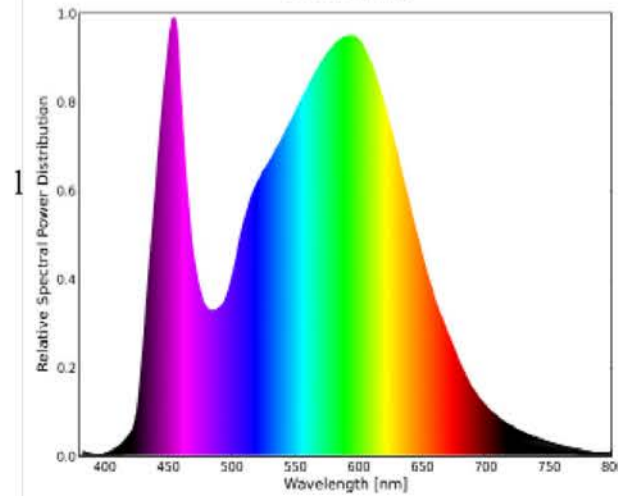


figure b.6: Spectral density distribution curves and effect on Bali Beach (digital)
for 11 different simulated lighting conditions.



Cluster colors, sized by number of pixels:

cluster	pixels	name	HEX	RGB	HSV	LCH	Lab	tags
	24.27%	211,205,197 swirl $\Delta E=1.2$	#D9D0C8	217 208 200	30 8 85	84 6 74	84 2 5	chance cloud coffee eighth half last malta milestone napa quarter swirl swiss truffle westar
	17.63%	175,172,160 off piste $\Delta E=1.2$	#ACA89B	172 168 155	48 10 67	69 7 100	69 -1 7	delta eighth foggy greyish napa off piste pravda quarter stonewall stonewashed swordfish yellowish grey
	15.10%	141,128,114 stonewashed $\Delta E=0.8$	#8C8073	140 128 115	31 18 55	54 9 75	54 2 9	antique americano half ironhide makara perfect pravda sandstone schooner squirrel stonewashed taupe triple white
	11.00%	205,183,158 bisque $\Delta E=0.9$	#D0BAA1	208 186 161	33 23 81	77 16 77	77 4 16	dark amber biscotti bisque double dough eighth grain kalgoorie sands soft sour vanilla brown
	10.18%	107,91,82 quarter lignite $\Delta E=1.9$	#66574D	102 87 77	24 24 40	38 9 62	38 4 8	cone dorado felix half judge kabul kiwi lignite mondo pine quarter stonehenge triple umber grey
	10.02%	193,150,118 half kalgoorie sands $\Delta E=3.1$	#C19379	193 147 121	21 37 76	65 24 56	65 14 20	pale light baroque half kalgoorie sands taupe
	8.16%	165,105,79 sepia $\Delta E=2.8$	#A56B54	165 107 84	17 49 65	51 30 47	51 21 22	claypot fe pinkish sante sepia brown
	3.65%	190,92,72 flame pea $\Delta E=3.0$	#C46249	196 98 73	12 63 77	53 49 40	53 37 32	copper flame pea red

IMAGE CLUSTER PARTITIONS

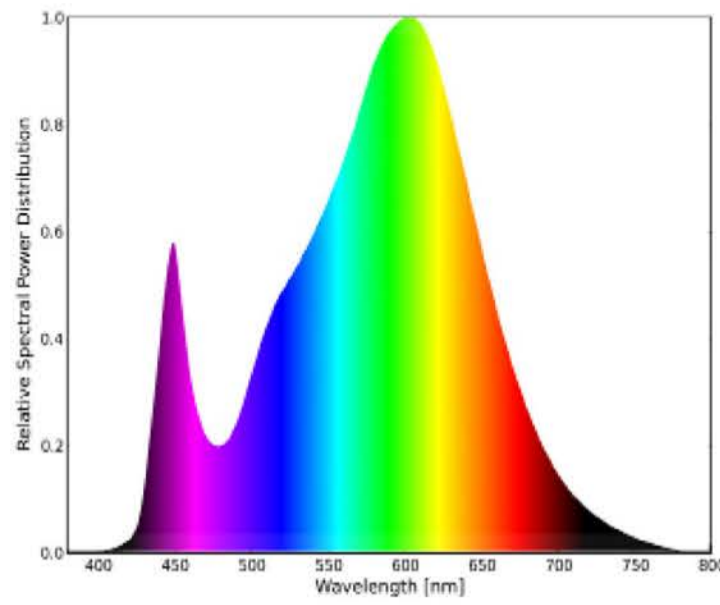
Pixels of the image assigned to each cluster. The border is the color of the cluster as calculated by the average value of its pixels.



figure b.7: Herons in sRGB color space.

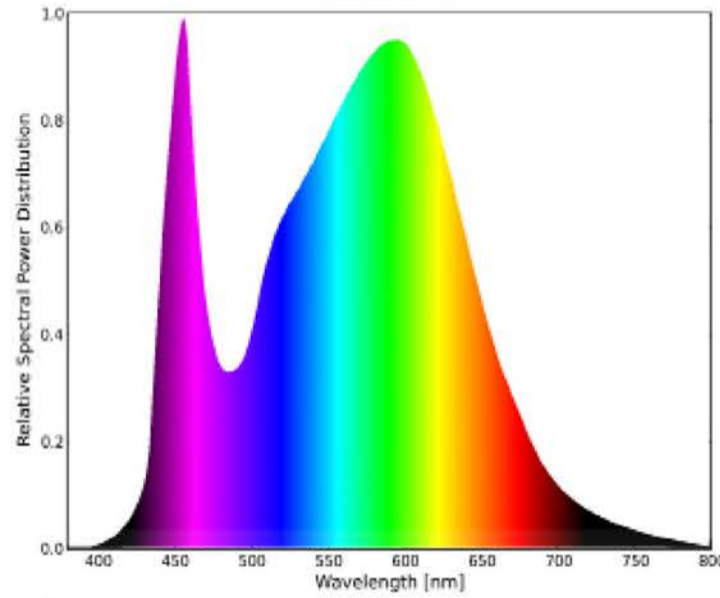
Lighting Condition 1:

Equivalent to
Lumileds Luxen 30302D LED Chip, 3000K
at 100% intensity and 150lux on image.



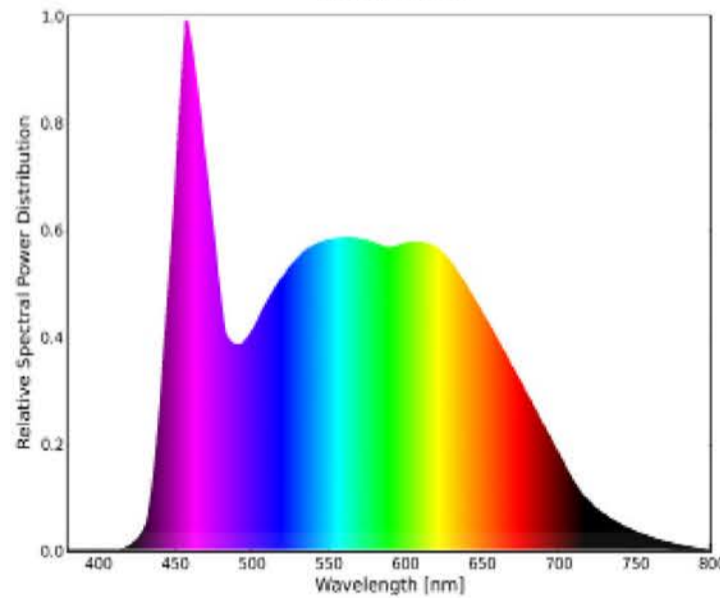
Lighting Condition 2:

Equivalent to
Lumileds Luxen 30302D LED Chip, 4000K
at 100% intensity and 150lux on image.



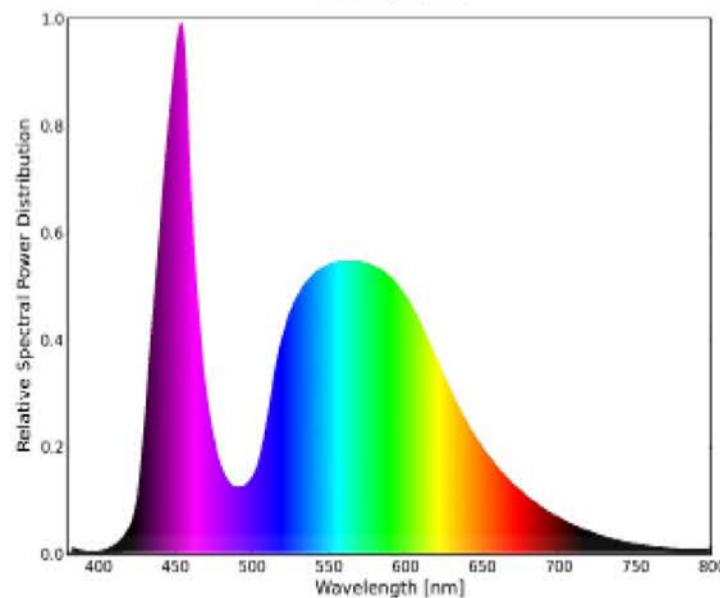
Lighting Condition 3:

Equivalent to
Lumileds Luxen 30302D LED Chip, 5000K
at 100% intensity and 150lux on image.



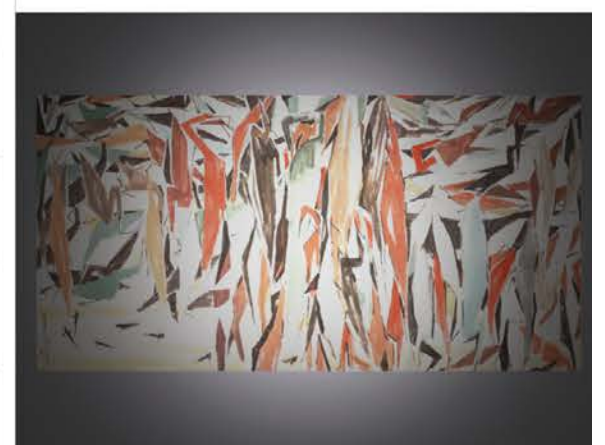
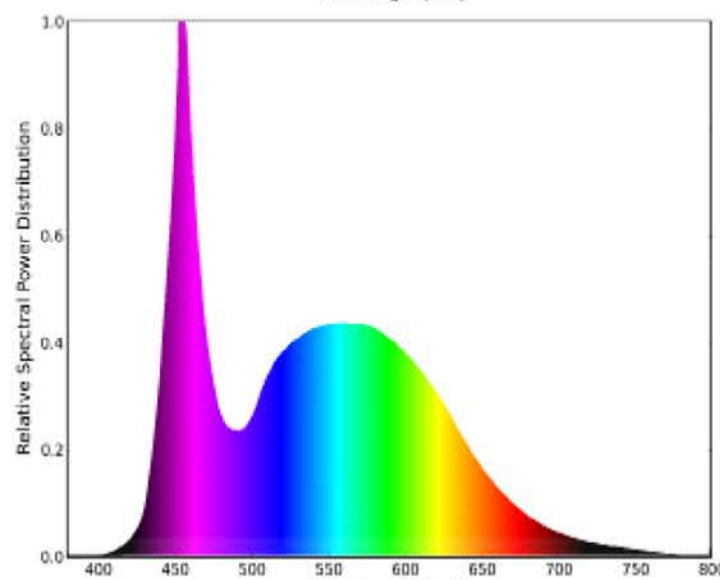
Lighting Condition 4:

Equivalent to
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



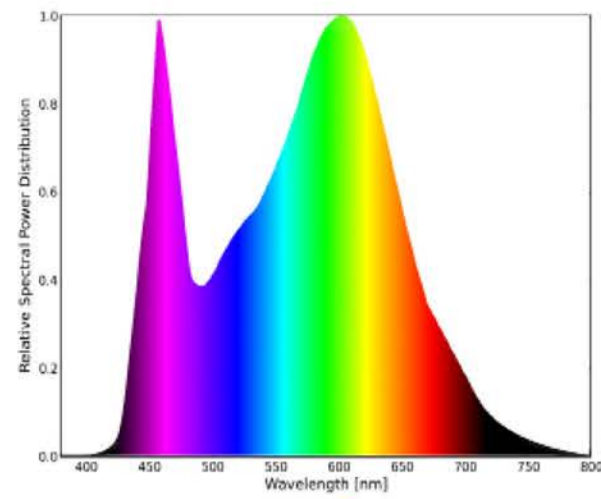
Lighting Condition 5:

Equivalent to
Lumileds Luxen 30302D LED Chip, 7000K
at 100% intensity and 150lux on image.



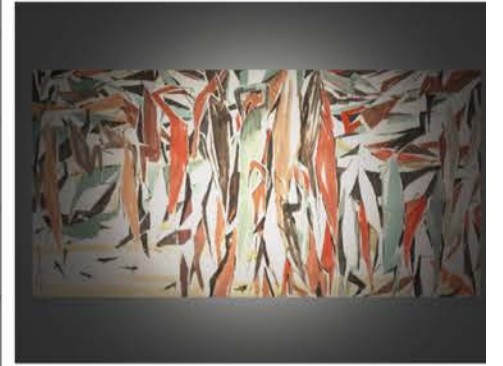
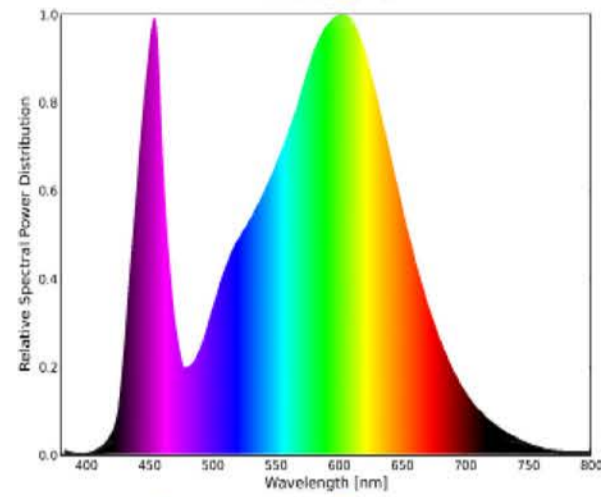
Lighting Condition 6:

Equivalent to 3000K and 5000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



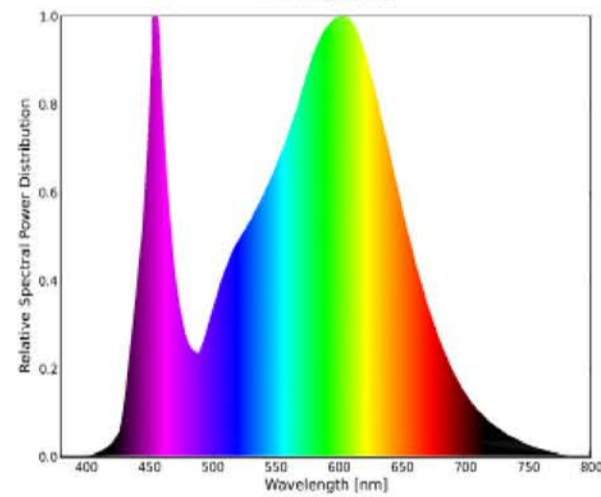
Lighting Condition 7:

Equivalent to 3000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



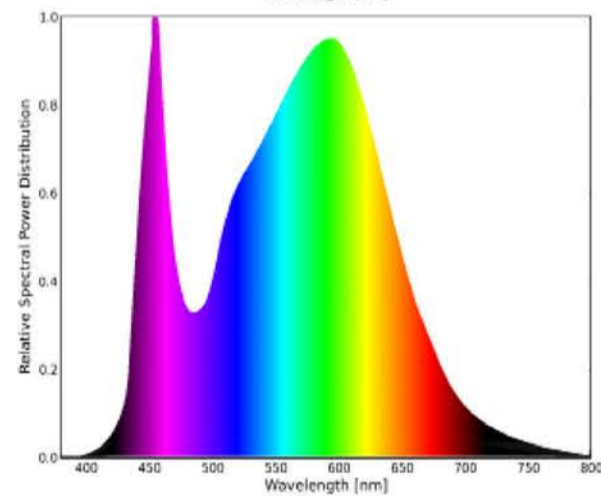
Lighting Condition 8:

Equivalent to 3000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



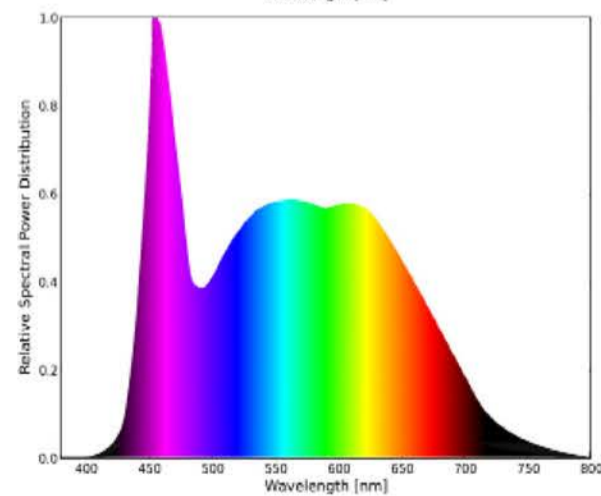
Lighting Condition 9:

Equivalent to 4000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 10:

Equivalent to 5000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 11:

Equivalent to 4000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.

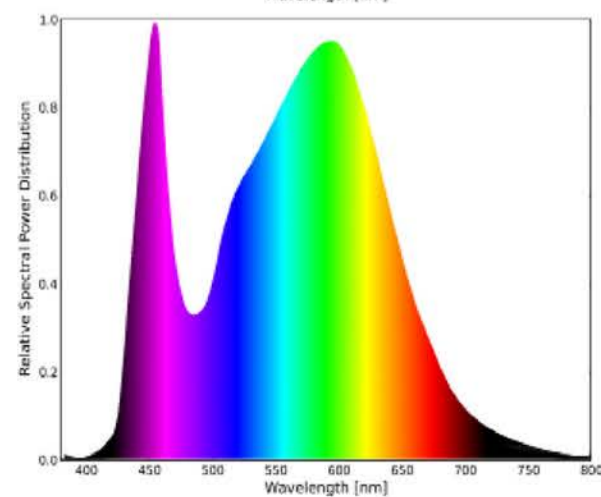


figure b.8: spectral density distribution curves and effect on Herons (digital)
for 11 different simulated lighting conditions.



Cluster colors, sized by number of pixels:

cluster	pixels	name	HEX	RGB	HSV	LCH	Lab	tags
	30.44%	223, 221, 214 ceramic $\Delta E=0.5$	#E0ED6	224 222 214	47 5 88	88 4 99	88 -1 4	barely ceramic cloud double eighth fog half haze hint of pasifika pointer quarter sea style tea there black grey white
	12.54%	205, 201, 190 half truffle $\Delta E=0.6$	#CAC8BD	202 200 189	52 7 79	81 6 104	81 -1 6	ash double eighth grass half ivory kangaroo lighthouse pointer quill titania truffle grey lemon white
	11.89%	152, 146, 128 quarter evolution $\Delta E=0.5$	#999483	153 148 131	47 15 60	61 10 97	61 -1 10	arrowtown cougar double evolution grass half heathered napa nomad pravda quarter settlement stonewall grey lemon
	11.23%	121, 117, 100 synchronise $\Delta E=2.6$	#7F7B6A	127 123 106	47 16 50	52 10 97	52 -1 10	aquashield arrowtown cobblestone half makara mondo portland pravda quarter stonewall synchronise talisman
	11.21%	178, 173, 158 eighth stonewall $\Delta E=0.6$	#81AE9F	177 174 159	50 10 70	71 8 101	71 -2 8	bedrock copyrite eighth grass half napa off pebble piste pravda quarter stonewall stonewashed yellowish grey lemon
	9.89%	102, 97, 86 karens pewter $\Delta E=1.4$	#636156	99 97 86	52 14 39	41 7 102	41 -2 7	chicago evolution friar gravel half karens masala pewter pure stonehenge talisman tapa triple grey
	8.04%	75, 72, 66 relic $\Delta E=1.6$	#474640	71 70 64	55 10 28	30 4 106	30 -1 4	deep armadillo double gravel half heavy ironsand masala merlin metal relic space tiri tuatara
	4.76%	168, 165, 125 grayish olive $\Delta E=2.6$	#B0AE85	176 174 133	56 25 69	70 22 105	70 -6 21	age chino coriander earthstone fawn grayish locust olive sage stone toi green

IMAGE CLUSTER PARTITIONS

Pixels of the image assigned to each cluster. The border is the color of the cluster as calculated by the average value of its pixels.

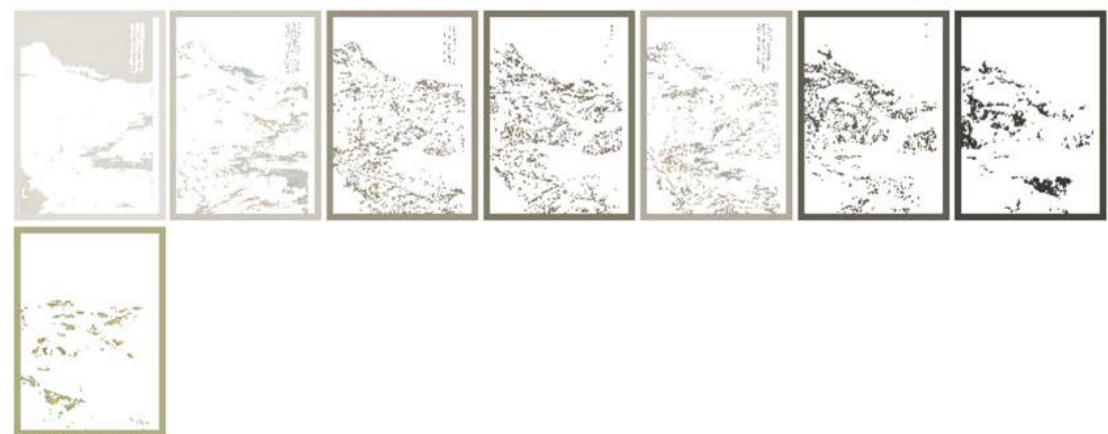
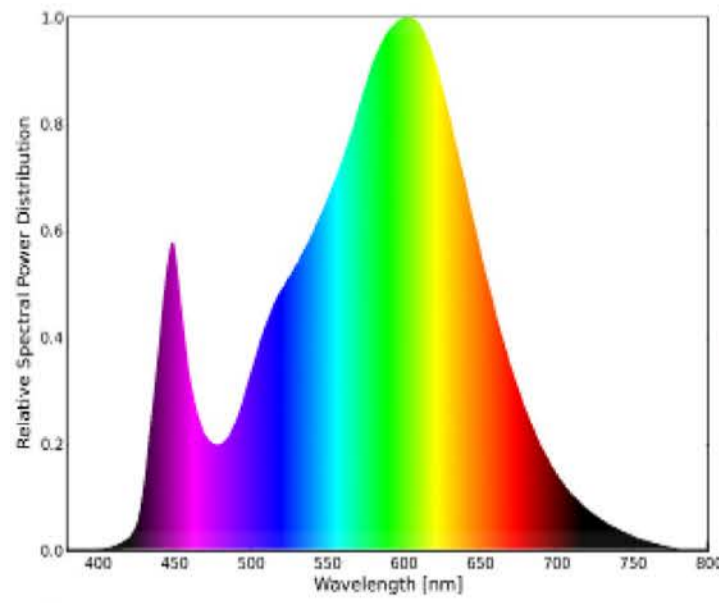


figure b.9: Landscape in sRGB color space.

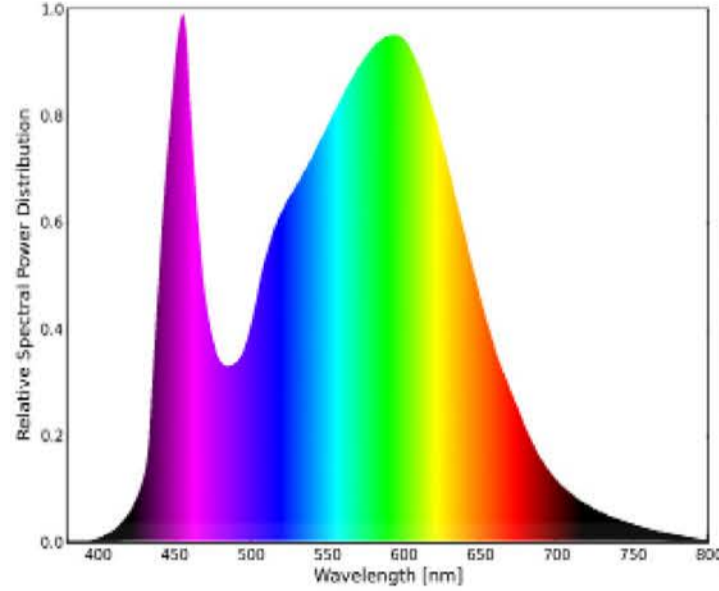
Lighting Condition 1:

Equivalent to
Lumileds Luxen 30302D LED Chip, 3000K
at 100% intensity and 150lux on image.



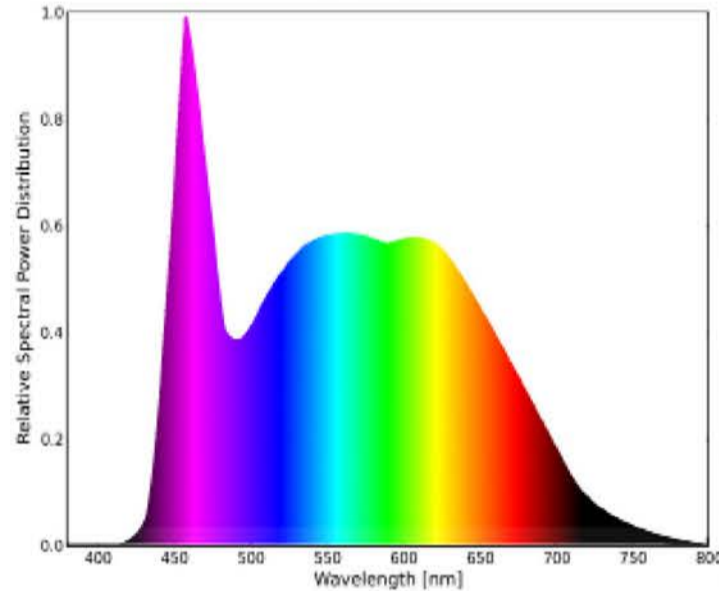
Lighting Condition 2:

Equivalent to
Lumileds Luxen 30302D LED Chip, 4000K
at 100% intensity and 150lux on image.



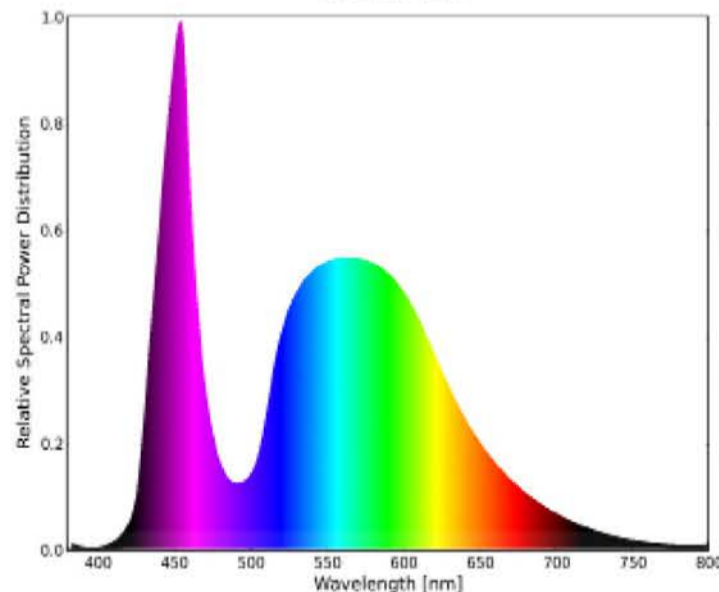
Lighting Condition 3:

Equivalent to
Lumileds Luxen 30302D LED Chip, 5000K
at 100% intensity and 150lux on image.



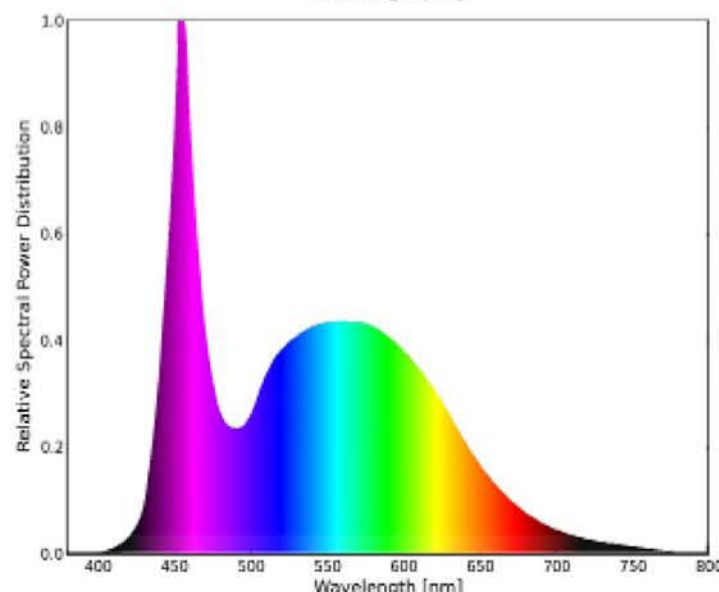
Lighting Condition 4:

Equivalent to
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



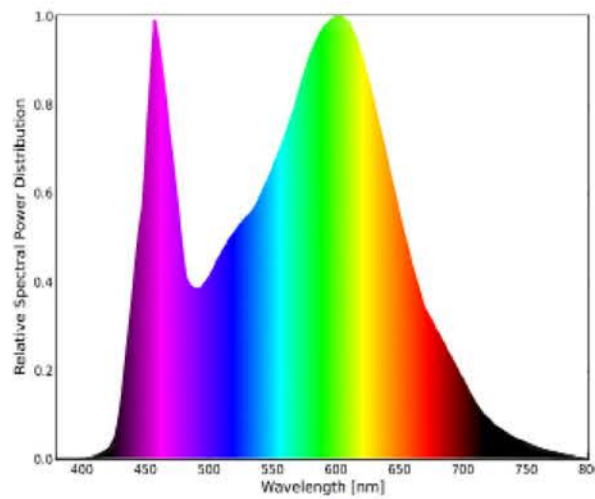
Lighting Condition 5:

Equivalent to
Lumileds Luxen 30302D LED Chip, 7000K
at 100% intensity and 150lux on image.



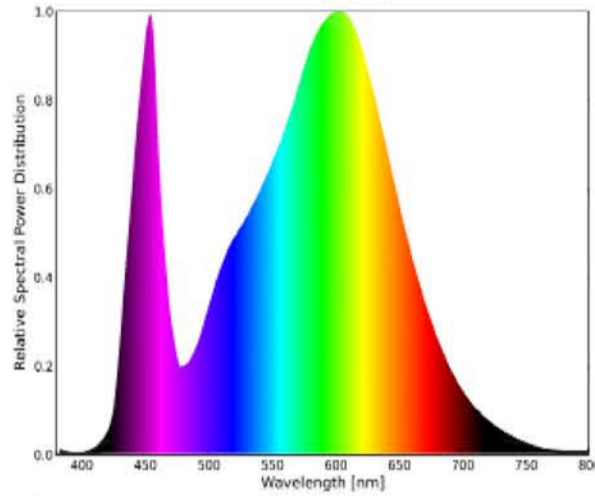
Lighting Condition 6:

Equivalent to 3000K and 5000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



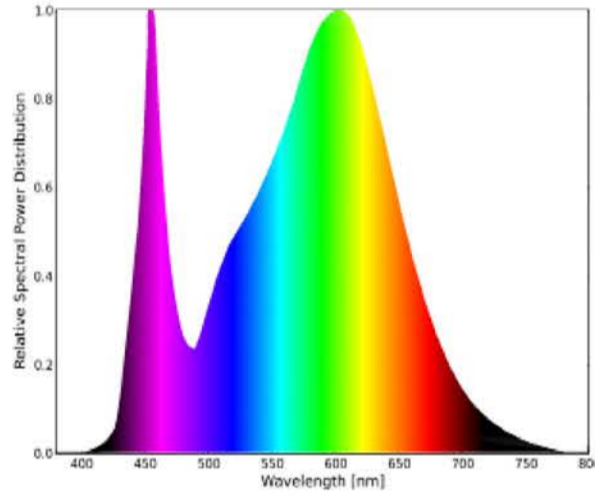
Lighting Condition 7:

Equivalent to 3000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



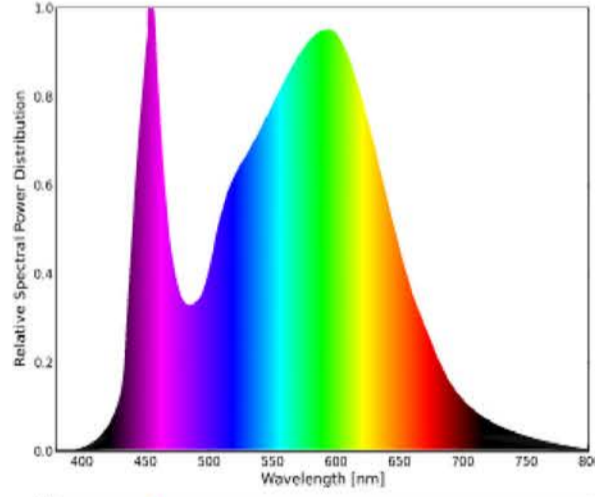
Lighting Condition 8:

Equivalent to 3000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



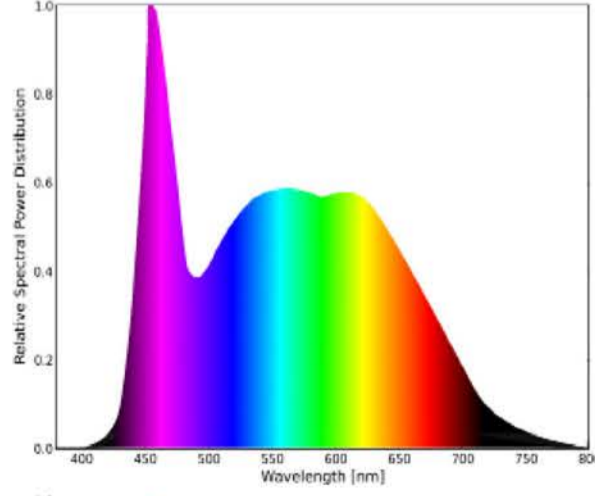
Lighting Condition 9:

Equivalent to 4000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 10:

Equivalent to 5000K and 7000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.



Lighting Condition 11:

Equivalent to 4000K and 6000K
Lumileds Luxen 30302D LED Chip, 6000K
at 100% intensity and 150lux on image.

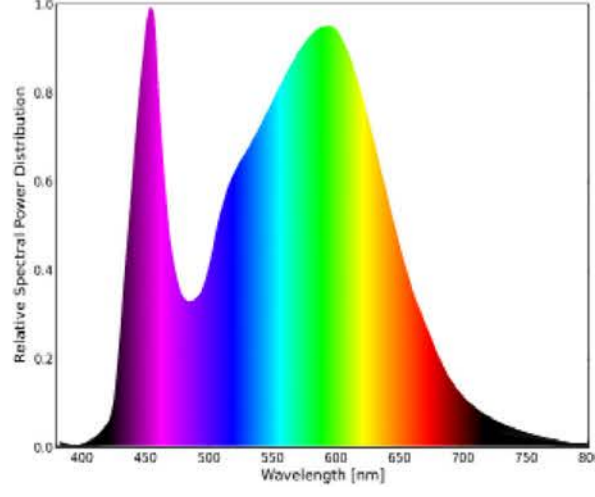


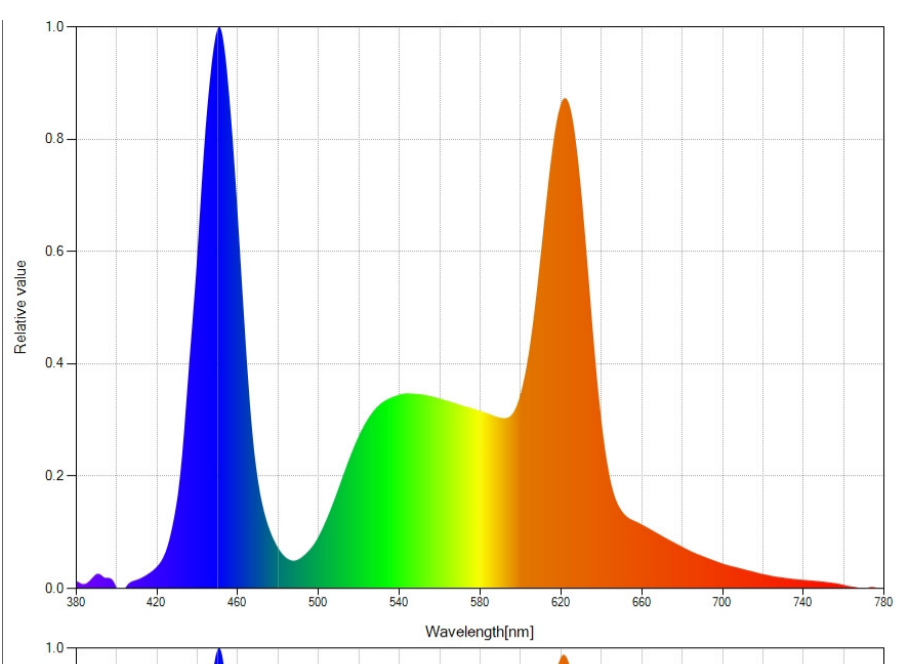
figure b.10: Spectral density distribution curves and effect on Landscape (digital) f
for 11 different simulated lighting conditions.

Experiments on real paintings

Refer to following page inserts

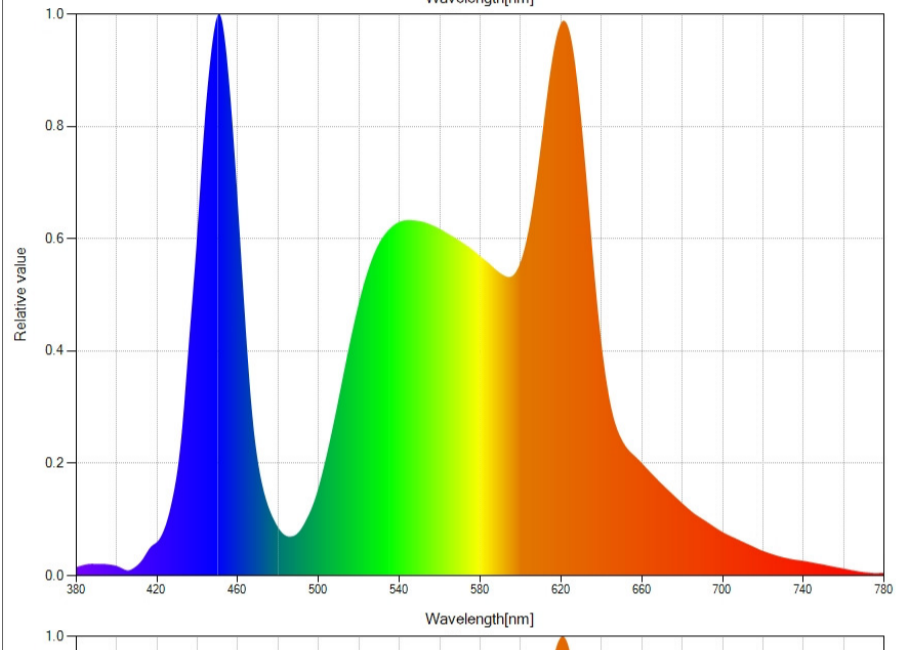
Lighting Condition 1:

Equivalent to 4000k
150lux on image.



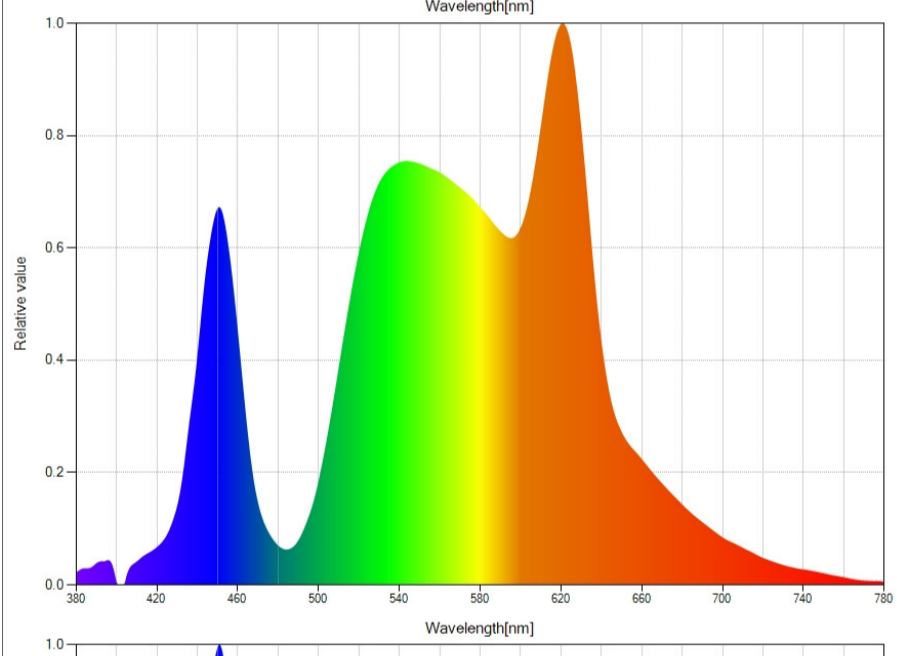
Lighting Condition 2:

Equivalent to 4000k
150lux on image.



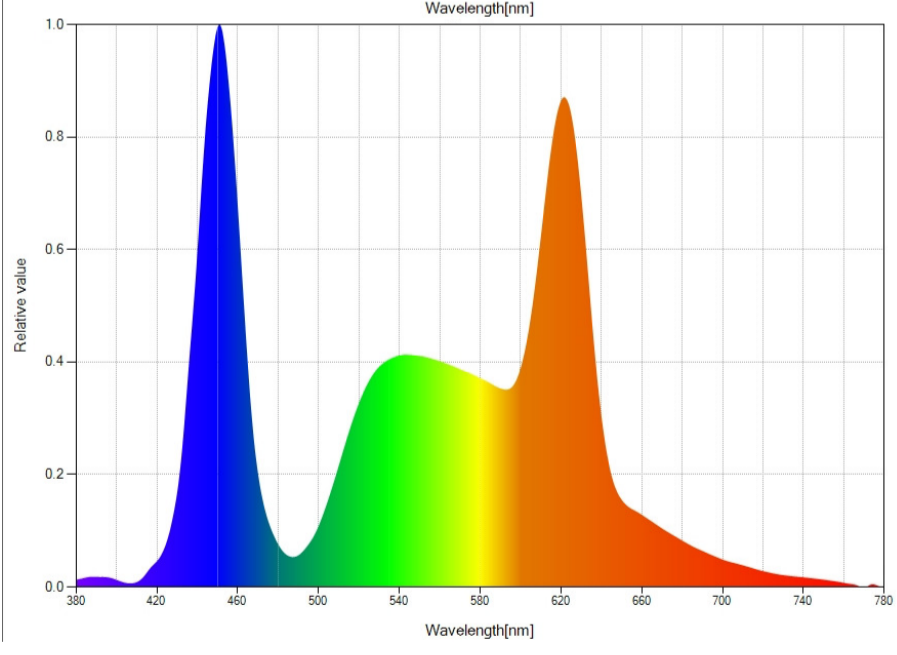
Lighting Condition 3:

Equivalent to 4000k
150lux on image.



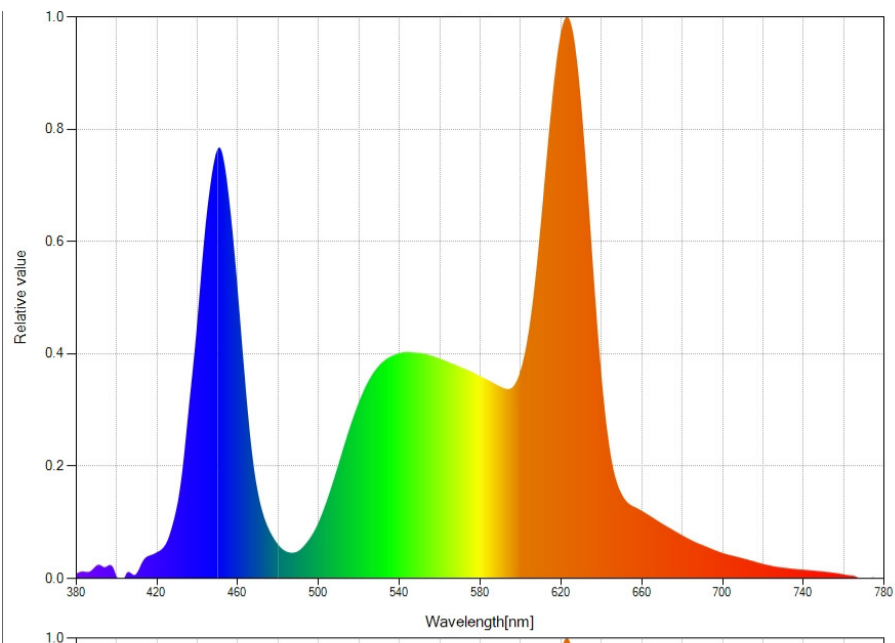
Lighting Condition 4:

Equivalent to 4000k
150lux on image.



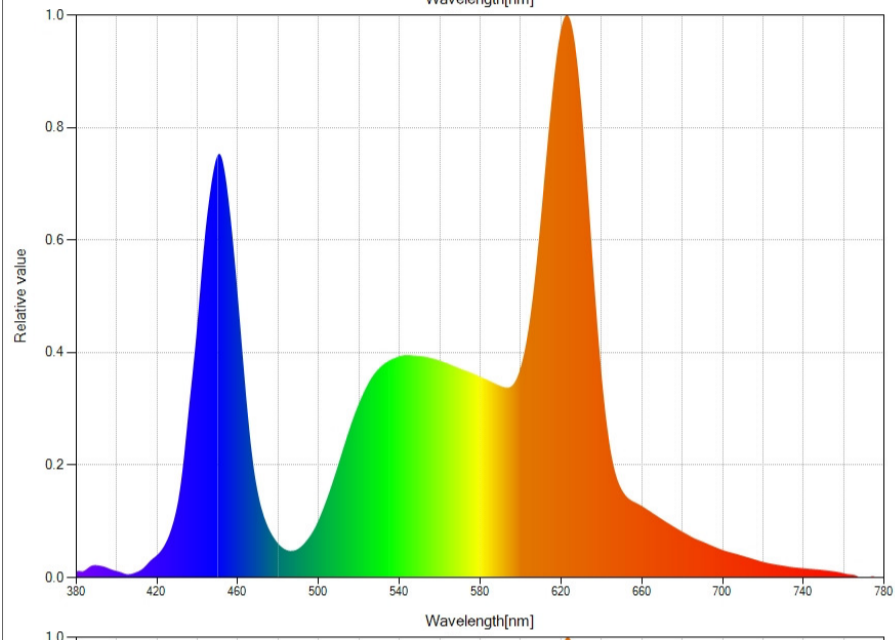
Lighting Condition 5:

Equivalent to 3500k
150lux on image.



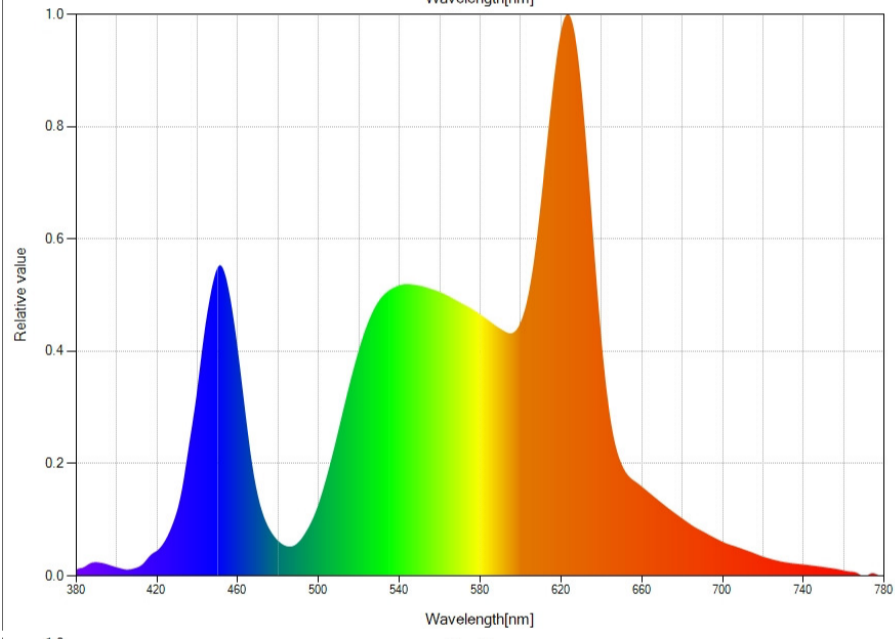
Lighting Condition 6:

Equivalent to 3500k
150lux on image.



Lighting Condition 7:

Equivalent to 3500k
150lux on image.



Lighting Condition 8:

Equivalent to 3500k
150lux on image.

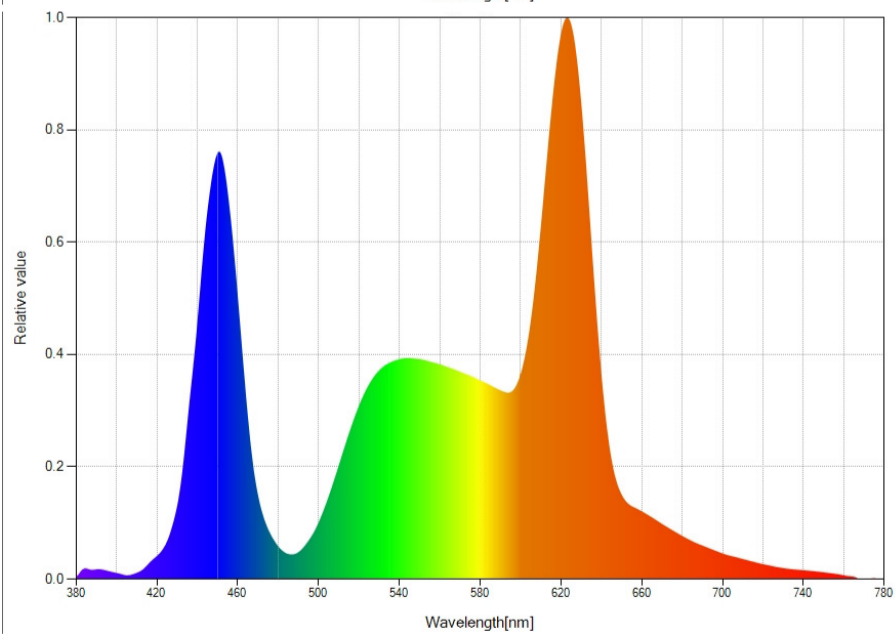
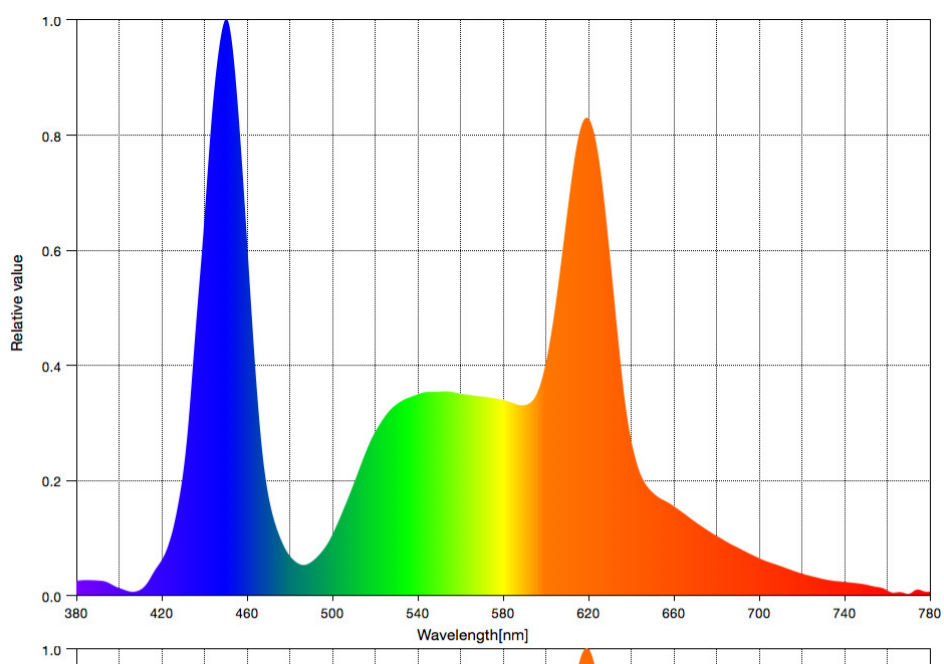


figure b.11: spectral density distribution curves and effect on Officials assembling for a trial at the hong of Canton for 8 different lighting conditions

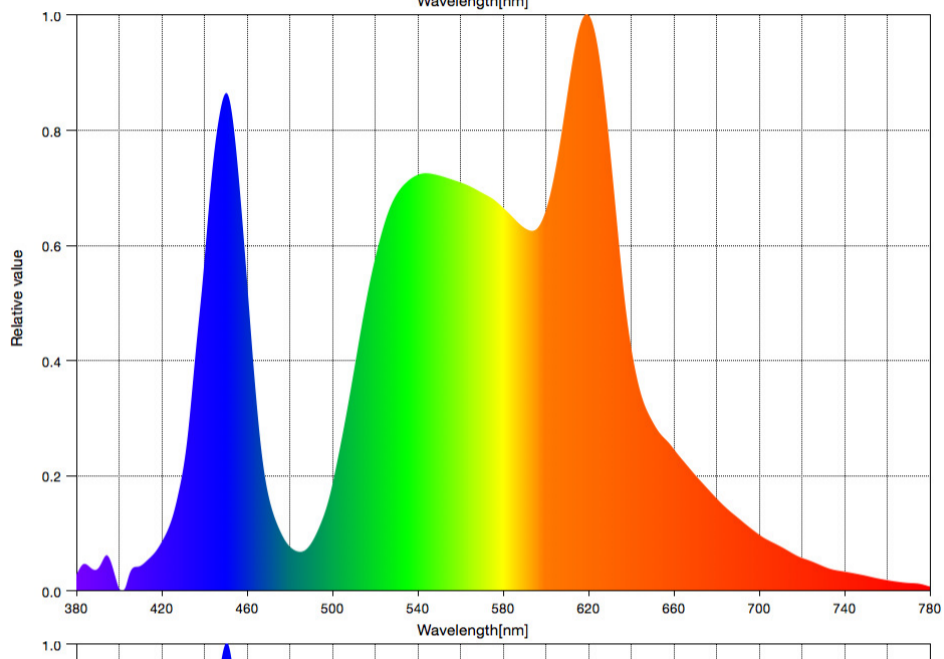
Lighting Condition 1:

Equivalent to 4000k
150lux on image.



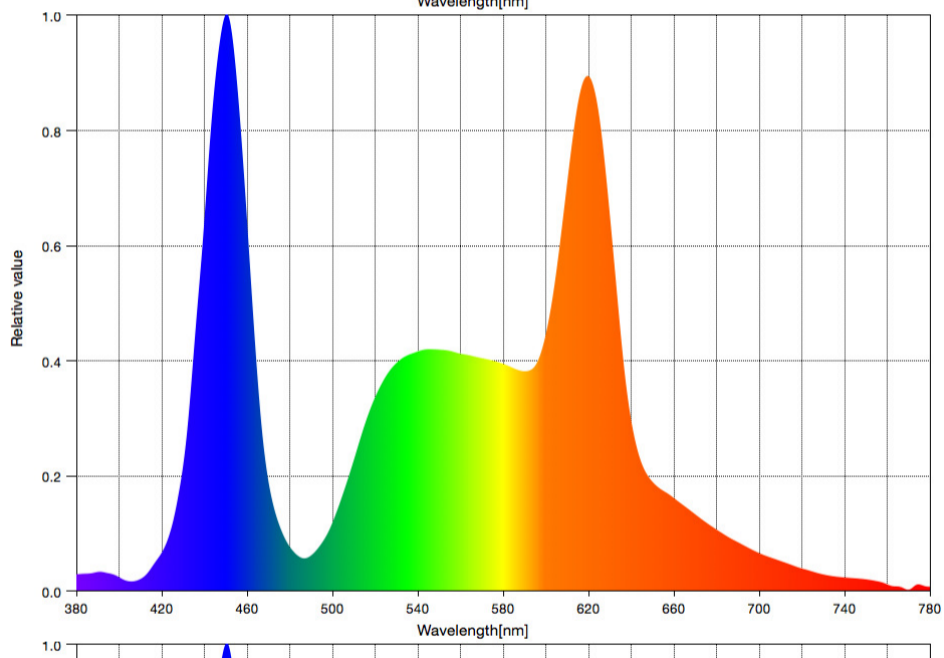
Lighting Condition 2:

Equivalent to 4000k
150lux on image.



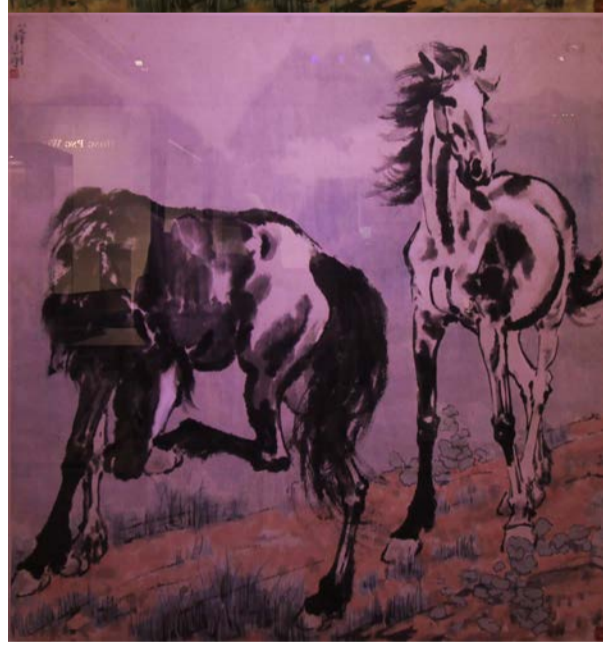
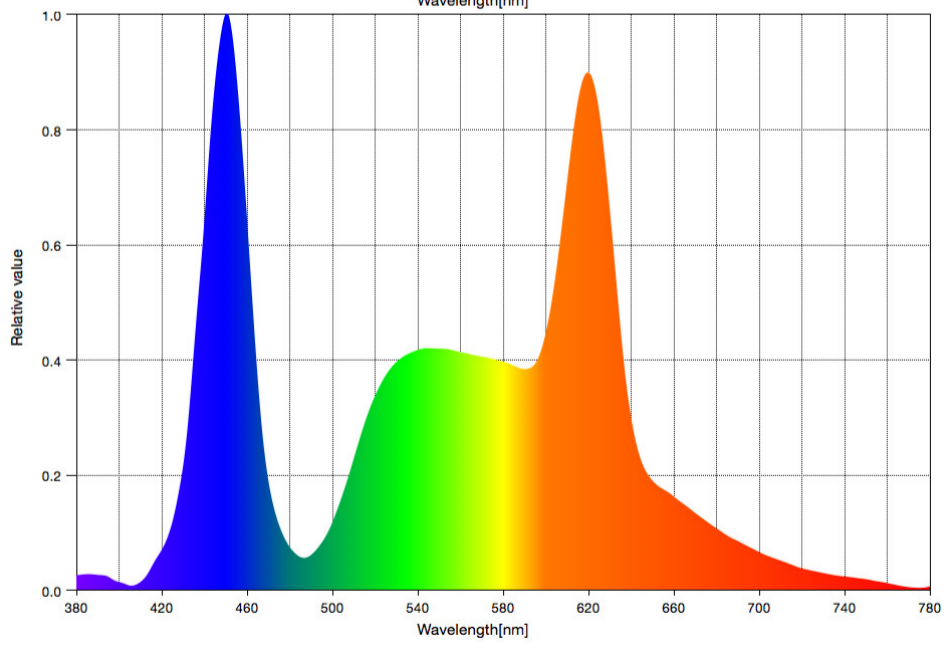
Lighting Condition 3:

Equivalent to 4000k
150lux on image.



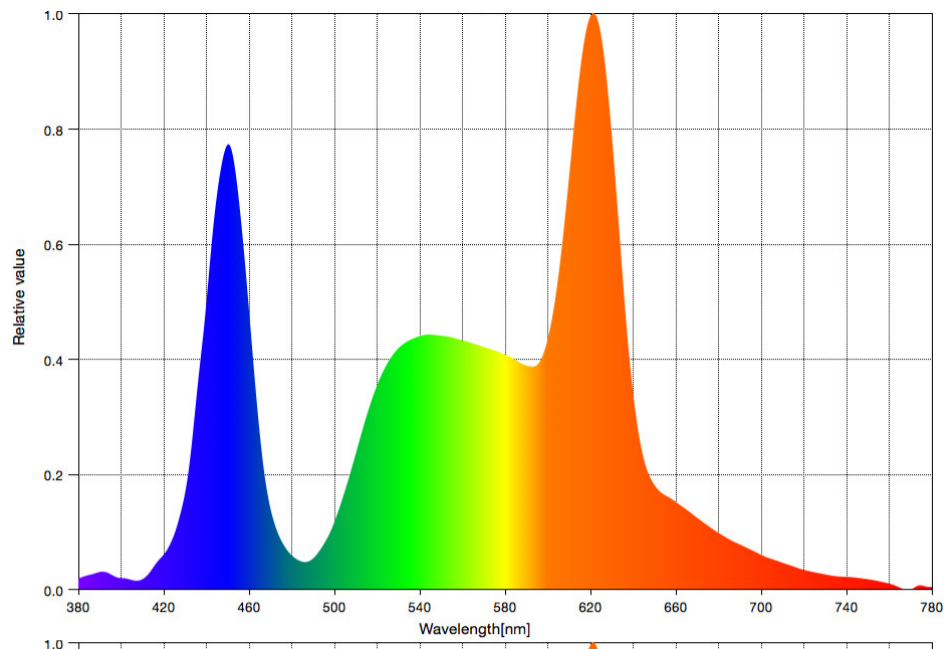
Lighting Condition 4:

Equivalent to 4000k
150lux on image.



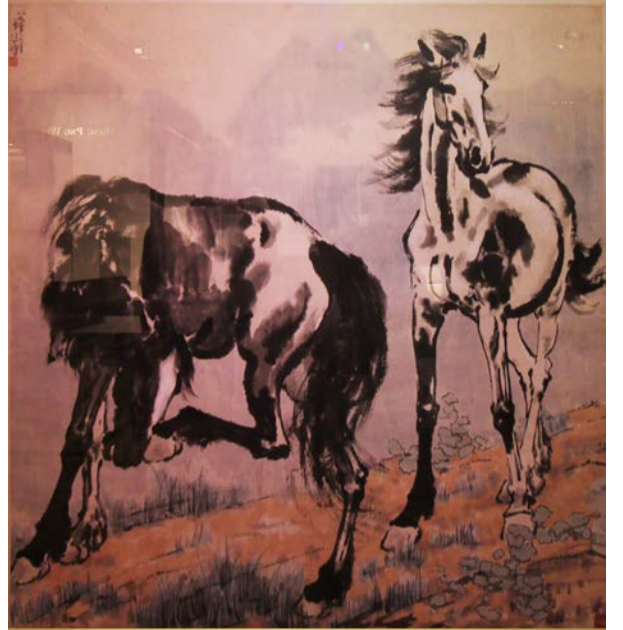
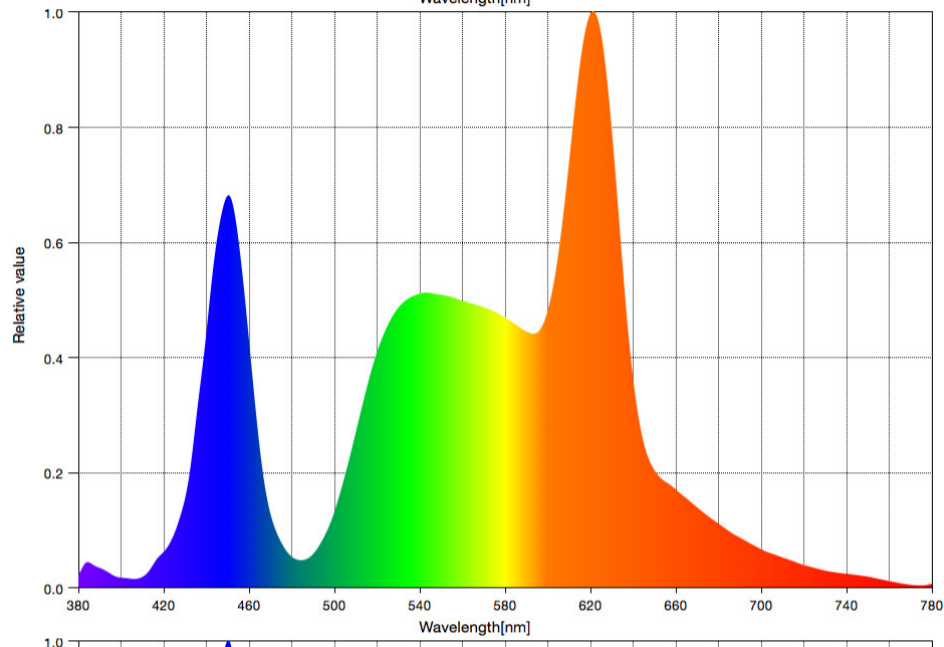
Lighting Condition 5:

Equivalent to 3500k
50lux on image.



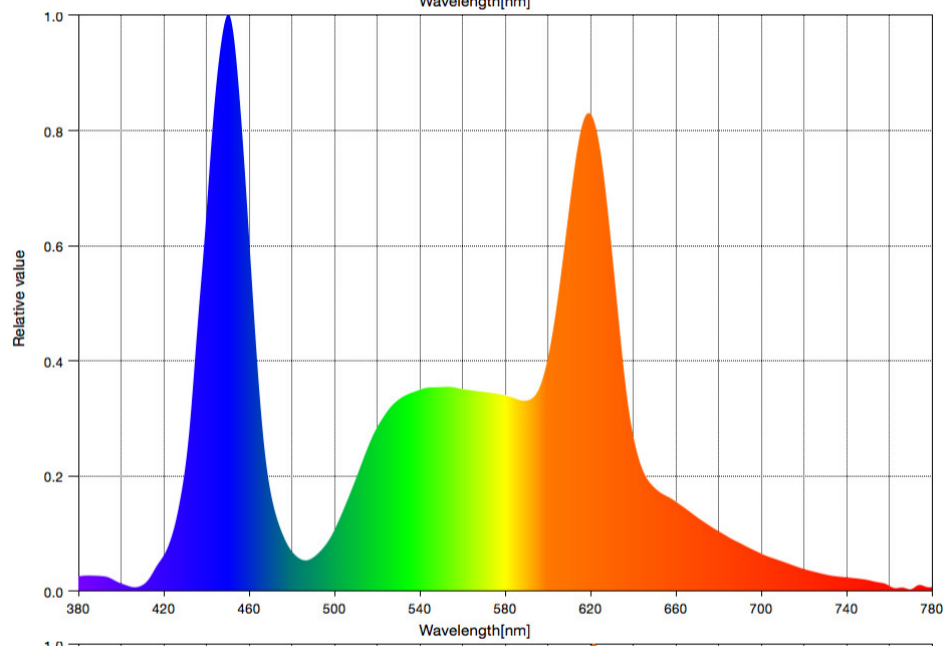
Lighting Condition 6:

Equivalent to 3500k
50lux on image.



Lighting Condition 7:

Equivalent to 3500k
50lux on image.



Lighting Condition 8:

Equivalent to 3500k
50lux on image.

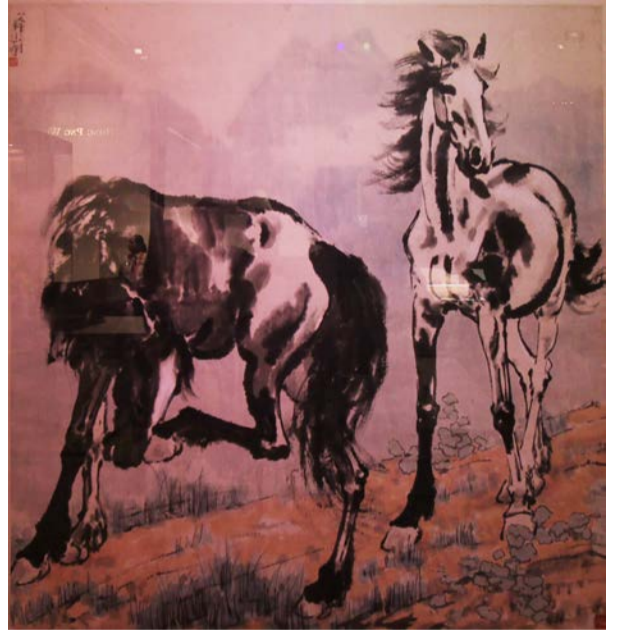
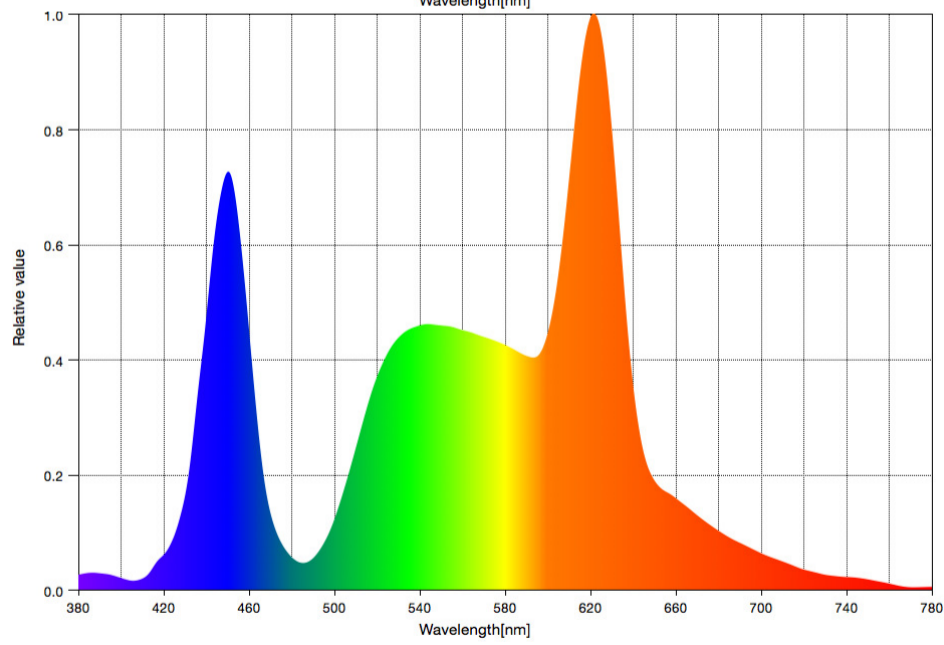
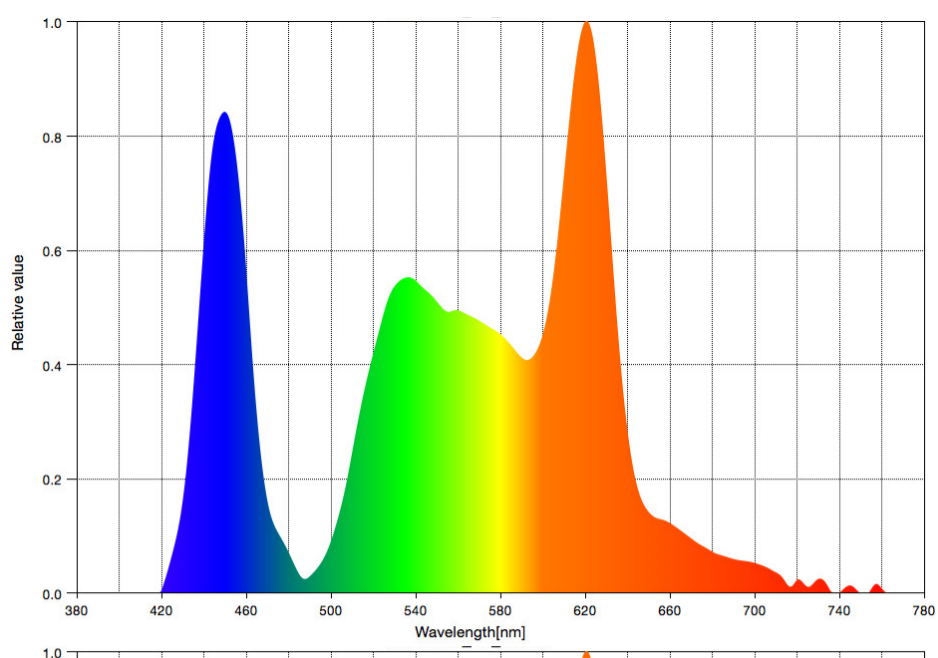


figure b.12: Spectral density distribution curves and effect on A Pair of Horses for 8 different lighting conditions

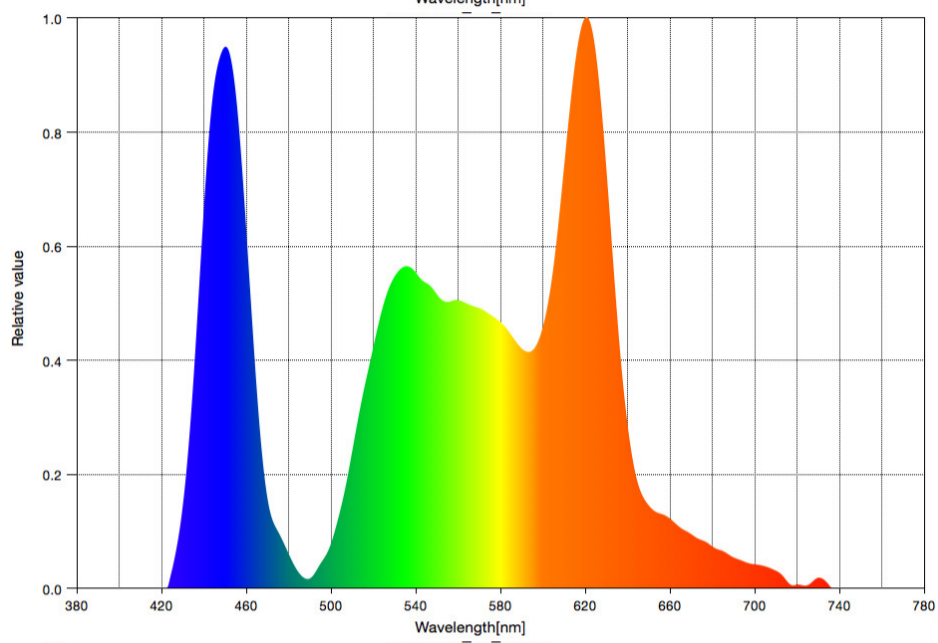
Lighting Condition 1:

Equivalent to 4000k
150lux on image.



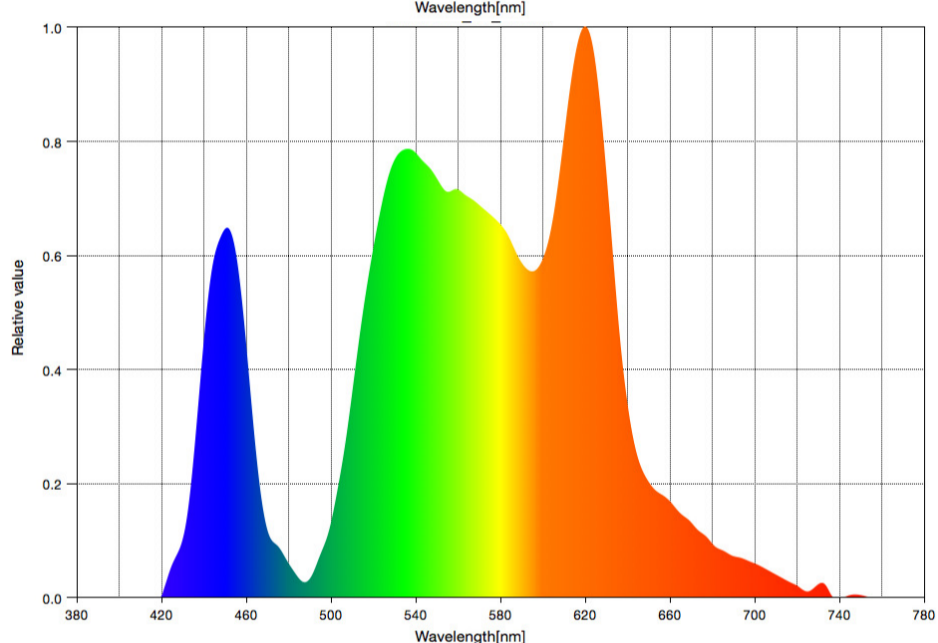
Lighting Condition 2:

Equivalent to 4000k
150lux on image.



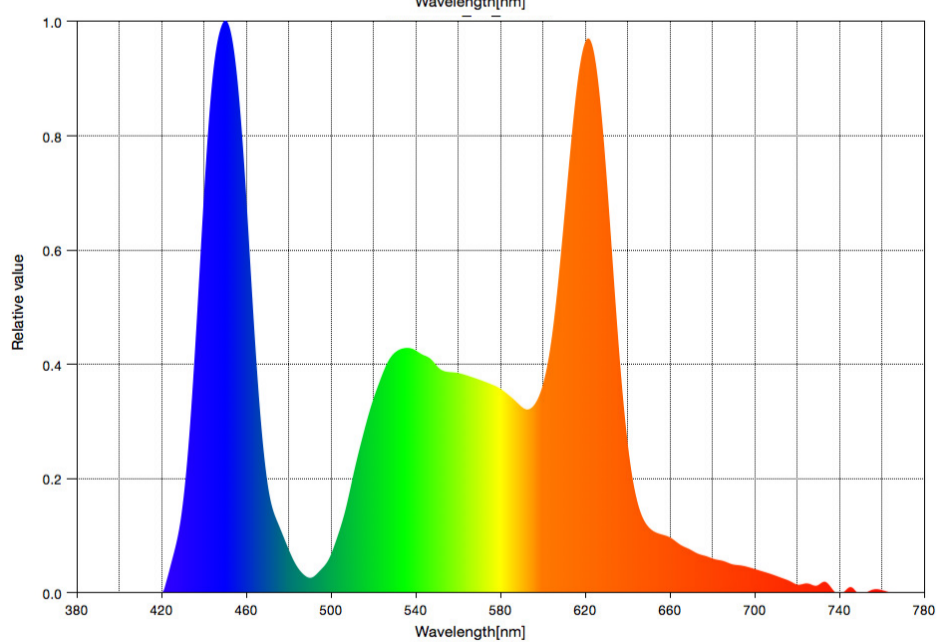
Lighting Condition 3:

Equivalent to 4000k
150lux on image.



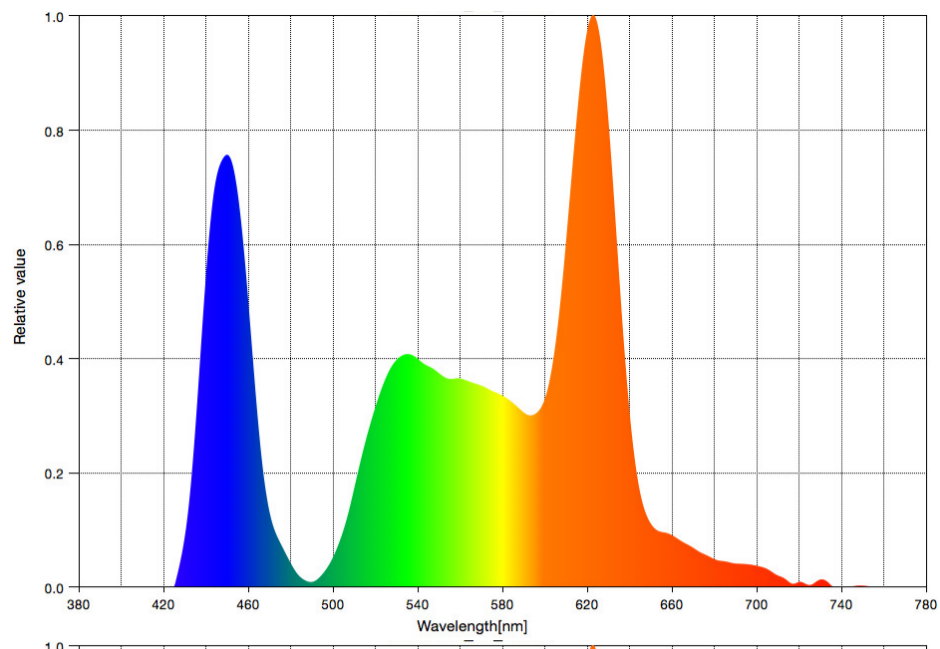
Lighting Condition 4:

Equivalent to 4000k
150lux on image.



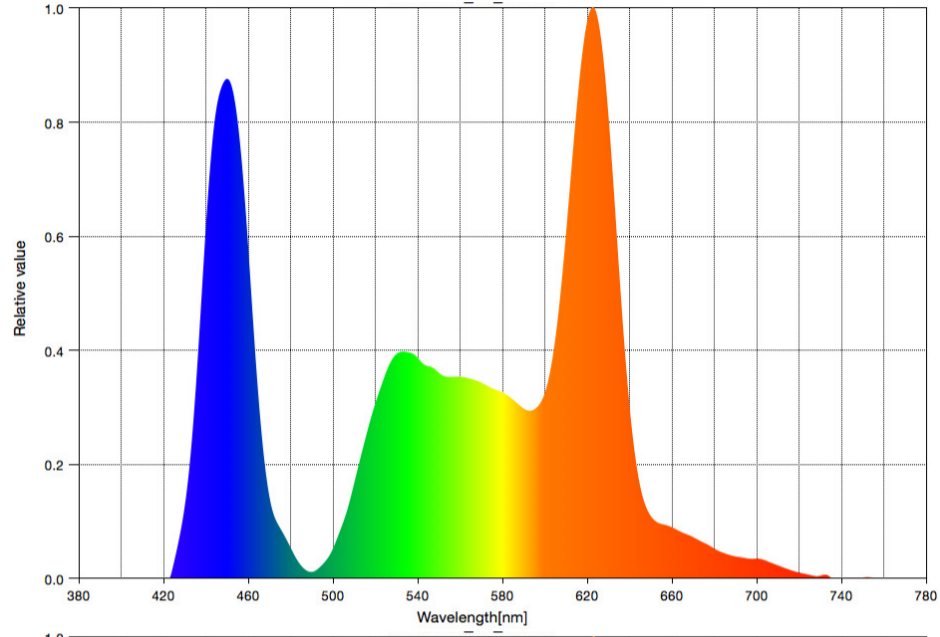
Lighting Condition 5:

Equivalent to 3500k
150lux on image.



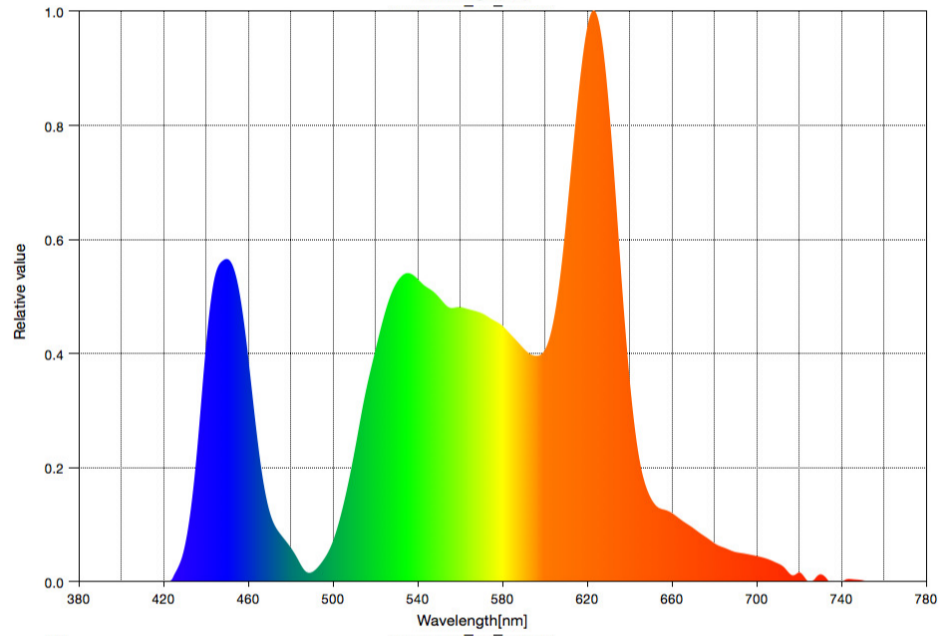
Lighting Condition 6:

Equivalent to 3500k
150lux on image.



Lighting Condition 7:

Equivalent to 3500k
150lux on image.



Lighting Condition 8:

Equivalent to 3500k
150lux on image.

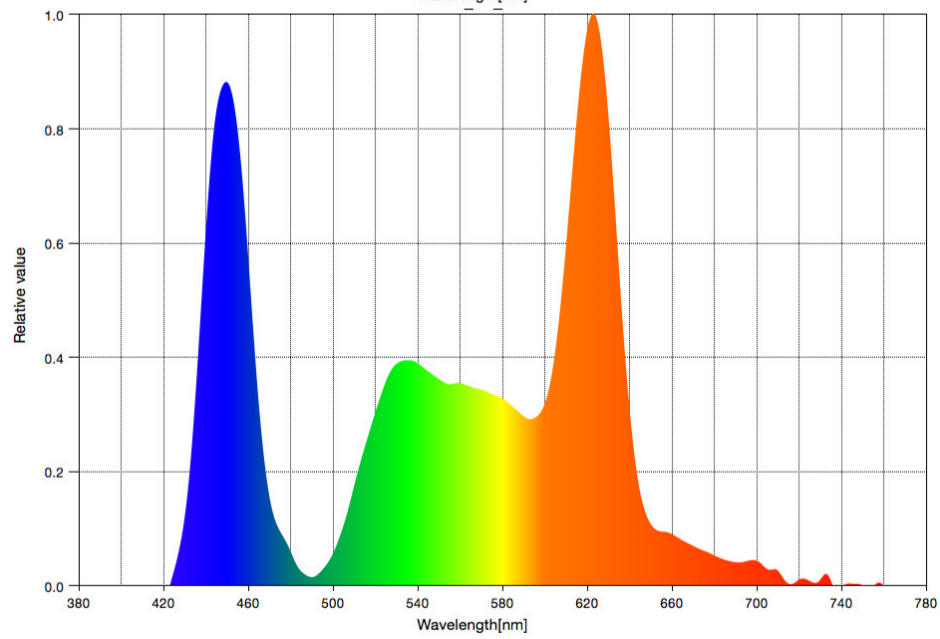
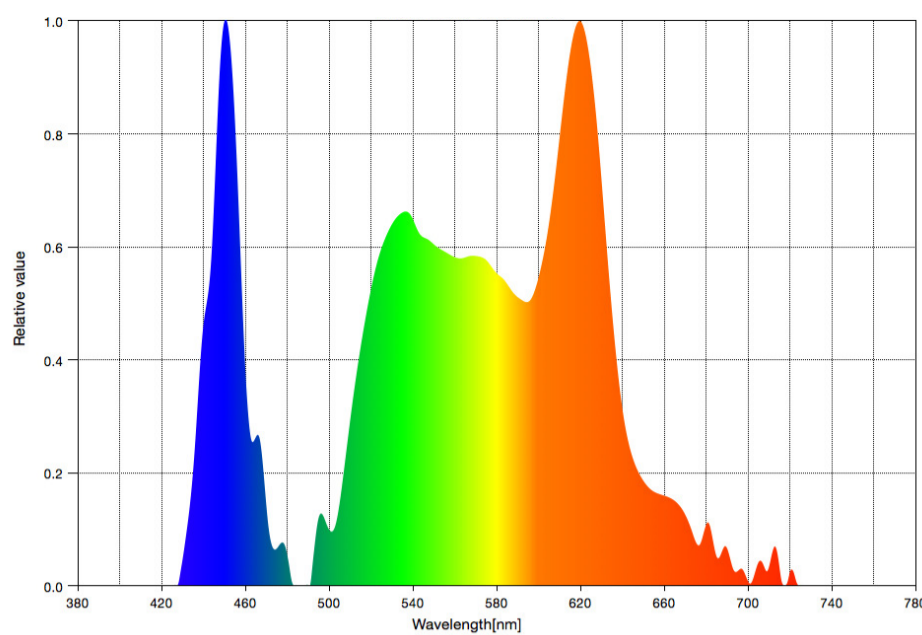


figure b.13: Spectral density distribution curves and effect on Lotus in a Breeze for 8 different lighting conditions

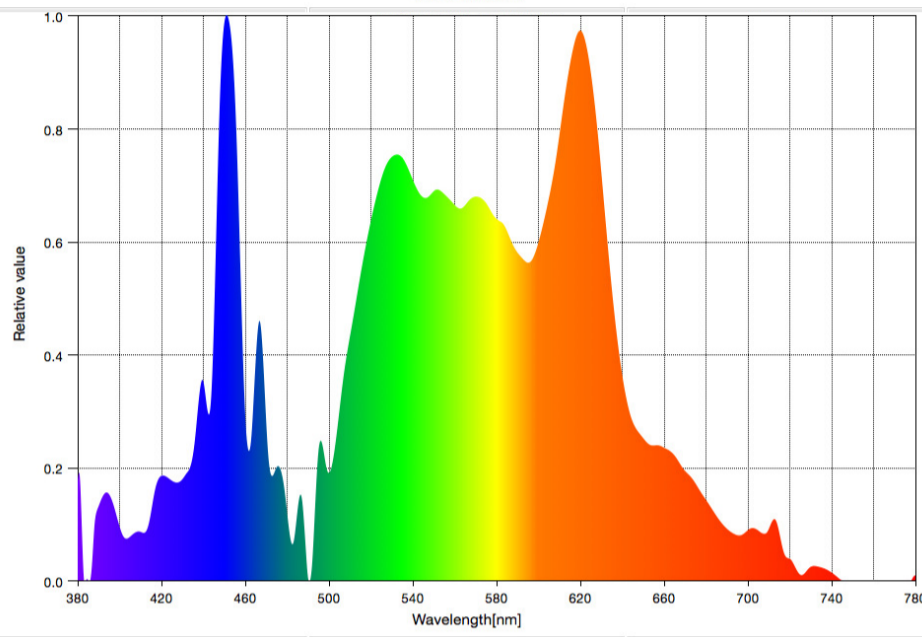
Lighting Condition 1:

Equivalent to 4000k
150lux on image.



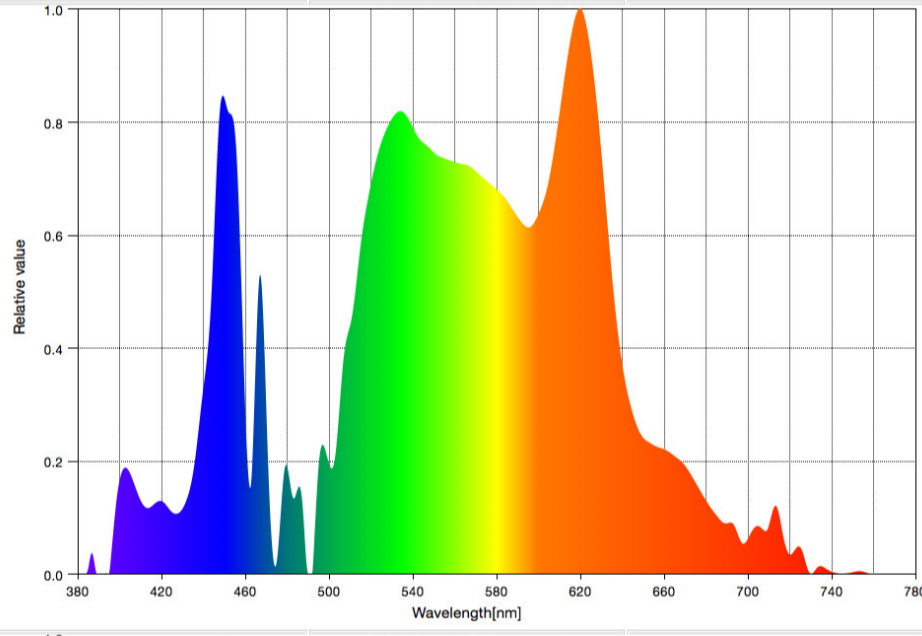
Lighting Condition 2:

Equivalent to 4000k
150lux on image.



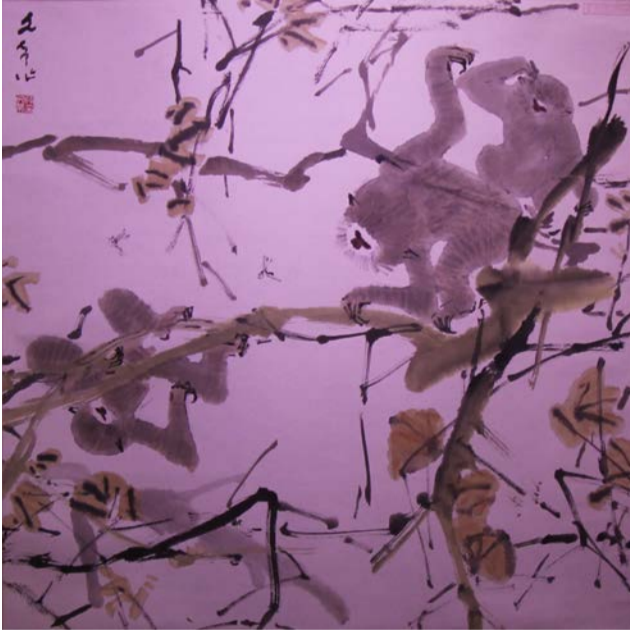
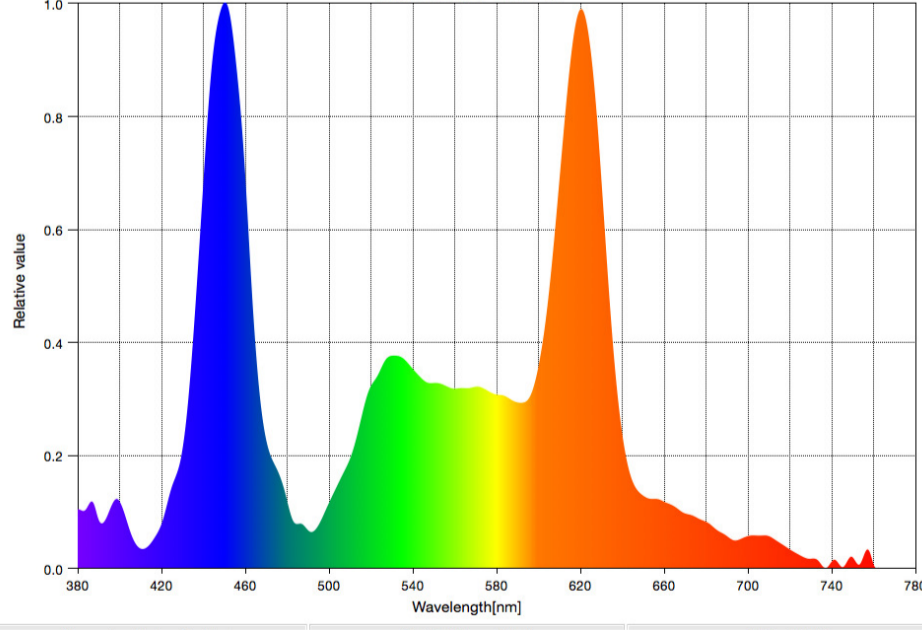
Lighting Condition 3:

Equivalent to 4000k
150lux on image.



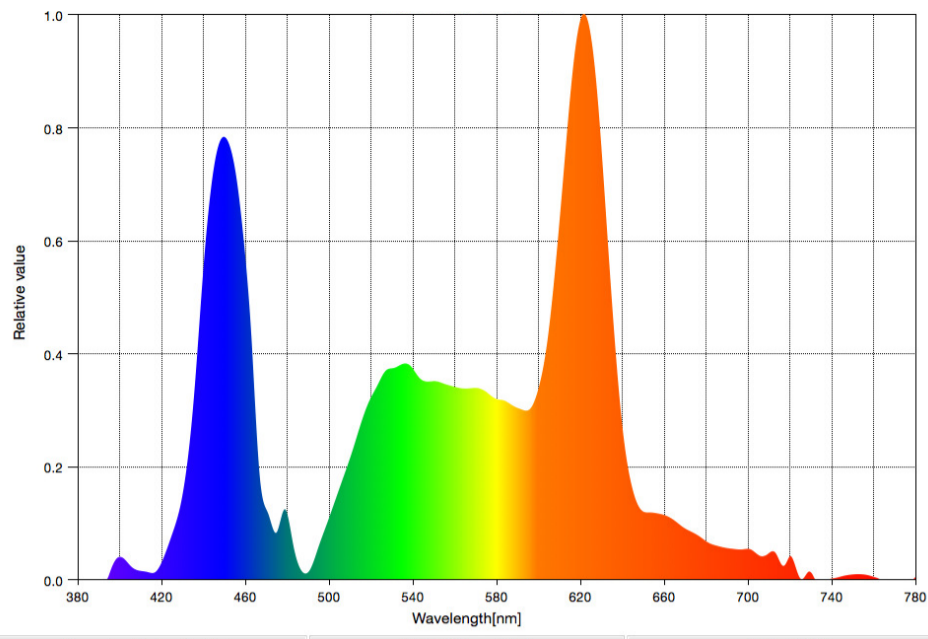
Lighting Condition 4:

Equivalent to 4000k
150lux on image.



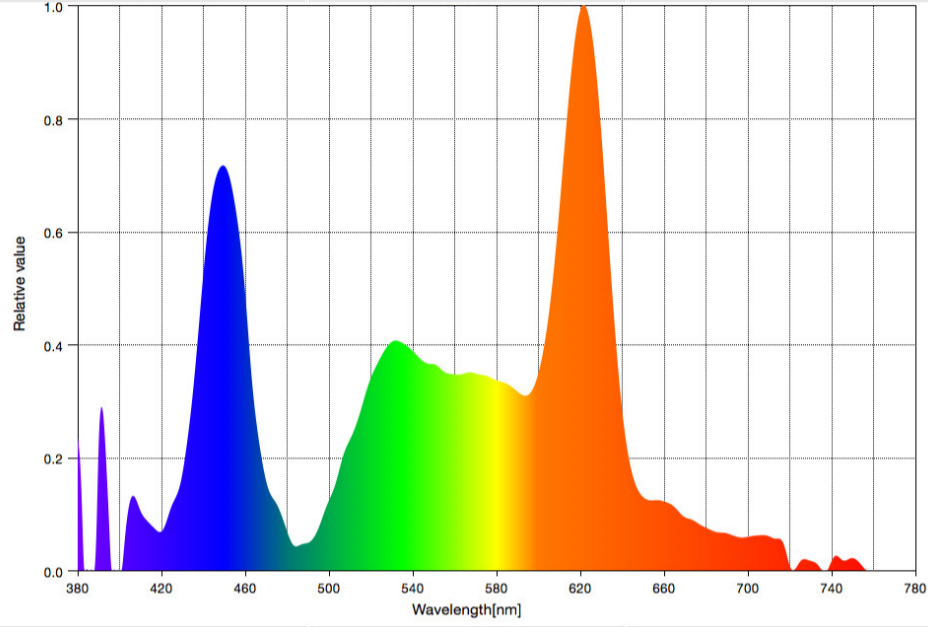
Lighting Condition 5:

Equivalent to 3500k
50lux on image.



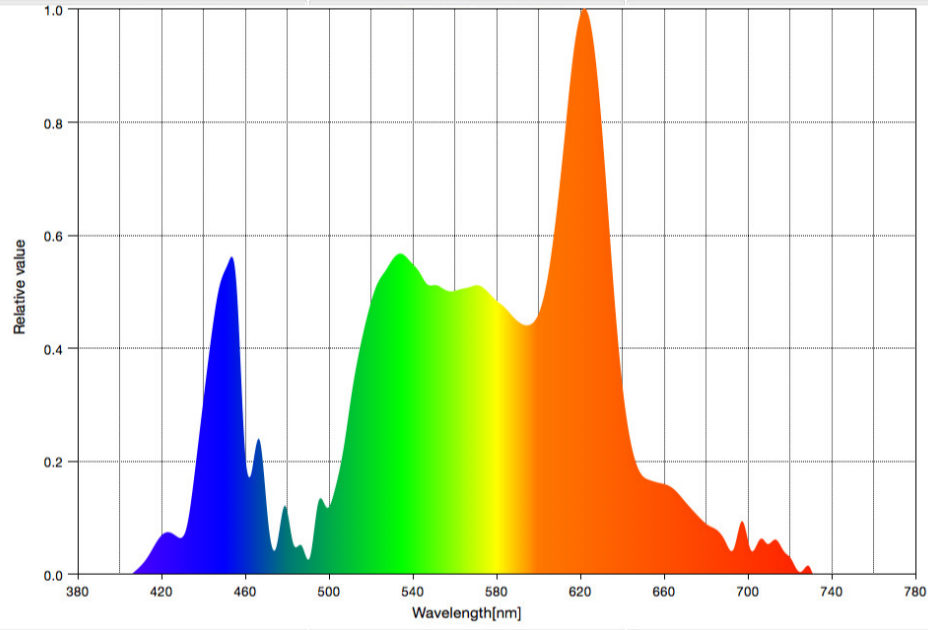
Lighting Condition 6:

Equivalent to 3500k
50lux on image.



Lighting Condition 7:

Equivalent to 3500k
50lux on image.



Lighting Condition 8:

Equivalent to 3500k
50lux on image.

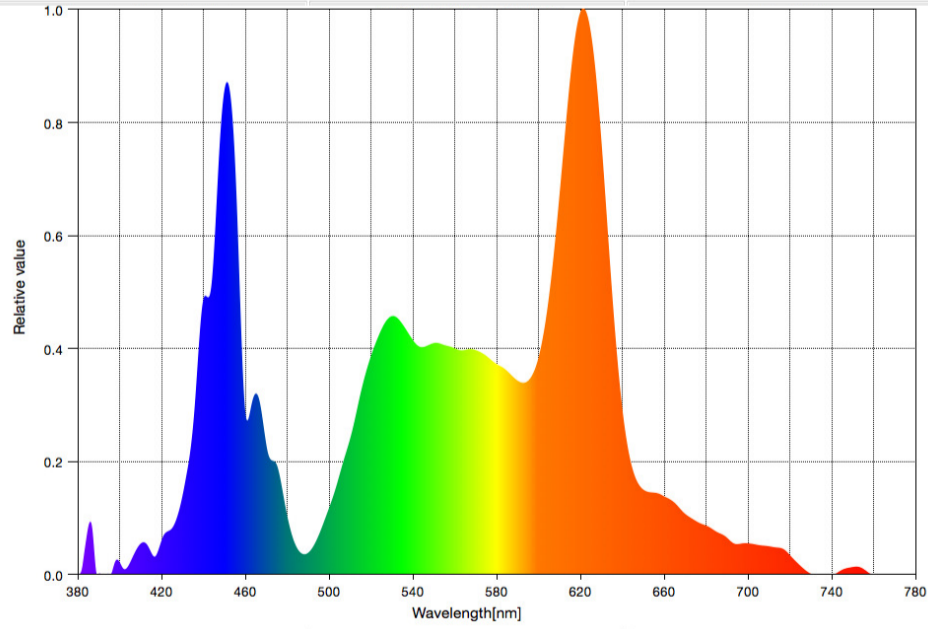


figure b.14: Spectral density distribution curves and effect on Gibbons for 8 different lighting conditions

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