School of Built Environment

Department of Architecture - Interior Architecture

The Atmospheric Influence of (red, green and blue) LED Lighting on Occupants of Hotel Guest Rooms

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DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signed:

Date: 19 July 2016

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Haider Alseaidi

Acronyms

Description	Acronym
Atmospheric impartial description	AID
Atmospheric metrics evaluation model	AMEM
Atmospheric negative description	AND
Atmospheric positive description	APD
Balanced Latin square	BLS
CIE 1976 colour space chromaticityof lightness a* represents the redness-greenness axis and the b* represents the yellowness-blueness axis	CIE 1976 (L*a*b*)
CIE Colour space of lightness, chroma and hue	CIE LCH
Colour correlation temperature	CCT
Colour preference scale	Qp
Colour quality scale	CQS
Confirmatory factor analysis	CFA
Cool white	CW
Digital multiplex lighting mixer	DMX
Exploratory factor analysis	EFA
Feeling of contrast index	FCI
Free power analysis program for a variety of statistical tests	G*Power
Gamut area index	GAI
Heart rate average	HRA
Heart rate variability	HRV
Inch	"
Infrared	IR
International Commission on Illumination	CIE
International Commission on Illumination colour space chromaticity	CIEXYZ
Intra-class correlations	ICCs
Kelvin	K
Length ×Width ×Height	L×W×H
Light colour rendering index	CRI
Light emitting diodes	LED

Lux	L
Meter	M
Multi-dimensional scaling	MDS
Nanometre	nm
National Institute of Standards and Technology	NIST
Pleasure-arousal-dominance dimensional approach	PAD
Principal axis factoring	PAF
Principal components	PC
Principal components analysis	PCA
Red, green and blue	RGB
Root mean square of successive differences	RMSSD
Self-assessment manikin	SAM
Semantic differential rating method	SDR
Spectral power distributions	SPD
Statistical Package for the Social Sciences	SPSS
Television	TV
The comparative fit index	CFI
The generalised linear mixed model	GLMM
The least significant difference	LSD
The nasal skin temperatures	NST
The non-normed fit index	NNFI
The positive affect negative affect scale model	PANAS
The root mean square error of approximation	RMSEA
The standardised root mean square residual	SRMR
The state-trait anxiety inventory test	STAI
Three dimensional video	3D video
Ultraviolet	UV
Virtual reality software	V-Ray
Visual analogue scale	VAS
Warm white	WW
Watts	W

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Abstract

Lighting can be utilised to evoke aesthetic responses and generate specified atmospheres in indoor spaces. Current red, green and blue (RGB) LED lighting technology, with its ability to change the hue and brightness of the lighting, makes it feasible to generate a variety of indoor atmospheres by using both coloured and white lighting combinations. However, the influences of coloured light on the atmosphere of different spaces have not yet been widely examined.

This study examines the influences of the brightness and hue of LED lighting on the perceived atmosphere of a hotel guest room. Specifically the study examined the influence of brightness and hue of lighting on the perceived atmosphere with regards to brightness, warmth, appropriateness for use and encouragement to return to the hotel guest room.

A quantitative study approach using a ‘Semantic Differential Rating’ (SDR)[1] was used to enable study participants to verbally describe the atmosphere of an indoor environment on a ranking scale (Tifler and Mark 1992). Vogels (2008a) established an SDR **model based on**

[1]*The Semantic Differential (SD) measures people's reactions to stimulus words and concepts in terms of ratings on bipolar scales defined with contrasting adjectives at each end*. (Heise 1970)

atmospheric descriptive evaluations to enable her study participants to describe the atmosphere of their environment, not how they felt in the environment.

Vogels' (2008) model was designed to reduce the non-environmental influence in the evaluation process. Also, the model was established specifically to evaluate the influence of the lighting in the indoor environment.

An English version of Vogels' Dutch questionnaire was used to elicit responses from 412 participants to photographs of five differently lit and coloured hotel rooms. These responses were statistically analysed to establish how well each of the adjectives used by Vogels, when translated into English, related to the atmosphere of the indoor environment and how the terms could be used to inform the current study.

Because of technical and financial constraints in conducting the lighting evaluations in real hotel guest rooms, 3D videos recorded the indoor environment in a hotel room illuminated by different lighting hues and brightness. After validating 3D video technology as an appropriate simulation tool for evaluating the atmosphere of actual indoor environments, the most suitable duration for exposure of study participants to the video was determined. This study found that two minutes' exposure to the 3D video had the highest correlation with a live visit.

The current study proceeded by inviting a sample of thirty-two adults to each examine sixteen lighting settings in a hotel guest room. The findings show that both lighting hue and brightness had a significant influence on the perceived atmosphere of the hotel guest room. The hue of lighting was demonstrated to have an influence on how 'positive', 'negative' and 'impartial' the atmosphere was perceived to be. The primary lighting hues such as red, green and blue were evaluated as being less positive and 'less impartial' than mixed lighting hues such as white, cyan, yellow and magenta. Four of the mixed lighting hue settings: white, general white, cyan and yellow, were evaluated as being more 'impartial' than the other examined lighting hue settings.

Red, yellow, green and general white lighting settings were evaluated as being significantly 'more positive' when lighting was of high brightness than when it was of medium brightness. There was no significant influence of brightness of lighting on the 'positive' evaluation for cyan, blue, magenta and white. The study also showed that for each of the eight lighting hues, a high level of brightness led to a significantly 'lower negative' evaluation than did a medium level of brightness. Both the brightness and hue of the lighting settings were shown to have an influence on how the atmosphere of the hotel guest room was perceived with regard to brightness, warmth, appropriateness, and the degree to which the guestwas encouraged to return to the hotel guest room.

Through this study, a questionnaire tool for English speaking researchers examining the atmosphere of indoor spaces has been developed. In addition, the suitability of 3D video as a legitimate means of studying the indoor atmosphere has been established.

Analysis of the influence of the hue and brightness of the lighting carried out showed that coloured lighting can be used to change the indoor atmosphere of a room and thus influence the experience of the occupants. Designers and stakeholders in the hotel industry could use this research to better service hotel guests.

Introduction

1. Background

With the emergence of every new lighting technology (such as candles and oil lamps, electric bulbs, fluorescent tubes, halogen lamps, sodium lamps, the compact fluorescent light, light-emitting diodes and recently, induction lighting) different lighting characteristics have been produced. The difference in the lighting characteristics can be associated with the difference in the lighting spectrum distribution (Thompson 2007). Each type of lighting influences differently how the occupants of the built environment perceive and evaluate the atmosphere of their surroundings. This study examined how light emitting diodes (LEDs) impact perception of the atmosphere of rooms.

LED lighting is a recent technology. The light-emitting diode is a semiconductor diode that emits light when stimulated. At first this technology had limited application, due to the limited lighting hues and the limited luminance. A significant transformation in this technology occurred in the 1990s, as the blue LED was explored and the luminance of the LED became more efficient.

According to a number of studies, LEDs are economical and produce less heat when they operate compared to incandescent lamps and fluorescent lampsin lighting units (Kim and Kim 2010). Haitz (2003) revealed that energy consumption for lighting could be reduced up to 75% if people use LED lighting, and could, in turn, reduce global fuel usage. Matsushima et al. (2008) reviewed LEDs in a number of projects in Japan. One of the projects utilised LED lighting in a mall instead of fluorescent lamps. The LED lamp energy consumption was approximately 70% less than fluorescent lamps and had the same efficiency. Matsushima et al. (2008) also found that LED downlights emitted less heat; as a result they could be installed to resolve heat problems, making the interior environment more comfortable (Matsushima et al. 2008).

Yeh and Chung (2009) also demonstrated some LED lighting features. One feature was that LED light could be produced in different coloured wavelengths – fiery-red, red, orange-red, orange, yellow, green and blue. In addition, the brightness and quality of LEDs could be controlled. Yeh and Chung (2009) also indicated that LED lighting could be used for indoor plant farming. Generally LEDs are economical and produce less heat when compared with other lighting technologies. They have a long life, and they can be manufactured in multi-coloured spectra and have adjustable light intensity (Yeh and Chung 2009).

It is clear from the above-mentioned studies that LED lighting is a feasible lighting source to be used in interior spaces. Lighting has multiple roles to play in the built environment. Light is no longer used for just functional needs. The effect of light on the built environment is beyond that. Light is part of the interaction between humans and their surroundings. This interaction can be shown through several human responses such as attitude, performance, emotional state, moods and behavioural changes. Researchers in interior design, architecture and environmental psychology, as well as lighting designers, have established different methods to evaluate the influence of lighting in the built environment. These researchers aimed to explore the effect of lighting in indoor spaces, believing that this enabled designers to enhance the building environment.

Several studies have been conducted to investigate the influence of LED lighting properties. These properties include lighting brightness, correlated colour temperature (CCT), lighting colour rendering index (CRI) and lighting hues. These studies were conducted in different spaces, such as residential, commercial, public and working spaces. These studies have raised the awareness of lighting designers and business stakeholders about lighting requirements in a variety of spaces.

One of the spaces examined in relation to lighting is that of hotels. Hotels are places where individuals or groups can stay when they travel to another city or country and reside for a limited period (Oxford Word-power 2006, 383). In addition, hotels can be open places for imagining. “Hotels present an opportunity to imagine a setting that is not a home and should not resemble one, either, but rather surpass one. Guests do not simply stay at the hotel but live there if for only one night” (Losantos 2006, 8).

Pile (1988) believed that hotels are places where guests look for comfort, and they expect entertainment areas like sports facilities, a casino, or a nightclub. Although hotels are alternative habitations, some guests may wish to continue their usual activities while others may wish to enjoy the luxury. In the end, a guest does not own the place but can treat it as her/his own.

For some people, hotels become part of their lifestyle because of the nature of their work, with some spending approximately a third of the year in hotels (Chang 2004). Therefore, they search for the best service, the most competitive prices as well as a range of facilities.

These might include the provision of transportation to and from the hotel, communication services that facilitate the completion of their work, or services that allow them to have a pleasant stay (Lu 2010).

In order to fulfil the varied expectations of guests, many hotel owners enhance their businesses through redesigning and renovating the interior spaces of their hotels (Curtis 2003). It is known that the design of the hotel can have a significant impact on hotel customers (Bitner 1992; Dubé and Renaghan 2000). As the hotel design provides a visual reference point, the design can enhance the marketing value of the hotel; therefore, the design should be considered in the process of hotel marketing (West and Purvis 1992). Quality of design is a way to gain and maintain loyal customers, and to promote positive impressions in the memory of hotel customers. The interior design of the hotel is part of this memory; therefore, the designers should be careful in the design process (McDonough et al. 2001).

One of the important areas of a hotel that can be enhanced through re-design is the guest room. Guest rooms are the places where the guests spend their private time. In addition, Curtis (2003) points out that the bedroom in the hotel is no longer just a bedroom; it has also become a personal office and therefore will require updated technology. Rutes, Penner, and Adams (2001, 168), claim that hotel guest rooms and bathrooms leave more lasting impressions on the lodging guest than any other single interior space.

As the hotel guest room is the space where guests rest and adjust to their new environment, room designers need to create an environment conducive to relaxation and sleep, as many guests may suffer from jet lag (Siguaw and Enz 1999). One of the important interior design components which can help the hotel guest to adjust is the lighting of the bedroom (Winchip 2007). Attention to lighting and its effects are growing in the hotel industry. This is due to a growth in client requests, mainly from female guests and business travellers, and also to new concerns about the increasing cost of energy (Pae 2009).

To some guests the hotel guest room is more than a place to sleep; it is also a place to complement their personalities and styles (Pile 1988). Some hotels give their guests the chance to choose the hue of lighting above the bed, as in St Martin’s Lane, London (Curtis 2003, 10), thus involving them in the design process and giving them more flexibility to control their space.

It is thus important to study the influence of lighting in hotel guest rooms, because hotels have an essential role to play in tourism. Indeed, a number of studies have investigated the influence of artificial lighting in hotel guest rooms, specifically the influence of lighting brightness and correlated colour temperature CCT of lighting on the users of hotel guest rooms. One such study examined how different cultures evaluated different lighting settings with regard to brightness and CCT (Pae 2009). Another study examined the influence of various lighting settings with regard to brightness and CCT on three kinds of activities in the hotel rooms: relaxation, work, and looking in the mirror (Fernandez, Giboreau, and Fontoynont 2012a). There have not, however, been many studies investigating the influence of light colour rendering index (CRI) of lighting and lighting hue. In addition, there are no studies investigating the influence of the hue of the lighting even though the guest may be able to adjust the hue of the lighting in hotels such as St Martin's, London (Curtis 2003), Hotel Encanto Acapulco, Mexico (Liarostathi 2013), and the Innovative hotel chain in Singapore (W Singapore - Sentosa Cove 2012).

Therefore, the current study examines the influence of coloured red, green and blue (RGB) LED lighting on the atmosphere of a hotel guest room under the exposure to different lighting hues and brightness.

It is important that in any study of human response to colour and brightness, the way in which humans receive and interpret visual information, is understood. For this reason, the following section provides a brief introduction to that process, which is referred to as visual perception, after which the remainder of the introduction will provide an overview of the research methodology that was used in the present study, state the study objectives, explain the significance of the research and summarise the configuration of the thesis

1.1 Visual Perception

Visual perception is broadly defined as the connecting canal between the users of any environment and their surroundings, and in the case of humans, the visual image of the environment is a combination of both physiological and psychological factors.

1.1.1 Physiology of Visual Perception

In terms of physiology, the human eye is the first part of the canal connection between the observer and his\her surroundings. Researchers usually describe the eye as an organ consisting of three layers. The first, or peripheral layer of the eye consists of the sclera and cornea; the second, or intermediate layer is made up of three parts – the iris, the choroid, and ciliary body – while the third layer is the retina. While the anatomy of the eye does not impact significantly on this study, the retina is the primary receptor for light and colour.

Colour results from the interaction of light with the nervous system. There are several components of the eye that affect colour perception, including the lens, which lies within the intermediate layer, the retina, and a colour processing mechanism within the optic nerve (Murch 1984).

The retina, which lines the back of the eye, consists of millions of neurons that work as photoreceptors. There are two main kinds of photoreceptors in the retina – rods and cones – so called because of their forms. There are nearly six times as many rods as cones. Rods respond to levels of light illumination and are far more sensitive than cones, although they do not indicate colour. The cone photoreceptors are sensitive to colours, and while they are fewer in number and grouped mainly in a relatively small area of the retina, they are responsible for the fine detail of the viewed image. There are three types of cones, each of which responds to a range of wavelengths, and therefore, colours. They essentially respond to red, blue and green, although there is some overlap. Around 64% of the cones are "red", 32% "green" and only 4% "blue". The cones also vary in sensitivity, with blue cones being the least sensitive, then green, with red cones being the most sensitive (Murch, 1984).

Although the iris controls the amount of light entering the eye, the photoreceptors themselves adjust their sensitivity to the overall light level, and the combined effect of both processes means that moving between areas of different lighting levels, such as moving from bright sunlight to an interior environment, or simply from a well lit room to one that is darker, requires some time for adjustment. There is also an absolute required minimum intensity level for the photoreceptors to respond, which for a healthy eye is actually very low. However, the level required for an individual to perceive their environment clearly and to be able to function or operate safely in that environment is much higher, and national and international agencies all set minimum lighting levels for various activities. The Australian/New Zealand standard AS/NZS 1680 was observed in this study to ensure that it was consistent with safe levels of lighting for the activity types normally carried out in guest hotel rooms (Australian/New Zealand standard 2009). In addition, during the response sessions, in which participants viewed the 3D display in subdued lighting conditions, time was allowed for them to adjust to the viewing environment before the response material was shown.

In terms of the response of the human eye to different hues, in addition to the sensitivity, number and arrangement of cones across the retina, other aspects of the physiology of the eye have an impact, in particular the lens, which focuses the incoming light on the photoreceptors of the retina. Different wavelengths of light have different focal lengths, with longer wavelengths having longer focal lengths. Red is the longer wavelength, so has the longer focal length, while blue, with a shorter wavelength, has a shorter focal length. This means that the lens must alter its curvature to focus the different colours, so if pure red and blue hues are juxtaposed the lens will be continually changing shape to correctly focus the light on the photoreceptors of the retina. The brain will process the information to "see" the image as sharp or in focus without us being aware of the continual changes of the lens, but it could result in tired eyes and a sense of discomfort.

The lens also absorbs a certain amount of the light that passes through it, with almost twice as much more blue light being absorbed than red. However as humans age, the lens yellows, so that the amount of blue light absorbed increases, and older people are therefore generally more sensitive to the yellow end of the visual spectrum than the blue. Other factors also mean that while older people tend to be less sensitive to all wavelengths, the sensitivity to blue decreases more than other colours. This decreased sensitivity, combined with difficulty in focussing blue light at the retina means that in lower lighting conditions, items that are predominantly blue may appear "fuzzy" with ill-defined edges, resulting in discomfort for the viewer.

For this reason, the participants in the study were classified in two groups; those between the ages of 20 and 40, and those over the age of 40, and particular note was made of any potential variation in the responses that may have resulted from the physiological effects of aging on sensitivity to particular hues.

1.1.2 Psychology of Visual Perception

The photoreceptors on the eye's retina send signals to the brain via the optic nerve. The brain interprets these signals to create a representation of the person's environment. However, Cycleback (2003) claims that visual perception is not just a physiological function of the eye collecting empirical data but a more complicated process that involves cerebral interaction. Cycleback (2003) states that "Despite popular misconception, humans do not see a direct representation of external reality, but a translation formed by their eyes and mind. This is not some coffee house philosophical argument, but physiological fact. Human eyes do a good, but far from a perfect job at detecting and processing light" (Cycleback 2005, 1).

That means that visual perception is not a simple process correlated solely to the eye’s role in collecting data from an observer’s surroundings. Intellectual activity is also involved in visual perception, and in this section three widely known theories of perception are discussed. They are the direct, or ecological theory of Gibson (2014), the indirect (constructivist) theory of (Gregory 1973) and the cyclic theory of Neisser (1992).

The first theory is the ecological theory of (Gibson 2014). Gibson’s theory is called ecological because it argues that perception is direct and can be explained in terms of the environment and the basic need to respond to stimuli (danger) within the environment. It is considered a bottom – up, approach because it states that humans, like all living creatures, use their physiology to collect visual data from their surroundings that is directed to the lower brain levels where it may trigger survival mechanisms before being passed on to higher areas of the brain for more complex consideration.

According to Gibson, humans do not observe their surroundings from a fixed viewpoint, but by moving around, supporting the idea that perception is completely dependent on action, and requires no prior knowledge on the part of the observer to process or respond to the visual information received from the sensory organs, in this case the eyes.

Gregory (1973), believed that perception was a much more complex process. He considered that the visual data that arrives in the brain from the retina is inadequate to build up a precise image of the surrounding environment and that it relies on previously acquired knowledge in order to construct an “accurate” understanding of the environment. According to Gregory’s theory, perception involves a sequence of hypothesis-testing exercises in which the nerve signals are tested against existing or experienced schemas in order to explain and understand the visual experience. This means that our understanding of the world is dependent on past experience. Because it relies on “higher” brain functions in the first instance to “identify” patterns in the data to construct the perceived environment, it is referred to as a constructivist approach that is top – down or indirect.

The theories of both Gregory and Gibson have demonstrated weaknesses, which led to the development of a third theory by Neisser (1992). His cyclical activity theory adopted a compromise view that included the core theme of both the constructivist theory and the ecological theory to interpret the intellectual aspects of the visual perception. Essentially, he argued that as people moved through their environment, visual data entering the brain was “sampled” to determine its basic importance. This allows the person to respond to immediately recognized urgent or dangerous situations in a direct, or bottom – up way. However, in his cyclical theory, unusual or non-urgent information is passed to other areas of the brain where it is tested against schemas that have been built up through the observer's past experience and knowledge to refine the accuracy and understanding of the environment, and in this way it incorporates the top – down theory.

The importance of the visual perception process in this study relates both to the physiological aspects of visual data collection by the eye, and how users of the space "perceived" and evaluated the environment. The selection of both the brightness and hues of the colours used in the study was made considering the physiological factors, in particular the relative brightness of the different colours due to the differing sensitivity of the eye to them. The DMX lighting control software used in the study allowed the researcher to generate levels of each colour that were perceived as being of equal brightness by the participants. This is explained in further detail in the methodology of the study.

In addition, care was taken in designing the path of the 3D camera through the rooms in stages two and three of the study to ensure that in both cases it reflected the natural "scanning" movement of people entering a room for the first time. A sample of people were asked to describe their actions on entering a room, and the points at which they paused, scanned the space horizontally and/or vertically, stood or sat were noted. They also noted key items that they recognized as significant in their exploration of the room. This information was then used to devise a camera path with movement, hesitation, and a series of horizontal and vertical scanning processes at various points as it tracked through the room. In stage three of the study, the hotel guest room was "dressed" with familiar items including a bowl of fruit on a table that established focal points that would normally attract the attention of participants and provide recognizable objects consistent with a hotel guest room environment.

The remainder of this introduction will provide an overview of the research methodology that was used in the present study, state the study objectives, explain the significance of the research and summarise the configuration of the thesis.

1.2 The research method

Several evaluation models have been established by researchers in the field of environmental psychology to measure the influence of lighting on users of the built environment (Flynn et al. 1973; Mehrabian and Russel 1974; Morris 1995; Osgood, Suci and Tannenbaum 1957; Russell, Weiss and Mendelsohn 1989; and Watson, Clark and Telleggen 1988). Most of these models were based on the self-report method, which depended on the emotional and mood state of the respondents.[2] However, an alternative, Atmospheric Evaluation Model was subsequently established by Vogels (2008b). Vogels' (2008b) model was widely adopted by researchers investigating the influence of lighting in the indoor environment (Bronckers 2009;Choy Calvin 2009;Custers 2008; Dijkstra 2010; Kuijsters et al. 2012; Salters and Seuntiens 2011 andvan Erp 2008), as the model's **main theme was to reduce the non-environmental influences in the evaluation processes**. The model asks the observer to describe the space, rather than how he/she feels in the space. Vogels' model was adopted and modified for the current study because this model is based on the way people define the observed atmosphere, not on their emotional states.

It is important to note that in adopting Vogels' model, the current study also adopted specific terms used by Vogels and subsequently by other researchers in this area. In particular, Vogels used the term `atmosphere' as a non-emotional description of the environment created by various lighting conditions rather than terms such as `aesthetic' or `mood', which may have artistic or emotional connotations, and this term is therefore used throughout the current study.

The current study reviews the how, where and what of evaluating the influence of lighting in the indoor environment. Firstly, a review was carried out of a number of studies that have been set up in different ways to evaluate the influence of lighting on the indoor environment. Some of the studies have been conducted in an actual space, others have used a replication of actual space and some have used a scale model (booth), coloured photographs and slide images; others have used videos, and still others have used the production of software program images. For this study, it was decided to use one of the simulation methods, a three-dimensional video visual experience as an alternative to visiting and evaluating the actual hotel room. This method was chosen to keep the expense of the project at a reasonable level and to overcome some of the obstacles in project management; in addition the video material could be preserved so that the study could be replicated later if required.

As a result, the design of the current study methodology included three stages. The first stage was the adoption and modification of Vogels' (2008b) questionnaire. Modification of Vogels' (2008b) questionnaire was necessary because the questionnaire was developed in the Netherlands with Dutch language-speaking participants; therefore, the current study needed to determine whether it would be suitable for Australian English users.

[2] A self-report study is a research method that uses a dimension rating evaluationquestionnaire, to address a research question which seeks to understand organizational phenomena through participants' responses(Spector 1994 385).

In its second stage, the study tested the feasibility of using the 3D video visual experience to evaluate the indoor space. In this stage, the study determined duration for viewing the video that was conducive to evaluating the small indoor space.

The third stage of the study was the main experiment using the measuring tool, Vogels' questionnaire (as per the findings of stage one) and the 3D video as an alternative to the visual experience of visiting the actual space (as per the findings of stage two). The third stage comprised two parts. In the first part, videos were produced of a hotel guest room with each of the lighting settings to be examined. In the second part, the videos were presented to the study participants in order to collect the data for the study.

1.3 Study objectives

This study was designed to assess the influence of diverse RGB LED lighting conditions in a hotel guest room on the observers. It was expected that participants' perceptions of the atmosphere of the hotel guest room (with regard to brightness, warmth, appropriateness and encouragement to come back to the hotel) would vary as a function of its lighting hue (Red, Yellow, Green, Cyan, Blue, Magenta, White and General White) and two level of brightness (High and Medium).

The general hypothesis of this study is that different RGB LED lighting hues and levels of brightness have an influence on the perceived atmosphere of hotel guest rooms.

The following research questions were asked:

1. To what extent does the hue of the (LED) lighting influence the perceived atmosphere of a hotel guest room?
2. To what extent does the brightness level of lighting influence the perceived atmosphere of a hotel guest room?
3. To what extent do the hue and brightness of the (LED) lighting interact to influence the perceived atmosphere of the hotel guest room in terms of:

a. brightness
b. warmth
c. appropriateness, and
d. whether the participants felt encouraged to return to the hotel guest room.

1.4 The significance of the research

‘The Australian hotel and tourism markets continue to expand with solid growth in visitor expenditure recorded in 2013’ (Farren 2014). This statement from ‘Colliers International report from the first half of 2014’ implies thatthe demand for accommodation, including hotel guest rooms, has grown as visitor expenditure has grown. The lighting of these rooms can have a significant impact on the running costs of a hotel. LED lighting is a recent alternative lighting technology that is energy efficient and is environmentally friendly compared with other lighting technologies, such as incandescent bulbs, fluorescent tubes, halogen lamps, sodium lamps, and compact fluorescent lights. LEDs are, therefore, starting to replace other types of lights in hotel guest rooms. How these lights influence the experience of the hotel residents is an important issue. The hotel residents’ wellbeing is the focus of this research, which regards the resident not as a customer but as a human being and user of the space.

Exploring the influence of the RGB LED lighting on the atmosphere of hotel guest rooms can be beneficial for both sides of the equation, the user and hotel owner as well as the lighting designer. The expectation was that the results of this study would reveal the users’ views with regard to the atmosphere of the hotel guest room under the exposure of RGB LED lighting.

1.5 Thesis configuration

Chapter two presents a review of studies examining the properties of artificial lighting in relation to hotel guest rooms. Chapter three presents a review of the methods of evaluation of human responsesto the built environment, as well as a discussion of the existing methods used to evaluate the influence of lighting in the indoor environment. Chapter four discuss the study methodology. Chapter five covers the process of adapting and validating the study’s measuring tool. Chapter six presents the validation process for the use of the 3D video as a means of evaluating the atmosphere of the indoor environment, as an alternative to visiting the actual environment. Chapter seven discusses the main study, the examination of the sixteen lighting settings and eight lighting hues at two levels of lighting brightness; high and medium. The main study used the modified measuring tool described in Chapter four and the 3D video as an alternative to visiting the hotel guest, as discussed in the results of Chapter five. Chapter eight presents the results from the main study. Chapter nine discusses the results of the main study, and Chapter ten presents the overall conclusions. Figure 1.1 below summarises the flow of the ten chapters.

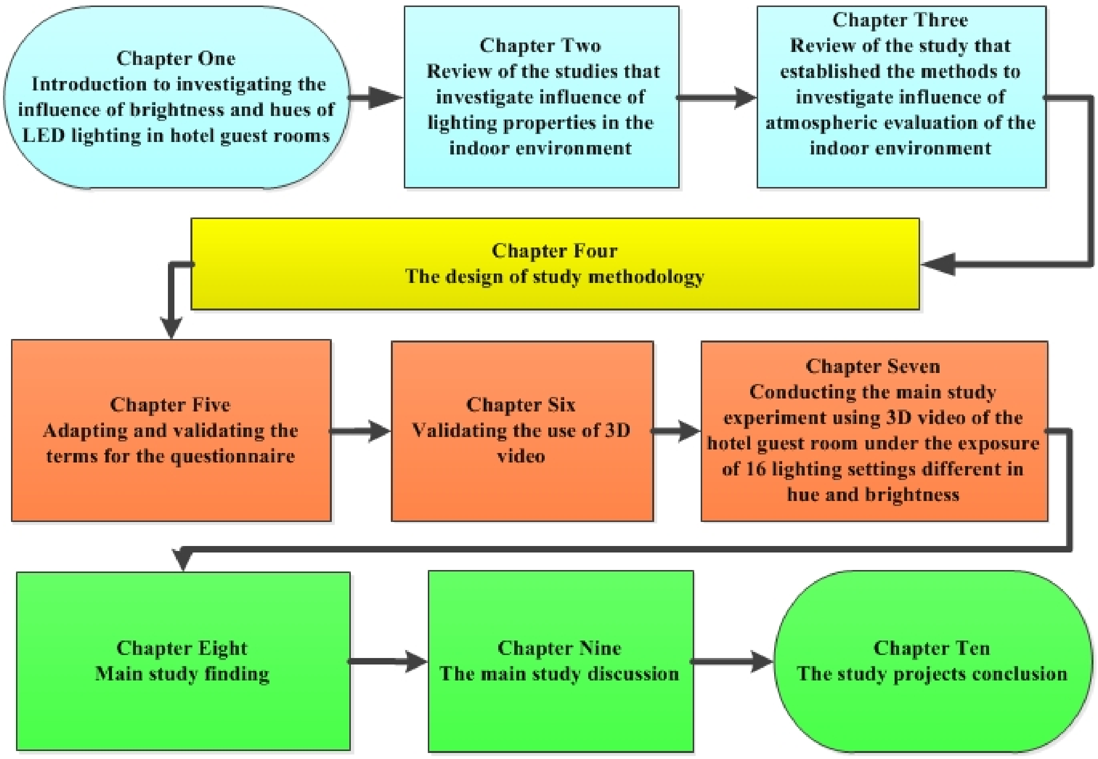

Figure 1.1 The study flowchart platforms of the current study

2. Artificial Lighting

This chapter presents a review of the literature on artificial lighting in regard to particular properties. Aspects discussed are lighting brightness, the correlated colour temperature (CCT) of lighting, the colour rendering index (CRI) of lighting, and coloured lighting with different hues. The chapter also discusses the importance of artificial lighting quality and the basic lighting principles for hotel guest rooms, and reviews studies that have examined these aspects of the hotel environment. Figure 2.1 gives an outline of the chapter.

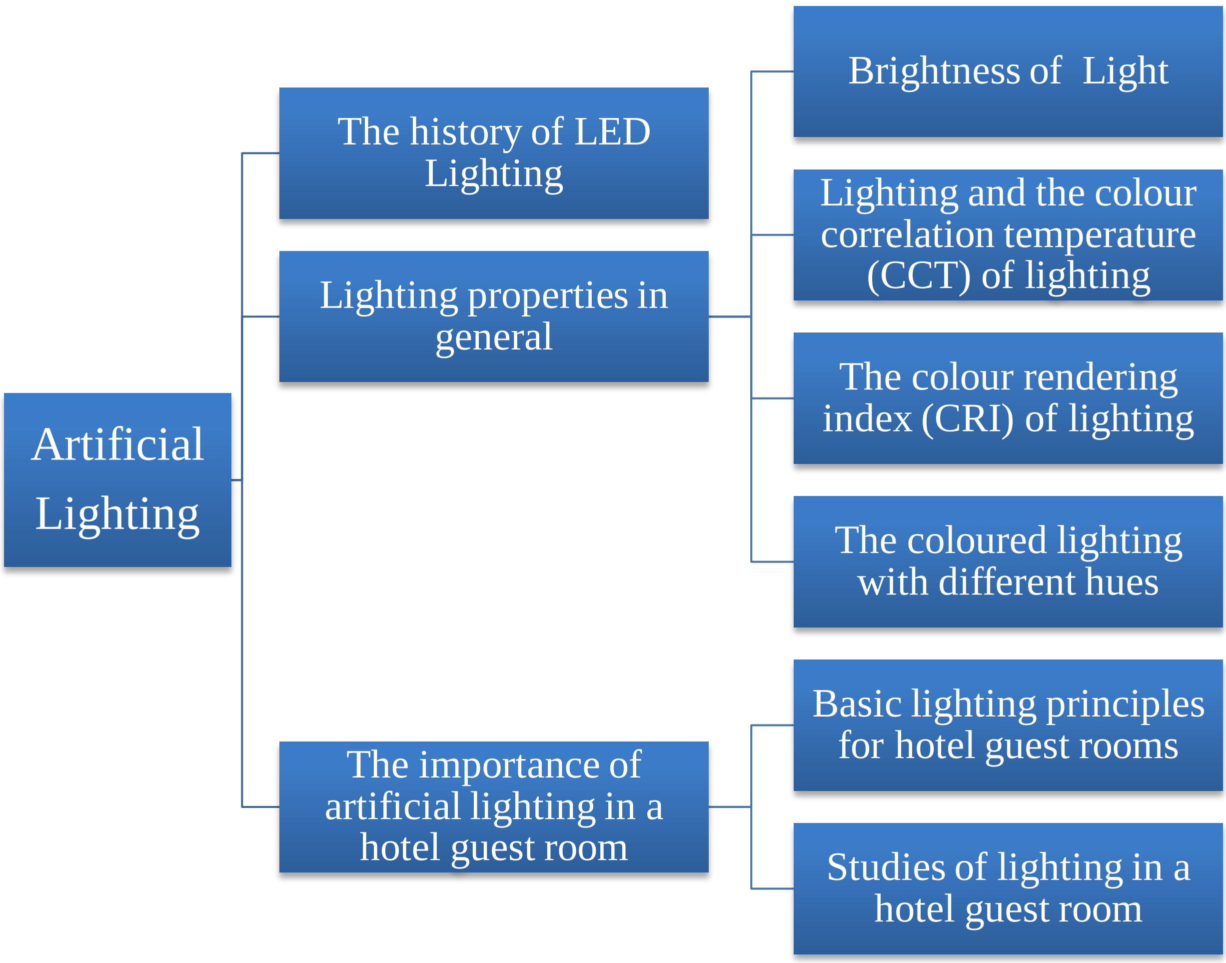

Figure 2.1 The flowchart of Chapter two's structure

Light is a part of the electromagnetic radiation spectrum which includes different kinds of electromagnetic waves. Electromagnetic waves can travel in space. When electromagnetic waves travel, they are reflected, absorbed, and/or diffracted. The differences in lengths between electromagnetic waves can be determined by the wavelength and frequency, the longest being Radio waves — 10^4 metres, andthe shortest being gamma waves — 10^{-13} metres (Innes 2012).

Newton (1700s) pointed out that white daylight couldbe broken down into the seven colours of the rainbow. Combining these seven coloured lights to produce a white light was a focus of interest to a number of researchers who studied light and colours in the eighteenth and nineteenth centuries. The work of Helmholtz (1852), Grassmann (1853), Wülnsch (1792), Young (1801), and Maxwell (1849) revealed that mixing red, green and blue can produce different coloured lights. This series of studies lead to the additive theory of mixed light colour (Maxwell 1861; Wintringham 1951).

The mix of the three primary light colours, red, green and blue, gives white light. By mixing any two of the primary light hues, the result is a subtractive (secondary) light hue which is brighter than the two mixed light colours. So, the mix of red + green= yellow; green + blue = cyan, and red + blue = magenta (Wintringham1951).

Various applications in daily life are based on additive light colour or RGB light theory. Application and inventions include coloured photographs, colour television, and a number of electronic appliances such as computers and mobile screens. Additive light colour theory relates to the physiology or mechanics of human visual perception. It is widely accepted by researchers in the field of light studies (McCann 1998) and is adopted by researchers studying the influence of light hues in the indoor environment.

The human eye can visualise only a limited part of the electromagnetic spectrum. The visible light wavelength starts at 380 nanometre (nm) with the violet colour and ends at 760 nm with the red light (Gordon and Nuckolls 1995). White light is a combination of seven coloured lights in this range: red, orange, yellow, green, blue, indigo and violet.

As stated, the human eye only perceives a limited range of the electromagnetic spectrum. If an object were to absorb all the visible range of the spectrum of light, the object would appear to the observer as black; in contrast, if the object reflected all the visible parts of the spectrum of light, the object would appear to the observer as white. The colour of objects which absorb parts of the visible spectrum and reflect parts of the visible spectrum dependson the reflected wavelengths. For instance, an object which absorbs all wavelengths other than 760 nanometre waves will appear as a red object (Gordon 2003).

In addition to allowing the human eye to perceive colour, artificial light plays an essential role, not only in satisfying functional needs, but also in aesthetic applications. Artificial light can be used by designers to create an emotional impact (Cullen 1986). Many studies have been conducted by researchers in the field of architecture and interior design, to examine lighting impacts on the occupants of a space (Kurtich 1996; Veitch 2001; Wangand Boubekri 2010). Some of these studies have investigated the influence of daylight on the occupants of an indoor space (Edwards 2002; Wang and Boubekri. 2010). Other studies have examined the impact of artificial light in indoor spaces (Barrett 2010). Some of these studies are discussed in this chapter: the studies of Kim et al. (2014); Moors (2009); Park and Farr (2007); Tyan-yu, Wu, and Sheng-guang Wang (2012); Van Erp (2008. These researchers have investigated the influence of the CCT and the brightness of lighting. Further: Islam et al. (2013), Countryman and Jang (2006), Glickman et al. (2006), Schanda and Madár (2007), Smet et al. (2010)and Wright, Lack, and Kennaway (2004) have investigated the influence of the CRI of lighting in the indoor environment. Studies such as: Bronckers (2009), Choy Calvin (2009), Hwang, Lee and Kim (2011b), Kuijsters et al. (2012), Varkevisser, Raymann and Keyson (2011) and Wan (2011) have investigated the influence of different lighting hues in the indoor environment. In addition, the studies of Fernandez, Giboreau and Fontoynont (2012b) and Pae (2009) have examined the influence of lighting in hotel guest room spaces.

Humans spend the majority of their life indoors. Controlling the indoor environment is important for efficient organisation of daily activities and for optimal wellbeing. Thus, artificial light as part of the indoor environment should be controlled to maximise its positive impact on building occupants.

Differing lighting technologies (e.g., candles and oil lamps,electric bulbs, fluorescent tubes, halogen lamps, sodium lamps, compact fluorescent lights, light-emitting diodes (LED) and, recently,induction lighting) have different lighting characteristics, resulting in different impacts on building occupants. LED lighting is one of the latest generations of artificial light sources. Its characteristics are high efficiency, long life, compactness, light weight, and zero mercury content. LED also has very slight infrared IR and ultraviolet UV emissions, which makes this lighting technology widely acceptable for use in the indoor environment. It is now used for sign and display devices, spot lighting, base lighting, and security lighting, andnew applications that cannot be realised currently with conventional light sources are expected in the future, according to Bessho and Shimizu (2012).

A number of studies have been conducted as each lighting technology has emerged. These studies (such asthose testing the influence of lighting brightness, CCT of lighting, CRI of lighting and lighting distribution) have been conducted to better understand how these different forms of lighting influence users physically and psychologically as well as their influence on the performance and attitude of users. This study focused on the impact of RGB LED lighting on the atmosphere in a hotel guest room; hence, to further understand LED lighting, a discussion follows of the history of LED lighting.

2.1 Brief history of the development of LED lighting

The particular properties of light emitting diodes (LEDs) have for some time been attracting the attention of researchers in the fields of physics, electricity, lighting, architecture and agriculture. The development of LEDs, according to several investigators (Bessho and Shimizu 2012; Yeh and Chung 2009), can be divided into three generations, each generation having its own specification which determines where the LEDs can be applied (Bessho and Shimizu 2012).

The first generation of LEDs was widely explored in the early 1960s by Nick Holonyak (Yeh and Chung 2009). These LEDs had low luminous efficiency of 10 lm/W (lumens per watt) (Yeh and Chung 2009). The LEDs of that generation were primarily used as indicators in alpha-numeric displays (Chang 2012; Liu 2009). The second generation of LEDs in the early 1980s had more colours, such as green, yellow, orange and red, and hence the applications became more diverse. LEDs were incomparable for example, in digital watches, calculators, and test equipment.

The third generation reached new heights. A Japanese researcher, Shuji Nakamura, succeeded in producing blue LEDs in 1993 (Chang et al. 2012; Yeh and Chung 2009). With this success it was possible to produce a white light LED which could be utilised in diverse industries (such as automotive, agriculture, lighting and electronics). Mixing or combining the three primary light colours (Red, Green and Blue) has made it possible to produce enormous light colour diversity.

Developments in LED lighting in the 1990s have made possible the utilisation of LEDs in numerous electronic appliances such as TVs, display projectors, mobile phones, computer screens, automotive applications, traffic control devices and artificial lighting in building environments (Yeh and Chung 2009). The development of this generation, however, has not been limited to greater diversity of colour but has also led to greater LED efficiency and enhanced light quality, because with 1W, 200lm/W can now be produced; in the first generation 1W produced only 10 l m/W (Liu 2009).

As a result of these developments, three methods used to produce white LEDs were established (Bessho and Shimizu 2012). White light production is based on combining lights of multiple colours. The first method combines the red, green and blue LEDs to produce white light. The second method combines the blue LED with yellow phosphor and the third method combines near-ultra-violetor ultra-violet LED + RGB phosphor (Bessho and Shimizu 2012).

As LED lighting technology continues to develop, investigations are required to understand the influence of this lighting technology on the atmosphere and the users. The influence of lighting on the indoor environment has been examined by researchers in the field of interior design, lighting design and lighting technology. The following section reviews that research by examining the influence of four lighting properties: brightness, correlated colour temperature (CCT), Colour Rendering Index (CRI) and the hue of the lighting — individually or in combination.

2.2 Lighting properties

Many researchers (Bronckers 2009; Custers 2008; Dijkstra 2010; Park and Farr 2007;Smet et al. 2010Van Erp 2008) have examined the properties of lighting. This section discusses: research that has been conducted on the quality of produced light; how objects appear under the lighting, taking into consideration the brightness of the lighting; the hue and the saturation; the distribution of lighting in the studied environment; the nature of the studied environment and the purpose of the light use (general lighting, task lighting and accent lighting). These aspects have been examined in order to diagnose human needs and make indoor environments more appropriate from both functional and aesthetic perspectives.

2.2.1 Brightness of Light

There are three aspects of brightness of light. The first one is the luminous flux. The luminous flux is the emitted light from a light source flowing in different directions. The amount of light flow in one square meter of the space is the brightness of that light source or luminous flux. The second term is 'illuminance'. The illuminance is the amount of light that falls on a surface from a light source, expressed in lumens per square meter or lux. The reflected light from the illuminated surface, called luminance, is expressed in candelas per square meter (Bronckers 2009; Custers 2008).

Brightness is understood in terms of the quantity of light perceived and can be stated in terms of illuminance and luminance (Bronckers 2009; Van Erp 2008). Brightness depends on the output from a light source and the light reflected from a surface within a space (Custers 2008; Pae 2009). Figure 2.2 shows the terminologies used to describe light quantities.

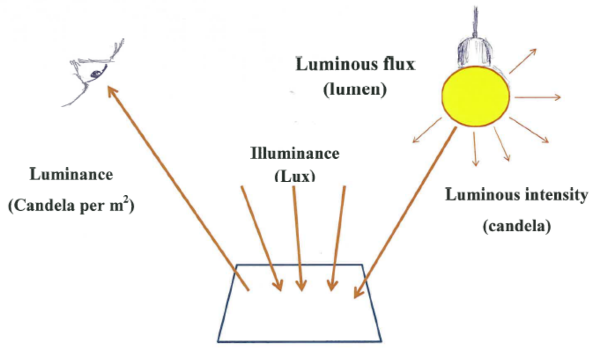

Figure 2.2 The four basic lighting quantities (including units).

Several studies have investigated the influence of light brightness in the indoor environment. For instance, the studies of Mc Cloughan, Aspinall, and Webb (1999), Dijkstra (2010) and Bronckers (2009) found that people perceive spaces with high illuminance as brighter than the spaces with low illuminance. This result is acceptable logically, as the difference in the amount of lighting which the observers perceive as level of brightness is the amount of the illuminance minus the sum of losses as a result of the absorption of light by objects and surfaces in the space. Furthermore, lighting designers are aware that brightness levels of lighting attract participants' attention (Custers, 2008 and Wilson 2006; Hopkinson and Longmore 1959). This knowledge has been utilised in the lighting design of museums and retailer outlets to encourage visitors to view what is displayed by the creation of contrast in the brightness of the lighting system in the indoor space.

In addition, other studies have established that there are other factors which affect participant perception (Loe, Mansfield and Rowlands 1994; Tifler and Rea 1992 and Van Erp 2008). These include a person's field of view. The field of view is defined as the 40 degrees vertical visual angle at normal eye height (Loe, Mansfield and Rowlands 1994). This means that in small spaces the average luminance of wall surfaces can be measured against the perception of brightness of the space. On the other hand, measurement of larger spaces should include the average luminance of the wall, ceiling and floor surfaces (Van Erp 2008).

There have also been a number of studies which have explored the influence of lighting distribution on perception of the light brightness. These studies have found that non-uniform luminance distribution requires less illuminance to match the subjective brightness impression of a room compared with a uniform luminance distribution (Tifler and Rea 1992). Tifler and Rea's (1992) study included two experiments. In the second experiment, the study examined four lighting distributions and two overhead lighting settings, overhead plus peripheral, and peripheral at the same level of brightness. The lighting setting distributions were adopted from Flynn's (1973) study. The study found that the overhead plus peripheral and peripheral lighting settings were evaluated as brighter than the overhead lighting settings' distributions. This means that when the light setting is directed to the walls of the space, the space looks brighter than if the lighting is distributed in a uniform way.

The walls in the indoor environment are one of the largest surfaces in any indoor space and they also surround the observer from different directions, and, as they are on the same level as the observer's eye, most of the luminance reflections are noticed by the observer. The walls form the background to each of the scenes for the observer in the space; therefore the luminance of the light is recognised more than if the light were directed to other surfaces in the space.

A study by Van Erp (2008) looked at human responses to lighting. Using different light combinations of high and low brightness, warm versus cold colours and directional light versus diffused light, he demonstrated that high lighting brightness was preferred to low brightness. Directional light was slightly preferred to diffused light, which means that non-uniform lighting distribution was preferred to uniform lighting distribution.

These studies show that different features of lighting influence the participants' evaluation of the level of brightness in the indoor environment. The quantity of illuminance in the examined environment comprises the lighting distributions, light brightness and the surfaces in the indoor space which reflect the lighting in the space; all influence the level of luminance (McColl and Veitch and 2001).

In conclusion, these studies have demonstrated that the evaluation of lighting brightness is important because it reveals the interaction of the lighting design with the other components of indoor space. What the observers perceive as a bright atmosphere or a less bright atmosphere is a consequence of a direct quantum of lighting on a part or parts of the indoor spaceand its components. This lighting arrangement can therefore create different impressions in the space or transform the atmosphere of the whole indoor environment. The next section discusses the influence of the other three lighting attributes: CCT, CRI, and lighting hues.

2.2.2 Light correlated colour temperature (CCT)

Correlated colour temperature (CCT), measured in kelvins (K) (Gordon 2003; Pae 2009), is a method that the lighting industry uses to describe whether a white light source appears cold or warm. Researchers use CCT to identify the light specifications. Measurement of the CCT is based on the fact that a black figure's spectral radiation is defined by Planck's radiation law (Custers 2008). The idea of describing the CCT of a light source comes from heating a metal object with a heating source. First the object changes colour to red; when it is heated more, the metal changes to yellow, then to white; when the object reaches the highest heat level it changes to a bluish white colour.

The warm white light is the light which appears yellowish and has a CCT rating of 3500K or less, while the cold white light is the light which seems bluish and has a CCT rating of 4000K or higher (Dijkstra 2010; Custers 2008). The estimated CCT for daylight, using artificial lighting, is 6500K (Judd et al. 1964). Figure 2.3 shows the CCT for different light sources.

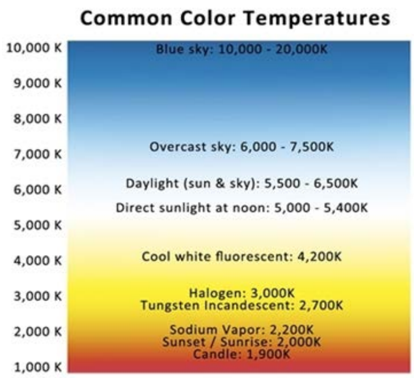

Figure 2.3 Correlated colour temperature for different light sources. Source: http://sustainability workshop.autodesk.com/buildings/colours-light

A number of studies have been conducted to investigate the influence of the CCT of lighting in the indoor environment. A study by Tyan-yu, and Wang (2012) investigated the influence of different lighting, CCT 2700K̊ and 5600K̊, at three levels, of brightness (150lux, 300lux and 500lux) in a dining space using the semantic differential ratings[3] of Mehrabian and Russel (1974). Thirty-two participants contributed to the study. The study found that dim warm lighting was 'more pleasurable' and created 'less arousal' and 'less dominance'. Cold bright lighting was evaluated as 'less pleasurable' with 'high arousal' and 'more dominance'. Warm bright white lighting was the 'most preferable' for a dining atmosphere. Thus, warm lighting gave the participants a pleasing impression, and the bright level of lighting brightness produced adequate visual clarity and a convivial atmosphere.

Similar results were found from Park and Farr's (2007) study, conducted to examine the influence of different CCTs of lighting in a retail environment across two cultures, Korean and American. Ninety-eight participants, 49 Caucasian-Americans and 49 Koreans contributed to the study. Park and Farr's (2007) study examined the influence of different CCT lighting settings in a double chamber in a lighting laboratory. The two chambers recreated the real life feeling of a fashion shop. The examined lighting settings were 3000K and 5000K, both at the same level of brightness.

The study showed that the lighting at high CCT (5000K) was evaluated as 'higher arousal' than the light at the low CCT (3000K) by both cultural groups. However, the American group evaluated the 5000k significantly more highly on the arousal factor than did the Korean group. Both cultural groups evaluated the 5000K as brighter than the 3000K at the same level of lighting brightness. Both cultural groups evaluated the lighting setting at 3000K CCT as being 'more pleasurable' than the 5000K and more preferred in the retail store. The lighting setting at 5000K CCT was evaluated as being higher in visual clarity than the 3000K CCT by the two groups. As to the influence of lighting brightness, the cold bright lighting was evaluated as brighter than the warm bright lighting. Both groups preferred the warm lighting setting for the atmosphere of the retail environment and found it more pleasurable. On the other hand, the study found that cold bright lighting was more 'approachable', especially for the Korean participants, and gave high visual clarity. Park and Farr's (2007) study also showed that there were some differences in the evaluation of the CCT for these two different cultural groups, in that the Americans evaluated the 5000K lighting as having significantly more 'high arousal' than the Koreans. However, there were

[3] The semantic differential rating scale is a method used to evaluate an environment or human situation by using terms to describe the emotional state or the mood state of a person on a 5, 7 or 9 point scale. See Section 3.1 for further discussion.

some similarities in the evaluations — both cultures evaluated low CCT of lighting as warmer and more pleasurable and high CCT lighting as cold with ‘high arousal’, giving the impression of high visual clarity.

The Park and Farr (2007) and Tyan-yu, and Wang (2012) studies described above were both conducted in spaces that required a welcoming warm atmosphere as well as an environment which provided clear and safe visibility. Therefore warm bright atmospheres were preferred in both studies.

A study by Kim et al. (2014) examined the influence of the CCT of white LED lighting in a lecture room. The study included three stages. In the first stage the study examined four different LED devices at four temperatures of CCT: 2600K, 3500K, 4600K and 5600K, all at the same level of brightness. In the second stage the researcher compared an individual lighting source with mixed lighting sources that produced the same level of CCT and brightness. In the third stage the researcher compared two mixed lighting sources that produced similar CCTs and the same level of brightness.

That study found that the individual light source with a high CCT appeared brighter than the light with a low CCT at the same level of lighting brightness. The study also showed that the mixed sources of lighting appeared brighter than the individual source of lighting at the same CCT and brightness. The third experiment showed that the mix of two lighting sources, with one high and one low CCT compared with a mix of two light sources having medium CCTs, produced the same level of CCT at the same level of brightness. The mixed lighting with the extreme high and low CCT appeared brighter than the two mixed medium CCTs. With regard to the result of the second and the third experiments of Kim et al. (2014), there is a possibility that the lighting with the highest CCT from the mixed lighting combinations had the dominant influence on the perceived atmosphere.

While the Kimet al. (2014) study was conducted in a lecture room, the study by Park and Farr (2007) was conducted in a retail space, and that of Tyan-yu, and Wang (2012) was conducted in a dining space. These studies have demonstrated that lighting at the high level of CCT is evaluated as brighter than white light with the same brightness and low degree of CCT. Rea also concluded from an earlier (2000) literature review that light with a high degree of CCT seems brighter than light with a low CCT at the same level of brightness.

A study by Van Erp (2008) which was designed to examine the effect of general lighting with different levels of brightness, CCT and distribution in a laboratory, found that warm white light was preferable to cool white light; and warm, direct bright light was evaluated as ‘livelier’, ‘less tense’, ‘less cosy’ and ‘less detached’ at a low CCT. Moreover, bright diffuse lighting at low CCT was perceived as ‘cosier’, ‘less tense’, and ‘less detached’ than lighting at a high CCT. In Van Erp’s study, lighting at a high level of brightness was evaluated as ‘more detached’ at a high CCT. However, lighting at a low level of brightness with both high and low CCT was perceived as equally ‘lively’. In addition, directional light was perceived as ‘cosier’, ‘livelier’, and ‘less tense’ compared to diffuse light at the same brightness. Thus, warm direct bright white lighting was evaluated as more comfortable and spirited than cold, bright, diffuse white, which was evaluated as encouraging practical activities in the indoor environment.

Moors’ (2009) study (cited in Bronckers’ (2009) study, was conducted in a lighting laboratory without identifying the use of the space; it examined the influence of both white and coloured light. According to Bronckers (2009 36) ‘*Moors (2009) used both white and coloured light and found that warm white light was perceived as more cosy, more lively, less tense and less detached’.*

In conclusion, these studies have shown that the CCT of lighting has an influence at different levels on occupants in different indoor environments. In particular, warm lighting with low brightness was preferred for relaxation spaces, and high brightness, high CCT was preferred for work and activity spaces. These studies have also shown that the nature of space use is another factor which should be considered with the design, in terms of the level of brightness the users of the indoor space need for day to day activities for their safety and their wellbeing. For instance, the studies have shown that the preferred level of brightness for workspaces is different from the preferred level of brightness for relaxing and entertainment.

As well as studies examining the CCT of lighting in the indoor environment, other studies have examined the influence of the colour rendering index in the indoor environment. The next section discusses the influence of CRI lighting in the indoor environment.

2.2.3 Light Colour Rendering index (CRI)

The appearance of standard colours under a particular light source compared with the appearance of these standard colours under a reference illuminated to simulate daylight conditions with the same level of CCT of light is called the colour rendering index (CRI) (Van Erp 2008). This method was acknowledged by the Commission Internationale

Del'éclairage (CIE) (International Commission on Illumination) as appropriate for different lighting technologies such as incandescent lamps, fluorescent tubes, halogen lamps, sodium lamps and compact fluorescents. A score of 100 indicates an impeccable agreement between a particular light and the reference light. The colours of objects and surfaces appear clearer and brighter under a light source with a CRI of 80 and above, while the colours of objects (especially natural objects) seem unattractive under light sources with a CRI of 60 or less (Boyce 2003; Custers 2008).

As LEDs have become more extensively used, a number of studies have examined the applicability of CRI on the performance of LEDs. The use of CRI as a standard for colour rendering under the exposure of LED white light is still in debate. The International Commission on Illumination, in their technical committee (TC 1-69) 2006, recommended an updated matrix or matrices for evaluating the colour appearance properties of white-light sources (Islam et al. 2013).

A number of researchers have attempted to find better matrices to describe the appearance of colours under the exposure of white LED light. Colour Quality Scale (CQS) is one of the methods that have been used to describe the appearance of an object's colour quality under the exposure of white LED light. This method was established at The National Institute of Standards and Technology (NIST) to examine LED white lighting, as the CRI method has limited accuracy. The CQS method used a colour chart with 15 Munsell samples in a colour chart with colour saturations different from CRI; the colour chart included eight colours at both low and medium levels of saturation (Ohno and Davis 2010). The method shows promise, but has not yet been approved by CIE. Figure 2.4 shows the colour charts used in the CRI and CQS methods of colour appearance under the exposure of light source.

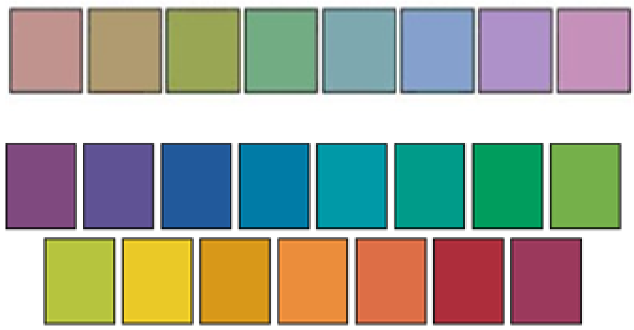

Figure 2.4 The first row shows the colour chart used in the CRI test; the second two rows show the 15 colours used in the CQS test method. Source: (Davis and Ohno 2010, 2,5)

Another study by Rea and Freyssinier-Nova (2008) tested two methods, the CRI and the gamut area index, as matrices to describe colour rendering under the exposure of white LED light. The gamut area is the area that has a polygonal shape enclosed by the eight CIE standard chromaticity colour samples used to calculate the colour rendering index (CRI) in CIE 1976. The reference of the gamut area index score is 100 for a light source with equal energy spectrum. The greater the distance between the selected colour points, the greater the gamut area. The greater the perceived saturation of hues, the better the discrimination will be among hues under that source of illumination.

Rea and Freyssinier - Nova in their study (2008), concluded that the CRI matrices and the Gamut Area Index (GAI) matrices method can be recommended to be used together, as the CRI matrices help to identify the fidelity of the colours, and the GAI matrices identify how natural and how vivid the colours appear under the light source. The GAI matrices model is another solution to evaluate how colours appear under different kinds of lighting technology. However, the method is not broadly accepted by the lighting industry and the CIE.

Davis and Ohno's 2006 study reviewed the development of CQS. The study showed that three kinds of CQS could be used, and all of them are beneficial in one way or another in the evaluation of the colours' appearances under the exposure of the white LED. Both the general CQS and the GAI methods are discussed above. Additionally, there is a third method —the Colour Preference Scale (Qp). The CQS Colour Preference Scale (Qp) is the same 'CQS method with additional weight on preference of object colour appearance. This matrix is based on the notion that increases in chroma are generally preferred and should be rewarded' (Davis and Ohno 2006, 20). The Colour Preference Scale (Qp) is an acceptable method to measure the colours' appearance under the light source. However, like the other CQS method, it has not been widely accepted by the lighting industry yet.

Hashimoto et al.'s (2007) study tested another method to examine the colour appearances under the exposure of the white LED light. The method used was the Feeling of Contrast Index (FCI). The method was derived from using a sample of the gamut area in CIELAB[4] colour space using four-colour combinations, red, yellow, green, and blue, in the examination process. The method used the visual clarity principle. The concept of the Feeling of Contrast Index is the relation between equal scenes of contrast under illumination of the examined light source and the reference source. Hashimoto et al. (2007) concluded that both the CRI and FCI methods are useful for evaluating the colour appearances. As CRI

[4]The CIELAB is one of the matrix methods to describe the colours' properties. The method will be discussed in the next section, 2.2.4.

indicates the colour fidelity and FCI indicates the visual clarity —brightness and colourfulness — both methods are appropriate for evaluating white LED light sources. The FCI method has been accepted by some of the American and Japanese lighting companies but has not yet been accepted internationally.

A study by Smet et al. (2010), reviewing a number of studies (Bodrogi et al. 2004; Davis and Ohno 2006; Narendran and Deng 2002; Szabó et al. 2007), examined the useability of CRI to examine LED light sources, and found that CRI is not the best method for evaluating the quality of LEDs. Smet et al. (2010) concluded that, when evaluating colour quality, the objective lighting parameters of LEDs should not be the only parameters considered. Subjective parameters also impact on the evaluation process.

Another study that examined colour quality was carried out by Islam et al. (2013). These researchers compared 21 white LEDs with three fluorescent lamps. The examined lighting settings of the LEDs had different spectral power distributions (SPDs). The sample lighting settings also included three levels of CCT — 2700K, 4000K, and 6500k. The study tested different methods for examining the colour rendering quality of the LED in addition to CRI. They were CQS, Gamut Area Scale (Qg), CQS, Colour Preference Scale (Qp) and Feeling of Contrast Index (FCI). This study, too, concluded that the CRI is not the best method to test LED colour quality; the CQS, Qg and CQS QP gave more accurate values with regard to the viewers' preferences. It was also found that the lighting settings with high CCT, such as 4500K and 6500K at the 500lux brightness, were preferred by the viewers.

In conclusion, these studies show that the CRI method is not the best method to examine colour appearances under theexposure of LED light sources. White LED lighting is one of the sources that have narrow band peaks in its spectrum. RGB LED lighting, for example, has powerful peak points in the red, green and blue areas and weak peaks in between the areas. Therefore, the less saturated colours showed less fidelity. The CRI chart standard includes the low and medium levels of saturation colours, as shown in Figure 2.5. Therefore, most of the LED lighting ranked low in most of the studies which examined the ability of light to render colours using the CRI. On the other hand, the standard saturated colours appeared sharp under the exposure of the LED light source.

No single method has been widely adopted to evaluate the colour rendering quality under white LEDs, although most lighting companies do use CRI to identify the colour rendering of objects under their white lighting products (Gordon 2008). The current study does not focus on the influence of colour appearance in the indoor environment for a number of reasons. Firstly, the study is focused on the influence of RGB LED lighting hues on the atmosphere of the hotel guest room. Secondly, the study aims to examine the influence of the LED lighting on the atmosphere of the indoor environment. There is a difference between the evaluation of colours' appearance individually and evaluating their appearance and influence in an indoor environment. Thompson's 2007 study showed that evaluating the influence of the lighting on detailed parts of the indoor environment, such as in a colour chart, is different from evaluating a colour in live scenes,as will be discussed in section (3.2.2 Scale model (booth)

Thirdly, the four white lighting settings that were examined in the current study cannot be compared with each other, as the general LED white lighting had a different spectrum distribution from the white wall washer RGB LED lighting which was used as accent lighting in the study. Fourthly, the current study used a simulation method using 3D video as an alternative to a live space visit. Perceptions of the colour appearance through a visual experience via video with those of a live visual experience have not yet been tested. Therefore the current study considers the CRI as a datum for comparison.

2.2.4 Lighting hue

In addition to studies on the CCT of lighting and the CRI of lighting, there have been studies on the influence of coloured lighting in the indoor environment. Daylight or light in general is part of the electromagnetic spectrum and is called the visible light spectrum. Visible light is a combination of a number of wavelength ranges between 760 nm and 380 nm which the human eye can perceive. Each of the ranges can be recognised as spectral coloured light, the range of 760–650 nm perceived as red light, the range 630 nm–600 nm perceived as orange light, the range 590 nm–580 nm perceived as yellow light, 540 nm perceived as green light and 450 nm perceived as blue light (Gordon 2003; Nuckolls 1983).

Coloured light is usually described using three descriptive features: hue, lightness and saturation. A number of matrices have been established in order to give a specific description to the qualities of coloured light. An earlier method was established by the Commission Internationale deL'éclairage (CIE) in 1931: the CIEXYZ, or the colour space mathematical model. The model was based on how humans perceive and recognise colours. The human retina has two kinds of photoreceptor nerve cells— the rods and cones. The rods are sensitive to the level of brightness. The cone nerve cells are sensitive to three kinds of wavelengths – long (L), medium (M) and short (S). The long ones are receptivetothe red colour, the medium receptive to the green colour and the short receptive to the blue colour. The CIEXYZ model is usually used as a measuring instrument but is not useful to describe colour properties; however, the model is a start for other matrices that may be able to provide an accurate metrical description of light sources for colour properties.

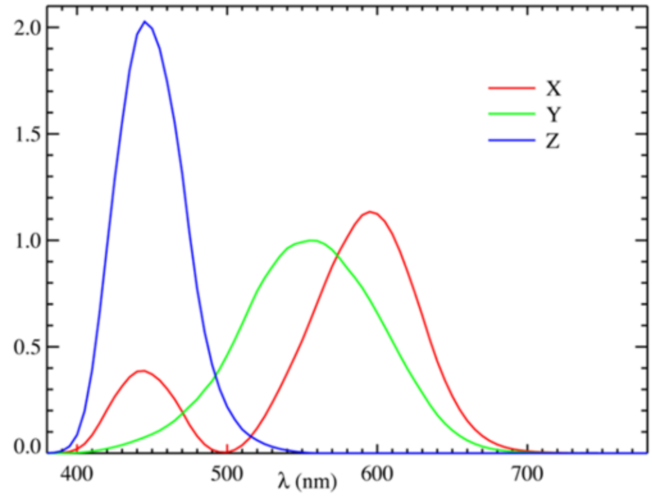

Figure 2.5 The vertical axis represents relative response from 0–2.0 (shown here) or reflective brightness. Source: (Wikimedia Commons 2014)

The CIExyY colour space or the chromaticity method was derived from the CIEXYZ method. Both x and y refer to the chromaticity parameters of the colour, while Y refers to the luminance of a colour. Figure 2.6 shows the graph of the chromaticity matrix model.

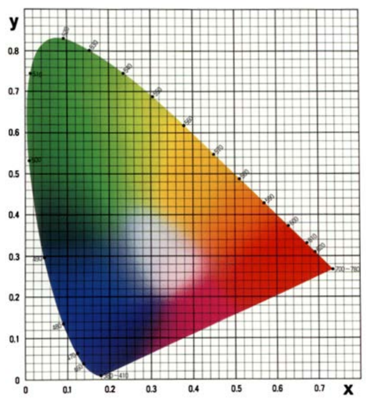

Figure 2.6 The CIExyY Chromaticity Diagram. Source: (www.google.image.2014)

Another colour space matrix model is the CIELAB Colour space. The model was acknowledged by CIE 1976 (L*a*b*) (Fairchild 1998; Wyszecki and Stiles 2000). This matrix model describes the features of coloured light with three parameters: the L* refers to the lightness, with the range starting with 0 and ending up at 100, the a* refers to the redness-greenness, and the b* refers to the yellowness - blueness. Figure 2.7 shows the CIELAB matrix model.

The fundamental point in this model is that the description of a colour cannot be the description of its complement. Therefore red is the opposite of green and blue is the opposite of yellow as axes in the chromatography system. In the (+a,-a) axis red is the extreme (+a) and (–a) is green. (+b) is yellow, and (–b) is blue. The vertical axis represents the value of lightness of the coloured light.

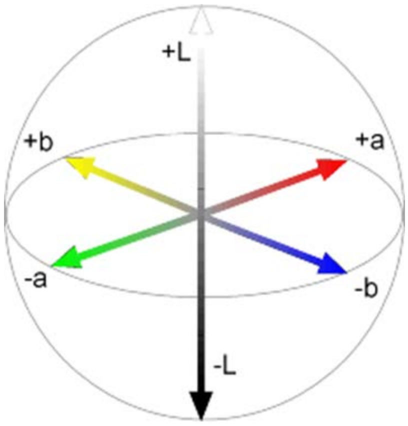

Figure 2.7 The CIELAB matrix model. Source: (Jisc. Digital Media- Modelling Colour (2015)

The CIELCH colour space is another matrix model to describe the features of coloured light. Three features are included in this model: (L*) refers to lightness, (C*) refers to chroma or (saturation), and (h*) refers to hue.

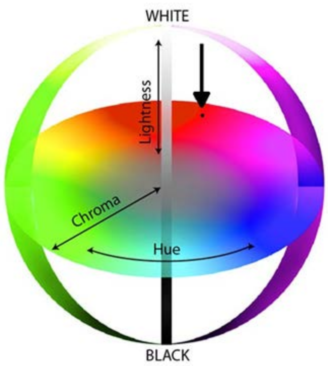

Figure 2.8 The CIELCH matrix model. Source: Source: the Print Guide (2010)

All these matrices can help researchers to identify the properties of light colours accurately. However, there are no specific recommended methods for investigating the influence of coloured lighting, and it is difficult to apply any of these matrices as they are based on different theoretical approaches.

From another perspective, DMX[5] light mixtures are used to apply and mix different hues in lighting settings. The DMX controllers that are usually used with RGB LED lighting are operated with an electronic system. Most of these systems still use the eight channels or what is called the 8 bit system operator (00000001); as a result each of the RGB parameters is divided by 255. For example, if a white light is produced, the DMX control reading will be R255, G255, and B255, the red light reading will be R255, G000, B000; the green light reading will be R000, G255, and B000 and so on. This system can work in coherence if the studies use electronic equipment such as computers, digital camera, photos or video. Figure 2.9 shows the DMX512 parameters for white light.

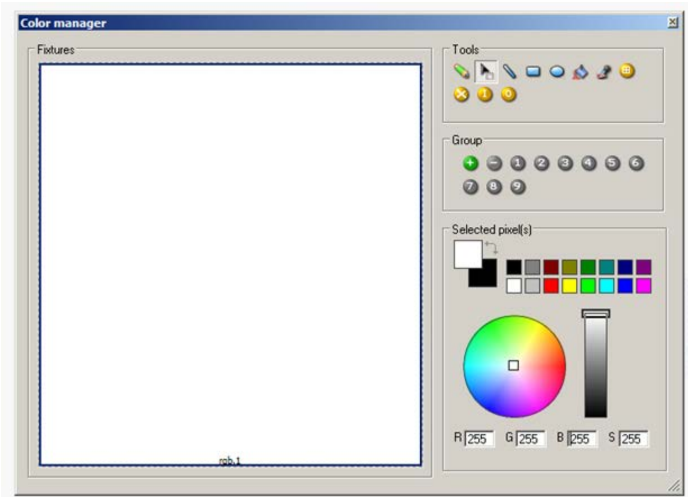

Figure 2.9 The DMX512 parameters' image of white light. Source: photo taken by the researcher of the superlight DMX512 controller used in the current study

Other studies have investigated the correlation between the level of brightness and the level of saturation. The study of Stalmeier and de Weert (1994) noted that increased light saturation of an object led to the object being perceived as brighter. This phenomenon is known as the Helmholz-Kohlrausch effect (Bronckers 2009). This aspect, then, should be considered in the design of coloured light investigations.

[5]DMX or the Digital multiplex lighting mixer is the lighting digital control standard method that are broadly used to create lighting artistic effects verify in the level of brightness and colours.

Lighting designers and designers in general use different techniques to produce a specific coloured light for their designs. They mostly use filters with incandescent halogen and fluorescent lamps for indoor and outdoor lighting. Recent developments in LED technology have led to the production of specific coloured lighting in a specific wavelength, used in the indoor environment for diverse reasons (Yeh, Wu and Cheng 2010).

A number of studies have examined the effect of coloured lighting on the occupants of interior spaces. In this section a review is conducted of studies examining the effect of coloured lighting with different hues on occupants of interior spaces. The majority of these studies utilised RGB LED lighting in the indoor environment.

Bronckers' (2009) study, carried out in the Netherlands, examined the influence of coloured LED lighting on the atmosphere of the indoor environment. The study was conducted in a lighting laboratory space. The study utilised a combination of general white lights and coloured wash wall lighting. Forty Dutch participants, twenty women and twenty men, participated in the study. Bronckers' (2009) study used Vogels' questionnaire to evaluate the influence of lighting in the indoor environment. The general white lighting was at two CCT levels — high 6000K and low 2800K. Each general white lighting setting was examined separately with a combination of coloured lighting. The coloured lighting was at two different levels of saturation, high and low, with the exception of cyan, yellow and blue colours, which were examined at only one level of saturation as a pilot study. Bronckers' (2009) main study, found that there was no difference in the evaluation of the lighting hues between the two levels of saturation. The study found that the high CCT white was evaluated as 'brighter', 'less cosy', 'less tense' and 'less detached' than the low CCT white lighting, although the participants considered the low CCT lighting was preferable for use in the living room. The white light with high CCT appeared brighter than the light with low CCT; these results are similar to those of Rea (1999), Van Erp (2008), and Kim et al. (2014)

The study participants also evaluated the lighting combination of the white-coloured lighting. High brightness lighting was evaluated as 'lighter', 'livelier' and 'preferable' to the low brightness light settings, while lighting with low saturated light conditions was perceived as 'more cosy', 'more detached', and 'less tense' compared to the maximum saturated light conditions. It is likely that the more saturated the lighting setting, the poorer the wavelength reflection of light will be in the atmosphere of the examined space. The high saturated light hue has a narrower band of wavelength emitting from the lighting source. Objects in any atmosphere when they are exposed under a light will absorb part of the light wavelengths which fall on them and reflect the rest of the light wavelength; that is how the human eye recognises the colours of the objects in any environment. The narrower the bands of the light wavelength spectrum used in the environment, the higher the possibility the objects will appear less colourful and reflect less light.

Human eyes are used to white light which includes a wide range of wavelengths from the visible spectrum. However, specific coloured lights can include a single band of the spectrum such as red in the 760- 650 nm range, green in the 500-550 nm range, and blue in the 450-400 nm range. According to Bronckers' findings, the wider the band ranges of the spectrum for the mixed coloured light, the more acceptable it will be. This may explain why the high saturation lighting settings were assessed to be 'less cosy', 'tenser', 'less detached', 'less preferred' and 'less appropriate' for a living room and workplace.

Another possible explanation is that illustrated by the CIE (International Commission on Illumination), in which they claim that the human eye responds differently to different hues of a light source even if the light source is at the same measured level of illumination. The human eye shows greater sensitivity to light hues at 555 nm (green-yellow) than light hues that lie towards the two ends of the visible light spectrum higher than 780nm (red) or lower than 380 nm (blue) (Warren 2006).

In Bronckers' (2009) study, the evaluations of lighting hues found that green and white are neutral colours, while warm colours are red, magenta and yellow; blue and cyan were evaluated as cool colours. These results are similar to a number of other studies examining the influence of pigment in the indoor environment (e.g., Mehta and Zhu 2009; Elliot et al. 2007; Kaya et al. 2004). The evaluation of the lighting hues showed that red and yellow were rated as being cosier than the other lighting hues (cyan, blue, green, magenta and white); in contrast magenta was rated as being least 'cosy' compared to the other hues. There is a probability that the participants of Bronckers' study correlated the 'cosiness' factor with the impression of warmth that they felt with regard to the warm lighting setting compared with the other lighting settings.

Bronckers' (2009) study also found red was rated as the 'most tense' hue; yellow was rated as being the 'least tense' hue. White was rated as the 'least lively' and 'most detached', followed by cyan; red was rated as the 'least detached' compared to the other hues. In Bronckers' (2009) study the red lighting setting was evaluated as the 'tenser' perhaps because red light is used as an indicator of danger, thus leading to feelings of attentiveness and tension. The yellow lighting was evaluated as more 'relaxing', as was the white warm light compared with the cold white light. Perhaps the yellow lighting was correlated with the light of the sun which emits warm light during the day.

Hwang, Lee and Kim in their (2011) study in South Korea found that different lighting hues at different levels of chroma purity affected the perceived ability of occupants in a particular living space to communicate comfortably — the lower the chroma purity at a particular hue, the more comfortable the occupants feel. Hwang, Lee and Kim's (2011a) study examined seven light hues: red, green, blue, cyan, magenta, yellow, and white, each of them at three different levels of chroma purity. The study found that white light was perceived as the optimum lighting hue for comfort and communication in the living room space, as was cyan lighting hue. This may be because the participants in this study correlated the cyan hue with the hue of sky during the day or withthe cold white light of workspaces. A number of studies such as those of Glickman et al. (2006), West et al. (2011) and Wright, Lack, and Kennaway (2004) examined the influence of lighting hues on human physiology and found that lighting hues with dominant short wavelengths had a significant influence on melatonin suppression. This suppression alerts the human body to be more active, and hence there was perhaps a connection between the aesthetic evaluation and physiological influence of the cyan lighting hue.

Hwang, Lee and Kim (2011a) also found that yellow, cyan and blue were evaluated as 'higher in comfort' at the three levels of chroma purity, 20%, 40% and 60%, while red and green at 40% and 60% of chroma purity were evaluated as the 'most dis-pleasurable' lighting hues in this study. Hwang, Lee, and Kim's (2011a) study validates the influence of lighting hues on a multipurpose indoor space — the living room.

The two studies by Bronckers (2009) and Hwang, Lee and Kim (2011) examined a wide range of different colours that included the primary and the secondary hues of lighting with different brightness, saturation and chroma purity. Although conducted in different countries, one with Dutch and one with South Koreans, some of the findings were similar. In both studies, the low saturated lighting was preferred and evaluated as more positive. The red colour was evaluated negatively and appeared darker to the participants than the other coloured lighting settings. The mixed lighting hues, such as cyan and yellow, with the exception of magenta, were evaluated more positively than the primary lighting hues such as red and green. Cyan and yellow lighting hues may have been evaluated more positively because people are used to seeing these two lighting colours as part of the daylight lighting hues at different times of the day. An additional reason could be that cold white fluorescent lighting is similar to cyan lighting colour, and yellow lighting colour is similar to the warm white light of incandescent lamps.

Reisinger et al.'s (2009) study in the Netherlands found that different lighting hues were evaluated differently without any common format. The study was conducted in a lighting laboratory without identification of the use of the space. The study used the semantic scales: cold-warm, heavy-light, tensed-relaxed and passive-active to evaluate the lighting settings. Seven lighting hues were tested: red, green, blue, orange, yellow, cyan, purple, with white light with a CCT of 6500K used as a reference light setting for comparison. The study examined each of the lighting hues twice by comparing them with the reference light; the position was randomised with the examined light hue to the right and to the left of the reference light. The study found that red, orange and yellow lighting hues were evaluated as warmer than the blue and cyan lighting hues. Bronckers' (2009) study showed a similar result. Figure 2.10 shows the mean ratings on the cold-warm scale for the 7 lighting hues:

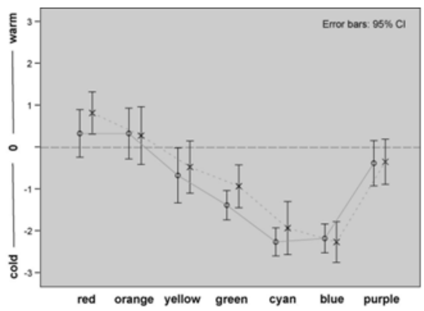

Figure 2.10 The ratings on the cold-warm scale for the seven lighting hues with 95% confidence intervals for experiments 1(x) and 2 (o). Source: Reisinger et al. (2009, 3)

The results show that the mixed lighting settings, cyan, orange and yellow were evaluated as more relaxing than the primary lighting hues red and blue, with the exception of the green light, which was evaluated as highly relaxed. This result is partly similar to the result of Bronckers' (2009) study in which cyan, yellow and green were evaluated as 'positive' compared with the other lighting hues, red and magenta, while the blue light hue was evaluated as less tense. Hwang, Lee and Kim (2011) found that cyan, yellow and blue lighting hues were evaluated as highly positive and red and green lighting hues were evaluated as 'highly negative', evoking displeasure. The common result for the three studies was that they evaluated cyan and yellow lighting hues as 'highly positive' and the red lighting hue as 'highly negative'. The difference in results was in the evaluation of the green lighting hue, as both the Reisinger et al. (2009) and Bronckers (2009) studies evaluated green light as 'highly positive' and Hwang, Lee and Kim's (2011) study evaluated green light as ‘less positive’. The difference in the results could be because both the Reisinger et al. (2009) and the Bronckers (2009) studies were conducted in a lighting laboratory without furniture to identify the use of the space. The other possibility that could have caused the difference in the results is the cultural differences, as Reisinger et al. (2009) and Bronckers (2009) conducted their studies in the Netherlands, and Hwang, Lee and Kim’s (2011) study was conducted in Korea. Figure 2.11 shows theme ratings on tensed-relaxed scales for the seven lighting hues:

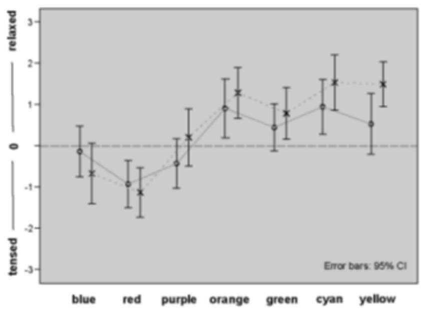

Figure 2.11 The mean ratings on tensed-relaxed scales for the seven lighting hues. Source: Reisinger et al. (2009, 3)

The semantic scales of passive-active and like-dislike in the results of Reisinger’s (2009) study showed that orange, yellow, cyan, green and blue were evaluated as more active compared to red and purple, which were evaluated as less active. In the study of Bronckers (2009) the same result was reached, that is, both red and magenta lighting hues were not preferred for use in workspaces, possibly because both lighting hues give the impression of a passive atmosphere. Cyan, orange and blue were slightly more preferred than red, purple, green and yellow. It is not clear whether the primary lighting hue or the mixed lighting hue was evaluated as more or less passive-active and liked-disliked. Figure 2.12 shows the mean ratings of passive-active and disliked-liked scales.

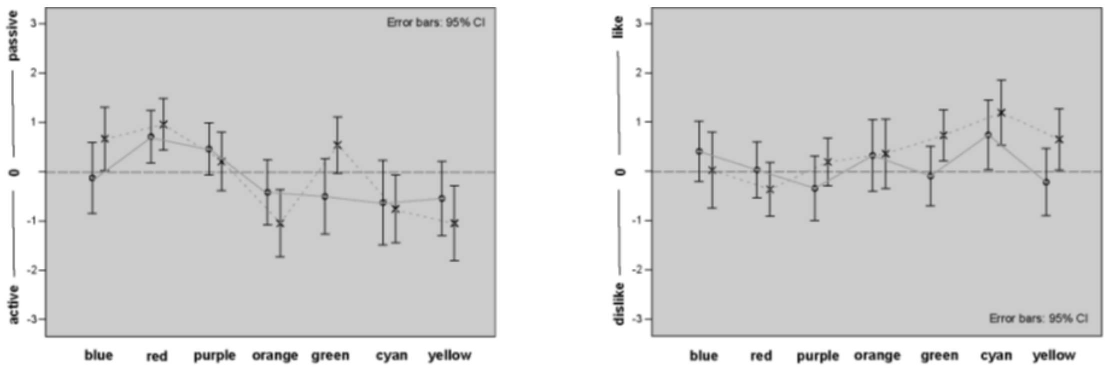

Figure 2.12 The mean ratings passive-active and disliked-liked scales. Source: Reisinger et al. (2009, 4)

Reisinger et al. (2009) also showed that different lighting hues were evaluated differently with regard to the four different semantic scales in an unfurnished space. These results were similar to Bronckers' (2009) results in that the secondary mixed lighting hues were ranked as more positive than the primary lighting hues, with the exception of the purple lighting hue. In both studies, the red and yellow lighting hues were evaluated as warmer than the blue and cyan lighting hues, and the red lighting hue was evaluated as being the 'most tense' lighting hue.

It is speculated that the similarity in results could be due to the fact that both studies were conducted in an unfurnished space in the Netherlands where the participants presumably had similar cultural backgrounds. However, the Hwang, Lee and Kim (2011) study also had similar results to the Bronckers (2009) and Reisinger et al. (2009) studies, although their study was conducted in South Korea. It may be that the similarity in results was not only because of thecultural correspondences, but could also be because of psychological or physiological factors.

A study by Nomoto et al. (2014) was conducted in a Japanese lighting laboratory. The aim of the study was to investigate the psychological and physiological influence of coloured light on humans. The study used both physiological measures of heart rate variability (HRV) and psychological measures to evaluate comfortable feelings and comfort levels. The study was conducted in booths. Seven different light hues were examined in this study: white, yellow, green, orange, pink, blue and red. The light settings were presented to the study participants in pairs. The study results showed that white, green and yellow lights at the low and high levels of brightness were evaluated more highly with regard to the sense of 'comfort' and 'security' compared to the other examined light settings — orange, pink, blue and red. The results for physiological heart rate variability (HRV) showed that cold and warm colours evoked low values, while neutral colours obtained high values.

Nomoto et al.'s (2014) study showed that coloured lighting hues had both psychological and physiological influences on the individuals who were exposed to these lighting settings. This study has some similarities with the results of Reisinger et al.'s (2009) study, as in both studies, both green and yellow lighting settings were evaluated as very comfortable or relaxed, and blue, red and pink were evaluated as less comfortable. In this respect, Nomoto et al.'s (2014) results have similarities with and differences from Hwang, Lee and Kim's (2011) results, as white and yellow lighting hues in both study were evaluated as very 'comfortable' and red and blue as less 'comfortable'; however, green lighting was evaluated as very 'comfortable' in Nomoto et al.'s (2014) study but was evaluated as less 'comfortable' in Hwang, Lee, and Kim's (2011) study. Two possibilities could explain the difference in the results of the two studies. The first one is that the combination of hues that were examined differed across the two studies. Nomoto et al. (2014) examined white, yellow, green, orange, pink, blue and red lighting settings. In contrast, Hwang, Lee and Kim (2011) examined white, yellow, green, cyan, blue, magenta and red lighting settings. The other probability is that Nomoto et al. (2014) exposed participants to pairs of light settings in an unidentified space, while Hwang, Lee and Kim (2011) examined responses to each of the lighting settings in combination with white light in a booth that included mock living room furniture.

Varkevisser, Raymann and Keyson (2011) investigated the influence of coloured lighting in the indoor environment. Their study aimed to explore the influence of the illuminance and colours of lighting on the wellbeing and physiology of humans in a work space. Two levels of lighting brightness, 45 lx and 195 lx of white lighting with low CCT of 3000K and four coloured lighting combinations, Red-Green (Yellow), Red-Blue (Magenta), Green-Blue (Cyan), Red-Green-Blue (White), were tested in their study. The self-assessment manikin (SAM) model of Bradley and Lang (1994) was used to evaluate the influence of the perceived environment. A test of momentary wellbeing included the following aspects: tension, fatigue, motivation, and annoyance (Varkevisser et al. 2007). In addition, a physiological test was conducted. The physiological test measured the heart rate average (HRA)[6] and heart rate variability (HRV) root mean square of successive differences (RMSSD) (Varkevisser, Raymann and Keyson 2011, 161).

[6]The physiological parameters were derived from electrocardiograph and skin conductance measures (Mobi8 polygraph, TMSi, The Netherlands). Heart rate has been shown sensitive to lighting in some studies (Cajochen et

Varkevisser, Raymann and Keyson (2011) found that, with regard to the wellbeing factors, the participants evaluated low level lighting brightness as creating higher 'tension' than a high level of lighting brightness; moreover, there were no significant effects for the colour of lighting on the 'tension' factor. The 'fatigue' factor was evaluated as higher for the combination of high brightness lighting with the colour group of magenta, cyan, and white, but low brightness lighting with the yellow hue was evaluated as causing higher 'fatigue'. A mixed lighting setting with a short dominant wavelength, magenta and cyan, was evaluated as causing high 'fatigue'at the high level brightness; these lighting settings were also evaluated as creating high 'arousal'. It can be concluded that the lighting setting which was evaluated as highly arousing can lead to an evaluation of higher levels of 'fatigue'. That is, the lighting setting hue that evoked a sense of arousal led ultimately to a sense of fatigue, or at least there was a correlation between the two evaluations.

The interesting result in this study was the evaluation of the yellow light setting as causing high 'fatigue'. In contrast, the yellow lighting setting has been evaluated in more than one study as giving a comfortable sensation; for example it was evaluated in Bronckers' (2009) study as 'cosy' and 'less tense'. In Wan's (2011) study the orange light hue setting was evaluated as one of the lighting settings thatcould be used to boost stress recovery. The difference in the results of the Varkevisser et al.'s (2011) study and Bronckers' (2009) and Wan's (2011) studies may be because Varkevisser et al. (2011) examined four hues of lighting settings, while Bronckers (2009) examined seven. The other possible reason for the difference in the results between Bronckers' (2009) and Varkevisser et al.'s (2011) studies may be because the latter study compared the highbrightness yellow lighting hue with the low brightness yellow one.

In Varkevisser et al.'s (2011) study, participants evaluated the 'motivation' factor as higher for all the low brightness lighting settings. Yellow was the highest among the coloured lighting settings, followed by white, cyan and magenta; but the other lighting settings were evaluated as less motivating than the yellow lighting setting. The result here is somewhat similar to Bronckers' (2009) study, in which yellow lighting was evaluated as one of the lively lighting settings, although the white lighting setting was evaluated as the least lively. The high brightness lighting settings were also evaluated as highly motivating, except for magenta lighting settings.

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al, 2004; Scheer et al., 1999). Heart rate variability appears to be a sensitive measure for mental load (Backs and Seljos 1994; Veltman and Gaillard 1996).

Varkevisser et al.'s (2011) results showed that the factor of 'annoyance' was evaluated as higher with the colour groups yellow and magenta than with the colour groups cyan and white. This does not agree with Bronckers' (2009) and Wan's (2011) results, as the yellow and orange in both their studies were evaluated as 'less tense' and 'more relaxing'. On the other hand, the magenta hue was evaluated as 'more tense' than the cyan and white lighting hues in Bronckers' (2009) study.

Varkevisser et al.'s (2011) study therefore provides another example of the influence of some lighting hues. The cyan and white lighting settings were evaluated as more positive than the yellow and magenta lighting settings; this is a different finding from Bronckers' (2009) study. In her study, cyan and yellow were the most preferred lighting settings. One can speculate as to the reason for the differences between the results. Varkevisser et al. (2011) used the SAM model to evaluate the influence of coloured lighting, whilst Bronckers (2009) used the atmospheric evaluation of Vogels (2008a). Thus, Varkevisser et al. (2011) examined the influence in working spaces only, and Bronckers (2009) examined the influence of lighting in work spaces as well as in living rooms. It could be that the participants in the Varkevisser et al. (2011) study correlated the lighting setting with the cold white light of fluorescent lighting, widely used in a work space. In Broncker's (2009) study the participants may have correlated the lighting setting in the work space with sunlight and therefore preferred cyan and yellow coloured lighting to the other lighting settings.

Venier (2013), an artist and colour therapy practitioner, has reviewed a number of studies, such as those of Berson, Pu, and Famiglietti (1998) and Brainard et al. (2001), which found that the colour of the sky at midday is received by the human eye as the cyan lighting hue. This lighting hue causes a reduction in melatonin which makes an individual more awake and active. Venier demonstrated that yellow and orange lighting hues were highly correlated with a pleasurable response. Venier also stated that the use of electronic devices such as a TV or computer that include blue and cyan light over a long period of time causes insomnia, which could be reduced by wearing yellow coloured glasses. Similarly, Wan (2011) found that the orange hue of lighting can be used to reduce stress. The physiological test results of Wan's (2011) study showed that the heart rate's average score was high under the exposure of low lighting brightness with magenta and white lighting settings. There was no significant influence of lighting with regard to the root mean square of successive differences (RMSSD) test.

Another factor that could further explain the differences in results between the Bronckers and Varkevisser etal. studies is that, while Bronckers' study used seven lighting hues, Varkevisser et al. used only four lighting hues. The compression in the evaluation between four lighting hue settings is different from the compression of seven lighting hue settings. The participants in Bronckers' study had to give their evaluation of a wider range of lighting hues, which evoked more varied responses to the influence of lighting hues on the indoor environment. Selecting one from seven could have led to a larger range of probability than selecting one from four.

A combination of coloured lighting and white lighting has also been utilised to create specific indoor atmospheres to stimulate the users of these spaces. Two studies have used this lighting design technique.

Kuijsters et al. (2012) examined how lighting settings influence users' perceptions of the atmosphere of the environment. Twenty-one elderly people participated — 12 females and nine males' aged 65 – 85 years, and fifteen younger participants — eight females and seven males aged 20 – 30 years also contributed to the study. Four lighting ambience settings were designed and examined — cosy, activating, relaxing and exciting ambiences. A mix of blue, orange, green and warm white was used to stimulate a cosy ambience and a relaxing one. A blue, cyan and cold white lighting hue mix was used to stimulate an activating ambience and an exciting one.

The study showed some differences in the evaluation of the atmosphere of the environment between the two age groups. The younger participants ranked each of the lighting design atmospheres differently, as they ranked the cosy lighting ambienceascosier than did the elderly participants; they also ranked both the activating and the exciting light ambient as more lively than did the elderly participants. Figure 2.13 shows the difference in ranking between the ages groups of the Kuijsters et al. study.

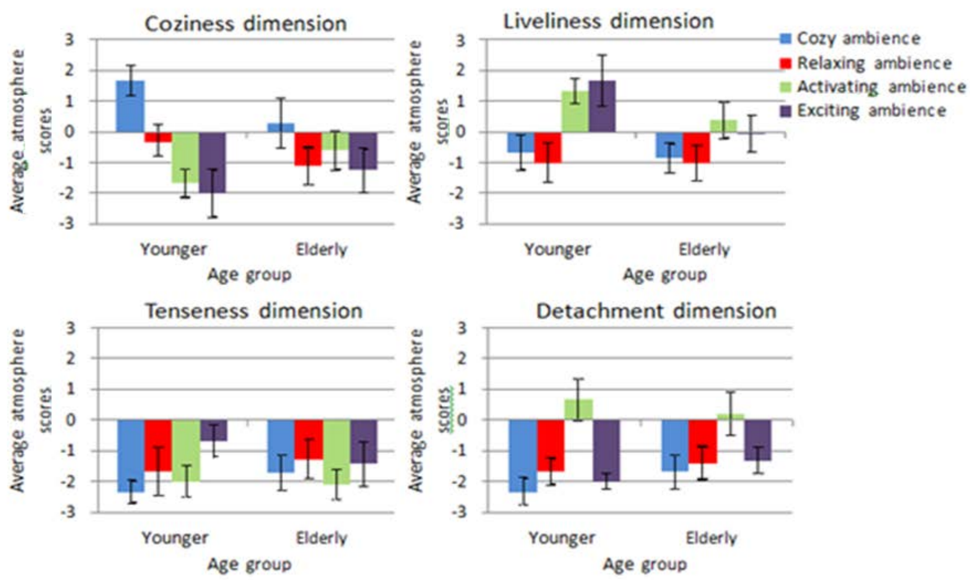


Figure 2.13 The results of the Kuijsters et al. study. Source: Kuijsters et al. (2012, 4)

The researchers gave the older participants the opportunity to discuss in individual interviews the lighting settings presented to them. The majority of the older participants stated that the ‘relaxing’ lighting setting seemed dim to them and they did not like the combination of green and blue coloured lighting. A number of the older participants found the combination of different colours in the ‘cosy’ and ‘relaxing’ lighting settings made them feel restless, and the blue lighting in both these lighting settings made them feel cold. Most of the older participants also stated that they did not like the ‘exciting’ lighting setting.

This study shows that the different age groups evaluated the atmosphere of the same indoor environment somewhat differently. The different evaluations could be correlated to the physiology of the eyes of the elder group, as the ability of the eye lenses to shrink or expand in order to adapt to the different lighting levels can decline with age (Glasser and Campbell 1999; Heys, Cram, and Truscott 2004).

Choy Calvin (2009) used a mixed combination of lighting hues to investigate the impact of lighting feature changes on perceptions of the atmosphere. Based on the results of a previous study by Seuntiens and Vogels (2008), Choy Calvin aimed to create two ambiences– ‘cosiness’ and ‘activeness’. The cosy lighting setting was designed to include low luminance and low CCT and two hues, blue and orange, while the activating lighting setting included a combination of high luminance high CCT lighting with cyan and blue lighting. Choy Calvin allowed the participants to modify the lighting setting, and then examined the changes. The changes indicated that the CCT of the ‘cosy’ lighting setting was increased to 800k while the

CCT of the 'activating' setting was decreased to an average 800k. The distinction in the hue of lighting that was made by the study participants was between yellowish to reddish for the orange hue in the cosy lighting setting; the changes in the cyan colour were between green and purple for the 'activating' lighting setting. The changes to the blue colour were between cyan and purple. In general the changes made by the participants were larger for the activating atmosphere than for the cosy atmosphere.

The summary of the study's three experiments showed that brighter white lighting was evaluated as 'less cosy' and 'less tense' and 'more lively' and 'detached' for both the atmosphere settings, 'cosy' and 'activating'. The increased CCT of lighting in the initial cosy atmosphere setting was evaluated by the participants as being 'less cosy' and 'livelier', 'more detached' and 'more tense'. On the other hand, decreasing the CCT of lighting for the initial activating atmosphere setting was evaluated by the participants as 'cosier', 'less lively', 'less tense' and 'less detached'.

With the changes of the hue of lighting in both atmospheric settings, the cyan and purplish hues were evaluated as 'cosier' and 'less detached' compared with the initial blue hue of lighting. In addition, the initial dark blue was evaluated by the participants in the cosy atmosphere as 'cold' and 'unpleasant'. The yellowish and reddish hues (changed from orange hue) were evaluated as 'cosy' with less frequency than with the initial lighting design. Moreover, the participants evaluated the reddish hue as being 'more tense' and 'unpleasant' for living room lighting. In addition, this hue was generally evaluated as being 'less lively' and 'more detached'.

The increased CCT of lighting in the initial cosy atmosphere setting was evaluated as being 'less cosy' and 'livelier', 'more detached' and 'more tense'. On the other hand, decreasing the CCT of lighting for the initial 'activating' atmosphere setting was evaluated as 'cosier', 'less lively', 'less tense' and 'less detached'. This result is similar to a number of studies that have examined the influence of CCT of lighting, such as the Van Erp study (2008) and the Bronckers study (2009) discussed previously.

The Bašelj and Kobav (2009) study examined the influence of different lighting hues: red, blue, yellow and green at diverse levels of saturation: high, middle and low. A sample of 100 participants, 47 females and 53 males, contributed to the study. The study used the Osgood (1957) semantic differential questionnaire. Yellow and red colours were evaluated as warmer. The blue lighting setting was evaluated as cold, beautiful, calm, similarly to the green lighting hue. It is difficult to compare this result directly to the Choy Calvin study as the blue hue lighting in that study was a combination of lighting hues, where as, in the Bašelj and Kobav study, the lighting setting was evaluated individually.

In Choy Calvin’s (2009) study the yellowish and reddish hues (changed from orange hue) were evaluated as ‘cosy’ less frequently than in the initial lighting design. Moreover, the participants evaluated the reddish hue as being ‘more tense’ and ‘unpleasant’ for living room lighting.

It can be relized from the Kuijsters et al. (2012) and Choy Calvin (2009) studies that the combination of the general white lights and the accent lighting which was applied through the different hues can be used to create different atmospheric impressions such as ‘cosy’, ‘active’, ‘exciting’ and ‘relaxing’. With the combinations of different hues in each of the created atmospheres, however, it is difficult to discern which hue had the dominant influence on the participants perceptions. The combination of the orange hue with the low CCT white lighting, even with the blue hue, was evaluated as ‘more cosy’ and ‘comfortable’ compared with the other lighting settings while the cyan lighting hue, with the combination of high CCT, was evaluated as ‘active’ and ‘exciting’.

Wan’s (2011) study was designed to determine the influence of the lighting hue when static or pulsing, and the ability of these hues to boost stress recovery in the indoor environment. Wan’s (2011) study included two pre-tests with three lighting hues — white, blue and orange, and three speeds of pulsing (fast, medium and slow). The result of the pre-tests showed that orange and white lighting hues had a strong influence on relaxation and the medium and slow pulsing lighting were more effective in reducing stress. Therefore the research design for the main study of Wan (2011) included four lighting settings, orange static lighting, orange pulsing lighting, white static lighting and white pulsing lighting.

Seventy-six participants contributed to the main study. They were asked to watch the pre-selected visual material on a monitor without knowing the purpose of the study; the background of the space lighting was one of the selected lighting settings. Each of the participants took part in the study under one of the four lighting settings. Six of the participants did not complete the experiment for different reasons.

The physiological test involved taking blood pressure, pulse and skin conductance measurements. The state-trait anxiety inventory test (STAI) (Spielberger, Gorsuch and

Lushene 1970)[7] was used in the study for the psychological evaluation. The atmospheric evaluation of Vogels (2008a) was used to evaluate the influence of the lighting. Another four questions tested the individual experience of the lighting in the space of the experiment using the descriptors: negative distraction, salience, positive distraction and annoyance of the space lighting.

The findings of the study showed that, with regard to the STAI, there was no gender effect. Also, the findings of the STAI test showed there were significant differences among the test scores; however, after the stressor (medical images) was displayed, the test results were highest.The results also showed there was no significant difference between the impacts of the colours of the lighting whether they were static or pulsating. On the other hand, the white static light and the orange pulsing lighting settings scored lower on the STAI in the post-baseline and post-wait time periods among the other lighting settings. With regard to the atmospheric evaluation, the colours of the lighting had significant load on three of the four dimensions of the model questionnaire. The influence of lighting was noted in the 'cosiness', 'detached' and 'liveliness' dimensions but not significantly in the 'tenseness' dimension.

The result showed that the pulsing lighting had a significant impact on the 'liveliness' dimension but there was no impact on the other three dimensions. The inter-beat interval test, one of the physiological tests, indicated that the participants felt more relaxed under the pulsing lighting; however, the other physiological tests, galvanic skin response and the standardised galvanic skin response did not show a significant difference in the assessment of the pre-test and post-test.

With regard to the stress reduction findings, measured by Vogel's atmospheric evaluation model, the pulsating orange lighting were evaluated as 'cosier' and 'less detached' than other lighting settings. In addition, pulsating lighting settings were perceived as 'livelier' than static lighting settings and were also shown to boost stress recovery. Likewise, the orange background lighting positively influenced the atmosphere of the indoor environment as it was evaluated as very 'cosy' and 'less detached'. The white static lighting setting was ranked second to the orange with regard to boosting stress recovery.

It could be concluded either that the galvanic skin response testing was not necessarily the most suitable way to measure the influence of the lighting in this study, or the duration of

[7] '*The State-Trait Anxiety Inventory (STAI) is a widely used scale of trait and state anxiety which been used in clinical settings to diagnose anxiety and to distinguish it from depressive syndromes. It also is often used in research as an indicator of caregiver stress*' (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983)

exposure to the lighting was not sufficient. In contrast, the use of Vogel's (2008a) atmospheric evaluation model did indicate significant stress reduction. An interesting result of Wan's (2011) study was that the orange hue lighting was effective in boosting stress recovery. The orange hue was used to give an impression of cosiness and energy and it was widely used in the dining areas. The blue hue is usually evaluated as giving the impression of a relaxing environment; however, in the first two pre-tests of Wan's (2011) study, the blue lighting hue did not seem to boost stress recovery. Boosting stress recovery may therefore require cosiness and a lively atmosphere; the blue lighting hue did not boost stress recovery despite the fact that other studies, Kaya, and Epps (2004), Elliot et al. (2007), and Mehta and Zhu (2009), showed that the blue pigment was linked to stress reduction.

The influence of coloured light on the human physiological system has been examined by a number of researchers such as Wright, Lack, and Kennaway (2004), Glickman et al. (2006), and West et al. (2011). These studies have focussed on nocturnal melatonin rhythm and seasonal affective disorder. For instance, Wright, lack, and Kennaway (2004) examined five light settings: yellow, red, blue, cyan, and green. The aim of their study was to determine whether the short light wavelengths such as (blue, cyan and green) had a significantly higher influence on the melatonin suppression of the human circadian system compared to the long light wavelengths such as (red and yellow). In this study, 42 volunteers (29 females, 13 males) contributed. The study found there were stronger influences on the human circadian system through the use of blue, cyan and green lighting settings rather than with the yellow and red lighting settings.

Another study by Glickman et al. (2006) examined the influence of the blue LED light and red dim LED light on twenty-four patients diagnosed with seasonal affective disorder. The participants were randomly selected to be treated by exposure to blue or red LED light for 45 minutes daily in the morning for three weeks. The study found that the blue LED was more efficient in reducing seasonal affective disorder.

West et al.'s 2011 study examined the influence of blue LED lighting and white cold 4000k light on suppression of melatonin in humans. The study showed that there were health concerns about using the blue light on human eyes. Eight volunteers contributed in this study. The study found that the blue LED lighting was more effective in suppressing melatonin than the white cold light. The study also found that continuous exposure to the blue light for eight hours was safe. The studies by Wright et al., Glickman et al., and West et al. show that coloured lighting hues, especially lighting hues with short wavelengths such as blue, cyan and green, influence not only human emotional states, but also human physiology.

In conclusion, the review of studies examining colour lighting hues and their influence on the atmosphere of the indoor environment has shown that, regardless of using diverse methods (visiting real space, visiting a replication of space, conducting the study in a lighting laboratory and using a booth), that differing hues influence perceptions of the indoor environment. Specifically, the studies have shown that, with the combination of white lighting with hue lighting, a lighting setting with high brightness and less saturation was preferred and evaluated as more positive than lighting with high saturation and less brightness. In contrast, lighting with high saturation and less brightness was evaluated negatively. Hence the saturation of the lighting hue is one of the essential variables which affects the evaluation of the occupants and has an influence psychologically and physiologically on the occupants of an indoor space. It should be noted, though, that most of the studies were conducted in the Netherlands (no doubt because they were supported by Philips). The concern about ‘seasonal affective disorder’ due to imbalances of daylight exposure throughout the year has led to many researchers in the Netherlands and the north of Europe examining the influence of the hue of lighting on the atmosphere of the indoor environment. However, it is not known whether similar results would be demonstrated in other countries.

2.3 The importance of artificial lightingin a hotel guest room

Hotel guest rooms are the spaces provided for travellers as alternatives to their residences and work-stations. Hence, the hotel guest room plays an important part in their daily activities; the rooms need to be multipurpose spaces with flexible lighting systems appropriate for a wide range of needs of travellers from different backgrounds and cultures.

The nature of many people’s work requires them to spend nearly a third of their year in hotels (Chang 2004). Studies have found that tourism is one of the major businesses around the world and is growing (Oleskow-Szlapka, Stachowiak and Golinska 2011). Along with the growth in client requests for hotels, mainly from business travellers, there are new concerns about increasing energy costs. These factors make hotels an interesting subject to study in regard to their economic importance and potential for saving energy costs. Utilising

LED lighting in the interior spaces is one of the methods that have been used to reduce energy consumption.

Specialists in tourism and hospitality endeavour to build a positive relationship with customers to achieve their satisfaction. They plan to establish a long-term relationship with their customers, referred to as customer loyalty. Studies take into account the services provided in the hotels and the facilities of the hospitality buildings. Two researchers, Bitner, and Booms (1981); and Bitner (1992) coined the term ‘servicescapes’ to refer to the built environment, particularly indoor hotel environments in relation to their role in providing service to customers. These studies demonstrate the influence of a hotel’s indoor environment on client behaviour and loyalty to the hotel, while interior design studies mostly aim to understand the influence of the indoor environment on the occupant of the indoor space.

One of the servicescapes studies was carried out by Countryman and Jang (2006) to examine the hypothesis that some of the components of the hotel lobby atmosphere had a significant influence on hotel customers. The components were style, layout, colours, lighting, and furnishings. The study used the Semantic Differential measuring tool to measure the responses of 102 participants to coloured photographs of the lobbies of four hotels. It was shown that three of the five components which were examined significantly influenced the participants’ responses. These three components were layout, colour and lighting, with colour having the highest influence among the elements. The Countryman and Jang (2006) study demonstrates that the lighting system in hotels, specifically hotel guest rooms, is one of the components which influence the satisfaction of hotel guests. This study further supports the studies, discussed previously in Sections 2.2.1 to 2.2.4, which indicated that the lighting of the indoor environment has an influence on the wellbeing of users. The next sections discuss the influence of lighting attributes such as lighting distribution, lighting brightness and CCT of lighting in hotel guest rooms.

2.3.1 Basic lighting principlesfor hotel guest rooms

Three kinds of lighting distribution are usually considered in the lighting design for indoor spaces. The first is general lighting or ambient lighting, which gives the user of the space the ability to perceive his/her surroundings and move and act safely. The second is task lighting. This kind of lighting is correlated with specific needs, such as lighting over the kitchen bench where food is cut and prepared, and direct lighting for reading. This kind of lighting is mostly created by using directional lighting fixtures.The third kind of lighting is accent lighting, which is used to create an aesthetic impression or mood in the indoor environment through emphasising the overall design of the environment or individual components such as accessories, art work, indoor plants or water features. Different lighting output sources can be used to produce accent lighting. Lighting fixtures that can be adjusted in brightness and hue are usually preferred.

The Australian/New Zealand Standard AS/NZS 1680 published the required lighting levels for the indoor environment that are acceptable for different space usage as a guide for lighting designers working in both countries. The AS/NZS 1680 shows that for safely, movement and orientation in indoor spaces, the level of brightness should be on average 40 lux. The AS/NZS 1680 also highlights that for intermittent use of an indoor environment the brightness level should be at least at 80 lux. For simple tasks such as infrequent reading the required level of illumination is 160 lux (AS/NZS 1680.2 2008). These three levels of lighting brightness are suitable for most of activites which usual take place in a hotel guestroom (safe movement within the space, passive relaxation and finally doing simple tasks such as light reading).

Therefore, based on these standards, the minimum levels of lighting that are generally applicable for use in hotel guest rooms vary from 40 lux for safe movement to 160 lux for simple tasks. There are different ways to distribute lighting in the design of hotel guest rooms. Each designer has his/her own view of the optimum lighting situation (Cullen 1986). Curtis (2003) suggests that hotel guest rooms are multi-purpose spaces which need precision in lighting design. Karlen and Benya’s index (Karlen and Benya 2004, 180, cited in Pae 2009, 27) provides a basic three-point guide for the design of hotel bedroom lighting, though there are a number of variables which may affect the design:

1. A ceiling surface luminaire can be mounted in the entry to distribute light widely, which is especially needed to illuminate the closet.
2. A lamp can be mounted on the wall between the beds. The lamp usually has two separate bulbs and shades, providing light for either or both beds. This lamp can be portable, but plugged into the wall.
3. Table and floor lamps can be located near each task.

This guide is based on the premise that a hotel guest room needs general lighting as well as lighting located for specific tasks.

2.3.2 The influence of artificial lighting in a hotel guest room

A few studies have been conducted to investigate the influence of lighting in hotel guest rooms. The following section reviews research examining the influence of lighting for one or more of the lighting properties. The lighting properties include brightness and CCT. One of the studies reviewed here examined the kinds of activities carried out by occupants of hotel guest rooms. The second study reviewed here examined how different cultures evaluated hotel guest rooms under different lighting settings.

These studies have concentrated on the functional use of lighting in hotel room environments. The Fernandez, Giboreau, and Fontoynont (2012b) study examined, from the user's perspective, the influence of lighting in a hotel guest room in Europe. The study was designed in three phases. The first phase aimed to evaluate the influence of lighting on users of the hotel room by interviewing 18 participants. The interviews revealed the factors affecting participants' evaluations. These factors were 'interaction with natural light, 'the quality of light', and the 'convenience' of facilities. Perceptions were also influenced by the user's 'activity' (Fernandez, Giboreau, and Fontoynont 2012a, 2). Lighting conditions in six situations were found to influence the participants: their first entrance into the hotel guest room, their relaxation period, their work period, when experiencing insomnia, the appearance of conditions with light on and light off. According to Fernandez, Giboreau and Fontoynont (2012a, 2) it is vital to be able to produce a lighting setting appropriate to the different requirements of a hotel guest room.

The second phase of the study was conducted to determine the considerations which could affect the personal evaluation of the lighting in the indoor environment. Thirty-nine two-dimensional images of a hotel room were produced using the V-Ray rendering program and classified into four lighting sets. The first set comprised the image of the hotel guest room under the exposure of bright white light at low CCT. The second set comprised the images of the hotel guest room under the exposure of bright white light at a high level of CCT. The third set comprised the images of the hotel guest room under the exposure of dark white light at a low level of CCT, and the fourth set comprised images of the hotel guest room under the exposure of dark white light at high level of CCT. The results revealed that the colour correlated temperature of light affected the indoor environment evaluation. The white lighting with high CCT was less significant than white lighting with low CCT. Different preferences were revealed according to the differing brightness and CCT of the lighting conditions.

The third phase aimed to explore the role of lighting brightness and colour temperature (CCT) on the occupants of the hotel room. The participants were asked to evaluate four lighting conditions using three kinds of activities. The activities were relaxation, work, and looking at themselves in the mirror. Two lighting characteristics were examined in this phase of the study: lighting brightness, 30% (Dim); 100% bright and CCT warm white (WW): 2700 °K; cool white (CW): 4200 °K (Fernandez, Giboreau, and Fontoynont 2012a 177). It was shown that for relaxation, a warm dim atmosphere was preferred. In the other two situations — working or looking in a mirror — the preference was for brighter lighting with high CCT which provided clear visual comfort.

This study is important as it identifies the main activities which the residents of the hotel room may conduct, as well as highlighting the most appropriate lighting for each of these activities with regard to the brightness of lighting and the CCT of lighting. However, the study did not mention the CRI of the lighting setting; thus it would be difficult to determine the CRI reading in the simulation part of the study using the V-Ray rendering program. It is unfortunate that in the third part of the study there is no CRI reading because the CRI of the lighting may have influenced the participants' responses, especially while looking in the mirror as human skin changes under different lighting colour metrics. For example, if the colour metric of the lighting rate is low the person's skin looks pale.

Another study which also examined the influence of lighting in a simulation of a hotel guest room in the USA was conducted by Pae (2009) in order to understand the cultural differences between Americans and Koreans when considering the light setting. The study considered the influence of the brightness and CCT of lighting in a hotel guest room. Similar to the previous study this study investigated different lighting settings: bright warm 2500K - 3500K lighting condition (A), bright cold 5000K lighting condition (B); dim warm condition 2500K – 3500K (C) and dim cold lighting 5000K lighting condition (D). Figure 2.14 shows graphic representation of the result of Pae's (2009) study. The study used Mehrabian and Russel's (1974) pleasure, arousal and dominance (PAD) questionnaire model to evaluate the influence of lighting on the hotel guestroom users. The study used simulated 2D images of the hotel guest room which were produced using software programs Auto Cad 2008, 3D studio 9 and V-Ray.

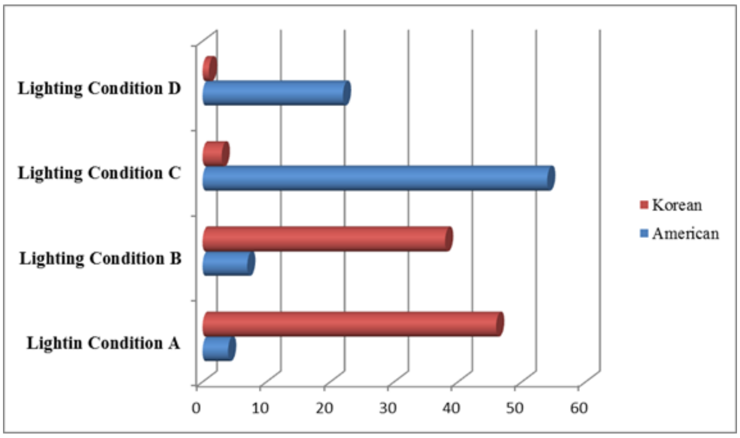


Figure 2.14 Evaluation of lighting brightness and CCT based on Pae (2009) study results.

Figure 2.14 shows that dim warm lighting was preferred by the American participants in the simulation of the hotel room. The Korean participants, however, preferred bright warm light and considered the bright lighting to be more arousing than dim lighting, in contrast to the American participants who considered dim lighting as more arousing than bright lighting. The results showed that the guestroom with low brightness and low CCT was preferred by the American participants; the guestroom with high brightness and low CCT was preferred by the Korean participants.

The review of the two studies investigating the lighting in hotel guest rooms has shown that different lighting settings suit different activities in a hotel guest room. In addition, one of the two studies showed that participants from different cultural backgrounds preferred different lighting settings. This has implications for the tourism industry. These two studies examined two of the lighting properties: lighting **brightness** and the **CCT** of lighting. Studies investigating the influence of CRI of lighting have not been found. In addition, no studies have been located that have particularly investigated the influence of the *hue* of the lighting, even though the hue of the lighting is being used in hotels such as St Martin's, London (Curtis 2003). An examination of the lighting hue in hotel rooms may uncover differing requirements with regard to activities or cultural preferences.

2.4 Chapter Two Conclusion

Through a review of the literature on artificial lighting in regard to particular properties such as lighting brightness, the correlated colour temperature (CCT) of lighting, the colour rendering index (CRI) of lighting, as well as coloured lighting with different hues, it was established that different methods have been used to examine the influence of lighting systems on the indoor environment.

It was also found that most of the lighting properties had a significant influence on the occupants' evaluations of the indoor environment. The hue of the lighting was the most interesting property, as participants' evaluations of its influence were wide ranging. Few studies have examined how bright the atmosphere of the indoor environment appears under different lighting setting hues.

In addition, few studies have investigated the *influence* of lighting in hotel guestr ooms; besides, these studies have focussed on functional task lighting more than casual lighting for relaxation. Studies that have examined the influence of lighting in hotel rooms have focussed on the **brightness** and **CCT** of lighting. No current studies have examined the influence of lighting hue on the atmosphere of the hotel guest room.

LED lighting technology continues to develop, and is now widely accepted as an indoor lighting system. However, the aesthetic and psychological influence of LED lighting technology requires more in-depth investigation.

The current study aimed to address the lack of research on the influence of lighting hue by investigating the atmospheric influence of RGB LED lighting in a hotel guest room. The study investigates the influence of seven LED lighting hues (white, red, yellow, green, cyan, blue and magenta) at two levels of brightness (high and medium) on casual lighting for relaxation; CCT and CRI of white lighting are considered as a baseline for comparison. Figure 2.15 shows how the exploration of artificial lighting has led to the current thesis.

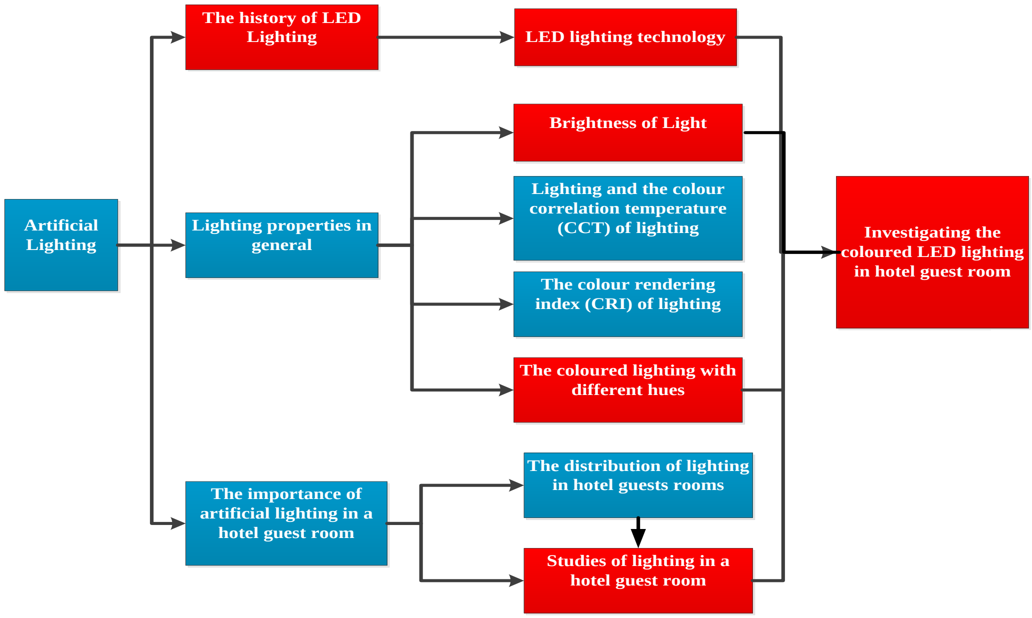


Figure 2.15 Action paths in exploring artificial lighting

Chapter Three reviews the measuring tools used to evaluate the influence of lighting in the indoor environment. Chapter Three also reviews the methods that were used to evaluate the influence of lighting in the indoor environment.

3. Evaluation of the human response in the environment

This chapter presents a discussion of the methodology chosen for this study. Specifically, this chapter presents a review of the established approaches used to evaluate the atmosphere created by lighting in indoor environments. The chapter then discusses the various processes of testing the influence of lighting in the indoor environment. Figure 3.1 shows the action path which led to the design of the study methodology.

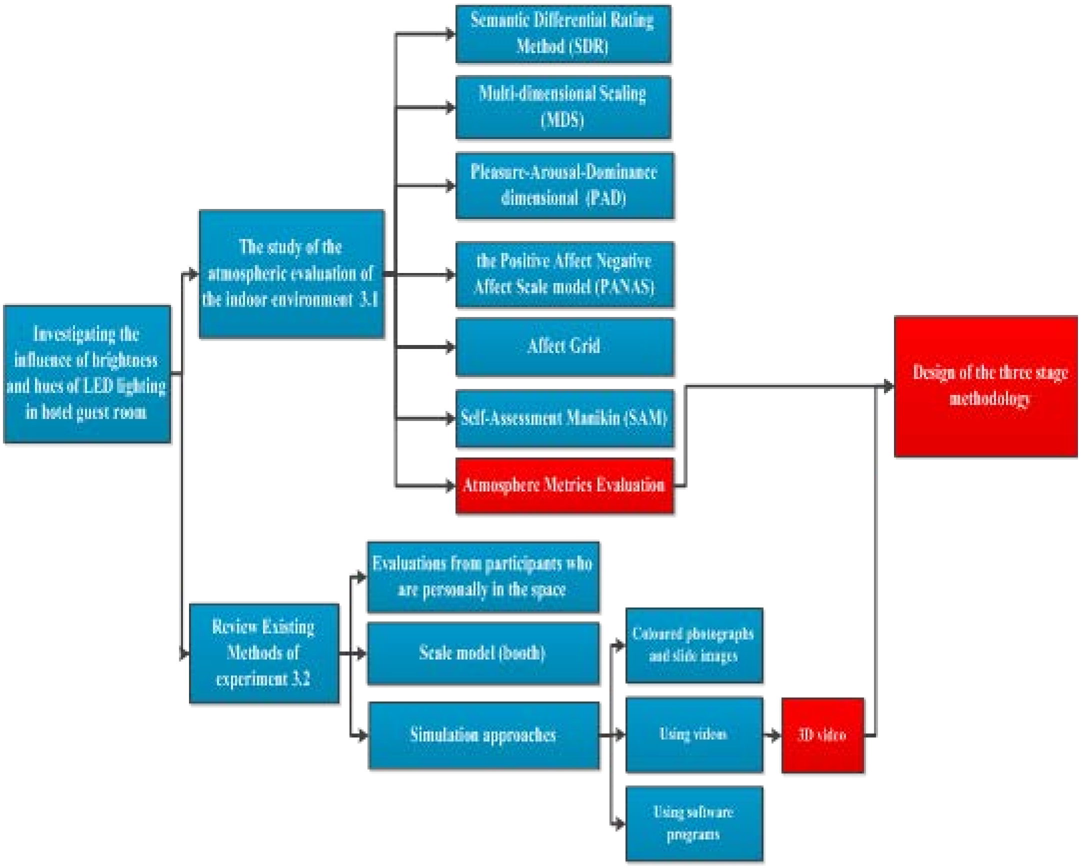


Figure 3.1 Action paths for experimental approaches to atmospheric evaluation and experimental models leading to study.

3.1 The evaluation of the atmosphere of the indoor environment

Studying the influence of lighting conditions on occupants of the indoor environment is of interest to interior designers, the people who work in the lighting industry and environmental psychology researchers.

This section reviews a number of the measuring tools which have been used by researchers and professionals in the field to develop a language to evaluate the influence of lighting in the indoor environment. Light should provide occupants of the space with an appropriate atmosphere as well as providing appropriate light levels for task accomplishment (Vogels 2008a). The role of lighting is therefore not limited to meeting the needs for functionality; it exceeds that by creating the atmosphere of the indoor space through interaction with the rest of the components of the interior space. To understand the influence of lighting on the perceived atmosphere of the indoor environment, researchers need measuring methods.

Researchers in the field of environmental psychology such as Osgood, Suci and Tannenbaum (1957); Flynn et al. (1973); Mehrabian and Russel (1974a); Mehrabian and Russel (1974b) Watson, Clark and Telleggen (1988); Russell, Weiss and Mendelsohn (1989) and Bradley and Lang (1994), have used verbal and non-verbal methods to study the influence of the indoor atmosphere on occupants. Both kinds of methods are based on self-reporting by individuals to reflect their emotions. Non-verbal methods are 'implicit verbal, gestural, body position cues plus the facial expressions' (Russell and Mehrabian 1977, 2). The self-report technique has been usedby the researchers to evaluate the influence of environments on people.

One of the earlier self-report methods, the Semantic Differential Rating method (SDR), has been applied in studies examining the influence of lighting in the indoor environment. The SDR method has been used to find the correlation between physical criteria and subjective responses using written or verbal response (Tifler and Rea 1992). It uses regularity – of - usage terms — polar opposite descriptive terms divided by a five to seven point rating scale (Osgood etal. 1957).

Osgood etal. (1957), in order to use the SDR more efficiently, devised terms which described the emotional state of individuals in a range of environments. They found three factors to be useful: 'evaluation', 'potency' and 'activity'; each of these factors comprised a number of polar opposite descriptive terms divided by a five or seven point rating scale. The 'evaluation' factor comprised the polar opposite terms: good-bad, kind-cruel, wise-foolish, beautiful-ugly, happy-sad, candid-deceitful, sociable-unsociable, friendly-unfriendly, willing-unwilling, honest-dishonest. The 'potency' factor comprised the polar opposite terms: hard-soft, strong-weak, heavy-light, masculine-feminine, and deep-shallow, potent-impotent, severe-lenient, domineering-lax, brave-cowardly, and large-small. The 'activity' factor comprised the polar opposite terms: active-passive, fast-slow, difficult-easy, hot-cold, motivated-aimless, moving-still, excitable-calm, alive-dead, emotional-unemotional, and complex-simple (Osgood et al. 1957 336-337).

A study by Flynn et al. (1973) adopted Osgood's SDR measurement tool to investigate the influence of the environmental lighting on ninety-six observers. Six different lighting settings were examined in the study using the SDR scale. The result of the study, which also included factor analyses of the SDR measuring tool terms, yielded five factors:'evaluative', 'perceptual clarity', 'spatial complexity', 'spaciousness' and 'formality'. Three of the factors – 'general evaluative', 'perceptual clarity' and 'spaciousness' - indicated a substantial difference between the six lighting settings.

Flynn et al. also developed the Multi-dimensional Scaling (MDS) model for evaluating the similarities and differences between different indoor environments. This model included a ten-point range scale instead of a seven-point rating scale as in the Osgood et al. (1957) model. The results demonstrated that the most useful dimensions were: 'peripheral-overhead', 'uniform-non uniform', and 'bright-dim'.Their study concluded that either the SD or the MDS model, or both used together, could be a useful tool to evaluate the indoor environment because either singly or together they could produce significant results with regard to the influence of lighting on the indoor environment; in addition, the participants could discriminate between different lighting settings.

Another dimensional approach is the Pleasure-Arousal-Dominance dimensional approach (PAD) developed by Mehrabian and Russel (1974b). Their scale of pleasure refers to the equilibrium of positive or negative pleasure emotion, dependant on a dimension of pleasantness. The dimension included the polar opposite terms: unhappy-happy; annoyed-pleased; dissatisfied-satisfied; melancholic-contented; despairing-hopeful; and bored-relaxed. Arousal is the capability to respond within that dimension ranging from sleep to frantic excitement. The dimension included the bipolar pairs of terms: relaxed-stimulated; calm-excited; sluggish-frenzied; dull-jittery; sleepy wide-awake; unaroused-aroused. Dominance signifies that the individual has freedom to act; in other words, he/she has the ability to control the surrounding environment. This dimension included the bipolar term pairs: controlled-controlling; influenced-influential; cared for-in control; awed-important; submissive-dominant; guided-autonomous. Many researchers have adopted this model (e.g.,Baker and Cameron 1996; Baker, Levy and Grewal 1992; Greenland, and McGoldrick. 2005; Lang et al. 1993; Mehrabian and Russel 1974b; Russell, and Mehrabian 1977 and Pae 2009) as it has been shown to produce reliable data for marketing, tourism and psychology studies.

Both the Osgood et al. (1957) and Mehrabian and Russell (1974a) models use a self-report evaluation. Both models include three inter-correlated dimensions. For instance, the first dimension of the Mehrabian and Russel model, ‘pleasure’, has a similar meaning to the first dimension, ‘evaluation’, of the Osgood model. Moreover, the second dimension in the Osgood model, ‘potency’, has the same main theme of the third dimension, ‘dominance’, of the Mehrabian and Russel (1974) model; both dimensions in the two models use terms which reflect the ability to control the surrounding environment. In addition, the third dimension of the Osgood model, ‘activity’, is equivalent to the second dimension of the Mehrabian and Russel model, ‘arousal’. Both models have been adopted by a large number of researchers in the field of environmental psychology. Both models cover an important part of human emotional interaction with the environment, such as the emotional states, of comfort, activity and control.

Yet another model has been used by a number of researchers – the Positive Affect Negative Affect Scale model (PANAS) developed by Watson, Clark and Telleggen (1988). This model contains ten Positive Affect expressions namely, attentive, interested, alert, excited, enthusiastic, inspired, proud, determined, strong and active. The ten Negative Affect expressions are distressed, hostile, irritable, angry, scared, afraid, ashamed, guilty, nervous and jittery. The model was based on using two opposite dimensions. The model may not describe the environment semantically in the same way as the Mehrabian and Russel (1974) and Osgood et al. (1957) models do; however, the Watson, Clark and Telleggen (1988) model can facilitate the subjective evaluation of occupants of an environment from different semantic perspectives by considering the positive and negative dimensions and the three emotional affect stimuli — comfort, activity and control.

Another model developed by Russell, Weiss and Mendelsohn (1989) proposed a singular item scale to evaluate pleasure and arousal, called the Affect Grid: A Single-Item Scale of Pleasure and Arousal. This is a two-dimensional grid, with one axis signifying the level of pleasureand the other axis signifying the level of vigilance. Figure 3.2shows the Affect Grid.

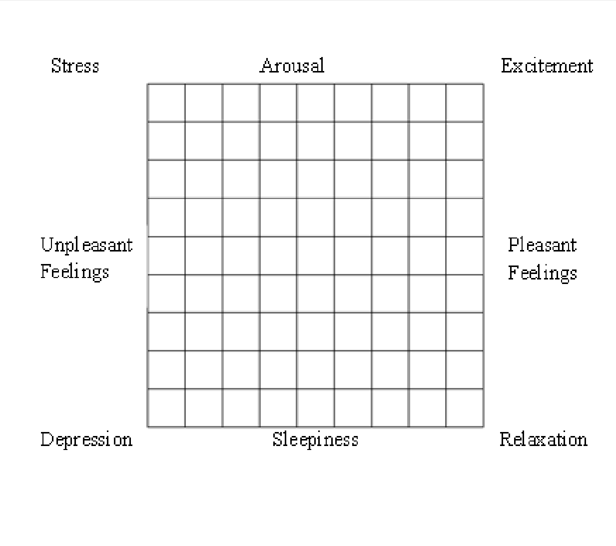


Figure 3.2 The Affect Grid: A Single-Item Scale of Pleasure and Arousal (Russell, Weiss, and Mendelsohn, 1989,494)

The model was designed by the researchers to create a compact measuring tool which could reduce the time of evaluation and be used in subjective and descriptive studies. The model, while reducing time, still has acceptable validity, especially when a large number of variables are being examined.

In yet another model by Bradly and Lang (1994), using the three dimensions of the PAD model, the visual observations and evaluation of the participants are involved, but without the disruption of oral description. The model, the Self-Assessment Manikin (SAM), instead allows the participants to evaluate a situation through the use of selected images (see Figure 3.3)

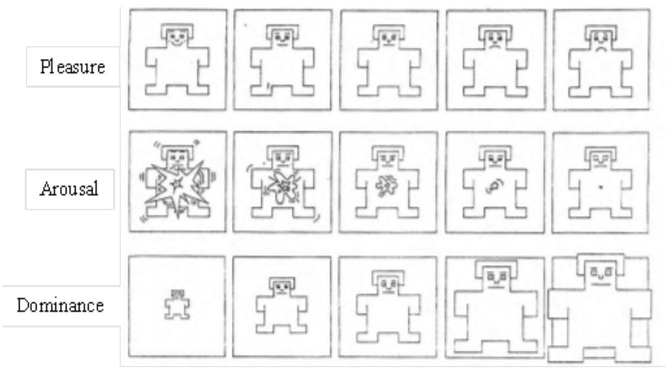


Figure 3.3 The Self-Assessment Manikin: Source: Morris (1995, 2)

The model includes a five-character scale for each of the dimensions. The evaluator can mark between the characters to produce a nine-point scale. The pleasure dimension is represented by five graphic characters, starting with a smiling figure representing happiness and ending with a sad figure representing unhappiness. The arousal dimension is also represented by five graphic characters, starting with an excited figure with open eyes and ending with a sleepy figure with closed eyes. In addition the dominance dimension is represented by the same number of graphic characters starting with a very small figure representing submissiveness and ending with a very large figure representing control or dominance (Morris 1995). The model has been tested in a number of studies such as those of Morris and Bradley (1994) and Morris (1995), in which correlation analysis was conducted using both the SAM and the PAD models; a significant correlation was found between the pleasure and arousal dimensions and a smaller, but still significant correlation, with the dominance dimension (Morris 1995).

The previous studies summarise the advantages of the SAM model: it is easy to use by different age groups (children and adults) and it only takes a short time for the subjects to respond. Moreover, it is culture free and language free. Therefore, as demonstrated by a number of studies (Lang, Greenwald, Bradley, and Hamm 1994; Müller et al. 1994), it can be used in different countries.

The models discussed here have been used to investigate the influence of the built environment on people, and to explore affective states such as mood and emotion with regard to environments. SD, MDS, PAD, PANAS, Affect Grid and SAM models are used to assess the emotional and mood states of individuals and elicit responses about their experience in a specific situation. Lazarus explains, however, that the emotional affective state of people in the space can be affected by numerous non-environmental aspects (Lazarus 1991). For instance, a person could feel uncomfortable in a comfortable environment when she/he has numerous tasks to do in a short time (Bronckers 2009; Van Erp 2008; Vogels 2008a and Vogels 2008b). Hence, measuring emotion may not be the best way to assess the effect of the environment on people's experience.

Vogels (2008a) developed a psychometric instrument to reduce the non-environmental effects which could influence people's assessment of a space. Specifically it was designed to quantify the perceived atmosphere of an indoor environment in the Netherlands. The development of Vogels' model consisted of two stages. The first stage involved the linguistic construction of the model in order to find out what terms could be used in the form of a questionnaire. Forty-three local Dutch individuals were asked to list the terms which they could use to describe indoor spaces in which they had been. One hundred and eighty four different Dutch terms were collected. The terms were classified into three groups:

- Group of adjectives associated with emotions or moods;
- Group of adjectives associated with the atmosphere of the indoor environment;
- Group of adjectives to give more or less objective description of the indoor environment.

This list was further reduced and translated into English by Vogels.

Table 3.1 Vogels (2008) Atmospheric Model — the English terms for atmosphere with their original Dutch terms based on Vogels (2008).

English term for atmosphere	Original Dutch term	English term for atmosphere	Original Dutch term
Accessible	Toegankelijk	Musty	Bedompt
Boring	Saai	Mysterious	Mysterieus
Business	Zakelijk	Oppressive	Beklemmend
Cheerful	Vrolijk	Personal	Persoonlijk
Chilly	Kil	pleasant	Gemoedelijk
Cool	Koud	pleasant	Gezellig
Cosy	Behaaglijk	relaxed	Ontspannen
Cosy	Knus	restless	Onrustig
Depressed	Deprimerend	romantic	Romantisch
Detached	Afstandelijk	Safe	Geborgen
Exciting	Enerverend	Spatial	Ruimtelijk
Formal	Formeel	Stimulating	Stimulerend
Hospitable	Gastvrij	Tense	Gespannen
Hostile	Vijandig	Terrifying	Beangstigend
Inspiring	Inspirerend	Threatening	Bedreigend
Intimate	Intiem	tranquil	Rustgevend
Lethargic	Sloom	uncomfortable	Ongemakkelijk
Lively	Levendig	uninhibited	Ongedwongen
Luxurious	Luxueus	Warm	Warm

The second stage of the study applied the questionnaire to a series of four experiments to test whether it could discriminate between the atmospheres of diverse environments. The first experiment involved eight participants visiting and evaluating eleven retail shops. In the second experiment, sixteen participants evaluated the atmosphere of a fashion shop in a lighting laboratory. The third experiment was conducted with 29 participants in a lighting laboratory without identifying the use of the space. The fourth experiment was similar to the third experiment,with 32 participants. All the previous experiments were conducted to evaluate the influence of the lighting setting on the perceived atmosphere of the indoor environment. The statistical analysis of the combined data in the four experiments revealed four factors. The four factors were ‘cosiness’, ‘liveliness’, ‘tenseness’ and ‘detachment’ (Vogels 2008b). Vogels’ model provides a useful method to measure the perceived indoor atmosphere, as it can reduce the influence of non-environmental effects in the evaluation process. As stated by a number of researchers, atmospheric evaluation of the indoor environment is more revealing than evaluation of the occupants’ emotional state and mood state (Bronckers 2009; Custers 2008; Van Erp 2008).

As the current study adopted Vogels’ model, which had been designed to be used in the Netherlands in Dutch, modifications were required before the questionnaire could be used with English speaking participants from Western Australia. Chapter Five describes the process of modifying Vogels’ model for use as a measuring tool in the current study.

A review of existing approaches to understanding the influence of interior lighting on the indoor environment

A new lighting technology, Light Emitting Diodes (LED), emerged in the 1960s. The properties of LEDs differ from the properties of incandescent and fluorescent lighting. Due to the increasing use of LED lighting in indoor environments there is a growing need to better understand the interaction between humans and their surroundings which incorporate LEDs.

Hospitality spaces, especially hotels, have been increasingly using LED lighting as feature lighting in areas such as restaurants, bars and lobbies. The intention of the current study was to determine the influence of LED lighting in a hotel guest room. Specifically, this study aimed to:

- Determine the influence of differing lighting colours (hues) in a hotel guest room;

- Determine the preferred LED coloured lighting (hues) in a hotel guest room; and
- Determine the influence of differing intensities of LED lighting in a hotel guest room.

3.2 Review of existing methods

All of the methods used to evaluate the comparative effects of various types of indoor lighting on the relationship between physical stimuli and mental phenomena focus on lighting-type and various physical and social aspects of the installation space. The research methods of various researchers:Corry and Thompson (1993); Heft and Nasar (2000); Ashmore and Richens (2001); Maunder et al. (2001); Sarawgi (2006); Park (2007); Shih and Hu (2007); Cubukcu, Cubukcu and Kahraman (2008); Vogels (2008); Choy Calvin (2009); Bronckers (2009); Whitehead (2010); Hwang, Lee and Kim (2011); Salters and Seuntiens (2011); Mizuno, Nakategawa and Kume (2012) and Post (2012) are reviewed below in order to provide a context for the research methods adopted in this study.

According to previous studies which have investigated the impact of indoor lighting, three locations have been used. Participants were personally in the space, such as in the studies of Flynn et al. (1973), Vogels (2008), Van Erp (2008), Custers (2008), Bronckers (2009), Choy Calvin (2009), and Dijkstra (2010) or looking at scale model mock-ups (booths) such as in the studies of Thompson and O'Reilly (2006) and Mizuno, Nakategawa and Kume (2012); or viewing simulations that imitate actual conditions, as in the studies of Flynn et al. (1977), Corry and Thompson (1993), Whitehead (2010). Studies carried out in each of these three locations are summarised below.

3.2.1 Evaluations from participants who were personally in the space

The response by participants to aspace can be evaluated either by having them visit the space or by replicating the space in a laboratory. The participants, after being in the space, express their impressions by answering a questionnaire.Vogels (2008) conducted a study on the atmosphere of indoor spaces with the assistance of participants visiting real shops in Eindhoven, the Netherlands. She combined the data from this experiment with the data from three other experiments that were held in an experimental lighting laboratory (one of which was a replication of a fashion store while the other two experiments were conducted in empty laboratories). The analysis of the data from the four studies shows that 38 Dutch-written terms previously discussed in Section 3.1 could be used to describe the atmosphere of indoor spaces.

Some or all of these terms have been used by several researchers such as Van Erp (2008); Bronckers (2009); Choy Calvin (2009); Custers (2008); Dijkstra (2010); Atlı (2010); and Varkevisser, Raymann and Keyson (2011). For example, Bronckers (2009) examined the influence of the hues and brightness of lighting in a laboratory to explore the influence of these lighting features in a general indoor environment. As this experiment was about the general effects of colour, not colour in a specific space or type of space, there was no attempt to create a sense of a particular type of space within the laboratory; it was simply a measurement carried out in a laboratory. The findings of Bronckers' study were summarised in Section 2.2.4, 'Lighting hue'.

Figure 3.4 The lighting hues in the laboratory space of Bronckers study. Source: Bronckers (2009, 18)

Another study by Choy Calvin (2009), examined the impact of lighting properties in a living room setting, created within a laboratory. The properties of lighting were varied and included brightness, colour temperature and hue, and the atmosphere was assessed in terms of aspects varying from cosiness to activeness. The study found that high brightness of lighting was evaluated as less cosy, less tense and more lively and detached. The low colour temperature lighting was evaluated as cosier, less lively and less detached.

It can be concluded from these studies that an effective method to evaluate the influence of lighting in the indoor environment is when the participants are within the space.

3.2.2 Scale model (booth)

Various studies have used scale model booths to examine the participants' reactions to lighting, including: Thompson and O'Reilly (2007; Hwang, Lee and Kim (2011) and Mizuno, Nakategawa and Kume (2012). Using booths in lighting research is an effective way to compare two or more lighting settings. These settings enable examination of the influence of colour temperature, brightness, rendering of colour index and/or spectral power distribution. For instance, Thompson and O'Reilly's (2007) study used a double booth experimental setting to study how participants perceive different white LED lighting settings with regard to their colour rendering index (Thompson and O'Reilly's 2007) (see Figure 3.5). The researchers compared seven sources of LED lighting that had the same light output in brightness and colour temperature but a different colour rendering index. They found that, when a different colour rendering index is applied, the colour chart sets appear differently. These studies have demonstrated that the double booth method approach can be used to compare two or more lighting settings.

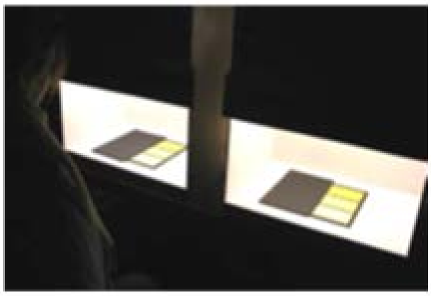


Figure 3.5 The side to side booth design of Thompson's . Source: Thompson et al. (2007, 4)

Another study by Thompson (2007) examined the influence of the colour rendering index of white lighting in an indoor environment. She used two kinds of double booths. The first one, the side by side booth, is shown in Figure 3.5. The participant using the side-by-side booth only needs to look forward. The face-to-face booth is shown in Figure 3.6. When using the face-to-face booth, the participant needs to turn his/her head to view the scene through each window. Each kind of booth provides a different angle from which to view the scene. The results in both booth tests were similar. It was found that, by applying the change in colour rendering index (CRI), the colour under the lighting appeared different. The correlations between the colour rendering index applied and the lighting differences observed were similar between the two kinds of booths.

Figure 3.6 Face to face booth. Source: Thompson et al. (2007, 4)

At a further stage in Thompson's (2007) study, the triple chamber method was used to compare the appearance of colours under different white lighting settings in an indoor environment. The triple chamber setting was used to present a 1:1 model of a real life scenario, as shown in Figure 3.7 (Thompson 2007). Two scenes were presented at the same time for the participants to compare; incandescent lighting and different LED lighting settings were used for each scene. The result was different from the previous stages with the two kinds of double booths.The change of the CRI in the lighting was not noticed by the majority of participants in this study. The researcher found that the main difference in perception was due to the angle at which the participants viewed the life scenarios in the three chambers.

Figure 3.7 Triple chamber in Thompson (2007) study. Source: (Thompson et al. 2007, 4)

The Thompson (2007) study demonstrated that direct observation of colours (using double booth) and observing the colours in a life scene using the same lighting settings produced differing results. Based on this research it seems that, to observe small details or objects, the double booth method is preferable. On the other hand, to observe the impact of lighting settings on the atmosphere of an interior space, the three chamber method seems to be preferable.

Other studies have used a single booth in such a way that participants can view the setting through a small window or opening in the booth. A study by Mizuno, Nakategawa and Kume (2012), using the single booth method, examined the physiological and psychological influences of different colour hues of lighting on humans (see Figure 3.9). Their study used the Visual Analogue Scale (VAS) to examine the psychological influence of lighting on the participants and the Nasal Skin Temperatures (NST) test to examine the physiological influence of lighting on the participants. Three lighting colours were used for the test — red, yellow and blue. Their results showed that blue and yellow lighting had a positive psychological influence on the participants while red lighting had a negative influence. Physiologically, the study showed a slight NST change with the colour lighting changes; the greatest change was with the red lighting. None of the results, however, showed a significant difference. The study showed, nevertheless, that single booths are a practical means to examine the direct physiological and psychological influences of lighting on humans. Figure 3.8 shows single booth design.

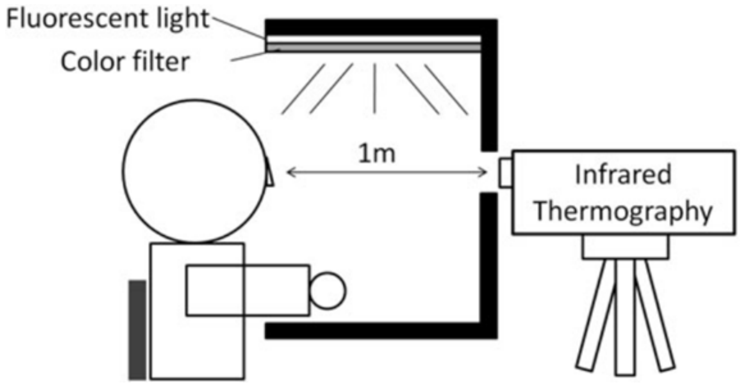


Figure 3.8 Single Booth design. Source:Mizuno, Nakategawa and Kume (2012, 520)

Another study, also using the single booth method, by Hwang, Lee and Kim (2011) evaluated the effect of different lighting settings on the participants. To evaluate the influence of the lighting settings, the participants sat in front of the booth. The study examined different coloured LED lighting settings to determine the most suitable lighting for comfort and effective communication in a living room scene. Seven lighting hues and three levels of saturation were used in the study. The colours were red, green, blue, cyan, magenta, yellow, and white (Hwang, Lee and Kim 2011). That study's findings were summarised in Section 2.2.4 'Lighting hue'.

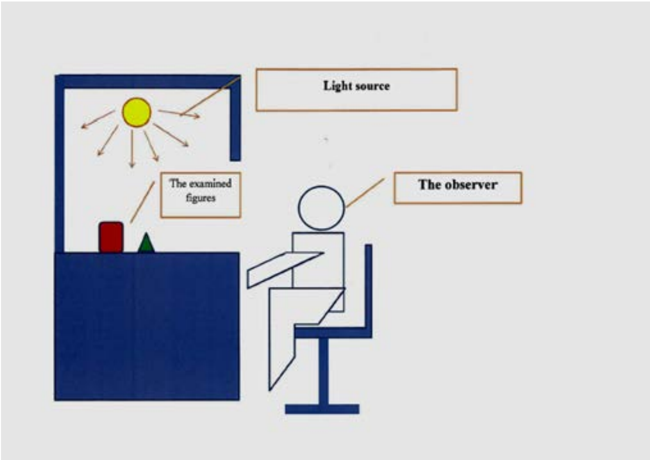


Figure 3.9 Single Booth design

It can be seen from these four studies that the use of booths to examine and compare the influence of different lighting settings in the indoor environment is feasible. In addition, the use of booths is a practical means of examining the direct physiological and psychological impacts of lighting on humans. The main disadvantage of using booths to study the effect of different lighting settings on the indoor environment is that the participants can only evaluate the atmosphere of the indoor environment from limited angles and a fixed sitting position.

3.2.3 Simulation approaches

Simulation approaches can include the use of photographs, videos or models of settings and computer graphic programmes. Utilising simulation images such as colour photographs, slides and motion images (two-dimensional videos) is acceptable in psychological studies of environments, according to several researchers, based on their empirical and theoretical studies (Chayutsahakij 1998;Marsden 1999; Nasar 1992, 1994; Sommer 1997; Stamps 1990). In the following sections a brief discussion is presented of studies which have used slide photos, screen monitors and videos to evaluate indoor and outdoor environments.

3.2.4 Coloured photographs and slide images as simulation tools

According to Pae (2009, 31), ‘Behavioural simulations (showing photographs, videos, or models of settings) are imitations of actual conditions and they are intended to resemble the real situation in many of its functional characteristics without being mistaken for it’.

Flynn et al. (1977) examined the quality of six lighting settings as well as the use of slide images instead of participants being in the actual space being examined. The data were compared with data collected from participants actually in the space. The results showed that it is feasible to use slide images to evaluate the built environment under lighting settings as there was a close correlation between their 1977 study and a previous study they had undertaken in 1973. The study also demonstrated that this method can reduce the cost of lighting studies.

Another study by Whitehead (2010), which used photo images to examine the influence of lighting in the indoor environment, compared the use of colour images from a special computer monitor called a High Dynamic Range (HDR) displayer and those from a conventional displayer with lighting settings directly experienced by the participants in the space of the study experiment. The study examined three images of diverse interior spaces under different lighting settings. The study concluded that the HDR may be used as a replacement for testing in the actual space both for lighting feature studies and for design work such as lighting design.

These two studies show that coloured static images (photographs, displayed images and slides) can be used to evaluate indoor environments as there is a high correlation with reality. The advantages of using coloured static images are they are cheaper to use in research and they provide the flexibility to collect data from participants individually or collectively. On the other hand, the static images can be viewed only from a limited angle. Further, the selection of the image plays an important role - it can affect the study either positively or negatively.

3.2.5 Using videos as a simulation tool

Using videos is another simulation approach for evaluating the indoor environment. Corry and Thompson (1993) studied the impact of 2D videos on viewers with regard to their preferences for interior designs — life style features and traditional features. The researchers firstly classified the participants into two groups —those with high exposure and those with low exposure to films and media. The classification was based on a questionnaire designed to determine the frequency of viewing films by the participants. The researchers then subdivided the participants of the study into an experimental group and a control group. Both groups participated in a pre-test where they viewed two sets of interior design slides (life style features and traditional features) using the semantic differential scales which had been developed by Kasmar (1970). The experimental group then viewed a 20 minute video which included a number of clips of interior spaces edited from popular films, and viewed another set of slides of interiors with similar design features to spaces in the pre-test. Both sets of slides in the pre-test and post-test were selected from 'National Design' publications (Corry and Thompson 1993, 29). The control group viewed only the set of slides of interiors (rather than the video) with similar design features to spaces in the pre-test. Both the experimental and control groups responded to a post-test questionnaire.

Corry and Thompson found that the participants with high exposure to films preferred the life style feature designs while the participants with low exposure to films preferred the traditional feature designs. Moreover, the study found that, with regard to preference for design features, participants with high exposure to films were more influenced by films than the participants with low exposure to films. This led to the finding that previous visual experience could affect the person's evaluation of his/her surroundings. Although the study was designed to investigate the influence of the media on people's preferences with regards to design style, the use of the video *in an interior design study* and the use of the *semantic differential scales* to evaluate the indoor environment are significant. These two points show that it is feasible to use videos for indoor environments using the semantic scales to evaluate indoor environments.

Heft and Nasar (2000) compared how participants evaluated scenes of remote suburbs using dynamic images (two-dimensional video films) and static images (a single frame snapshot from the same film). The researchers utilised a number of video clips which had been edited from film captured from a moving van in a rural area. The researchers also used frozen images from the same film to determine if there were any differences in the evaluation of the outdoor environment between the two display methods (the dynamic and static images) (Heft and Nasar 2000).

The data collected from the two methods were weakly correlated. The static image was preferred by the observers, who stated it was *more comfortable to view*, while the dynamic images were preferred for *exploring the environment*, *stimulating curiosity* and a *desire to learn more*. The observation of comfort may be an important consideration when a researcher wishes to evaluate the atmosphere of an environment. However, it is also important to consider the three advantages of the dynamic image method: it can reduce the expense of the studies; using video images allows the researcher the flexibility to collect data from participants individually or collectively; and using video images increases the desire to explore and learn about what is being displayed in the video scenes.

More recently, three-dimensional (3D) images and videos have been used in research studies; typically they have been used to overcome technical obstacles such as dangerous or remote environments. For example, Liu (2001) used 3D technology to capture aquatic creatures in deep seas. 3D technology has also been used in agricultural studies to monitor plants and to acquire remote expert advice (Shih 2003). Shih and Zen Hu (2007) examined the use of 3D technology to control and manage interior design projects from a remote position. The study found that the 3D technology accurately captured the reality of the indoor space. This could save time and provide for remote control of the design projects.

It is clear that using 3D technology not only provides the flexibility to examine the lighting conditions of an experiment at times that are convenient for the researcher and participants and reduce the cost of the implementation of studies, but can also provide stereoscopic images which correlate directly with real visual experience.

3.2.6 Using software programs as a simulation tool

A number of studies have used graphic software programs to create simulations of indoor and outdoor environments. Architects, interior architects and lighting designers have used software programs such as Lumen Micro-Designer, Ecotect, Autodesk VIZ, AGI32, SuperLite, 3ds Max, Radiance and Lightscape to simulate indoor environments (Sarawgi 2006). There are debates about which simulation programs are most suited for which studies. Sarawgi (2006) conducted a study to determine the kind of simulation programs users preferred in their design work. The results of the study were mixed, with the participants having different opinions about the preferred software to use in their design projects.

Another study conducted by Salters and Seuntiens (2011) was designed to test the simulation program method. The study compared the evaluation by participants of the lighting settings of an indoor environment directly and via two kinds of simulation outputs (still images on a monitor and printed images). The findings showed no significant correlations between the direct evaluation of the atmosphere space ‘live’and the simulation outputs of the same space with regard to the evaluation of the lighting brightness and the colour temperature. However, there was a significant correlation with regard to the main effect of presentation and the main effect of fixtures (Salters and Seuntiens 2011).

These results appeared to call into question the use of graphic simulations. However, Salters and Seuntiens suggested that the poor results arose from the technical quality of the images rather than from the methodology itself. As a result of their study, they recommended using simulation facilities such as faster hardware and better quality rendering software and displays with better screen quality in order to gather results correlating with the real ‘live’ conditions.

A study by Post (2012) examined the quality of software output images. The study included two experiments. The first experiment compared two rendered images which had been produced using two different simulation software programs. One comparison was between the graphic simulation output and the real life scene; another was between the two graphic simulation outputs without viewing the real life scene.The second experiment examined rendered images of materials and specific types of lighting. The findings indicated that, although the use of simulated images could accelerate the testing process, the output of the simulation software needed to be enhanced further in order to approach an acceptable image of reality (Post 2012).

Another study by Maunder, Donn, Curtis and Lee (2001) was conducted to test the rendering ability of two of the lighting architecture simulation programs used to display the influence of lighting in design work. The two simulation programs were Lightscape and Radiance. The output images of these two programs were compared with an actual mock up. The results of the study showed that it was feasible to use Lightscape in the design process but it was not sufficiently accurate to evaluate space. On the other hand the study found that the Radiance program could give accurate images of the actual mock up. However, according to Maunder et al. (2001), the Radiance program takes a long time to produce an image — one hour to render a simple single image.

These studies show that the use of software simulation programs gives researchers the flexibility to control and modify the design of their projects. In addition, the use of software simulation programs may reduce the expense of the studies. Also, the software simulations (printed image or using digital displayers) can display the output of the rendered image produced by the software simulations in more than one presentation approach, that is, printed image and/or displayed through a monitor. Although there is a wide range of software for architectural and lighting design purposes, however, the output of these programs does not yet approach an acceptable simulation of reality for research purposes.

4. The design of the current study methodology

Figure 4.1 shows the design of the current study methodology.

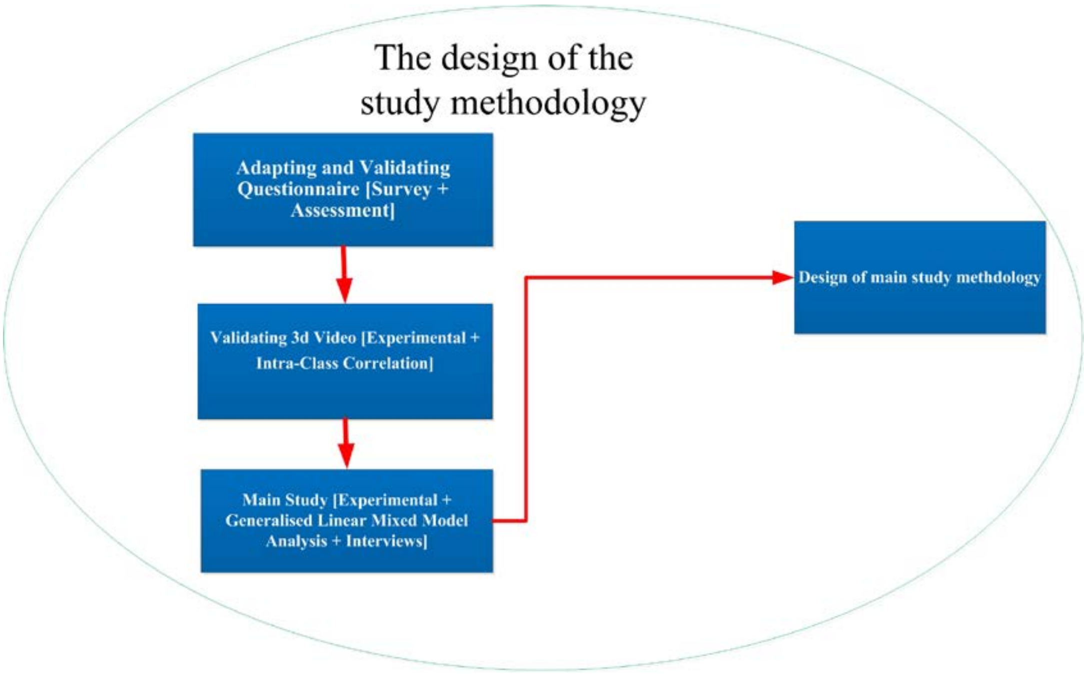


Figure 4.1 The design of the current study methodology

4.1 The Methodology Chapter Introduction

This chapter illustrates and discusses the research methodology and methods used in the current study. The study objectives were to identify the influence of RGB LED lighting with eight different lighting hues (red, yellow, green, cyan, blue, magenta, white and general white) and two levels of lighting intensities (high and medium) on the perceived atmosphere of the hotel guest room. The study uses a mixed methods methodology which comprises three stages: adapting and validating the measuring tool (questionnaire); validating the use of 3D video; and examining the influence of the RGB LED lighting in a hotel guest room. The mixed methods methodology comprises three stages: refining the measurement instruments, the validation of the use of the 3D video visual experience as an alternative to an actual indoor environment, and the main experimental study.

4.2 Vogels' Atmospheric Metrics Evaluation Model (AMEM) as a measuring tool for the study

As has been argued in Chapter Three, Section 3.1, Vogels' Atmospheric Metrics Evaluation Model (AMEM) isappropriate for this study as it was designed to avoid the non-environmental effects in the evaluation process. Also, the AMEM helps the participants to assess and describe their individual experience of the indoor environment. Further, the AMEM was designed to assess the influence of lighting in the built environment, since the majority of researchers who have adopted Vogels' model have used it for that purpose. This is consistent with the main aim of the current study, which was also to evaluate the influence of lighting on the atmosphere of a particular indoor environment - a hotel guest room. Therefore, the current study adopted Vogels' Atmospheric Metrics Evaluation Model (AMEM) as a measuring tool in the three stages of the study.

4.3 The use of 3D video

After due consideration of the three main possibilities for evaluating the influence of lighting in indoor environments — evaluations from participants who are personally in the space, scale model booths, and simulations that imitate actual conditions (photos, videos and software) — it was decided that this study would not use participants in the space because this method is expensive to apply and difficult to manage. It was also decided not to use booth models because the participants can only evaluate the atmosphere of the indoor environment from limited angles and a fixed sitting position. Further, it was decided not to use software programs for simulations because the output of these simulation programs do not yet approach acceptable reality for research purposes due to the limited capability of the simulation programs to produce a dynamic moving image and the considerable amount of time it would take to produce the required simulations. It was decided instead to use 3D Video because expenses could be kept to a reasonable level, and it allowed the flexibility to collect data from individuals or collectively, and the visual experience of the participants would arguably be close to reality.

While Shih and Zen Hu's(2003) study, using 3D technology, focussed on management/control of an interior design project, this researcher saw the opportunity to test 3D video to establish whetherit could be used to examine the influence of an indoor environment. The current study also adopted Vogels' model because the model was designed to reduce the non-environmental effects on the participant evaluations of the indoor environment, and AMEM could be used in conjunction with the 3D video discussed in the following section.

The study adopted the standard AMEM which requires the participants to be within the space for eight to ten minutes in order to evaluate the atmosphere of the space. This means that the participants would be able to move and view the whole space in order to evaluate it. The current study therefore set out to create a similar atmosphere to the real space with the use of 3D video. 3D video was used, therefore, as dynamic visual images (video) are the nearest visual experiences to reality (Shih and Hu 2007).

Also the study took into consideration that the influence of the RGB LED lighting in the built environment is not just the direct effect of RGB LED lighting on the user of the space; it is an interaction between the user of the space and the atmosphere of the space related to his/her visual experience of the changing lighting settings through time. It is the holistic dynamic visual image of all the components of the atmosphere of the indoor environment, not just one component.

4.4 Design of this study (mixed method methodology)

The study had adopted mixed method methodology which included three stages discussed below. The mixed method methodology can be used to imply various approaches that are qualitative and quantitative (Rocco et al. 2003). Based on Hunter and Brewer (2003) (cited in Johnson, Onwuegbuzie and Turner (2007), the mixed method could include more than one stage or a chain of studies. These studies can be connected to each other in order to establish accumulated or interacted knowledge. It is not necessary for research adopting the mixed method to use a mixture of qualitative and quantitative approaches. The research could use more than one quantitative approach, for example, survey research with quantitative experimental or qualitative observation with qualitative in-depth interviewing. Hunter and Brewer (2003) preferred to call the Mixed Method methodology ‘multimethod’ research.

Different ways are used to apply the mixed method methodology. One way of applying mixed method methodology is the use of mixed model research, which comprises qualitative and quantitative approaches in different stages of the research process, such as questions, data collection, data analysis and data interpretation (Tashakkori and Teddlie 2010). Another way to interpret the mixed method methodology is to apply different mixed methods of research such as gathering and/or analysis of qualitative and/or quantitative data in separate studies, in which data are gathered synchronously or respectively, with the process of data integration occurring in one or more of the research stages (Tashakkori and Teddlie 2010). The third way to interpret the mixed method methodology is to plan and conduct qualitative and/or quantitative studies individually. Each of the studies aims to provide a solution to sub-topics of the whole study, sequentially or interactively at different stages of the study process. The results of these studies form a comprehensive image of the project (Bloor and Wood 2006).

The current study follows the third interpretation of the mixed method methodology, as the general guideline of the current research is quantitative. The study, investigating the influence of coloured RGB LED lighting on the perceived atmosphere of a hotel guest room, applied an experimental method to reach its goals. As shown in Figure 4.1, a preliminary survey and experiment were required before the main study could proceed. Therefore three stages were included in the current study methodology.

In the first stage of the study, the survey method was used to collect data from English-speaking West Australians. Thesuitability of using the translated terms of Vogels' questionnaire model as a measuring tool for this sample was examined. At Stage 1, the number of questionnaire items was reduced to an acceptable minimum. Multiple techniques of analysis were used to produce an English version of Vogels' (2008) questionnaire. This chapter shows in detail the procedure and discusses the establishment of the measuring tool of the current study.

In the second stage of the study the feasibility of using a 3D video visual experience to evaluate the indoor space was examined to verify that it could be used as an alternative to visiting the actual space. Also, the optimum time required for the duration of the 3D video to evaluate the indoor environment was considered. An experimental method was used to find the correlation between the visual experiences live and through the use of 3D video. This stage used the modified measuring tool which was the result of the first stage of the study to find the correlation between how the participants evaluate the indoor environment live and through the 3D video. The technique of intra-class correlation (ICCs) (Graham, Milanowski and Miller, 2012) was used to find the correlation between the live and the 3D video visual experiences. This stage of the study also aimed to determine the most suitable video duration to evaluate a small size space. Chapter Six includes the procedure and discusses the validation of the use of the 3D video visual experience as an alternative to an actual indoor environment.

In the third stage of the study's methodology, the main study adopted an experimental method to achieve the aims of the study, implementing the findings of the first stage of the study methodology, using the Vogels questionnaire as a measuring tool. The study also used the 3D video as an alternative visual experience to visit and evaluate the hotel guest room. A quantitative approach was used to analyse the data which was collected from the study participants. Generalised Linear Mixed Models (GLMMs) implemented through SPSS's Version 22 were used to analyse the main study data. The GLMM is 'generalised' in the sense that it can handle outcome variables with markedly non-normal distributions; the GLMM is 'mixed' in the sense that it includes both random and fixed effects. The third stage of research also conducted a brief structured interview with the study participants in order to review the participants' perspectives with regards to the study measuring tool and the use of the 3D video technology in the current project. The procedure and the discussion of the main study are covered in Chapter Seven.

Applying the Mixed Method Methodology in the current project was a useful way to reach the study objectives. In first stage the research modified and validated the measuring tool of the research project. The second stage of the study established the simulation tool to evaluate the indoor environment. The first two stages of the study solved technical issues to ensure the main study of the research went to plan. Each of the stages in this study established base knowledge to be used in the following stage. The use of both the modified measuring tool of stage one, and the 3D video technology visual experience as alternative to the real visit visual experience, enabled the researcher to test a wide range of lighting settings of different hues and intensities in a shorter time and a more controllable environment than if the study had beenconducted in a real space.

4.5 Ethical issues

The research posed no threat to any persons or groups within society. The participants were informed that their participation was completely voluntary and that they were at liberty to withdraw at any time without giving a reason for withdrawal. Also, the research did not involve potential physical or psychological harm. Every possible precaution was taken to minimise the participants' discomfort and inconvenience. The participants were assured that the data provided by them would remain confidential and they themselves would be anonymous (see Appendix 5).

At no stage were participants directly or indirectly pressured or forced into contributing to this study. Ethical approval for research involving humans was obtained from the Human Research Ethics Committee of Curtin University for this study (BE-70-2012). In accordance with Curtin University's ethics policy, this study was carefully designed to avoid hazard or harm.

4.6 Chapter Conclusion

The study uses the mixed methods methodology which comprises three stages. Three kinds of methods are used in the current study – a survey for the first stage, an experiment for the second stage and an experiment and constructed interview in the main stage of the research. Each of the studies was designed, conducted, discussed and presented individually. An overview of the research project will be presented in the concluding Chapter Ten. The next three Chapters – Chapters Five, Six and Seven, describe in detail the procedure of the three stages of the research.

5. Adapting a survey measuring tool

As discussed in Chapter 3, Vogels (2008) developed a questionnaire in Dutch to quantify the perceived atmosphere of lighting environments in buildings in the Netherlands. The questionnaire was designed to reduce the influence of non-environmental effects in the evaluation of the indoor environment and has been used by a number of researchers such as Van Erp (2008); Custers (2008); Bronckers (2009); Choy Calvin (2009); Dijkstra (2010); Kuijsters et al. (2012); Wan (2011); Salters and Seuntiens (2011). All these researchers used the Dutch version of Vogels' (2008a) questionnaire model; however, the number of terms used by these researchers varied; some of the studies used 38 terms while others used only four. Thus the questionnaire seemed an appropriate tool to use in the current study if it could be validated in English.

The overall objective of this chapter is to describe the evaluation of an English version of Vogels' questionnaire for use in the current study as an instrument for assessing the atmosphere of an indoor environment. The original Dutch version contains 38 Dutch terms separated into four factors, namely: cosiness, liveliness, tenseness, and detachment (Bronckers 2009; Custers 2008; Vogels 2008a). The model was translated by Vogels from Dutch to English. Two of the Dutch terms have a similar English meaning after the translation; 'behaaglijk' and 'knus' both translated to 'cosy', and 'gemoedelijk' and 'gezellig' both translated to 'pleasant'; therefore, the English version of the questionnaire included 36 adjectives. An English version of Vogels' (2008a) questionnaire model has not to date been used by any other researcher.

Vogels' publication, the 'Atmosphere metrics development of a tool to quantify experienced atmosphere' (2008) describes the establishment and testing of the instrument through two experiments. The data show that the questionnaire terms loaded on two factors, 'cosiness' and 'liveliness', which have not been adopted by other researchers. In another publication of Vogels, 'Atmosphere metrics: A tool to quantify perceived atmosphere' (Vogels 2008a), the items that loaded on each of the factors were not clearly identified. Vogels (2008a) did, however, provide a sample of the terms loading on each of the four factors.

Van Erp's (2008) study was one of the first studies that adopted Vogels' model. Van Erp conducted a factor analysis of Vogels' instrument which led to the same four factor solution: cosiness, liveliness, tenseness, and detachment. Van Erp's study elaborates the analysis procedure. Van Erp's study also shows the distributions of terms across each of the four factors. Therefore this chapter describes the testing of Van Erp's proposed 4-factor structure of Vogels' instrument with English-speaking participants. Figure 5.1 describes the development of a survey measuring tool for this study.

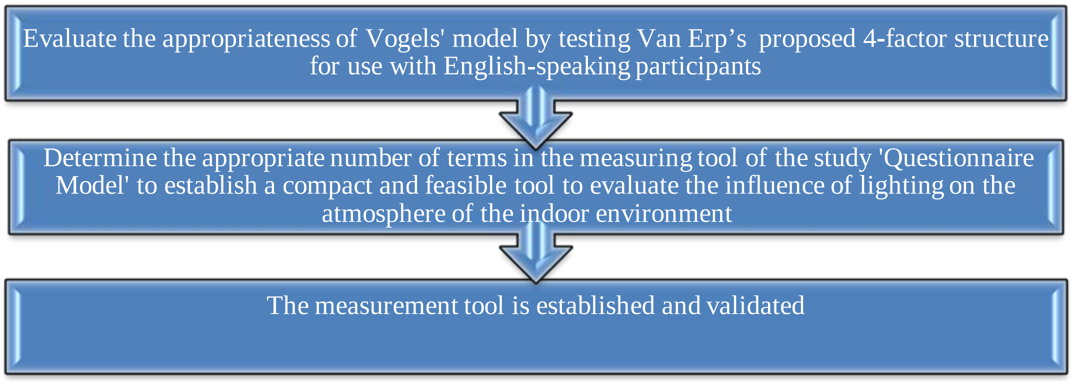


Figure 5.1 First stage of the study flowchart

5.1 Method

The English version of Vogels' model questionnaire was tested. The factor solution from the current study was compared to Van Erp's 4-factor solution. Firstly a description of the study participants is given. Then the instrument is clarified. After that, the procedure of the method is illustrated. In the following sections of this chapter, the data analysis, the results and the discussion are presented.

5.1.1 Participants

Questionnaires were distributed to a 'convenience sample'[8] of 412 adult participants in Perth, Western Australia. The sample consisted of 205 males and 207 females; 80 participants were over the age of 40, and 332 were below the age of 40. They all returned completed questionnaires, providing five participants for each of the 36 free parameters in Van Erp's four-factor model. According to Kline (2005), five participants per parameter is anadequate sample size for reliably testing factor models.

[8]The convenience sample is one of the non-probability sample methods used by researchers. It is called a convenience sample as the researchers have ready access to this group of participants. The sample could be any one passing by, college, university students or through email invitation (Lavrakas 2008).

5.1.2 Instrument

When translated into English by Vogels, two pairs of Dutch terms had the same meaning: '*behaaglijk*' and '*knus*' both translated to 'cosy', and '*gemoedelijk*' and '*gezellig*' both translated to 'pleasant'; therefore, the English version of the questionnaireincluded just 36 adjectives. Adjacent to each of the 36 adjectives was a 7-point Likert scale for rating the degree to which the adjective described the room's atmosphere (1 = least applicable; 7 = most applicable). In addition to the 7-point Likert scales, the questionnaire included three 7-point bipolar scales for rating the room's atmosphere from bright (1) to dark (7), warm (1) to cool (7), and appropriate (1) to inappropriate (7). The questionnaire also collected data on the participants' gender and age.

Five versions of the questionnaire were developed; each version presented a different high-definition colour photograph of a hotel room (see Figure 5.2). The photos were selected from a website (http://www.google.image.com.au) of hotel guestrooms, including hotels in Perth, Western Australia, as well as international locations such as London. As can be seen from Figure 5.2, the guest rooms were different from each other in design, colour and lighting conditions. The full questionnaire is reproduced in Appendix 2.

5.1.3 Procedure

The five versions of the questionnaire were randomly distributed equally amongst participants such that roughly one fifth of the participants received Version 1, one fifth received Version 2, and so on. Participants were asked to study the photo of the hotel guest room and then to rate each of the 36 adjectives on the 7-point Likert scale according to the degree to which they thought it described the room's atmosphere (1 = least applicable; 7 = most applicable). Participants were then asked to rate the atmosphere of the room according to each of the three 7-point bi-polar dimensions described previously (bright [1] / dark [7], warm [1] / cool [7], appropriate [1] / inappropriate (7]). The data were collated and analysedwith LISREL (Version 8.8) (Jöreskog and Sörbom 2006) and SPSS (Version 22) (IBM-Corp 2013).

Medina Grand Adelaide Treasury
Source: Hotel Management. (2011)

Good Earth Perth
Source: Booked.net.2016

Rendezvous Hotel Perth central
Source: www.google image.2016

St Martins Lane, London
Source: Unique Hotels. (2012)

Criterion Hotel Perth
Source: www.google image (2016)

Figure 5.2 The photos appearing in the study questionnaires

5.2 Data analysis

The data analysis consisted of four steps. In Step 1, a confirmatory factor analysis (CFA; LISREL Version 8.80) was conducted in order to determine whether Van Erp's 4-factor model (cosiness, liveliness, tenseness, detachment) provided an acceptable fit for the Australian data. Five fit statistics were used to evaluate model fit: Chi-square divided by its degrees of freedom ($\chi2/df$), the comparative fit index (CFI) (Bentler and Peter 1990); the non-normed fit index (NNFI) (Bentler and Peter 1990); the standardised root mean square residual (SRMR) (Miller, Bierly and Daly 2007); and the root mean square error of approximation (RMSEA) (Browne et al. 1992). The criteria for a good fit are a $\chi2/df$ statistic less than or equal to 3, CFI and NNFI values greater than or equal to .9, an SRMR value less than or equal to .1, and an RMSEA value less than or equal to .08 or having a 95% confidence interval that containsthis value.

The data failed to fit Van Erp's 4-factor solution, so the analysis proceeded to a second step that involved finding a better-fitting solution. Step 2 of the analysis consisted of conducting an exploratory factor analysis (EFA) on a randomly selected 150 participants from the sample of 412. There are several types of EFA. Because the adjective ratings were more appropriately interpreted as belonging to an 'emergent' variable system than a 'latent' variable system (Cole et al. 1993), Step 2 of the analysis used principal components (PC) analysis which is more suited to emergent systems rather than principal axis factoring (PAF) which is more suited to latent systems. The PC analysis (PCA) was implemented through SPSS (Version 22) (IBM-Corp 2013). Strictly speaking, PCA extracts components (emergent variables) rather than factors (latent variables). For ease of exposition, however, the term 'factor' will be used throughout.

PCA initially extracts as many factors as there are adjectives (36 in this case). The factors that explain most of the variability among the adjective ratings — generally the factors with eigenvalues greater than one — are retained for the final solution and the other factors are discarded. The 'eigenvalue > 1' rule is known as the Kaiser criterion. The Kaiser criterion is the SPSS default for determining the number of factors that should be retained, but it tends to retain too many factors. Parallel Analysis is a much more reliable method for determining the number of factors that should be retained (O'Connor 2000). Parallel analysis was therefore used in Step 2 of the analysis. The factors identified through parallel analysis were then rotated. Rotation is a statistical procedure for minimising the number of adjectives with cross-loadings (adjectives with salient loadings on more than one factor). Two types of rotation are possible: orthogonal (which prevents factors from correlating) and oblique (which allows factors to correlate). Because the data were more consistent with a correlated factor solution, Step 2 of the analysis conducted an oblique rotation using the 'Promax' method.

Step 3 involved conducting a CFA on the remaining 262 participants in order to confirm the PCA solution derived in Step 2 from the randomly selected 150 participants. Finally, Step 4 of the analysis involved testing the generalisability of the PCA solution across the five photographs.

5.3 Results

The results from each of the four steps of the analysis are reported below.

5.3.1 Step 1: Conducting a Confirmatory Factor Analysis (CFA) to test Van Erp's factor structure for Vogels' model

The CFA conducted on the entire sample of 412 participants yielded the following fit statistics: χ^2/df = 7.14, CFI = .859, NNFI = .849, SRMR = .134, RMSEA = .122 (95% CI =

.119, .126). According to the cut-offs given in the previous section, Van Erp's 4-factor solution did not fit the Australian data. This is not surprising; Vogels herself has argued that the English translations only approximate the Dutch meanings and 'should certainly not be used to make an English version of the questionnaire' (Vogels, 2008, 28).

5.3.2 Step 2: Principal components analysis (PCA)

Given the poor fit of Van Erp's 4-factor solution to the Australian data, a PCA was conducted in an attempt to uncover the factor structure that might have generated these data. The Kaiser criterion indicated an 8-factor solution. It was argued, however, that the Kaiser criterion tends to retain too many factors and that parallel analysis provides a more reliable procedure for identifying the important factors. Parallel analysis indicated a 3-factor solution. A 3-factor solution was, therefore, requested from the PCA and then obliquely rotated using the 'Promax' method. As explained above, rotation is a statistical procedure for minimising the number of adjectives with cross-loadings. In this instance, however, several cross-loadings remained following rotation. A secondary aim of the Stage 2 analysis was to reduce the number of adjectives to a number that was more conducive to repeated testing. The adjectives with cross-loadings were, therefore, removed and the remaining adjectives were subjected to a second PCA. This procedure was repeated until there were no more cross-loadings. The final solution (reported in Table 4.1) consisted of 18 adjectives. Adjectives 1–8 appeared to reflect the positive aspects of the atmosphere of the room, adjectives 9–14 appeared toreflect the negative aspects of the atmosphere of the room, and adjectives 15–18 appeared to reflect the impartial (practical) aspects of the atmosphere of the room.

Table 5.1 Factor Loadings for PCA Following Promax Rotation

Adjectives	Factor		
	1	2	3
Intimate	.781		
Inspiring	.774		
Cheerful	.724		
Personal	.698		
Relaxed	.686		
Lively	.628		

Luxurious	.609		
Cosy	.604		
Tense		.831	
Hostile		.759	
Musty		.662	
Lethargic		.655	
Restless		.647	
Detached		.547	
Business			.816
Spatial			.753
Accessible			.636
Formal			.611

5.3.3 Step 3: Conducting a CFA to confirm the PCA solution

A CFA was conducted on the remaining 262 participants in order to confirm the PCA solution derived from Step 2 from the randomly selected 150 participants. The CFA yielded the following fit statistics: χ^2/df = 2.48, CFI = .931, NNFI = .920, SRMR = .068, RMSEA = .075 (95% CI = .065, .086). According to the cut-offs given in the previous section, the 3-factor solution provides a good fit for the data.

5.3.4 Step 4: Testing the generalisability of the PCA solution across the five photographs

The bivariate correlations among the 18 adjectives were computed for each of the five photographs across the entire sample of 412 participants. LISREL was used to conduct 10 pairwise comparisons among the five correlation matrices (Photo 1 matrix versus Photo 2 matrix, Photo 1 matrix versus Photo 3 matrix, Photo 2 matrix versus Photo 3 matrix, and so on). The chi-square global goodness of fit test was non-significant for each comparison, indicating that the bivariate correlations among the adjectives were invariant across the five photographs; therefore, the overall factor solution reported above (which was derived from these matrices) was also expected to be invariant across the photographs.

The invariance of the adjective *correlations* across the photographs does not imply that the adjective *ratings* were themselves invariant across the photographs. Indeed the photographs differed significantly in terms of their mean ratings on 13 of the 18 adjectives. Interestingly, the photos did not differ significantly for ratings on five of the six 'negative' adjectives: hostile, detached, restless, tense, and lethargic. The results are reported below.

- Cosy ($F[4,407] = 4.63$, $p = .001$)
- Formal ($F[4,407] = 19.12$, $p < .001$)
- Inspiring ($F[4,407] = 10.44$, $p < .001$)
- Intimate ($F[4,407] = 15.80$, $p < .001$)
- Cheerful ($F[4,407] = 15.80$, $p < .001$)
- Lively ($F[4,407] = 3.67$, $p = .006$)
- Luxurious ($F[4,407] = 27.14$, $p < .001$)
- Musty ($F[4,407] = 5.94$, $p < .001$)
- Relaxed ($F[4,407] = 5.38$, $p < .001$)
- Personal ($F[4,407] = 6.67$, $p < .001$)
- Business ($F[4,407] = 21.47$, $p < .001$)
- Spatial ($F[4,407] = 14.58$, $p < .001$)
- Accessible ($F[4,407] = 5.77$, $p < .001$)
- Hostile ($F[4,407] = 2.23$, $p = .065$)
- Detached ($F[4,407] = 1.58$, $p = .179$)
- Restless ($F[4,407] = 1.99$, $p = .094$)
- Tense ($F[4,407] = 1.66$, $p = .158$)
- Lethargic ($F[4,407] = 1.59$, $p = .177$)

The photographs depicted hotel bedrooms that differed in design, colour presentation and lighting conditions. It is no surprise, therefore, that the rooms were rated differently on most of the adjectives. Despite the differential ratings, however, relationships among the ratings were invariant across the photographs. This supports the stability of the instrument across qualitatively different interior spaces.

5.4 Discussion

Step 1 of the data analysis showed that Van Erp's 4-factor solution provided an unacceptable fit for the Australian data. This might reflect a less than perfect correspondence between the meaning attributed to the Dutch adjectives in Van Erp's study and the meanings attributed to the English translation in the present study. Translation problems were evident for the Dutch adjectives '*behaaglijk*' and '*knus*', which had the same English translation of 'cosy'. Similarly, '*gemoedelijk*' and '*gezellig*' had the same English translation of 'pleasant'. It is possible, therefore, that the adjectives are not interpreted identically across the two cultures. This might have caused a shift in the factor structure between the two cultures.

In Step 2 of the data analysis (n = 150), a 3-factor solution rather than Van Erp's 4-factor solution emerged. This solution was confirmed on the hold-out sample (n = 262). The discrepant findings might merely reflect the following differences in statistical methods.

- This study extracted factors using principal components analysis (PCA); Van Erp's study extracted factors using principal axis factoring (PAF);

- This study used parallel analysis to determine the number of factors that should be retained; Van Erp's study retained the factors 'that explained most of the variance', which turned out to be at least 6% per factor.

- This study used the 'Promax' procedure to obliquely rotate the retained factors; Van Erp's study used the Oblimin procedure to obliquely rotate the retained factors.

When the present adjective ratings were re-analysed with PAF and Oblimin rotation, the same pattern of results emerged. The decision to use PCA and Promax rather than PAF and Oblimin appears to have had little impact on the results. Moreover, using Van Erp's 6% cut-off as a criterion for factor retention indicated three factors for both PCA/Promax and PAF/Oblimin. The screen plot from both analyses also indicated three factors. (The Kaiser criterion, which was previously criticised for retaining too many factors, indicated five factors in both analyses.)

It is unlikely, therefore, that differences between the factor solutions in the present study and Van Erp's study reflected differences in statistical methods. It is more likely that the adjectives were not interpreted identically across the two cultures and that this caused a shift in the factor structure. Therefore the current study used the 3-Factor solution. The three factors were named Atmosphere Positive Descriptive (APD), Atmosphere Negative Descriptive (AND) and Atmosphere Impartial Descriptive (AID). The adjectives intimate, inspiring, cheerful, personal, relaxed, lively, luxurious and cosy load on the APD factor; the adjectives tense, hostile, musty, lethargic, restless and detached load on the AND factor; and the adjectives business, spatial, accessible and impartial load on the AID factor.

5.4.1 Further discussion derived from this study aligns with other studies which have examined the influence of lighting in the indoor environment

The multidimensional method of the self-report technique has been used to evaluate the influence of the indoor environment on the users of the environment by a number of researchers, as reported in Chapter Three, Section 3.1, 'The evaluation of the atmosphere of the indoor environment'. Osgood et al.'s (1957) were among the earlier researchers who showed interest in structuring a tool to measure the influence of the environment on people interacting with their surroundings. Osgood et al.'s (1957) model comprised three factors or 'dimensions'. Their factors were 'evaluation', 'potency' and 'activity'; each of these factors comprised a number of polar opposite descriptive terms divided by a five or seven point rating scale.

The modified model of the current study is significantly different from the Osgood et al. (1957) model. Both models may correlate as they used the self-report technique and both included three factors. However, Osgood et al.'s (1957) model was based onemotional states. The participants in studies adopting this are asked to report their emotional state or how they feel in the environment; in the current study, however, participants were asked to describe the environment presented to them.

Flynn et al. (1973) conducted a factor analysis on the items used in Osgood et al.'s (1957) SDR evaluating model. With the factor analysis produced a somewhat different solution of three factors. The three factors were 'general evaluative', 'perceptual clarity' and 'spaciousness'. Flynn et al.'s (1973) solution was more devoted to evaluating the atmospheric influence of lighting in the indoor environments. Flynn et al. (1973) developed another model using different items, in order to make the model more suitable for evaluating the influence of lighting in the indoor environment. Examining the same lighting setting they had tested using Osgood et al.'s (1957) SDR model, they ended up with another three factor solution 'peripheral-overhead', 'uniform-non uniform', 'bright-dim'. Flynn et al. (1973) called this model the Multi-dimensional Scaling (MDS) model.

Flynn et al. (1973) recommended both models, the SDR and the MDS, for evaluating the indoor environment under the influence of lighting. Both models concentrate on the influence of lighting distribution and its importance in the indoor environment. There is no doubt that both the Flynn et al. (1973) models were important and established a foundation for researchers in the field of indoor space lighting. However, the Flynn et al. (1973) models were closer to the emotional state measuring tool than the atmospheric evaluation tool. Also, the Flynn et al. (1973) model was focussed more on evaluating the lighting in the atmosphere than the atmosphere of the space itself. The current study's modified model is closer to the atmospheric descriptive evaluating measuring tool.

Mehrabian and Russel's (1974) evaluating model comprised three factors, Pleasure-Arousal-Dominance (PAD). Mehrabian and Russel's (1974) model is different from the factor solution of the current study, as their model was based on the emotional state of the participants, while the current study asked the participants to describe the atmosphere of the indoor environment. Mehrabian and Russel's (1974) model included positive and negative terms for each of the three factors, that reflect the participants' feelings in the indoor environment with regard to the pleasantness, activeness and controlling of the surroundings. On the other hand, the current study's model included the positive description of the atmosphere of the indoor environment with regard to both the pleasantness and activeness in one factor, Atmosphere Positive Descriptive (APD). The current study model also categorised the negative description of the atmosphere with regard to pleasantness and activeness in the second factor, Atmosphere Negative Descriptive (AND). The third factor of the current evaluating model categorised the non-emotional description of the atmosphere, Atmosphere Impartial Descriptive (AID).

Watson, Clark and Telleggen (1988) established the Positive Affect Negative Affect Scale model (PANAS). This model is again different from the current study model as it was based on emotional state evaluation, similar to the previously mentioned models in this discussion. There was a similarity, however, with the current study model as it categorises the terms which are used to evaluate the indoor environment into positive factors and negative factors with regard to describing the level of pleasantness and activeness. However, Watson, Clark and Telleggen's (1988) model did not include a spatial description of the test environment.

Russell, Weiss and Mendelsohn (1989) developed the Affect Grid: A Single-Item Scale of Pleasure and Arousal model from Mehrabian and Russel's (1974) model. The model is a compact model that can save time during the evaluation process. However, the model is still based on the emotional state of the participants. Russell, Weiss and Mendelsohn included less items to evaluate the tested environment and also included two factors ‘pleasantness and activeness’ while the current study model included three factors, as mentioned previously.

Bradley and Lang (1994) established the Self-Assessment Manikin (SAM) model. Bradley and Lang (1994) transformed the Mehrabian and Russel (1974) model from a verbal model to a visual graphic model. This transformation thus overcame the linguistic obstacles. The visual conversion of the model from solo language model to multi-cultural model makes the model suitable for those who have limited language skills, such as children or individuals with special needs. However, the model is still based on the emotional state and thus is different from the current model. The SAM model would be useful with a wide range of participants from different cultural backgrounds or individuals with special needs, and it may save time as it is easy to undertake.

The review of evaluating models in Section 3.1 has shown that the models used different terms to describe the examined environment. The number of terms and their distributions across factors may influence environmental evaluations in one way or another. For example, participants may interpret the terms differently to the researcher. Therefore, consistency between the evaluators’ responses is an important point to explore in looking at how the majority of respondents evaluate the examined environment.

Another point to consider is that the participant may be in a positive or negative emotional situation, which might confound the evaluation of the environment. For example, having a huge work pressure in a comfortable working environment may influence the individual’s feelings and make her/him feel tense despite the comfortable environment. This is one of the points that encouraged the current study to adopt Vogels’ (2008) model, as discussed in Chapter three.

5.5 Summary

Vogels’ (2008) questionnaire terms were translated from Dutch to English to determine appropriateness of the model for an English speaking community. The results suggested that Western Australian participants had different understandings of the terms. Therefore the model needed to be modified before it could be applied in the current research.

Van Erp’s (2008) adaptation of Vogels’ model was used as a starting point to develop a useable indoor environmental evaluation tool for Western Australian participants. The use of the modified Van Erp questionnaire enabled the Western Australian participants to discriminate among different indoor environment designs and lighting settings, as discussed in Chapters Five and Seven.

The model covered three of the essential emotional and non-emotional descriptions for the environment which are usually used in the multi-method of self-report evaluation models: the level of comfort, the level of action and the spatial description for the environment, and reduced the non-environmental influence in the indoor environmental evaluation.

6. Validation of the 3D video as a tool for evaluating the atmosphere of the indoor environment

As discussed in Chapter Three, the impact of lighting in indoor environments can be assessed by participants in three different ways — when they are actually in the space being examined, when they look at scale model mock-ups of the space being examined, or when they view photographic, video or model simulations of the space being examined. This chapter describes the validation of 3D video technology as a simulation tool for evaluating the atmosphere of actual indoor environments. An experiment was designed in which participants observed the indoor environment 'live' and then evaluated its atmosphere using the instrument developed in the previous chapter; these evaluations were then compared to the evaluations of the same indoor environment viewed via 3D videos of two, four, six and eight minute durations. The aims of the study were: 1) to determine whether there were correlations between evaluations of the 'live' indoor space compared to the viewings of 3D videos of the space; and 2) to determine which of the four video durations elicited ratings most similar to those elicited in the 'live' space. Figure 6.1 shows the flowchart of the validation process of the 3D video technology to be utilised in evaluating the indoor environment, in order to determine the correlations with evaluations of the 'live' visual experience.

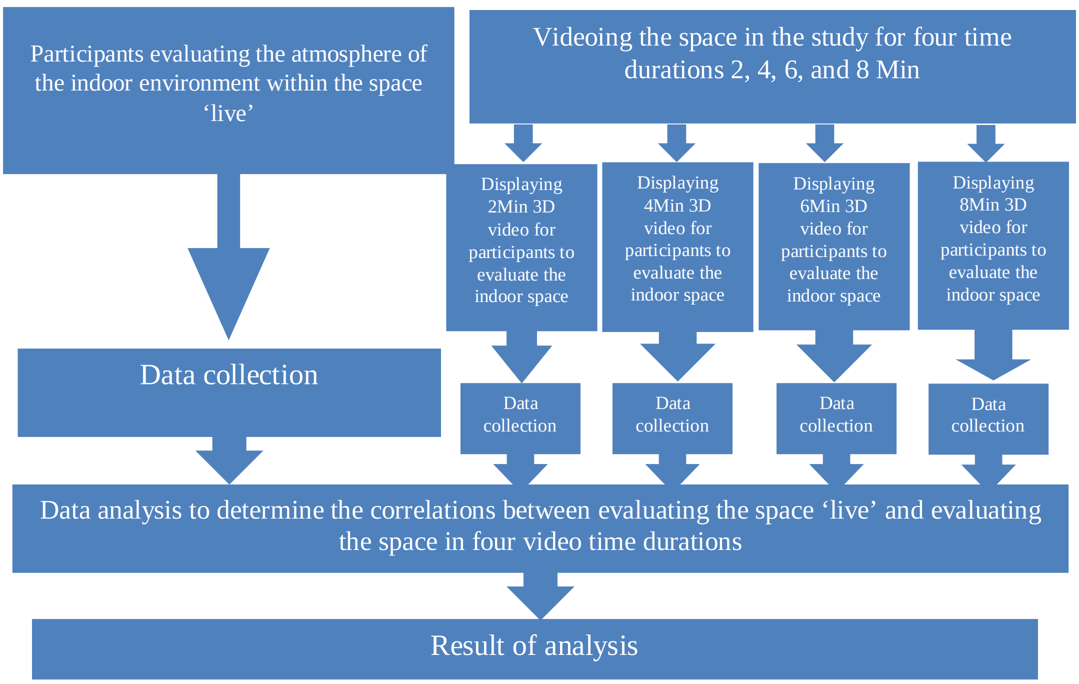


Figure 6.1 Flowchart of the validation process of the 3D video technology

6.1 Method

The aim of this stage of the study was to test the validity of using 3D video as a tool for evaluating the atmosphere of an indoor environment. It also aimed to determine the most suitable video duration for evaluating an indoor environment. Firstly, the study participants' details are described. The instruments and apparatus used in the study are then described and evaluated, before statistically comparing 'live' and 3D video conditions.

6.1.1 Participants

Sample size

The research design (described in detail later) consisted of five viewing conditions ('live', and 3D videos of two, four, six and eight minute durations). According to a study by Zou (2011), 10 ratters per condition are required in order to obtain reliable estimates of intra-class correlations (ICCs) for 18 items rated across the five conditions. The other analysis (Generalized Linear Mixed Models) required a sufficient number of participants to detect an interaction between Condition (5 levels) and Factor (3 levels). According to G*Power (Version 3.1) (Faul et al. 2009), 55 participants are required (11 in each of the 5 conditions) for an 80% chance of capturing a 'moderate' (f = .23) Condition x Factor interaction at an alpha-level of .05.

Sample description

A 'convenience sample' of 55 participants (staff and postgraduate students from Curtin University) volunteered for this experiment (31 females and 24 males) and were randomly allocated to each of the five visual experiences (a 'live' viewing condition and four 3D video conditions) such that there were 11 participants for each visual experience. The number of the participants in each of the five visual experiences was based on statistical calculations reported above in Section 6.1.1.

6.1.2 Instruments, apparatus and spatial configurations

The rating instrument

Participants used the 18-item questionnaire validated in Chapter Five for evaluating the atmosphere of the indoor environments 'live' and through the 3D videos (see Appendix 2 for complete questionnaire).

Evaluating the atmosphere of the indoor space via the 3D videos

Forty-four participants looked at 3D videos, 11 in each of the four 3D video conditions (two, four, six, and eight minute's duration).

The 3D videos

Before recording the 3D videos, interviews were conducted with a convenience sample of six participants, four females and two males, aged between 27-60 years. The average age was 40.5 years; all the participants had a university qualification and were from different professional backgrounds. The backgrounds of the participants was assessed to be sure that individuals from architecture and interior design backgrounds and participants from non-related fields of work had similar perspectives to exploring indoor environment for the first time. Two of the six participants were from architecture and interior design backgrounds. Participants were asked: 'how will you explore a space for the first time?' Responses to this question were used to create a realistic video that could simulate an individual's visit to interior space.

Marina Lommerse, interior architecture scholar and academic staff member at the School of Built Environment, Curtin University, when interviewed, said: '*first I will search for a spot or position where I can sit or stand still to have a general observation of the whole space; then I will focus on the details that I want to carefully observe in the indoor space.'* In a similar manner the rest of the participants stated that they would walk within the space and scan it. Three of the interviewees said they would search for a spot or find a position where they could sit or stand still to focus on the details of the environment, and the other two stated that they would go directly to the spot which interested them the most. All the interviewees stated that they would initially carry out a general observation of the space and then focus on details within the space. After the interviews, further discussion was conducted with the thesis committee and experts from the Department of Film, Television and Screen Arts, Curtin University with regard to the direction of the camera's path through the indoor space.

A number of tests were conducted using different methods to record the atmosphere of the elected space of this study. The aim of these tests was to produce 3D video recordings with low visual discomfort. The tests included a number of video recording techniques, such as using a mobile tripod attached to the camera, using a portable camera, using a portable camera with a pillar, using a portable camera with a dolly, and different speeds of movement in the experiment room.

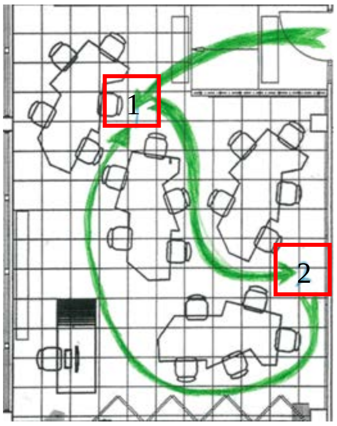
For the tests, a portable camera with dolly was used to make the camera more stable when the cameraman moved. The speed of the cameraman's movement was slower than the regular speed of a person walking in a space. Also the rotation movement to the right and left and directing the camera up and down was slower than a person turning his/her head to view his/her surroundings. The video recording tests were evaluated by number of technicians from the Department of Film, Television and Screen Arts, Curtin University with regard to their visual comfort quality.

Based on the results from the six participants together with specialists' advice, four camera paths were designed — one for each of the time durations. The camera paths were designed so that the cameraman recorded the space by moving through the space between the objects within the space. The camera, a Sony 3D TD10, was held at eye level, around 1.6m from the ground.

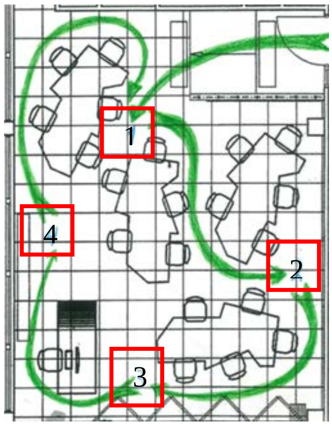
As a starting point, the researcher queried Vogels on her recommendation for time duration. Vogels stated in an email to the researcher that participants of a study require staying approximately eight to ten minutes in an indoor environment in order to evaluate the indoor environment using the questionnaire model.

Watching a video of a furnished room without any human figures or audio can be less stimulating for the observer than observing and walking through a real indoor space. There is therefore the possibility the observer can become bored and this could perhaps influence the evaluation of the atmosphere of the room in a negative way. To avoid the negative effects of boredom, the video was recorded for four different time durations, eight minutes, six minutes, four minutes and two minutes. Reducing the time duration of the video viewing could reduce the possibility of negative effects from boredom.

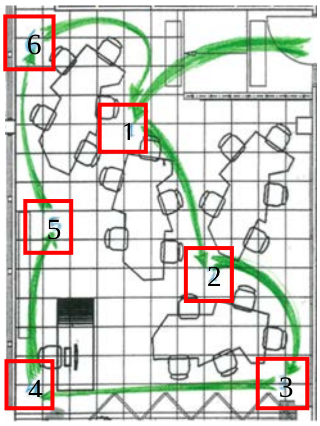
There were eight camera stations for the eight minute video, six stations for the six minute video, and so on. The path of the camera and the station positions for each of the four 3D video durations are shown in Figure 6.2. At each station, the camera moved left, right, up and down, in order to completely scan the indoor space. At the final station, the camera scanned the space and then focussed on some of the details in the space. The videos were recorded in a tutorial room, here referred to as Room A on the Curtin University campus.



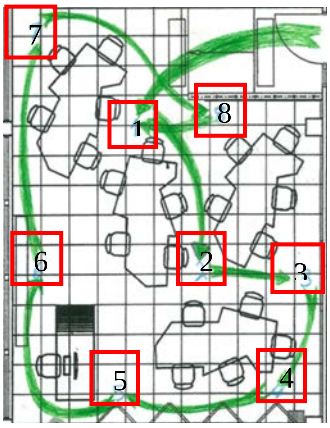
The two minutes camera path



The four minutes camera path



The six minutes camera path



The eight minutes camera path

Figure 6.2 The path of the camera and the station positions for each of the four video recording durations. Room A

During the video recording, the lighting brightness (illuminance) was measured at each of the eight camera stations mentioned previously (see Table 6.1). The measurements were used to ensure that the lighting brightness at each station on each of the recording days was maintained at the same or similar levels. They were also used to ensure that the lighting brightness at the stations was the same on the two recording days as on the days when participants evaluated the space ‘live’. In addition, a temperature sensor was installed near

Station 2 before the start of the video recordings. At the time of video recording, it was found that the temperature remained in the comfort range of 22.5°C to 24°C on both days of recording.

Table 6.1 The lighting brightness (lux) in the experiment room during the two days of video recording

Measurement date	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
30-8- 2012	35.2	42.2	14.3	10.1	38.7	36.5	28.1	29.2
12-9- 2012	35.3	42.5	14.3	10.1	38.9	36.6	28.9	29.2

Room C on the Curtin University campus was used to display the videos to the study participants. The room was chosen as it was designed to be isolated visually and acoustically. Figure 6.6 shows room C and two other spaces attached to the room, rooms C1 and C2.

A two-seater sofa was provided for participants to sit and watch the 3D videos, and a 30cm high coffee table was situated two and a half meters from the sofa. The sofa and the coffee table were there to create a homely comfortable atmosphere for the study participants. The distance between the 3D TV screen and the participants was designed so that the participants' visual field concentrated on the centre of the TV screen. Based on Tam et al.'s (2011) study, the optimal distance between the 3D TV screen and the viewer for a 55" screen is between 2.0 m and 2.39 m. Figure 6.3 shows optimal viewing distance for 3D TV. The research found that sitting 2.5m from the 3D TV screen did not influence the viewer. A Sony 3D 55" Television HX75 was placed on the coffee table and connected to a Sony BD blue-ray displayer BDP5590. A Samsung SE 506 AB blue-ray burner was used to burn the video data from the camera.

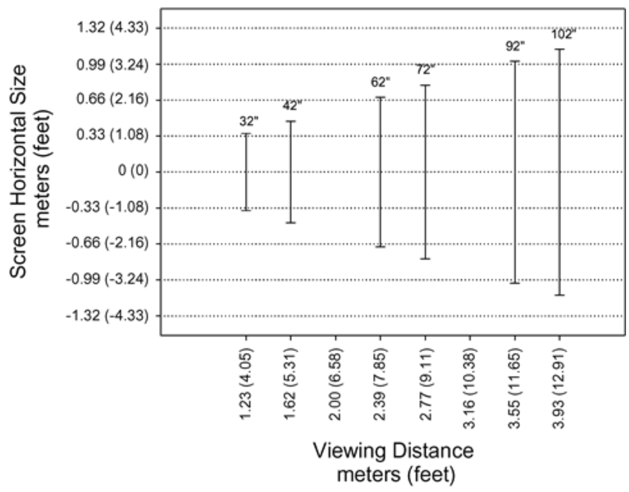


Figure 6.3 Optimal viewing distance for 3D TV. Source: Tam et al. (2011, 339)

Standardisingthe 'live' environment

A testo AG (Lux Meter) was used to measure the brightness of the lighting in the tutorial room that was used as the 'live' environment (see Figure 6.4). A lighting brightness measurement was conducted on the eight stations, numbered 1–8 in Figure 6.5. In addition, the temperature in the room was measured near Station 2. The temperature during the experiment was found to be in the comfort range of 22°C to 23°C. These procedures ensured the atmosphere and lighting settings were nearly the same in the room during each of the four days of the evaluations and the two days of video recording (see Table 6.2).

Table 6.2The lighting brightness (lux) in the experiment room during the 'live' experiment

Measurement date	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
26-9-2012	35.2	42.2	14.3	10.1	38.7	36.6	28.2	29.2
3-10- 2012	35.3	42.5	14.3	10.1	38.9	36.8	29.1	29.2
10-10- 2012	35.4	42.6	14.3	10.2	39	36.9	29.2	29.3
17-10- 2012	35.6	42.5	14.3	10.3	38.5	36.6	29	29.2

Figure 6.4 Room A - The space of the study experiment

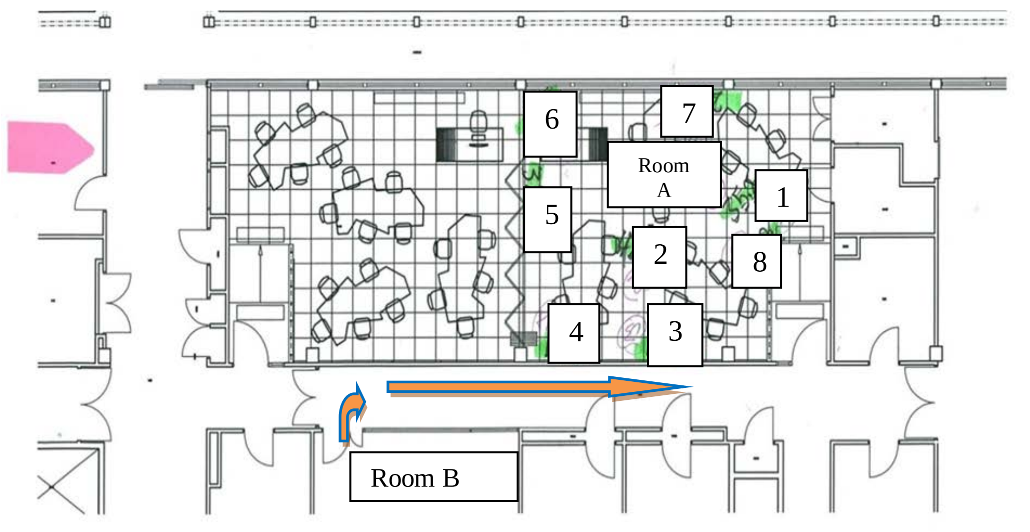


Figure 6.5 Room A and Room B: 'live' visit experiment; the orange path shows the participants' movement between the two rooms

6.13 Procedure

Evaluating the atmosphere of the 'live' space

Eleven participants took part in this stage of the study.Room B (see Figure 6.5), close to Room A, was used to prepare the participants. It was here that participants provided a written agreement to participate in the experiment. The level of lighting in Room B was similar to that in Room A (the Curtin University tutorial room pictured in Figure 6.4) so that the participants could adapt to the lighting brightness level of Room A before they entered it. Upon entering the computer Room A, they moved within it for eight minutes, after which time they evaluated the atmosphere of the room using the 18-item questionnaire that was validated in Chapter Five.

Evaluating the atmosphere of the indoor space via the 3D videos

Forty-four participants took part in this stage of the study. They were randomly assigned to the four video durations (two, four, six and eight minutes). After viewing the video of the indoor space individually, the participants evaluated its atmosphere. Except for the instructions, the questionnaire for evaluating the atmosphere of the room was essentially the same as the one used previously in the ‘live’ condition. For the video questionnaire, the participants were instructed to evaluate the atmosphere of the experiment room after viewing it through the 3D video displayed in front of them; in the questionnaire for the ‘live’ conditions, participants were instructed to evaluate the atmosphere of the room after visiting it (see Appendices 2 and 3).

The videos were displayed to the participants in Room C. This room was selected for several reasons. The space was designed in such a way it could be isolated acoustically and visually and the level of lighting brightness could be controlled. Room C1 was attached to Room C and linked to Room C2, which was the main entrance to the experimental space. Room C1 was used to prepare the participants — giving them time to adapt to the low brightness of lighting in Room C — and to obtain their written approval to participate in the experiment (see Figure 6.6)

The participants were asked to move to Room C. After the aims of the study were explained to them and they had adapted to the low level of light in Room C, each participant was left alone to watch the video. The participant was asked to go back to Room C1 when the video had ended. The participant was then asked to evaluate the space in the video recording by filling in the 18-item questionnaire.

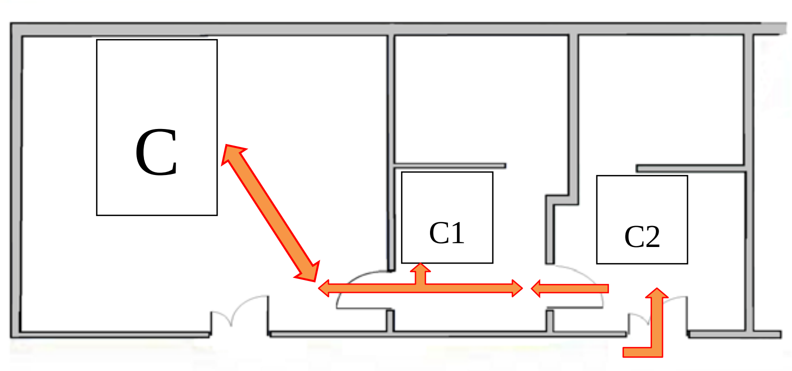


Figure 6.6 Experiment Rooms C2, C1, C and the path of the participants

6.2 Data analyses

Two types of analyses were conducted. Each analysis was implemented through SPSS (Version 22) (IBM-Corp 2013). The first analysis focused on inter-rater agreement, that is, the degree to which the participants' evaluations of the room's atmosphere in the 'live' condition were consistent with their evaluations in each of the four video conditions (of two, four, six and eight minutes duration). Inter-rater agreement was measured with Intra-class correlations (ICCs) (Graham, Milanowski and Miller, 2012). An ICC was computed between evaluations in the 'live' condition and evaluations in each of the four video conditions. The ICCs greater than 0.75 would indicate a good agreement between the two conditions in terms of participant ratings across the 18 items (Portney and Watkins 2000). There are several procedures for computing the ICC. The appropriate procedure for aparticular data set depends on whether the same *number* of raters (not the same raters) is used in each of the conditions, whether the raters are sampled from a population rather than representing the entire population of raters, and whether the researcher is interested in testing for *identical* ratings or *correlated* ratings across conditions (Landers 2011). For the present data, there were the same number of raters (11 participants for each visual experience), they were a 'convenience sample', and the experiment was interested in testing for correlated ratings. The ICC was therefore computed with a 2-way random model, using a consistency-type of agreement.

The second analysis focused on differences among the five conditions in terms of the Atmosphere Positive Descriptive (APD), Atmosphere Negative Descriptive (AND), and Atmosphere Impartial Descriptive (AID) factors. The APD factor contains the adjectives intimate, inspiring, cheerful, personal, relaxed, lively, luxurious and cosy; the AND factor includes the adjectives tense, hostile, musty, lethargic, restless and detached; and the AID factor includes business, spatial, accessible and formal. The significance of the differences among the conditions on each of the three factors was tested with the Generalised Linear Mixed Model (GLMM) as implemented through SPSS's (Version 22) (IBM-Corp 2013) GENLINMIXED procedure. The GLMM represents a special class of regression model. The GLMM is 'generalised' in the sense that it can handle outcome variables with markedly non-normal distributions; the GLMM is 'mixed' in the sense that it includes both random and fixed effects. For the present GLMMs, there was one nominal random effect (participant), three categorical fixed effects (condition and factor, and the Condition x Factor interaction). Condition included five levels: live and the four video durations of two minutes, four minutes, six minutes, eight minutes. Factor included three levels: APD, AND, AID.

Statistical assumptions of the GLMM

For mixed designs (i.e., designs that include both a between-subjects and a within-subjects factor) such as this, the assumptions of normality and homogeneity of variance must be met. The GLMM 'robust statistics' option will be invoked to accommodate any violations of these assumptions.

6.3 Results

The reported results of this study include the inter-rater agreement (as measured by the ICC) between the live condition and the four video conditions. Also the differences among viewing conditions in terms of the participant ratings are reported in this section.

Inter-rater agreement

The ICCs between the 'live' condition and each of the four video conditions are reported in Table 6.3. All ICCs were significantly greater than zero (*p*s< .001), and there were high levels of agreement (ICCs > .75) between the live condition and each of the four video conditions in terms of how participants evaluated the room's atmosphere across the 18 adjectives. Evaluations of the two-minute video were in closest agreement to the 'live' evaluations.

Table 6.3: Inter-rater agreement between the live condition (n = 11) and each of the four video conditions (ns = 11)

Comparisons	ICC	Test statistic	Significance
Live and 2 minutes	.934	F (17, 357) = 15.21	p < .001
Live and 4minutes	.891	F (17, 357) = 9.21	p < .001
Live and 6 minutes	.921	F (17, 357) = 12.70	p < .001
Live and 8 minutes	.899	F (17, 357) = 9.85	p < .001

Differences among conditions

There was no interaction between condition and factor (*F* [8,150] = 1.40, *p* = .201). This means that the main effect for factor (*F* [2,150] = 68.52, *p*< .001) applies to all five viewing conditions, and the main effect for condition (*F* [4,150] = 2.95, *p* = .022) applies to all three factors.

Least significant difference (LSD) post-hoc contrasts conducted on the main effect for factor indicated that, *for all five viewing conditions*, impartial ratings were significantly higher than positive ratings (*p*< .001) and positive ratings were significantly higher than negative ratings (*p*< .001). LSD post-hoc contrasts conducted on the main effect for condition indicated that, *for each of the three factors*, the mean rating in the 'live' condition was not significantly different to the mean ratings of participants in the 2 (*p* = .110), 4 (*p* = .555), 6 (*p* = .095), and 8 (*p* = .473) minute video conditions. These results are graphed in Figure 6.7.

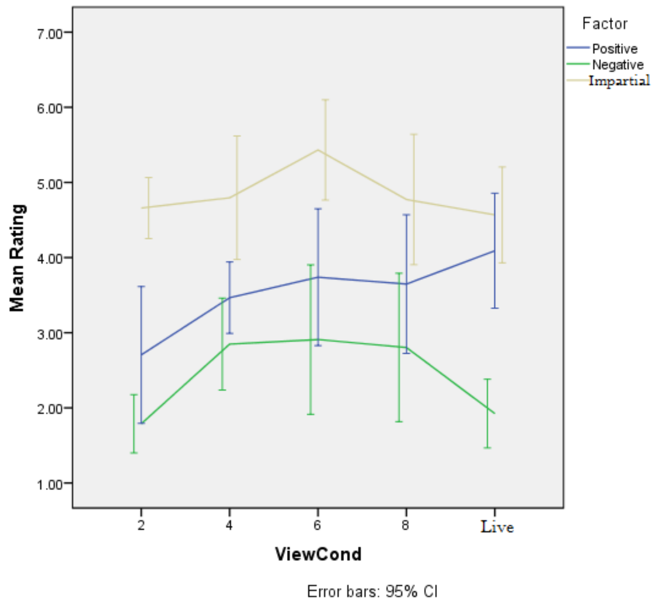


Figure 6.7 The impact of viewing conditions (2, 4, 6, 8 minutes, and 'live') on mean ratings for the three factors: Positive, Negative, and Impartial

6.4 Discussion

Data for the inter-rater agreement between the four videos' time durations and the real space show that all the video durations had high intra-class correlation. Live and 2 minutes ICC =.934, live and 4 minutes ICC =.891, live and 6 minutes ICC = .921, and live and 8 minutes ICC =.899. The acceptable level of agreement is (ICCs > .75). Turning to the GLMM analyses, for each of the three factors the mean rating in the 'live' condition was not significantly different to the mean ratings in the 2 (p = .110), 4 (p = .555), 6 (p = .095), and 8 (p = .473) minute videos. These results indicate that the participants evaluated the atmosphere of the space in the 'live' condition and through a 3D video similarly, although the highest inter-rater agreement was between the 2 minute video and the 'live' condition.

It is noted that there were differences between the five experiences. The path of the camera in the examined space with regard to each of the video durations varied. In the 'live' visual experience the participants had free will to move within the space during the time of their visit while with the video visual conditions, the participants had no option but to view what the video offered. The video offered the participants dynamic sequential images. Viewing dynamic sequential images of the videos provided a similar sense of visual experience 'live' (visiting space). However, the two visual experiences were not identical.

On the other hand, the analysis of data collected from the five visual conditions was highly correlated. The aim of this stage of the study was to discover an adequate alternative for evaluating the atmosphere of the indoor environment without visiting the real space. The results showed that any of the durations of the 3D video visual experiences could be used as an alternative to the visual experience of visiting the real space for the purpose of evaluating the indoor environment with preference of the two-minute video as it has the highest correlation with the 'live' condition.

6.4.1 Alignment of this study with other studies utilising simulation visual methods

Previous studies which have evaluated the indoor environment have used photographs to examine the indoor environment. The findings of these studies (e.g. Flynn et al. 1977, and Whitehead 2010) showed that their methods using photographs were feasible for research examining the influence of lighting in indoor environments. These methods saved the researchers' time and financial cost without losing the accuracy of evaluating the indoor environment.

However, the study of Heft and Nasar (2000) found that there was a difference between observing the outdoor environment through static images and through video of the same environment. The difference was that the video's visual experience encouraged the observers to explore the environment, stimulated curiosity and promoted a desire to learn more. This conclusion encouraged the use of video in the evaluation process, as both curiosity and desire to learn more are factors which make the observer more alert and aware of her/his examined environment.

A number of psychology studies have also used 2D video in evaluating different emotional states in the laboratory (e.g.Gross and Levenson 1995; Kreibig et al. 2007; Philippot 1993; Schaefer et al. 2010); these studies selected parts of videos already produced by professionals in the media industry in order to evaluate different human emotional states. These studies used the method of self-report to collect their data. They showed that the use of video is more efficient for eliciting emotional states than other methods such as interactions with trained confederates, hypnosis, repeating phrases, facial muscle movements, imagery, music, slides and films[9]. The benefit of using videos in psychology studies is that videos are stimulating, contain no deception, and are dynamic rather than static. Videos also have a comparatively high degree of environmental validity (Gross and Levenson 1995). These studies and the current study are similar in their use of the video and self-report method for collecting data from participants. There are, however, several differences between these studies and the current study.

In the current study, the videos were produced specifically for the study. The aim of the current study was to explore how individuals perceive and evaluate the indoor environment in the videos. On the other hand, the psychology studies listed above used the materials in the video to stimulate the emotional state of respondents. No audio or human figures appeared in the current study videos, whereas the psychology studies used video which included different stimulating techniques. The current study used the atmospheric evaluation model to evaluate the visual experience to avoid or reduce the impact of the participant's emotional state on their evaluation process; thus this was different from the psychology studies which focused on evaluating the participant's emotional state.

[9] For more information please see Gross and Levenson (1995) as this study mentioned the study which used these methods.

Finally, the current study used 3D video instead of using 2D video. The above discussion shows that this study was not the first study to use a video technique with self-report methodology. However, the current study used a partly different model, the modified atmospheric evaluation model. The current study was not concerned about how the participants felt when they viewed the video, but how they evaluated the indoor environment in the video. Further, the current study used 3D video technology instead of 2D video technology because it was considered to have different character images and better quality (Dumbreck, Abel, and Murphy 1990; Kaptein et al. 2008; Lambooij et al. 2011).

The use of 3D visual experience in research and practical work was supported by Shih (2003). Shih found that 3D visual experience was a useful tool for monitoring and administering interior design projects remotely. Shih (2003) used 3D cameras and scanners to establish a remote synchronous monitor projects system. The system gives immediate monitoring directly between the project site and the supervisor's office on the project, and the 3D technology gave more accurate details. The 3D video did not just show what was happening on the work site, it also determined where any object was positioned based on three axis x, y and z. The current study, when compared with Shih's study, produced some minor differences regarding the visual experience. The observer in Shih's study could see what was happening in the real space at the actual time, while, in this study, the time frame was different; the 3D video of the space was recorded in the past and displayed later to the participants. Nevertheless, it is clear that a visual video experience can help individuals to recognise and place themselves in the monitored environment similarly to the person who visits the real environment.

There are differences, though, between the 'live' experience and the viewing of 3D video; they include the participant's awareness of sound and smell and temperature in the environment; these elements provide a holistic evaluation. The temperature, the smell and the sounds in the environment, however, could be considered independent variables which may or may not influence the evaluation of the atmosphere related to lighting. Another potentially confounding factor was that the individuals who watched the 3D video were deprived of free will to move around and observe the environment. Thus, all the individuals who watched the 3D videos observed the same amount of visual data.

The aim of the main study of this project was to examine the influence of the RGB LED lighting in a hotel guest room. Therefore the other components and variables in the indoor environment had to be maintained at a stable level for all the examined conditions, in order to concentrate on the changes caused by the changes of the lighting specification. The 3D video visual experience was controlled such that the influence of the other components of the indoor environment was minimised.

The distance between human's eyes, 6.3 cm, gives a sense of depth in the visual process. The 3D video technology simulates the image which the human eyes capture from their surroundings (Seuntiens 2006). Therefore, 3D video technology produces a visual experience nearly similar to visiting an environment. Another key point is the camera path. The moving camera design was selected on the basis of the initial interview (Section 6.1.2) which suggested that a moving camera would provide a realistic stimulation of a real visit to a space for the first time.

The movement and speed of movement of the cameraman were also considered. In the earlier 3D video recordings, the movement of the cameraman as well as the camera spin in scanning the space right to left and up to down were sharp and uncomfortable for the viewers. All these points were extensively worked on with a number of technicians and experts from Curtin University; thus the visual experience of the study participants was enhanced and an acceptable 3D video was produced.

6.5 Chapter Six Conclusion

In conclusion, all the five viewing conditions were found to be acceptable for use in evaluating the atmosphere of the indoor environment in a hotel guest room. All of the four 3D video durations showed significant inter-rater agreement with the 'live' viewing conditions; of the four video durations the 2-minute video had the highest inter-rater agreement with the 'live' viewing conditions. *Therefore it was decided that the main study of this thesis would use the two-minute 3D video in order to fulfil the study objectives.*

The use of the 3D video technology as an alternative to a real visit to the indoor space saved time and provided flexibility to collect data. Also it enabled the study expenses to be kept to an acceptable level. Figure 6.8 shows the flowchart of the experimental process discussed above.

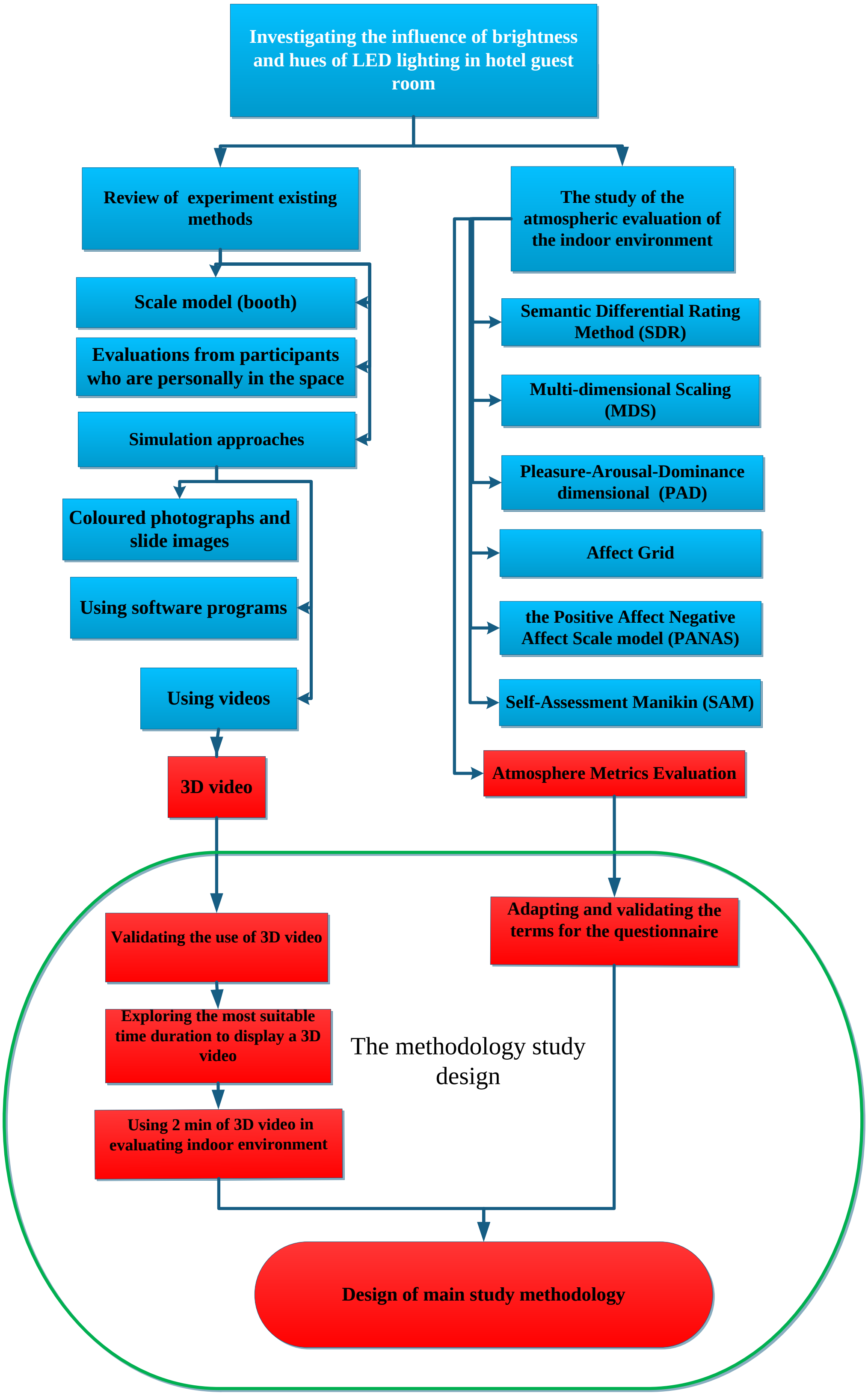


Figure 6.8 Flowchart of the study design after validation process of the 3D video technology

7. Main Study method

The aim of the main study of this thesis was to establish a better understanding of the influence of the RGB LED lighting on the indoor atmosphere of a hotel guest room. The study was designed such that the study population would view different lighting conditions in a hotel room in order to assess the desirability of the indoor atmosphere. Participants viewed the hotel guest room via a 3D video rather than visiting the real space (in accordance with the findings explained in Chapter Six). As discussed in Chapter Five, the tool used for rating the indoor atmosphere was an English version ofVogels' (2008b) Dutch questionnaire. The study participants also rated the room in terms of brightness, warmth, appropriateness, and the degree to which they felt encouraged to return to the hotel guest room. These responses to the hotel guest roomwere tested as potential moderators of the impact of hue and brightness on the three atmospheric ratings – atmosphere positive descriptive, atmosphere negative descriptive and atmosphere impartial descriptive. The research process for the main study is shown in Figure 7.1

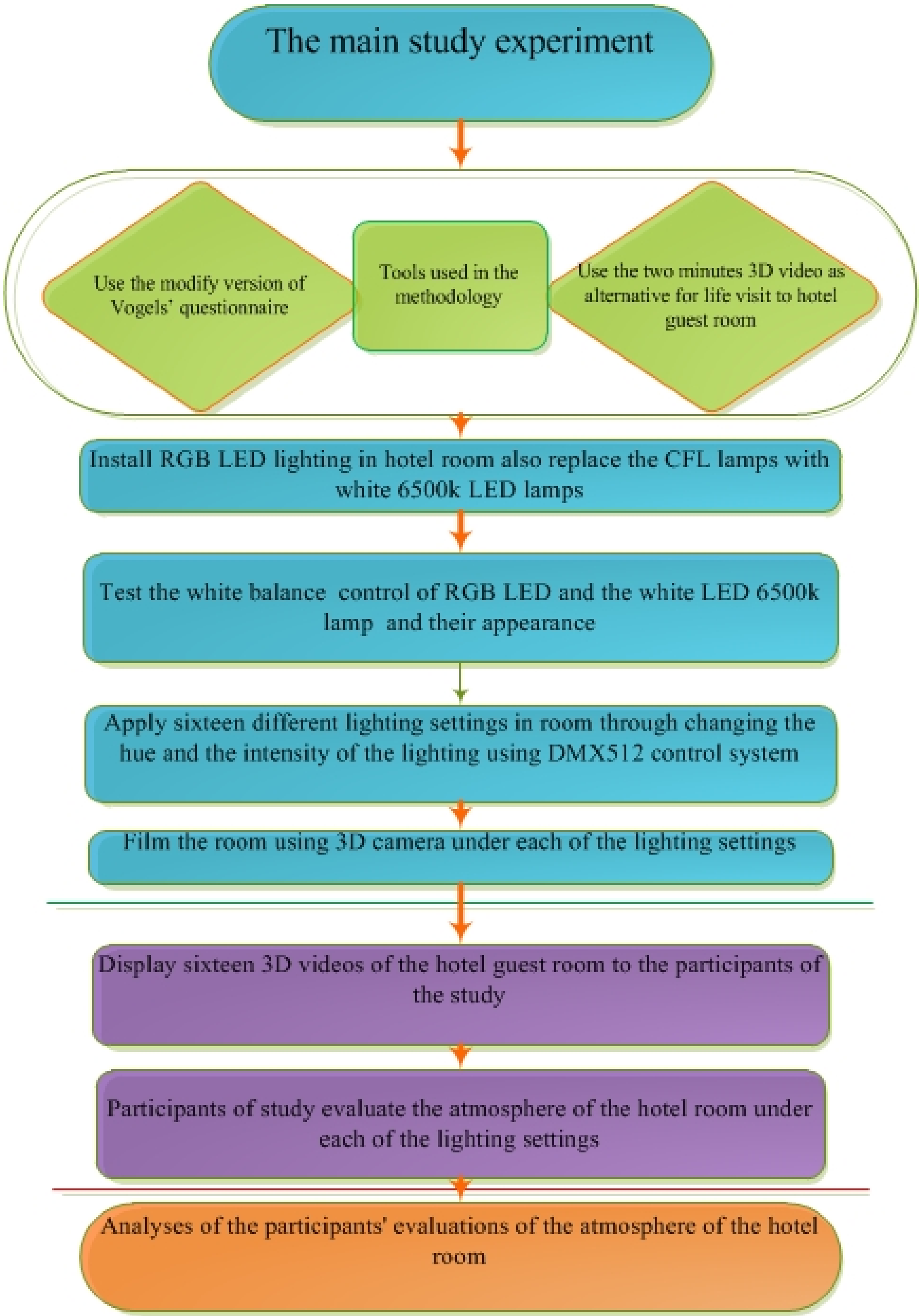


Figure 7.1 Main study flowchart

7.1 Method

The aim of this stage of the study was to evaluate the atmosphere of the hotel guest room under the exposure of the RGB LED lighting settings in different hues and intensities. The study used the findings described in Chapters Five and Six and the measuring tool developed in Chapter Five. The study also used the 3D video technology as an alternative to visiting the real hotel room, as explained in Chapter six.

Firstly the study participants' details are described. The instruments and apparatus used in the study arethendescribed, followed by the research design, procedure, data analysis, and discussion.

7.1.1 Participants

A convenience sample of 32 postgraduate students from Curtin University (20 females and 12 males) participated in the study. The convenience sample is one of the non-probability sample methods used by researchers; it has a number of advantages as it saves time and cost. The convenience sample comprised staff and postgraduate students as all of them had been involved in work trips, had contributed to conferences and had participated in tourist trips. The study by Kam, Wilking and Zechmeister (2007) showed that campus staff can be more suitable than the general local population for studies such as this. The sample was divided into two age groups (20 to 40 years and 41 years and above), because some of the studies that have examined the influence of lighting show that different age groups evaluate the influence of lighting in the indoor environment differently. The current study chose to use aconvenience sample; therefore, it was hard to create a balance between the age groups.

7.1.1 Instruments and apparatus

The following instruments and apparatus were used in this study:

Questionnaire

An 18-item atmosphere questionnaire (the development of which was discussed in Chapter Five), plus four additional questions that used a 7-point Likert scale to rate the room's brightness, warmth, appropriateness and the degree to which participants felt encouraged to return to the room.

Spaces used in experiment

The dimensions of the hotel guest room where the 3D video was recorded were L5.04m×W3.60m×H2.40m for the guest room and L3.60m×W2.03m×H2.40m for the service area, the bathroom and the kitchenette (see Figure 7.5).The dimensions of the space where the 3D video was presented to the participants were L14.5m×W9.5m×H5m. The room was designed as a highly controlled indoor environment with isolated acoustics, light control board and no daylight access.

Furniture used in the experiment

- A two-seater sofa for the participants to sit on and watch the 3D videos;
- A coffee table, 30 cm high, to support the 3D TV screen;
- Two study tables and two chairs.

Equipment

- Six (LED Visage) Retro fit LED light bulbs CCT 6000-6500k, CRI 75;
- Nine (Superlight) Scorpion RGB 8x3W LED Down lights;
- A master DMX512 control system, model Superlight SL5055;
- Testo AG (Lux Meter) Model Number 540 Serial 39015797007;
- A Sony 3D camera TD10 for recording the videos;
- A Samsung SE 506 AB blue-ray burner for burning the recorded data from the camera to the blue-ray CD;
- A Sony 3D 55" Television HX75 for displaying the 3D recordings of the experiment;
- A Sony BD blue-ray player BDP5590 for replaying the recordings;
- An Ocean Optics Red Tide USB 650 spectral light reader.

Software support equipment operating

- Super-DMX LED Software for DMX512 Interface;
- Vernier — Logger Pro V 3.7

Testing the instruments prior to the main study

The study used a combination of white general LED light 6500K and RGB mixed white lightat two levels of intensities. The general white LED light at two levels of lighting brightness were also considered as reference lighting to indicate the changes on the perceived atmosphere of the hotel guest room after applying the wall wash lighting hues. Seven wall wash lighting hues (red, yellow, green, cyan, blue, magenta and the mixed RGB white) were used as the other parts of the lighting combination to be examined in the hotel guest room. All the seven lighting hues, plus the general lighting in the hotel guest room, were examined at two levels of brightness — high and medium; thus,16 lighting settings were examined in the current study. First the general white LED lamp was installed in the hotel guest room. Then wall wash lighting fixtures were installed as will be explained later in the section, 'Employment of instruments and apparatus in the hotel room'.

The general white LED and the mixed RGB white light used different technology to emit white light. As the current study used a 3D camera video which is sensitive to light capture, a test was required to establish if the two LED lighting sources appeared similar to each other in the 3D video.

The brightness of the general lighting, 'general white LED lamp' was controlled by the lighting switches of the hotel guest room and the number of lamps in each of the light fixtures. The medium level of lighting brightness for general lighting was created by using one white LED lamp bulb in each of the two ceiling lighting fixtures without putting on the LED lamps over the bedside tables. Two LED lamp bulbs in each of the two ceiling lighting fixtures and one lamp bulb in each of the bedside table lamps were used to create the high level of lighting brightness of the general lighting.

The DMX 512 lighting control was used to apply equal parameter readings for the three colours of the red, green and blue RGB LED lights to create the white wall-wash lighting. The high and medium brightness light settings for the white wall wash appeared more purplish than the general white lighting. This meant a control white balance was needed for the lighting setting general white + RGB mixed white wall-wash at the two levels of brightness. It was determined that the purplish hue of the wall wash lighting was due to two factors. The first was that the RGB light fittings actually emitted a higher red and blue output than green, and the secondwas that there was a mismatch between the LED light and the general white light. This meant that when the camera white balance was used to allow for the LED offsets, the general lighting of the room appeared greenish; and when the camera was balanced to the general white lighting, the LED offset was exaggerated, resulting in the purplish hue. A white general lighting with a CCT of 6500K̊ and CRI of 75 was chosen to obtain a closer match to the LED fixture output, which could then be balanced to the nearest pure white wall wash lighting, using the DMX lighting controller. The Sony TD10 camera white balance and exposure settings were used as the primary tool to measure the white light accurately. The DMX512 control was used to change the white lighting parameters.

Appendix 4 shows the DMX512 control reading that was used to emit the RGB LED white lighting that best matched the white lighting of 6500K used in this study and the other lighting settings of the experiment. Figure 7.2 shows, on the left, the lighting setting using equal parameter readings for the three parameters RGB. The right hand photo in the figure shows the white light combination after the white balance control.

Figure 7.2 The white wall wash in the first test configuration

Employment of instruments and apparatus in the hotel room

Three kinds of lighting fixtures were used in the study: the ceiling white lighting CCT 6500K and CRI 75, the wall white lighting fixtures over the bedside tables with CCT 6500K and CRI 75, and the RGB LED down light for wall wash lighting. Figure 7.6 shows the distribution of the lighting fixtures in the hotel guest room. Figure 7.3 shows the ceiling and the lighting fixtures over the bedside tables of the general lighting in the hotel guest room. Six of the nine RGB LED down-lights were directed upwards onto the walls of the hotel guest room after installing them in specially made plastic holders (see Figure 7.4). The other three RGB LED down-lights were fitted into a standing lamp, a table lamp and hidden behind a travel bag (see Figure 7.5).

Figure 7.3 The general ceiling white lighting and the wall white lighting fixtures over the bedside tables.

Figure 7.4 The lighting fixtures which were designed to direct the RGB LED down-light upwards onto the walls of the hotel room.

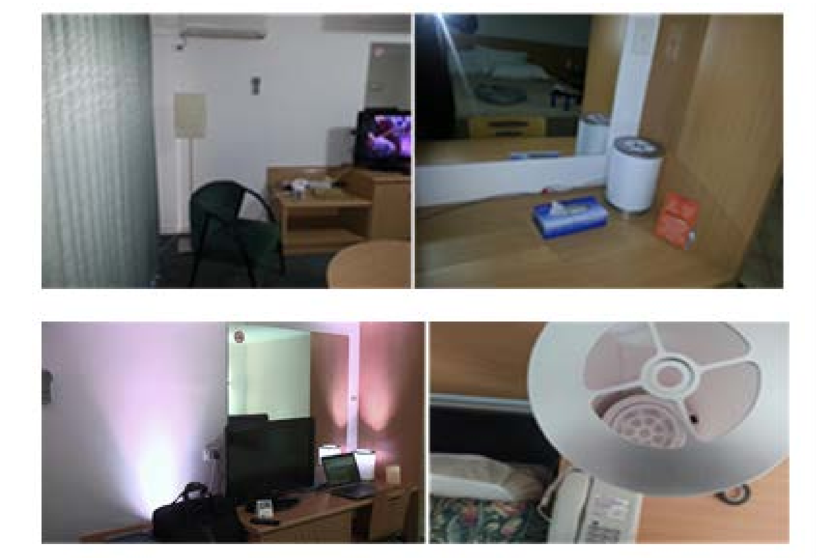


Figure 7.5 The three RGB LED down-lights were fitted into a standing lamp, a table lamp and hidden behind a travel bag (see Figure 7.5).

Lighting settings

Two lighting criteria were considered in the main study. The first criterion was the lighting brightness: high brightness and medium brightness based on the DMX512 parameters and the reading of the light-lux meter. The second criterion was the hue of the lighting. The study considered the additive light colour theory as a basis to examine the coloured lighting hue settings - three primary lighting hues: red, green, and blue; the three mixed secondary lighting hues: magenta, cyan and yellow; and the RGB mixed white. Added to the study design was the general white lighting setting as the primary lighting condition of the hotel guest room before applying the wall-wash coloured lighting. Therefore, the study design included 16 lighting settings (see Table 7.1). Each of the lighting hue spectrum distributions was measured using Ocean Optics Red Tide USB 650 spectral light reader in order to identify each of the lighting hue characteristics. See Appendix 5.

Table 7.1 The lighting settings used in the main study experiment

Lighting criteria	red	magenta	blue	cyan	green	yellow	White	general white
High brightness	High brightness	High brightness	High brightness	High brightness	High brightness	High brightness	High brightness	High brightness
Medium brightness	Medium brightness	Medium brightness	Medium brightness	Medium brightness	Medium brightness	Medium brightness	Medium brightness	Medium brightness

The coloured correlation temperature (CCT) of the general and task lighting was 6500k and the CRI was 75. The study did not focus on the influence of the colour rendering index CRI, as the study was designed to evaluate the general atmosphere of the hotel guest room. Another matter not considered was the quality of the colour rendering of the indoor space component which was a combination of coloured and white lighting, as it would have been difficult for the study participants to recognise the influence of the white light colour quality (the colour rendering under the light).

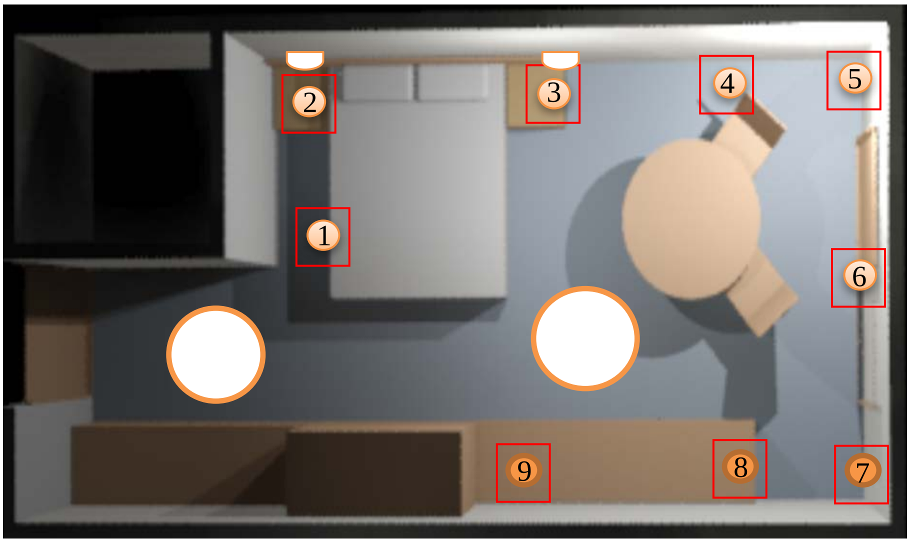


Figure 7.6 The lighting distribution: lighting fixtures 1-6 are the direct wall wash and 7-9 is the hidden wall wash; the white spots with the orange lines are the general light fixtures.

Recording the hotel room under the designated lighting settings

As mentioned earlier, the recording was conducted in a hotel room.[10] Firstly, the RGB LED lighting fixtures were installed in the room, as shown in Figures 7.3, 7.4 and 7.5. The lighting brightness and hue saturations of the upward fixtures were controlled using the DMX512 LED lighting controller. Light lux meters were used to measure the lighting brightness for each of the lighting settings in five stations around the room.The average lighting brightness level of all the lighting setting was higher than the 40 lux required for safe movement according to the Australian/New Zealand lighting standard AS/NSZ 1680 (AS/NZS 2009).

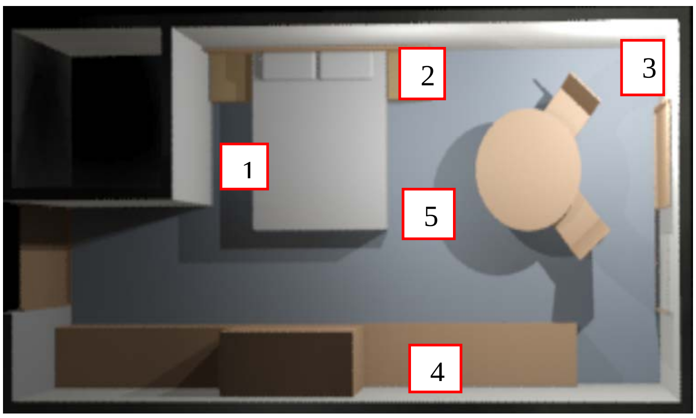


Figure 7.7 Perspective plan of the hotel room with the five light lux meter reading stations

[10]Room No.18 in the Great Eastern Motel, Perth WA was used to recording the hotel guest room under the exposure of the examined lighting setting of the study.

Recordings were made using the 3D camera of the hotel room under each of the 16 lighting settings shown in Table 7.1. Some of the lighting settings were recorded more than once if the quality of the recording was not considered acceptable for the study. A camera path method was used to scan the room and then focus on the details of the room.Thiswas similar to the method used when testing the appropriateness of using a video to test people's responses to the atmosphere in a room, as described in Chapter Six.

Based on the results described in Section 6.3, the 3D videos for each of the lighting settings were two minutes long. Each of the videos captured the atmosphere of the hotel guest room under one of the 16 lighting settings shown in Table 7.1.

Table 7.2 Light meter readings (in lux) in the hotel guest room.

Colour	Bed Left Station 1	Bed Right Station 2	Wall / Corner Station 3	Desk Station 4	Centre Station 5
Gen White High	77	114	34	40	235
Gen White Medium	36	74	15	20	127
Wash White High	280	323	246	360	404
Wash White Medium	72	88	100	122	165
Red High	206	247	160	170	334
Red Medium	88	98	101	112	155
Yellow High	254	316	245	248	360
Yellow Medium	108	142	150	170	182
Blue High	82	107	56	62	236
Blue Medium	30	39	33	37	114
Magenta High	205	244	176	169	331
Magenta Medium	145	164	152	143	197
Green High	146	200	108	167	295
Green Medium	85	101	99	106	165
Cyan High	168	223	153	178	315
Cyan Medium	98	125	130	127	177

7.1.2 Research design

RGB LED lighting was installed in a hotel room with a DMX lighting controller to control the hue and brightness of light emitted from the RGB LED lighting fixtures. Three-dimensional video recordings were then made of the hotel room under each of the 16 lighting conditions. The general white lighting was applied as reference lighting for the experiment and it was considered as one of the lighting settings. The experiment also included seven lighting hue settings—red, green, blue, cyan, magenta and yellow, as well as the mixed RGB white lighting. Each of the eight lighting conditions was shown at a moderate and a high level of brightness. This produced an 8 (Hue: red, magenta, blue, cyan, green, yellow, white, general white) x 2 (Brightness: high, medium) within-subjects research design. The design is illustrated in Table 7.3.

Table 7.3: The 8 x 2 Within-Subjects Research Design with Consecutively Numbered Cells.

Brightness	**Hue**							
	Red	Magenta	Blue	Cyan	Green	Yellow	White	G.White
High	1	2	3	4	5	6	7	8
Medium	9	10	11	12	13	14	15	16

The time duration to evaluate each of the lighting settings was estimated to be two minutes, plus two to five minutes to fill in the questionnaire form, plus a two-minute break between any two lighting setting evaluations. Thus, each of the study participants needed nearly 144 minutes to evaluate all the lighting settings of the study. It was therefore considered necessary to break the evaluation process into two visits.

The 16 conditions were counterbalanced across participants with a Balanced Latin Square (BLS) design allowing for two visits to the laboratory for each participant. In this design (see below Table 7.4), each condition appears exactly once in each row and exactly once in each column. The BLS design is implemented by randomly allocating two participants to each of the 16 sequences listed in Table 7.2 (*N* = 32).

Table 7.4: The Balanced Latin Square Design (the numbers in the body of the table represent the cell numbers from Table 7.3)

		First visit								**Second visit**							
Participants 1 & 2	Sequence 1	1	2	16	3	15	4	14	5	13	6	12	7	11	8	10	9
Participants 3 & 4	Sequence 2	2	3	1	4	16	5	15	6	14	7	13	8	12	9	11	10
Participants 5 & 6	Sequence 3	3	4	2	5	1	6	16	7	15	8	14	9	13	10	12	11
Participants 7 &8	Sequence 4	4	5	3	6	2	7	1	8	16	9	15	10	14	11	13	12
Participants 9 & 10	Sequence 5	5	6	4	7	3	8	2	9	1	10	16	11	15	12	14	13
Participants 11 & 12	Sequence 6	6	7	5	8	4	9	3	10	2	11	1	12	16	13	15	14
Participants 13 & 14	Sequence 7	7	8	6	9	5	10	4	11	3	12	2	13	1	14	16	15
Participants 15 & 16	Sequence 8	8	9	7	10	6	11	5	12	4	13	3	14	2	15	1	16
Participants 17,	Sequence 9	9	10	8	11	7	12	6	13	5	14	4	15	3	16	2	1

18																	
Participants 19 & 20	Sequence 10	10	11	9	12	8	13	7	14	6	15	5	16	4	1	3	2
Participants 21 & 22	Sequence 11	11	12	10	13	9	14	8	15	7	16	6	1	5	2	4	3
Participants 23 & 24	Sequence 12	12	13	11	14	10	15	9	16	8	1	7	2	6	3	5	4
Participants 25 & 26	Sequence 13	13	14	12	15	11	16	10	1	9	2	8	3	7	4	6	5
Participants 27 & 28	Sequence 14	14	15	13	16	12	1	11	2	10	3	9	4	8	5	7	6
Participants 29 & 30	Sequence 15	15	16	14	1	13	2	12	3	11	4	10	5	9	6	8	7
Participants 31 & 32	Sequence 16	16	1	15	2	14	3	13	4	12	5	11	6	10	7	9	8

The 18 atmosphere items were presented to the participants according to four random sequences (see Table 7.5). Eight participants were randomly allocated to each of the four sequences.

Table 7.5: Scheme for randomly allocating participants to random sequences of adjectives

Sequence of terms	Sequence 1	Sequence 2	Sequence 3	Sequence 4
1) Intimate	8	9	12	16
2) Inspiring	1	4	2	13
3) Cheerful	14	2	5	17
4) Personal	13	18	7	2
5) Relaxed	16	6	9	4
6) Lively	3	3	18	6
7) Luxurious	7	14	6	9
8) Cosy	15	15	8	8
9) Tense	2	5	13	5
10) Hostile	17	11	10	7
11) Musty	6	13	11	1
12) Lethargic	11	7	16	12
13) Restless	5	10	14	14
14) Detached	4	8	15	15
15) Business	9	12	1	11
16) Spatial	18	1	17	18
17) Accessible	12	17	3	10
18) Formal	10	16	4	3

7.1.3 Procedure

The 3D videos were located in a TV studio room at Curtin University. The studio was furnished with two tables and two chairs.This part of the studio was used to prepare the participants for entry into the visual experience by allowing them to adapt to the level of lighting, to obtain from them written approval to participate in the experiment, and to check if any of the participants had a colour blindness problem. In another part of the studio, a two-seater sofa was placed for the participants to sit on and watch the 3D videos individually on a Sony 3D 55" Television HX75. The television was placed 2.5m in front of the sofa. A Sony BD blue-ray player BDP5590 was attached to the 3D TV to display the 3D videos; both the 3D TV and the blue-ray player were placed on a coffee table as shown in Figure 7.8. The temperature in the studio where the experiment was conducted was maintained in the comfort range of 22.5°C to 24°C.

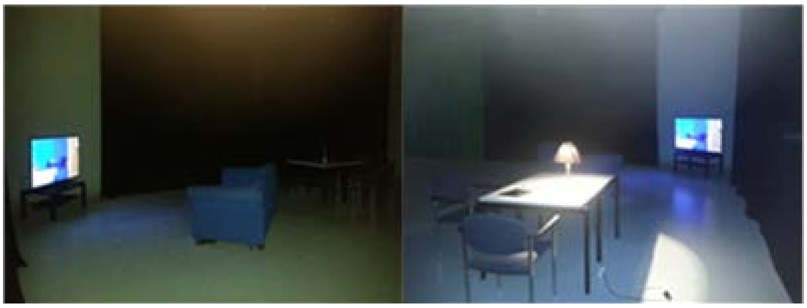


Figure 7.8 TV studio where participants viewed the video of hotel guest room.

Participants were tested individually. They entered one at a time from the main door of the studio and then moved to the interior door of the studio, where they entered the studio and were guided to a chair at a table where they could read the information sheet and the letter of consent. During thistime,participants were adapting to the new level of lighting. After the participants finished reading the information sheet and the letter of consent, they were administered Ishihara’s (1976) colour blindness test. They were asked if they were comfortable and if they had adapted to the level of lighting in the displaying area of the studio.

Participants were invited to sit on the sofa to view the 3D video of the hotel room under one of the lighting settings. Participants were told they were to watch the video of the hotel guest room and use the questionnaire to evaluate the space. After the participants finished watching the 3D video, they were asked to move back to the table where they could record their evaluation of the atmosphere of the hotel room under one of the lighting settings of the study.

The measuring tool for this part of the study was the same 18-item questionnaire that was used to verify the use of the 3D video camera (see Section 5.3, Chapter five) discussed in Chapter Six with minor modifications; except that the presentation orders of the 18 items were randomly determined, as shown in Table 7.5. The participants were asked to evaluate the atmosphere of the hotel guest room that they had viewed in the video by rating each ofthe 18 descriptive terms from 1 [least applicable] to 7 [most applicable]. Five new items were added to the questionnaire. The first asked participants to evaluate the level of light brightness; the second asked participants how warm or cold they found the lighting in the video; the third question was designed to ascertain how appropriate the lighting was in the hotel room from the participants' perspectives; and the fourth question was designed to determine the degree to which they felt encouraged to return to the hotel. An additional section was added to the questionnaire regarding the demographics of the participants (see Appendix 3 for the complete questionnaire).

After the participants finished evaluating the hotel room shown on the video, they had a two minute break; then they went back to the sofa to examine another 3D video of the hotel guest room under another lighting setting. This procedure was repeated for each participant eight times on their first visit and eight times on their second visit. Therefore, each participant viewed and evaluated 16 videos of the hotel room in total.

7.2 Data analysis

A series of Generalised Linear Mixed Models (GLMMs) were tested in order to determine how hue and brightness impacted ratings of the hotel room's atmosphere. The GLMM represents a special class of regression model. The GLMM is 'generalised' in the sense that it can handle outcome variables with markedly non-normal distributions; the GLMM is 'mixed' in the sense that it includes both random and fixed effects. For the present GLMMs, there was one nominal random effect (participant) and two categorical fixed effects (Hue and Brightness) and the Hue x Brightness interaction. The GLMMs were implemented through SPSS's (Version 22) GENLINMIXED procedure.

7.3 Interviews related to use of 3D video

A short interview was conducted with each of the 32 participants of the main study. The aim of the interview was to be sure that the use of the 3D video visual perception experience was a viable alternative to the real visit and that the study questionnaire had been a suitable tool to collect the data for the main study experiment.

The questions were as follows:

1. **How do you find the 3D video technology visual experience with regard to transforming the atmosphere of the hotel guest room under the exposure of the lighting setting?**
2. **Do you think that the use of 3D video is a good way to evaluate the lighting in a hotel guest room?**
3. **What is your opinion of the questionnaire model? Do you feel that you gave your objective opinion or you gave an emotional reflection with regard to the atmosphere of the hotel guest room?**
4. **Do you have any suggestions for this study?**
5. **What is your main conclusion from contributing in the current study experiment?**

Responses to and discussion of the question 'how do you find the 3D video technology visual experience transforms the atmosphere of the hotel guest room under the exposure of the lighting setting?'

Thirty-one of the 32 participants regarded the use of 3D video technology as an acceptable alternative to a real visit. Only one of the participants did not find it generally acceptable. Participant 22 stated that looking at the 3D video:

> *Makes me feel more uncomfortable, it makes it less real. I am looking at a picture that is a normal thing to see but, looking at a 3D video takes me away from the scene. 2D video or photo would be better.*

Participant 17 generally accepted the use of the 3D video technology but she stated:

> *It is very near the real thing but I still feel that I am an outsider; I am not inside the space.*

Participant 7 took a short time to get used to the 3D video visual experience, then it worked positively for him. He said:

> *It takes a while to get used to 3D video. After watching a couple of the videos, it became visually closer to reality. It is different from being in the real space but the 3D video is more effective than the photo.*

The other 29 participants were highly accepting of the use of the 3D video technology. It seems that participant 22 was the only one who experienced some discomfort during the visual experience. Studies by Tam et al. (2011) and Lambooij et al. (2009) found that some individuals experience a number of physiological reactions when they perceive 3D videos, such as dizziness, headache and/or uncomfortable visual symptoms. The other possibility is that participant 22's sense of awareness of 3D video technology was high. That awareness may have prevented her from accepting her visual experience. Participant 17's response was somewhat emotional, influenced by her awareness of her position as observer seems to have influenced her reflections on her visual experience. Participant 7 provided a different response to the 3D video visual experience; he needed some time to adapt to the 3D video visual experience.

The great majority of the study participants accepted the 3D visual experience. Statements from these participants included:

> *I find it looks like the real situation.It was very good — it was very real.It is clearer than 2D video; I can see the light in the corner.* (Participant [19])

> *3D is an improvement for the visual experience; you just feel you are more involved with the scenes.* (Participant [10])

> *It is good. I can feel the situation in the reality. It really represents the real condition of the hotel.* (Participant [18])

> *Almost the same experience as in the room, 3D is better when the camera is moving; you can look at the images from different perspectives seeing the angles.* (Participant [11])

> *The image pops out it is different. I imagined myself in the room; the one you use shows the real thing as it is. I think it is new idea, similar to real life.* (Participant [16])

> *I have a feeling that I am in the same space. I think it is so real it helps me; I could imagine myself in the space.* (Participant [31])

It is clear that most of the participants of the study considered the 3D video visual experience to be an acceptable way of evaluating the atmosphere of the hotel guest room.

Responses to and discussion of the question 'do you think that the use of 3D video is a good way to evaluate the lighting in a hotel guest room?'

For this question, there were two main types of responses from the participants of the study. Twenty of the 32 participants were very confident that they could distinguish between the examined lighting settings. Of the remaining 12 participants 11 stated that they had experienced some kind of confusion with regard to the lighting settings. Only one participant stated that he could only clearly distinguish between the examined lighting settings after watching several videos.

For those who felt some confusion in differentiating between the various lighting settings it may have been as a result of four white lighting settings with different intensities and lighting distributions being part of this study. Also, each of the hue lighting settings was examined at two levels of lighting brightness (high and medium). Participants found it hard to memorise clearly the difference between the lighting settings, especially as the sequence of displaying the examined lighting setting was randomised. Therefore, there were different opinions about their ability to distinguish between the lighting settings.

There follows a number of statements that were made by the study participants which show how they felt confused in discriminating between the lighting settings. Some of the comments were:

> *I can tell most of the colours, but some are very similar.* (Participant [17])
>
> *It is good way to determine the colours of red, blue and orange. If the lighting is white, it is hard to determine the difference.* (Participant [1])
>
> *It is sometimes difficult to discern between some similar lightings. There are some which seem quite similar. But, I can distinguish between the other lighting settings.* (Participant [3])

It can be concluded that nearly two-thirds of the participants were confident in identifying the difference in the lighting settings. The other third of the participants experienced some level of confusion when discriminating among similar lighting settings. This level of confusion is not critical as the study was designed to examine how each of the lighting settings influenced the atmosphere of the hotel guest room using a quantitative method.

Responses to and discussion of the question 'what is your opinion of the study questionnaire'?

The study questionnaire has been discussed in more than one place in this project — first in Chapter Three when the selection of the questionnaire model was explained, then in Chapter Five when the questionnaire model was tested with Western Australian participants. The model was adopted because it had been designed to reduce the non-environmental influence in the evaluation process.

This interview shows that two-thirds of the participants believed that when they answered the study questionnaire they had provided an evaluation without emotional reflection. Some of the participants, however, stated that they could not isolate the objective evaluation from their emotional state with regard to the atmosphere of the space.

There follows a number of statements by the participants who found it difficult to isolate emotions from their evaluation:

> *I don't know if it is my emotion or I am giving my judgment.* (Participant [16])
>
> *Some of the terms are related to instincts.* (Participant [6])
>
> *In other questions you give more analysis and think about the space. I depend on my emotions; it is a bit of both.* (Participant [7])
>
> *I try to distinguish between how I feel and giving a judgment, but I think it is a bit of both.* (Participant [26])
>
> *I hope to give my judgment but my emotion is there. Isn't the atmosphere evaluation based on the emotions* (Participant [25])
>
> *I cannot separate between them. I was trying to give my objective opinion but I think it is a bit of both.* (Participant [31])

Five of the participants thought that, when responding to the questionnaire, they were giving their emotional reflection concerning the atmosphere of the hotel room. This group of participants concentrated on interpreting the terms that were used in the questionnaire model, not on how the questions asked them to use these terms to describe their evaluation of the atmosphere of the hotel guest room. One of these participants stated that he was using his instincts to answer the question. Another three participants stated that they provided objective opinions with regard to the atmosphere of the hotel room. One participant did not discuss this question.

The atmospheric evaluation model used in the present study was adopted from the emotional state self-report technique. Personal opinions are either subjective emotional states or objective judgement or a mix of both. The statistical procedure that is usually used in quantitative methodology will transform the personal responses into reliable subjective evaluations which reveal the central tendency of participant judgements with regards the environment. It is, undoubtedly, difficult to give your personal opinion without being influenced by your emotional state. The study evaluates the influence of the indoor atmosphere. Therefore, if the evaluation in the current study is a judgment or subjective reflection or mix of both in the end, the results will be reliable because of the statistical analysis procedure used.

Responses to and discussion of the question 'do you have suggestions for this study?'

The participants were asked if the research had considered the influence of the outdoor temperature on the participants' evaluation. Participant 15 stated '*A person's judgment could be different depending on the weather. I choose a natural lighting hue for natural weather, but in winter I prefer the warm lighting hues.'*

This point is taken up in the recommendations for future research.

Responses to and discussion of the question: 'what is your main conclusion from contributing to the current experiment?'

Four main topics were raised by the study participants with regard to what they had concluded from contributing to the study. The first topic was the use of coloured lighting in the indoor environment. The second topic was the influence of light in general. The third topic raised was the use of 3D video technology to examine the indoor environment. The fourth topic was the atmosphere of the indoor environment.

The first topic was how participants looked at the coloured lights. Twelve of the 32 participants mentioned the effect of the coloured lights in their conclusion. The main theme that these participants spoke about was the coloured lighting at the medium level of brightness, especially the red and the blue hue settings. These two lighting colours were not preferred by the participants who mentioned them. Some of the comments were:

> *Red and blue don't look real.* (Participant [3])

> *Dark colours were not good.* Participant [28])

> *Red lighting is not good for reading in the room; maybe it is good for resting.* (Participant [17])

> *Dark blue makes me feel uncomfortable. I think I dislike the intense warmer colour but not as much I dislike the cold colour. It is interesting; I don't like both intense colours now. I have not seen them in real hotels.* (Participant [22])

> *The most inappropriate colour was the intense colour.* (Participant [18])

> *I think red makes me feel unsafe, blue and light blue are more calm and cool.* (Participant [24])

> *Extreme blue, extreme red and purple are inappropriate for the hotel. I still prefer white light in the hotel.* (Participant [9])

> *The dark is tense, it is restless.* (Participant [16])

Some of these participants indicated their colour preferences in the hotel guest room in terms of the level of brightness of the lighting colour rather than the colour itself. It seems that the less intense the hue of the light, the more acceptable it was to the participants. A similar result was shown by Hwang, Lee and Kim (2011), as their study showed that lighting settings with low purity were evaluated as more pleasant than those with a high level of purity.

The current study participants made comments such as:

> *I liked the orange lighting setting better than the other examined lighting settings.* (Participant [3])

> *The blue light was more cheerful.* (Participant [8])

> *For business chats, white light teamed with a colour like red would be a good light setting. White lighting is still preferable for me in a hotel guest room.* (Participant [17])

> *I prefer the bright colours; for leisure I like the magenta.The cream colour is the best.* (Participant [16])

It could be concluded from these and the previous statements that the mixed or the secondary coloured lighting settings such as yellow, cyan, magenta and white were preferred by the participants. Some of the participants' statements did not use the same terms to describe the lighting colours which the study had used; for instance, light blue here refers to cyan and orange and cream refer to the yellow lighting hue. Again, these results are in alignment with a number of previous studies such as those of Bronckers (2009), Hwang, Lee and Kim (2011), and Nomoto et al. (2014), which demonstrated that mixed lighting colour settings, e.g., yellow, cyan, magenta and white, are preferable to the primary lighting colour settings, red, green and blue. These results will be discussed in more detail in Chapter Nine.

The second topic which was raised by the participants in response to the concluding question was **the influence of light in the indoor environment.** Most of the statements concerned how important lighting is in the indoor environment, and the participants stated that [before doing the experiment] they had not imagined that changes in the lighting brightness and hue could change their impressions of the same space.

For example:

> *I think I'd never paid attention to lighting before, it is important.* (Participant [25])

> *Lighting is a sensitive issue and the effect of colour is very difficult to be evaluated, I had never thought about the light in this way before.* (Participant [13])

> *It sometimes looks like it is a different room in a different place.* (Participant [15])

> *We can adjust the lighting and it can improve your mood.* (Participant [29])

> *The RGB lighting can produce different colours. I realised how light and colour for the hotel room can change the atmosphere. Quite significant changes; I was quite surprised, and changed my view of the room.* (Participant [6])

There is no doubt that lighting properties have a significant influence on the atmosphere of the indoor environment and how the residents perceive the indoor environment. Chapter Two presented a discussion of a number of studies which investigated different lighting properties such as lighting brightness, lighting CCT, lighting CRI and lighting hue. More detailed discussion with regard to the influence of lighting on the perceived atmosphere of the hotel guest room follows in Chapter Nine.

The third topic which was raised by the study participants was the use of the 3D video technology in examining the indoor environment. Eleven of the 32 participants in the study made statements about the utilisation of the 3D video technology. Most of the conclusions were positive and encouraging. Some of the following statements indicated participants' appreciation of the 3D video method in evaluating the indoor environment:

> T*he 3D video was an interesting experiment. It was quite new, and it was a good 3D experiment.* (Participant [3])

> *I think this method is effective. I think it is a very creative idea.* (Participant [4])

> *I thought the 3D technology is good to use in such a project. It worked very well.* (Participant [16])

The study had already validated the use of the 3D video visual perception experience, which was highly correlated with the 'live' visual perception experience. Therefore, the participants' opinions with regard to the use of the 3D video support the result already obtained from the second stage of the study methodology.

Other comments from the participants of the study provided more details about their 3D video experience:

> *With time you get used to watching the 3D.* (Participant [5])

This participant needed time before he got used to the 3D visual experience, as the expectation of the screen observer is to see a regular 2D motion picture.

Another comment described how the 3D video visual experience influenced the participant step by step:

> *The 3D animation really helps me to see the real condition of the hotel. It is a good way to collect data.* (Participant [14])

More than one statement was included in this participant's response. There was gradual awareness in the perception experience. First the 3D video helped to see what was in the space;then this visualisation process engaged the observer with the atmosphere of the hotel guest room. These two steps led the participant to conclude that this is a good way to collect data.

One of the participants had had previous experience with the 3D visualisation experience, as he used 3D software programs in his work as an architect and video games for entertainment. This participant stated:

> *I use 3D graphic drawing in my work as an architect; I also play 3D video games. You changed my perspective for the 3D visualisation. It is a good way to test the light in the indoor environment. Using the 3D video technology for testing the light in the indoor environment is a new thing for me. It was a good way of managing your study project; instead of taking your study participants to the hotel they came to the University and you reduced your study expenses.* (Participant [26])

Another participant stated that 3D is a good technique*:*

> *In terms of looking at a room it is a useful way to do it; it's a good technique… it'squite an immersive experience. Getting people to look at rooms or space, I can distinguish the difference between colours and feelings. Even if you use other variables, it will be a useful way to test the space. I think it is a useful technique.* (Participant [32])

The statements of the last two participants show the advantages of using 3D video technology in evaluating the atmosphere of an indoor environment.

The fourth topic was the atmosphere of the indoor environment. Three participants mentioned the role of the atmosphere of the indoor environment in the current study. Participant 7 reflected:

> *It has got me thinking more about the different uses of the space. Thinking about personal recreation in the room. Thinking about the business use of the hotel room and how we may [change lighting settings for different uses]…even with different videos for different lightings…. I still see the actual room. Seeing the video of the actual hotel was more important sometimes than the emotions I felt in the space. [But] there are characteristics of the room you cannot change regardless of changing the light.*

Participant 7 found that the videos made him think about the uses of the space clearly. He reflected on the influence of the coloured light. The changes in the lighting setting made him thinks about the different uses of the hotel room. Different lighting settings are suitable for different activities. But, he added that if the same changes occurred in another hotel guest room with more luxurious space, the evaluation would be different, because he believed that with all possible changes the basic characteristics would remain.

It can be seen from the responses quoted above that the project encouraged the participants to think more about the use of the indoor environment. Raising the level of awareness with regard to the role of atmosphere in the indoor environment is not the aim of the current study; however, light is one of the components of the indoor environment and this study aims at understanding the influence of lighting in the atmosphere of the hotel guest room. Moreover, thinking about the atmosphere of the indoor environment is a precursor to understanding its influence on the residents of the environment.

This study was not conducted in a luxurious hotel guest room but in a similar achromic coloured space. The aim of the study was to find if the brightness and the hue of lighting influence the atmosphere of the hotel guest room.The following two statements by two participants show the greater awareness of the perceived atmosphere of the indoor environment created by this study.

Participant 11, concluded:

> *It gets me to think about the atmosphere of the space and I enjoy it if it's good.*

Participant 26 stated:

> *I never thought the atmosphere could influence how people react.*

7.3.1 Interview conclusions:

From the above interpretation of participants' responses to the interview, it can be concluded that:

- The 3D video visual experience was an acceptable method to simulate the visual experience of visiting a hotel guest room; however, it has to be noted that there is still a probability that some people will have discomfort visual experience.
- The 3D video was an effective way to distinguish the differences which occurred in the atmosphere of the indoor environment with the change of the lighting properties in brightness and hue.
- The primary lighting hues such as red and blue at low level of lighting brightness were less preferred than the mixed lighting hues such as yellow, cyan, magenta and white at the high level of brightness.
- Light has a significant influence on the perceived atmosphere of the hotel guest room,
- 3D video technology is a creative way to evaluate the influence of the indoor environment components on the perceived atmosphere.
- The study has raised the level of awareness of the importance of lighting's influence on the perceived atmosphere of the indoor environment.

7.4 Conclusions

This study used a verified research instrument (questionnaire as discussed in Chapter Five) and an innovative visual tool (3D video as discussed in Chapter Six) to collect data on the influence of coloured LED lighting on the atmosphere in hotel guest rooms. The study applied sixteen different lighting conditions to a real hotel room and filmed the results using a 3D camera. The 3D videos were displayed to 32 participants 16 times each in order to enable them to evaluate the influence of coloured LED lighting on the atmosphere in a hotel guest room. Using 3D videos saved research time when collecting data. The 3D camera also proved to be easily managed compared to conducting a study in a real space. The data from the study was analysed using a series of Generalised Linear Mixed Models. The following chapter, Chapter Eight, records the findings and analyses the influence of RGB LED lighting on the atmosphere in hotel guest rooms.

8. Findings

This chapter presents the findings of how people appraise the atmosphere of a hotel guest room in response to a variety of RGB LED lighting. This chapter has six sections. The three main sections report the influence of hue and brightness on participants' atmosphere positive descriptive (APD), atmosphere negative descriptive (AND) and atmosphere impartial descriptive (AID) appraisals of the hotel guest room's atmosphere. The three sub-sections report the influence of hue and brightness on the degree to which study participants rated the hotel guest room's atmosphere as bright, warm, appropriate and encouraging under each of the study lighting settings. Finally a summary of the chapter is presented.

8.1 The impact of hue and brightness on positive ratings of the atmosphere of a hotel guest room

Means and standard deviations for each of the eight Hues and two Brightness conditions are reported in Table 8.1. Figure 8.1 presents the mean positive ratings of the hotel guest room's atmosphere as a function of the hue and brightness of its lighting.

Table 8.1: The Means (Ranked from High to Low) and Standard Deviations of Positive Ratings as a function of Hue and Brightness (N = 32).

Medium brightness			**High brightness**		
Hue	**Mean**	**Standard deviation**	**Hue**	**Mean**	**Standard deviation**
White	4.45	1.07	Yellow	4.83	0.90
Yellow	3.72	1.18	White	4.30	1.04
Cyan	3.68	1.35	Cyan	3.88	1.34
Magenta	3.50	1.35	Magenta	3.88	1.02
Blue	3.44	1.30	General white	3.85	1.45
Green	3.02	1.29	Green	3.76	1.33
General white	2.96	1.18	Blue	3.55	1.19
Red	2.52	0.97	Red	3.53	1.11

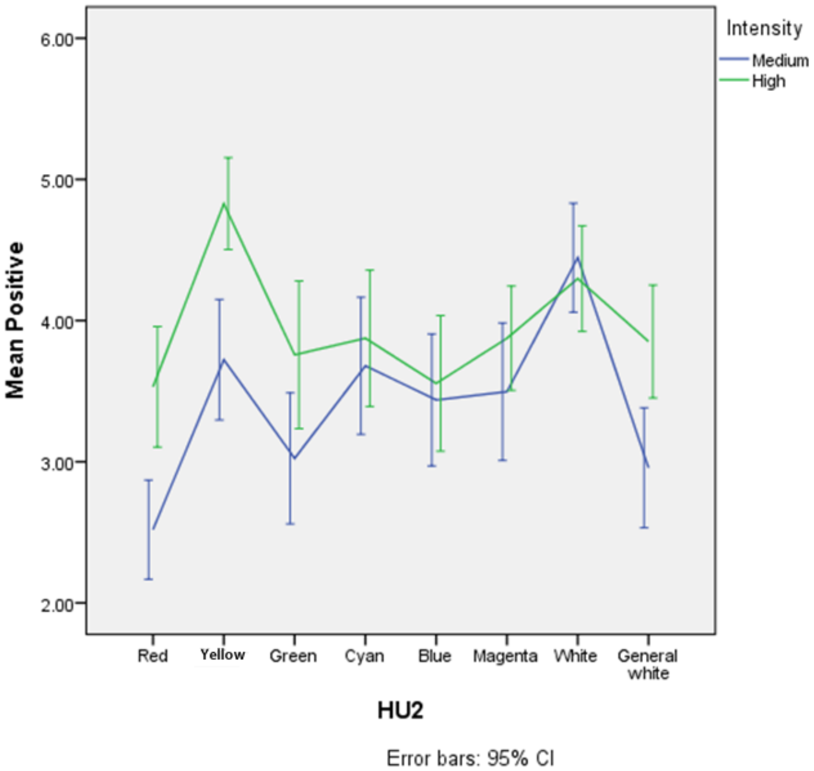


Figure 8.1 *Mean positive ratings as a function of hue and brightness (N = 32).*

The Generalised Linear Mixed Model (GLMM) analysis indicated a significant Hue x Brightness interaction ($F[7, 496] = 3.09$, $p = .003$), which means that the main effect of hue ($F[7, 496] = 12.02$, $p < .001$) and the main effect of brightness ($F[7, 496] = 33.05$, $p < .001$) cannot be interpreted independently of one another. Least Significant Difference (LSD) post-hoc contrasts conducted across the simple main effects of brightness showed significantly higher positive ratings for the high brightness condition compared to the medium brightness condition for red ($t[496] = 3.84$, $p < .001$), yellow($t[496] = 4.19$, $p < .001$), green ($t[496] = 2.78$, $p = .006$), and general white ($t[496] = 3.39$, $p = .001$).There was no significant effect of brightness on positive ratings for cyan ($t[496] = 0.74$, $p = .459$), blue ($t[496] = 0.44$, $p = .657$), magenta ($t[496] = 1.44$, $p = .151$), and white ($t[496] = 0.56$, $p = .574$).

The simple main effect of the high brightness hues was investigated by comparing the high brightness general white condition to each of the other seven high brightness hues. The simple main effect of the medium brightness hues was investigated in a similar way by comparing the medium brightness general white condition to each of the other seven medium brightness hues. The results are presented in Figure 8.2.

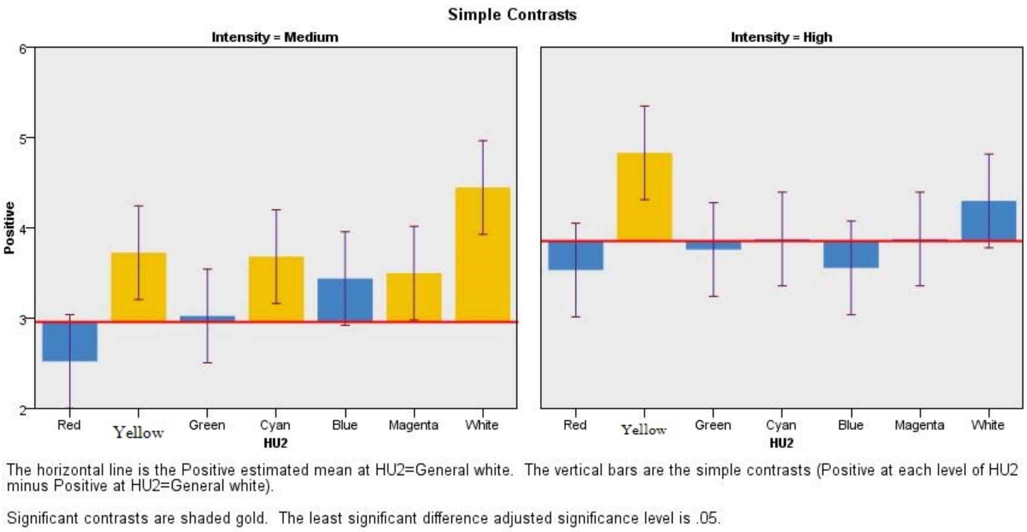


Figure 8.2 *Mean positive ratings of seven hues compared to general white (the red line) in the high and medium brightness conditions (N = 32).*

Medium brightness general white was rated as significantly less positive than medium brightness yellow, cyan, magenta, and white. The positive rating for medium brightness general white was not significantly different to the positive ratings for medium brightness red, green, and blue. High brightness general white was rated as significantly less positive than high brightness yellow. The positive rating for high brightness general white was not significantly different to the positive ratings for the other six hues.

An additional GLMM was tested to determine whether age (20 – 40, 41+) and gender interacted with brightness and/or hue. Age did not interact with brightness ($F[1, 464] = 0.09$, $p = .765$), hue ($F[7, 464] = 1.73$, $p = .100$), or the Hue x Brightness interaction ($F[7, 464] = 0.39$, $p = .909$). Similarly, gender did not interact with brightness ($F[1, 464] = 0.33$, $p = .565$), hue ($F[7, 464] = 1.65$, $p = .119$), or the Hue x Brightness interaction ($F[7, 464] = 0.90$, $p = .504$). The above results therefore apply to males and females in both age groups.

Do ratings of the room's brightness, warmth, appropriateness, and the degree to which participants felt encouraged to return moderate the impact of hue and brightness on positive ratings of the hotel room's atmosphere

A separate GLMM was developed for each of the four potential moderators (brightness, warmth, appropriateness, and encourage return) of the impact of hue and brightness on positive ratings. There were significant main effects for brightness ($F[1,480] = 73.30$, $p < .001$), warmth ($F[1, 480] = 66.63$, $p < .001$), appropriateness ($F[1, 480] = 370.92$, $p < .001$), and encourage return ($F[1, 480] = 572.79$, $p < .001$). Generally speaking: The higher the brightness, warmth, appropriateness, and encourage return ratings, the higher the positive rating. The effect of hue was moderated by brightness ($F[7, 480] = 2.42$, $p = .019$) such that hue had a stronger effect on positive ratings at higher levels of perceived brightness.

8.2 The impact of hue and brightness on negative appraisals of the atmosphere of a hotel guest room

Means and standard deviations for each of the 16 Hue x Brightness conditions are reported in Table 8.2. Figure 8.3 presents the mean negative ratings of the hotel room's atmosphere as a function of the hue and brightness of its lighting.

Table 8.2: The Means (Ranked from High to Low) and Standard Deviations of Negative Ratings as a function of Hue and Brightness (N = 32).

Medium brightness			High brightness		
Hue	Mean	Standard deviation	Hue	Mean	Standard Deviation
Red	4.01	1.25	Red	3.43	1.34
Green	3.73	1.06	Green	3.32	1.03
General white	3.47	1.03	Magenta	3.22	1.29
Blue	3.44	1.24	Blue	3.17	1.12
Yellow	3.17	1.14	Cyan	2.91	1.07
Magenta	3.15	1.18	General white	2.86	1.12
Cyan	3.07	1.12	Yellow	2.76	1.30
White	2.53	1.14	White	2.71	1.06

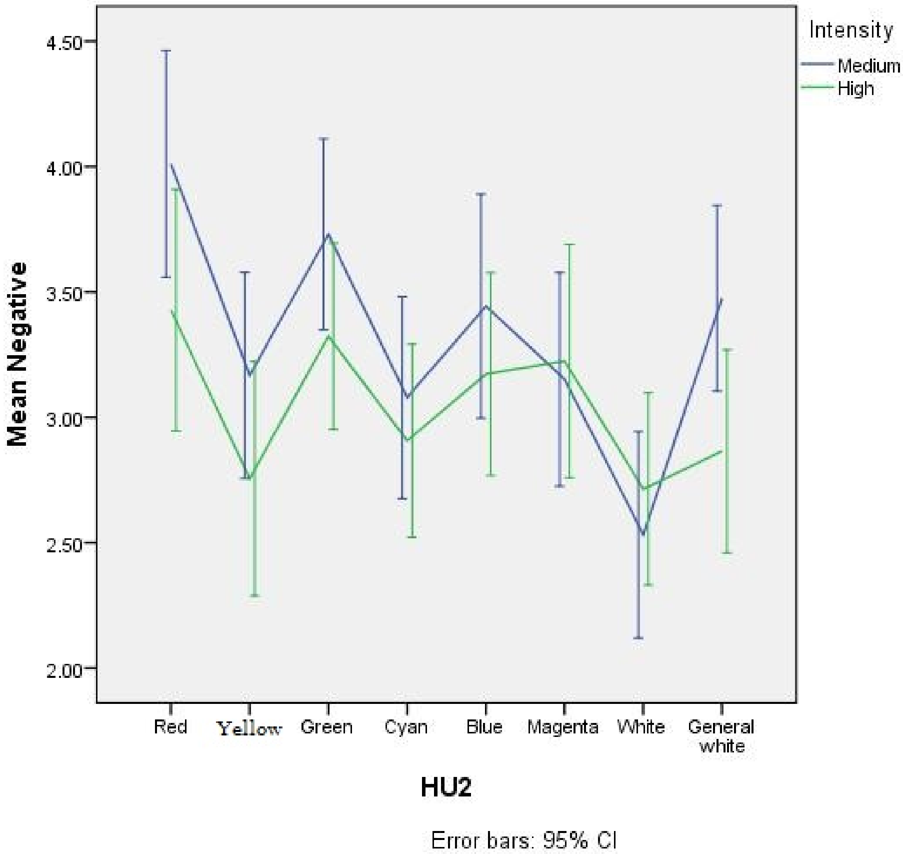


Figure 8.3 *Mean negative ratings as a function of hue and brightness (N = 32).*

The Generalised Linear Mixed Model (GLMM) analysis indicated a non-significant Hue x Brightness interaction (*F*[7, 496] = 1.51, *p* = .161), which means that the significant main effect of hue (*F*[7, 496] = 8.49, *p*< .001) and the significant main effect of brightness (*F*[7, 496] = 10.94, *p* = .001) can be interpreted independently of one another. The brightness effect reflects significantly lower negative ratings for the high brightness condition compared to the medium brightness condition; this effect applies to each of the eight hues.

The hue effect was investigated by comparing the general white condition to each of the other seven hues. The results are presented in Figure 8.4. General white was rated as significantly less negative than red, and green, and significantly more negative than white. The negative rating for general white was not significantly different to the negative ratings for yellow, cyan, blue, and magenta. These results apply to both high and medium brightness hues.

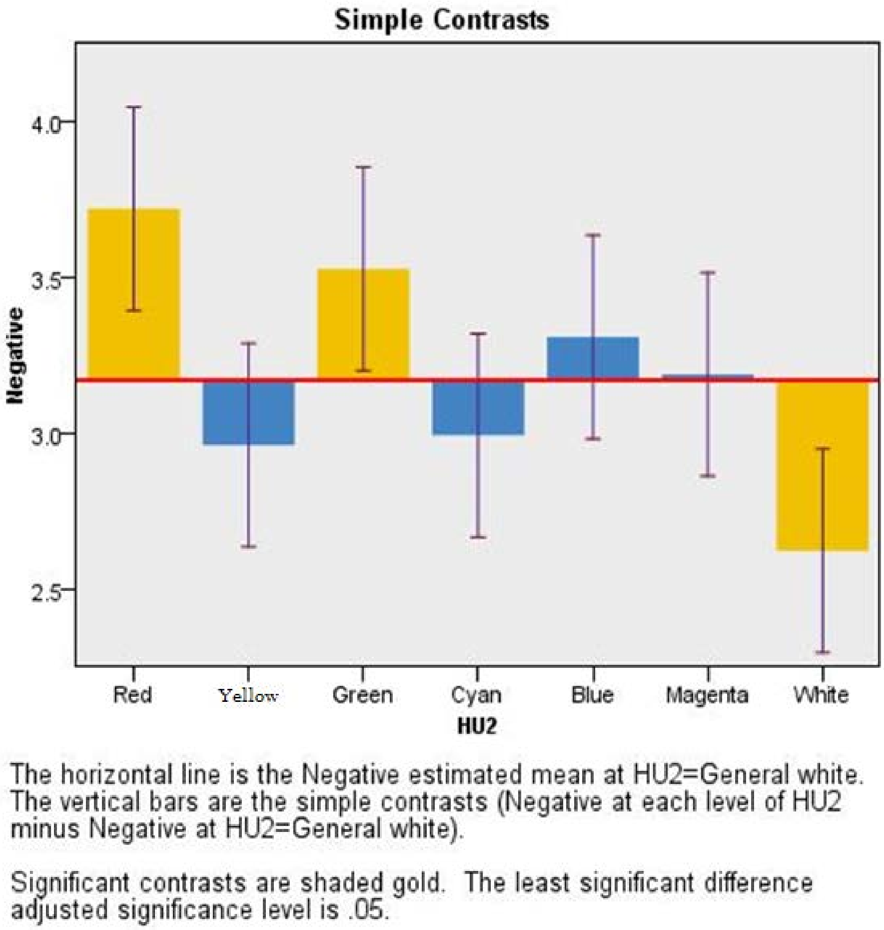


Figure 8.4 *Mean negative ratings of seven hues compared to general white (the red line) (N = 32).*

An additional GLMM was tested to determine whether age (20 – 40, 41+) and gender interacted with brightness and/or hue. Age did not interact with brightness ($F[1, 464] = 0.24$, $p = .626$), hue ($F[7, 464] = 0.81$, $p = .580$), or the Brightness x Hue interaction ($F[7, 464] = 1.05$, $p = .399$). The above results therefore apply to both age groups. Gender did not interact with hue ($F[7, 464] = 0.95$, $p = .468$), or the Brightness x Hue interaction ($F[7, 464] = 0.42$, $p = .890$). Gender did, however, interact with brightness ($F[7, 464] = 5.25$, $p = .022$). For males, there were no significant differences in negative ratings between high and medium brightness colours ($t[464] = 0.39$, $p = .700$); for females, the high brightness colours were rated as significantly less negative than the medium brightness colours ($t[464] = 3.71$, $p< .001$). The females therefore carried the brightness effect reported above.

Do ratings of the room's brightness, warmth, appropriateness, and the degree to which participants felt encouraged to return moderate the impact of hue and brightness on negative ratings of the hotel room's atmosphere

A separate GLMM was developed for each of the four potential moderators (brightness, warmth, appropriateness, and encourage) of the impact of hue and brightness on negative ratings. There were no significant main effects for brightness ($F[1,480] = 1.19$, $p = .276$) and warmth ($F[1, 480] = 0.001$, $p = .970$). There were significant main effects for appropriateness ($F[1, 480] = 48.89$, $p < .001$) and encourage ($F[1, 480] = 71.10$, $p < .001$). Generally speaking: The lower the appropriateness and encourage ratings, the higher the negative rating. The effect of brightness was moderated by warmth ($F[7, 480] = 2.42$, $p = .019$) such that brightness had the strongest effects on negative ratings at moderate levels of perceived warmth.

8.3 The impact of hue and brightness on impartial appraisals of the atmosphere of a hotel guest room

Means and standard deviations for each of the 16 Hue x Brightness conditions are reported in Table 8.3. Figure 8.5 presents the mean impartial ratings of the hotel room's atmosphere as a function of the hue and brightness of its lighting.

Table 8.3: The Means (Ranked from High to Low) and Standard Deviations of Impartial Ratings as a function of Hue and Brightness (N = 32).

Medium brightness			High brightness		
Hue	Mean	Standard deviation	**Hue**	Mean	Standard deviation
White	4.60	1.31	**White**	4.71	1.22
General white	3.89	1.26	**General white**	4.64	1.33
Cyan	3.65	1.46	**Yellow**	4.27	1.17
Yellow	3.23	1.19	**Cyan**	3.69	1.46
Blue	3.06	1.04	**Blue**	3.38	1.00
Magenta	2.91	1.02	**Green**	3.16	1.11
Green	2.84	1.06	**Magenta**	2.85	1.03
Red	2.27	0.83	**Red**	2.78	1.05

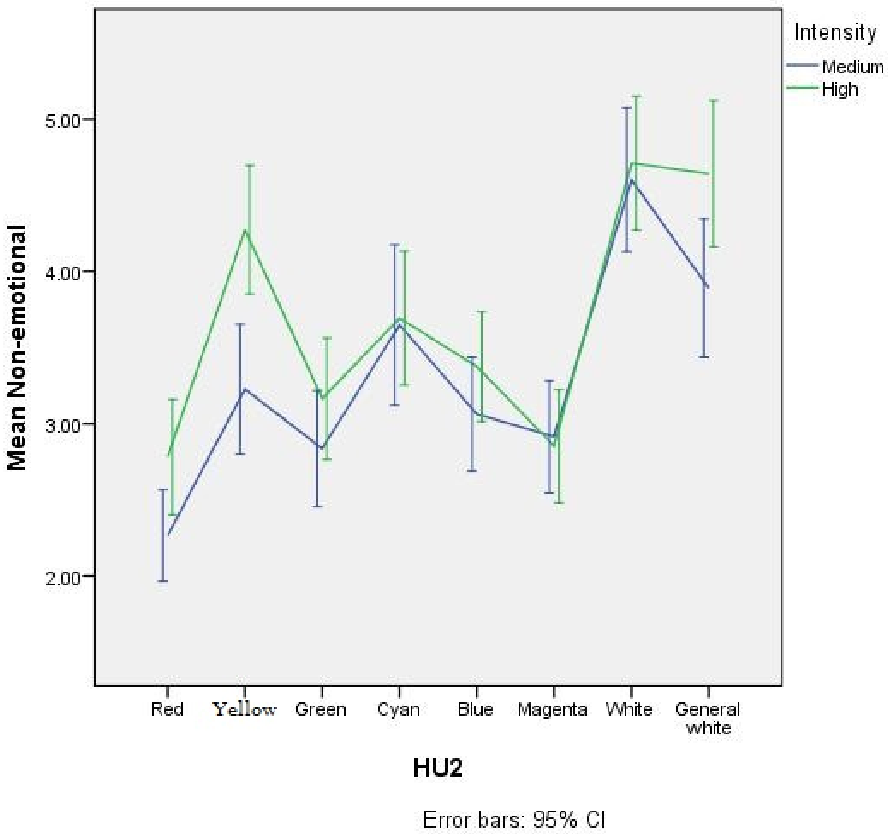


Figure 8.5 *Mean impartial ratings as a function of hue and brightness (N = 32).*

The Generalised Linear Mixed Model (GLMM) analysis indicated a significant Hue x Brightness interaction (F[7, 496] = 2.66, p = .010), which means that the main effect of hue (F[7, 496] = 39.56, p< .001) and the main effect of brightness (F[7, 496] = 21.80, p< .001) cannot be interpreted independently of one another. LSD post-hoc contrasts conducted across the simple main effects of brightness showed significantly higher impartial ratings for the high brightness condition compared to the medium brightness condition for red (t[496] = 2.24, p = .026), yellow (t[496] = 4.54, p< .001), and general white (t[496] = 3.25, p = .001). There was no significant effect of brightness on impartial ratings for green (t[496] = 1.42, p = .155), cyan (t[496] = 0.19, p = .848), blue (t[496] = 1.36, p = .176), magenta (t[496] = 0.27, p = .786), and white (t[496] = 0.47, p = .635).

The simple main effect of the high brightness hues was investigated by comparing the high brightness general white condition to each of the other seven high brightness hues. Similarly, the simple main effect of the medium brightness hues was investigated by comparing the medium brightness general white condition to each of the other seven medium brightness hues. The results are presented in Figure 8.6.

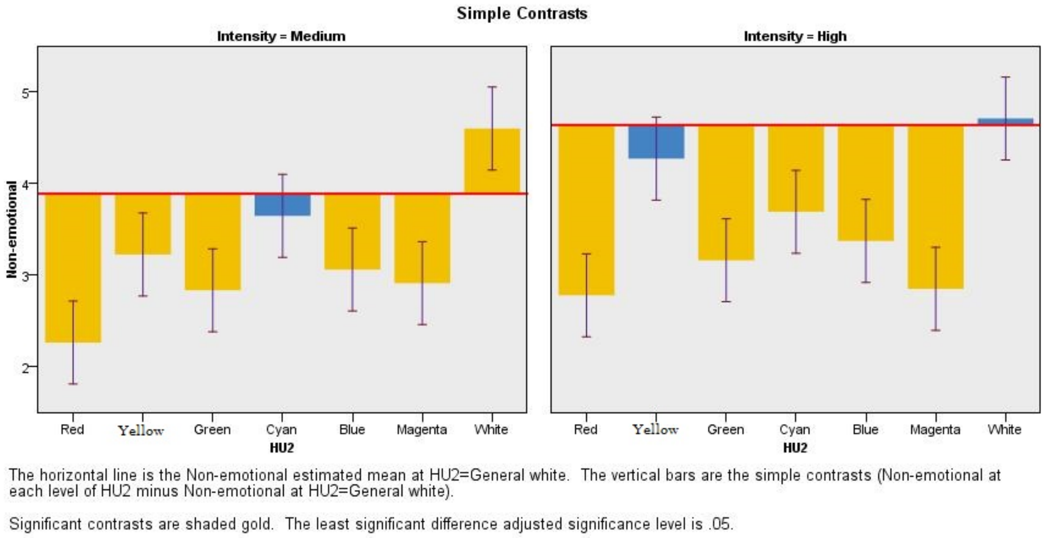


Figure 8.6 *Mean impartial ratings of seven hues compared to general white (the red line) in the high and medium brightness conditions (N = 32).*

Medium brightness general white was rated as significantly less impartial than medium brightness white. The impartial rating for medium brightness general white was not significantly different to the impartial rating for medium brightness cyan. The impartial rating for high brightness general white was not significantly different to the impartial rating for high brightness yellow and white. High brightness general white was rated as significantly more impartial than high brightness red, green, cyan, blue, and magenta.

An additional GLMM was tested to determine whether age (20 – 40, 41+) and gender interacted with brightness and/or hue. Gender did not interact with brightness (F[1, 464] = 0.01, p = .907), hue (F[7, 464] = 1.99, p = .054), or the Brightness x Hue interaction (F[7, 464] = 1.55, p = .148). Age did not interact with brightness (F[1, 464] = 0.30, p = .583) or the Brightness x Hue interaction (F[7, 464] = 0.74, p = .637). Age did, however, interact with hue (F[1, 464] = 3.08, p = .004). Although the above results apply to males and females in both age groups (there was no 3-way Brightness x Hue x Age interaction), red was rated as significantly more impartial by participants over 41 compared to the younger participants (t[464] = 2.06, p = .040). There were no significant differences between age groups in their impartial ratings of the other hues.

Do ratings of the room's brightness, warmth, appropriateness, and the degree to which participants felt encouraged to return moderate the impact of hue and brightness on impartial ratings of the hotel room's atmosphere

Once again, a separate GLMM was developed for each of the four potential moderators (brightness, warmth, appropriateness, and encourage) of the impact of hue and brightness on impartial ratings. There were significant main effects for brightness ($F[1,480] = 84.89$, $p < .001$), warmth ($F[1, 480] = 5.89$, $p = .016$), appropriateness ($F[1, 480] = 179.24$, $p < .001$), and encourage ($F[1, 480] = 138.75$, $p < .001$). Generally speaking: The higher the brightness, warmth, appropriateness, and encourage ratings, the higher the impartial rating. The effect of hue was moderated by brightness ($F[7,480] = 5.60$, $p < .001$) such that hue had its strongest effects on impartial ratings at higher levels of perceived brightness.

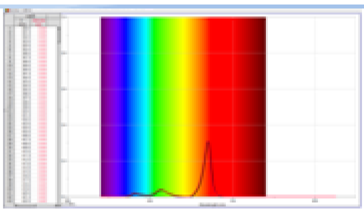
8.4 Summary of the atmosphere evaluations

With regard to the positive evaluation of the atmosphere of the hotel guest room, the brightness of the lighting moderated the influence of hue for red, yellow, green and general white (dominated long and medium wavelength spectrum) but not for cyan, blue, magenta and white (dominated short wavelength spectrum). The spectra distributions of light hues that were examined in the current study are showed in Figures 8.7 and 8.8.

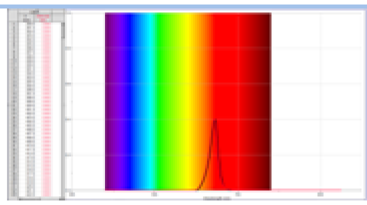
The brightness of the lighting had a significant influence on the negative evaluation of the atmosphere of the hotel guest room. The high brightness conditions were ranked less negative compared to the medium brightness conditions; this effect applied to each of the eight hues. In addition, significantly higher impartial ratings were reported for the high brightness condition compared to the medium brightness conditions for red, yellow and general white. There was no significant effect of brightness on impartial ratings for green, cyan, blue, magenta and white.

At the medium level of lighting brightness, general white was rated significantly less positively than yellow, cyan, magenta, and white; there were no significant differences between general white and red, green and blue. At the high level of lighting brightness, yellow was ranked significantly more positively than the other seven hues. Moreover, general white was evaluated significantly less negatively than red, and green, and significantly more negatively than white. There were no significant differences between general white and yellow, cyan, blue, and magenta. These results apply to both high and medium brightness hues. There was a gender effect on the negative evaluations of the atmosphere of the hotel guest room; females evaluated high brightness lighting colours significantly less negatively than the medium brightness colours compared with males.

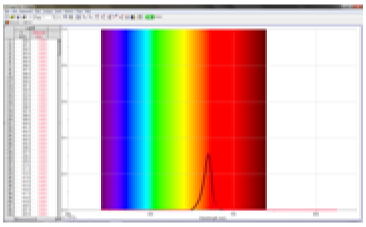
The influence of hue on impartial evaluations of the atmosphere of the hotel guest room showed that, at the medium level of brightness, general white was rated as significantly less impartial than white but significantly more impartial than the other hues; there was no significant difference in impartial ratings between general white and cyan. At the high level of lighting brightness,impartial ratings for general white were not significantly different to impartial ratings for yellow and white. In contrast, general white was evaluated as significantly more impartial than red, green, cyan, blue, and magenta. There was a significant age effect; the older age group evaluated red as significantly more impartial than the younger age group.



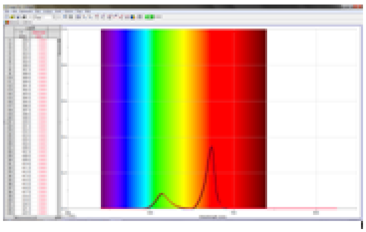
Spectrum distribution of the Red high light



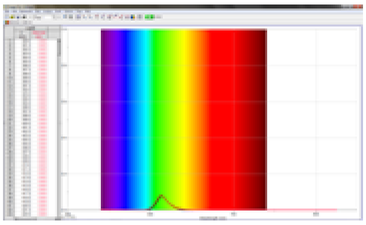
Spectrum distribution of the Red medium light



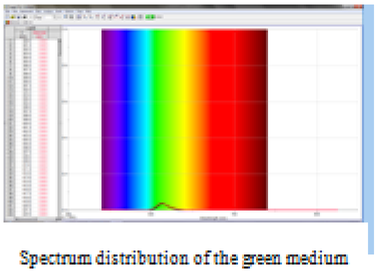
Spectrum distribution of the yellow high light



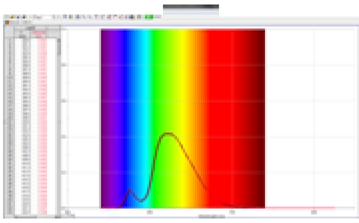
Spectrum distribution of the yellow medium light



Spectrum distribution of the green high light



Spectrum distribution of the green medium light



Spectrum distribution of general white light high

Figure 8.7 The spectrum distribution of the light setting with dominated long and medium wavelengths

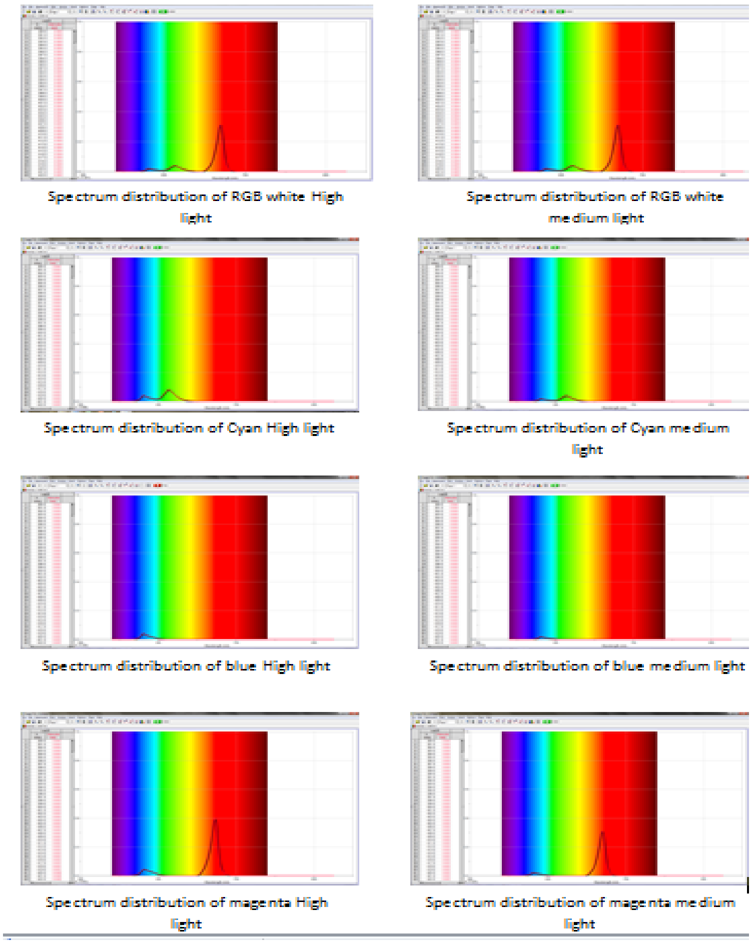


Figure 8.8 The spectrum distribution of the light setting with dominated short wavelengths

Positive ratings were significantly associated with ratings of brightness, warmth, appropriateness, and the degree to which participants felt encouraged to return to the hotel guest room. The higher the brightness, warmth, appropriateness, and ‘encouraged’ ratings, the higher the positive rating. Conversely, the lower the appropriateness and encouraged ratings, the higher the negative ratings; ratings of brightness and warmth were not correlated with negative ratings. Finally, the higher the brightness, warmth, appropriateness, and encourage ratings, the higher the impartial ratings.

9. Discussion

This study aimed to investigate the influence of different lighting hues and intensities on the participants’ perceptions of the atmosphere in a hotel guest room. It was discovered that these perceptions could be usefully classified under three atmospheric factors, Atmosphere Positive Descriptive (APD), Atmosphere Negative Descriptive (AND) and Atmosphere Impartial Descriptive (AID).

Before discussing the results of the primary study, the extensive preliminary research work will be discussed. The study derived a measuring tool from Vogles’ (2008b) model for evaluation of indoor atmosphere consisting of three factors, Atmosphere Positive Descriptive (APD), Atmosphere Negative Descriptive (AND) and Atmosphere Impartial Descriptive (AID). As an alternative to visiting the real hotel guest room, a 3D video visual experience was used to evaluate the room’s atmosphere under the exposure of different lighting hues and intensities. The design of the main experiment with regard to the lighting setting was based on the additive light colour theory. The study examined the primary lighting hues of red, green and blue, and the secondary lighting hues that were produced by mixing two of the primary lighting hues. The secondary ‘mixed’ lighting hues were yellow, which is the mix of red + green; cyan, which is the mix of green + blue, and magenta, which is the mix of blue + red. Two white lighting settings were included in addition to the coloured lighting hues. The general white lighting hue setting is the lighting condition setting before applying the coloured lighting setting. The mixed RGB white lighting setting is the result of mixing the three primary lighting hues ofred, green and blue. All the eight lighting settings were examined at two levels of brightness — the high level of brightness, which was the highest reading of DMX lighting controller, and the medium level of lighting brightness, which was the middle reading of the DMX lighting controller.

9.1 The evaluation of the indoor atmosphere

The hotel room’s atmosphere was evaluated using three descriptors: atmosphere positive (APD), atmosphere negative (AND), and atmosphere impartial (AID). Examination of the impact of various lighting hues at two lighting intensities on these three atmosphere descriptors revealed significant effects. Lighting hues and intensities also influenced how participants ranked the hotel room’s atmosphere related to brightness, warmth, appropriateness and the degree to which visitors were encouraged to return to the hotel. These effects are discussed below.

9.1.1 Positive description of the hotel guest room atmosphere

The results of this study show that red, yellow, green and general white lighting were rated significantly more positivelyin the high brightness condition than the medium brightness condition. There was no significant influence of brightness of lighting positive evaluations of cyan, blue, magenta and white.

These results indicate that the brightness of lighting is more important for lighting hues with high and medium dominant wavelength spectra than for lighting hues with a dominant short wavelength spectrum; however, the white lighting setting, which was a mix of RGB lighting, was evaluated like the lighting hues with short wavelength peaks. In the current study the general white spectrum distribution was different from the white mixed RGB lighting distribution (see Appendix 6). The general white light spectrum distribution had continuous high peaks in the area of 650nm to 500nm, which included the red, orange, yellow and green spectrum distribution area; on the other hand, the mixed RGB white light had discontinuous three peak spectrum distribution in the red area 650-600 nm, green area 530-500 nm and the blue area 450-420 nm. The reddish orange, orange and yellow area was not included in the spectrum distribution of the mixed RGB white light setting, which might explain the difference in the evaluations between the two white lighting settings.

This finding can provide guidance to lighting designers as it suggests that, in some cases, increasing the level of lighting brightness can increase the positive impression of the atmosphere in a hotel room. This finding may be relevant to the results of studies by Wright, Lack, and Kennaway (2004) and Wright and Lack (2001); both studies examined five light settings: yellow, red, blue, cyan and green. The aim of both studies was to explore the influence of different lighting settings on human melatonin suppression. The studies found that there were stronger influences on the human circadian system from lighting hues with short wavelengths through the use of blue, cyan and green lighting settings (short to medium wavelengths) than with the yellow and red lighting settings (medium to long wave lengths). This suggests that the hues of lighting with dominant short wavelengths may have a stronger influence on observers than does the brightness of the light. This may explain why participants in the current study were not influenced by level of brightness when evaluating blue, cyan and magenta. Possibly, there is a connection between the physiological and the aesthetic influence of lighting hues on humans.

This study showed that general white was rated as significantly less positive than the hues yellow, cyan, magenta, and white at the medium level of lighting brightness. The results also showed that there was no significant difference between general white and red, green, and blue at the medium level of lighting brightness.

The hotel guest room was exposed to a general white lighting setting was used in before being exposed to the accent lighting (wall washer lighting). The general white lighting was used as the reference base for comparing the evaluation of each of the different hue lighting settings. Yellow, cyan, magenta and white lighting settings were secondary lighting hues or a mix of two primary lighting hues, with the exception of the white lighting hue which was a mix of the three primary lighting hues of red, green and blue. The primary lighting hue settings (red, green and blue) were evaluated as equally less positive than the mixed lighting settings (yellow, cyan, magenta and white).

There is some similarity between the results of the current study and the studies of Reisinger et al. (2009) and Nomoto et al. (2014); Hwang, Lee, and Kim's (2011) study shows comparable results to the current study.

Reisinger et al.'s (2009) study found that yellow, cyan, orange and purple were rated as being 'highly relaxing', which is a positive evaluation. The green lighting setting was also evaluated as 'highly relaxing' in the Reisinger et al. (2009) study. In the current study, the green lighting setting was evaluated as being 'less positive'. The difference between the two results may be because, in the Reisinger et al. (2009) study, the researchers did not identify a particular use for the space; the other possible explanation is that the researchers compared the lighting atmosphere created with two spotlights while, in the current study, the coloured light covered the four walls of the hotel guest room.

Observing a component of indoor space is different from observing the whole space. Gestalt theory argues for the '*The recognition of wholeness and overall rather than of individual component elements. The Gestalt movement of early mid-twentieth emphasised that the whole is different from the sum of the parts'* (O'sullivan et al. 1994, 129). According to this argument, evaluating the visual experience of one of the components need not be consistent with the evaluation of the whole of the space.

From the perspective of interior design, the lighting system is one of the components of the indoor environment; however, the evaluation of the influence of the hue and brightness of the lighting setting is more effective when the whole space is observed rather than a part, as the interaction between the lighting setting and the other components of the indoor environment is clearer when viewed in the whole space. This is because lighting requirements for different indoor spaces vary as a function of how that space will be used. The lighting requirement of a kitchen, for example, differs from the lighting requirement of a bedroom, and so on. Therefore, the evaluation of specific lighting settings is expected to be different or partly different depending on the use of the space.

Similar findings to the current study were shown by the Nomoto et al. (2014) study which was conducted in Japan. Their study, like the current study, found that white, yellow and green lighting hues were seen as providing ‘more comfort’, and were therefore evaluated ‘more positively’ than blue, red and pink. However, Nomoto et al. (2014) found the green lighting hue was evaluated as ‘highly positive’ and pink was evaluated as ‘less positive’, whereas the current study found green was evaluated as ‘less positive’ and magenta was evaluated as ‘highly positive’. There are several possible explanations for the differences between the two studies. Nomoto et al. (2014) examined white, yellow, orange, red, green, blue and pink lighting hues, and the current study examined general white, white, yellow, green, blue, cyan, red and magenta lighting hues. Further, the examined lighting hue settings in both studies were not identical. Nomoto et al.’s (2014) study evaluated more lighting settings that included long and medium wavelengths in their spectrum distribution; yellow and green were the lighting settings which included medium wavelength spectra, and red, orange and pink included high peaks of long wavelengths in their spectra. In contrast, the current study included more balanced lighting settings — the three primary lighting settings and the equal mixed lighting hues of two of the primary lighting hues and the white mixed lighting setting. Thus, the evaluations could be expected to be different. In addition, Nomoto et al.’s (2014) measuring tool focused on level of comfort and comfortable feelings, while the current study used the modified Vogels’ model with a far greater variety of terms. Further, Nomoto et al. (2014) used the booth method to examine the influence of lighting whereas the current study used 3D video of the hotel guest room space. Also, Nomoto et al. (2014) did not identify the use of the space where the lighting was evaluated. The current study did identify the space, the hotel guest room.

Somewhat comparable to the current study results were the results of Hwang, Lee and Kim’s (2011) study conducted in South Korea, which showed that the mixed lighting settings, yellow and cyan, were evaluated as causing 'less displeasure' at three levels of hue — chroma purity low, medium and high. The magenta lighting hue was evaluated as causing 'less displeasure' at low and medium levels of chroma purity but not at a high level of chroma purity. The primary lighting hues in Hwang, Lee and Kim's (2011) study, red and green, were evaluated as causing 'high displeasure' at the medium and high level of chroma purity; the exception was with the blue lighting hue, which was evaluated as causing high displeasure only at the high level of chroma purity. The differences were with the magenta hue from the mixed lighting hues and the blue from the primary lighting hues. The difference in the result may be because Hwang, Lee and Kim measured pleasure-displeasure with the Likert scale to evaluate the atmosphere of the living room under the exposure of different lighting hues, whereas the current study used eight different expressions to describe the positive evaluation for the hotel guest room atmosphere, namely: intimate, inspiring, cheerful, personal, relaxed, lively, luxurious and cosy.

From the above discussion, the current study shows that the participants' evaluation of the atmosphere of the hotel guest room under the different lighting hues could be classified into two lighting hue groups. The first lighting hue group, which was evaluated as significantly 'more positive', included the mixed lighting, white, yellow, cyan and magenta. The second group of lighting settings, which was evaluated as significantly 'less positive' than the first group,included the primary lighting settings, red, green and blue.

The mixed lighting hues were evaluated as 'more positive' than the primary lighting hues. Therefore, in order to produce a positive impression in a hotel guest room, it would be preferable to apply the mixed lighting hues rather than the primary lighting hues. That does not mean that primary lighting hues do not give a positive impression of the atmosphere of the hotel guest room. They are significantly 'less positive' compared with the mixed lighting hues; however, at the high level of lighting brightness, their mean ranking was higher than the middle ranking (see Figure 8.1, Chapter Eight). Within each of the lighting hue groups there was no significant difference between the lighting hues. Each of these lighting hues can give the impression of a positive atmosphere depending on a person's motivation and how the hue of the lighting setting arouses the observer.

The results of this study show that at the high level of lighting brightness, general white was rated as significantly less positive than yellow, but equally positive to the other six hues. The yellow lighting was evaluated as significantly 'more positive' than the other lighting hue settings. The rest of the lighting hue settings, general white, white, red, green, cyan, blue and magenta were ranked second positive equally without any significant differences among them. These results are similar to those obtained by several researchers such as Bronckers (2009); Reisinger et al. (2009); Hwang Lee and Kim (2011); and Varkevisser, Raymann and Keyson (2012), and their studies examined different lighting hue settings including the yellow lighting hue.

Varkevisser, Raymann and Keyson's (2012) study examined the influence of lighting hues in an office workplace in the Netherlands. The researchers evaluated the yellow lighting hue, with 'low valence' at the low level of brightness and 'high valence' at the high brightness level.

The yellow lighting setting was evaluated as the 'most motivating' lighting setting. This result is similar to the results of the present study, in which the yellow lighting hue was evaluated as 'highly positive'. Even though Varkevisser, Raymann and Keyson's (2012) study took place in a work space, the results suggested that designers could use yellow lighting to create a space conducive to work, whether it is a work space or a hotel guest room.

In Bronckers' (2009) study the yellow lighting setting was evaluated as being 'least tense' among the examined lighting settings and providing the 'most cosy' lighting setting. This result shows that the yellow lighting setting was evaluated as creating a highly positive atmosphere, just like the yellow lighting hue in the current study. This demonstrates that lighting hues with a medium-long wavelength, such as yellow, produce a more positive impression on the user of the indoor space.

Hwang, Lee and Kim's (2011) study shows that the yellow lighting setting produced an acceptable level of comfort and communication. The yellow lighting setting at two of the examined levels of chroma purity, low and medium, was evaluated as highly positive with no significant difference between the two, and the white lighting hue was considered the optimal lighting setting. A notable difference in the evaluation appeared at the high level of chroma purity of the lighting, even though the yellow hue was evaluated as the least annoying lighting setting at the high level of lighting chroma purity. This result supports the current study's finding that the yellow lighting hue at high and medium levels of brightness was evaluated as 'highly positive'.

The evaluation result of the yellow lighting hue as ‘more positive’ than the white lighting hue at the high level of brightnessis interesting. This result occurred possibly because the examined white hues, both the general white and the white, looked colder than the yellow lighting hue, as both of them were at K6500 CCT which is recognised as the colour of daylight in north and west Europe. Two studies which examined the influence of white lighting settings differing in lighting brightness and CCT in hotel guest rooms were carried out by Pae (2009) and Fernandez, Giboreau and Fontoynont (2012), and their results similarly showed that the bright warm yellowish white lighting was evaluated as more positive and was preferred to the cold bright white lighting.

Reisinger et al.’s (2009) study found that yellow lighting hue settings were evaluated as ‘highly relaxing’, ‘less active’ and ‘highly liked’ compared with other lighting settings (red, blue and magenta). These results are partly in line with the current study in which the yellow lighting setting at the high level of brightness was evaluated as ‘highly positive’; yellow lighting hues were evaluated ‘less active’.

These differences in results may be because Reisinger et al.’s (2009) study used semantic scales - cold-warm, heavy-light, tensed-relaxed and passive-active - rather than Vogels’ evaluation model. The passive-active scale enabled the Reisinger et al.’s (2009) study participants to evaluate the active more positively than the passive, while the passive evaluation could be correlated with the relaxed and stable environment or impression.

To sum up, the yellow lighting hue was shown to exert a positive influence on the atmosphere of the indoor environment. This hue can give the impressions of cosiness and relaxation, and be motivating for creation. Thus, the yellow lighting hue has been evaluated ‘positively’ in more than one indoor environment such as the living room, work offices and in indoor spaces of unidentified use (lighting laboratories); there was no difference between these spaces and the hotel guest room, which was perceived as ‘highly positive’ under the exposure of the yellow lighting hue. The yellow hue as background lighting can contribute to the atmosphere of the hotel guest room for all purposes of relaxing and performing different activities. At a high level of brightness, the yellow lighting hue could be counted as one of the most preferred lighting hues for creating a positive atmosphere in a hotel guest room.

In this study, cyan, magenta, white, red, green and blue at high levels of brightness were all assessed as being equally positive but not as positive as yellow. White, cyan, yellow and magenta were evaluated as 'highly positive' among the lighting settings of the study at the medium level of brightness, and the red, green and blue lighting hues were evaluated as the 'least positive' lighting settings. The implication, therefore, is that white, cyan, yellow and magenta lighting hues will provide a better atmosphere in a hotel guest room. At the high level of lighting brightness, the yellow lighting hue was evaluated as the 'most positive' among the lighting settings. These findings could impact on the choices made by lighting designers and Stakeholders. The implications for the lighting industry are that the lighting hues evaluated in this study as 'highly positive' will leave positive impressions on the hotel guests. These impressions may encourage them to stay longer in the room or to come back in the future to the same hotel, or recommend the hotel to other customers.

Do ratings of the room's brightness, warmth, appropriateness, and the degree to which participants felt encouraged to return moderate the impact of hue and brightness on positive ratings of the hotel room's atmosphere

There were significant main effects for brightness, warmth, appropriateness and encouragement to return. Generally speaking, the higher the atmosphere of the hotel guest room was ranked in terms of brightness, warmth, appropriateness, and encouragement to return ratings, the higher the positive rating. The effect of hue was moderated by brightness, such that hue had a stronger effect on positive ratings at higher levels of perceived brightness.

The higher the brightness, the more positively the atmosphere was evaluated. A number of studies have shown similar results; however, these studies examined only the white lighting hue with different CCT and level of brightness. In Van Erp's (2008) study it was found that the brighter white lighting setting was evaluated as 'more positive' than the darker lighting setting. Similar results occurred in the studies of Fernandez, Giboreau and Fontoynont (2012a) and Park, Pae, and Meneely (2010) which were conducted in hotel guest rooms. Thus, it would be preferable to use brighter lighting to create a more positive hotel guest room atmosphere.

With regard to **warmth evaluation**, several studies which have evaluated white lighting settings with different CCT have shown that the bright warm white lighting was evaluated as more positive than the cold bright white lighting. The bright warm white lighting setting was also evaluated as more positive than the dark warm and dark cold white lighting settings. This result was observed in Fernandez, Giboreau and Fontoynont (2012a) and Park, Pae, and Meneely (2010) studies, which were conducted in hotel guest rooms, as well as in the Van

Erp study, which was conducted in a lighting laboratory with no identification of the use of the space.

Moreover, **warm** lighting hues were evaluated as 'more positive' than the cold lighting hues. For example, Bronckers' (2009) study evaluated red and yellow lighting hues as 'highly cosy' compared with other lighting hues.With regard to the suitability of lighting hues for a living room in Bronckers' (2009) study, it was shown that red, white and yellow hues were more suitable than magenta, blue, cyan and green. For the use of office space, Bronckers' (2009) study showed that white and cyan were more suitable than red, magenta, blue, green and yellow. Red and magenta were the least suitable lighting hues for an office.

Reisinger et al.'s (2009) study evaluated yellow and orange lighting hues as 'highly relaxing', along with green and cyan. It is not clear if, in this study, the warm and neutral lighting hues were evaluated 'more positively' than the cold lighting hue, as the cyan lighting hue was also evaluated as 'highly relaxing'. Even in the 'like – dislike' evaluation it is not clear if the evaluation was correlated with the evaluation of how warm or cold the light hue was. The result of the current study, and a number of studies which have been discussed in this section, suggest that a warm lighting hue creates a more positive atmosphere in a number of indoor environments, and the hotel guest room is no exception. Thus, if warm lighting hues are used, hotel guests are more likely to have positive memories of their stay and are more likely to return to the hotel.

The result of the current study showed that the lighting hue settings at the high level of brightness were ranked as more **appropriate** than the lighting settings at the medium level of brightness. It seems that the lighting settings which were evaluated as 'highly positive' in the current study were evaluated as more appropriate for use in the hotel guest room. Similar results were reported in Bronckers' (2009) study, where the lighting settings at high level of brightness were more suitable for a living room and work spaces than lighting setting hues at the low level of brightness.

Hwang, Lee and Kim (2011) also examined different lighting hues in a living room but their evaluation was based on enhancement of comfort and communication. The cyan, white and yellow lighting hues at the low level of chroma purity were evaluated as more appropriate than the other examined lighting hues. Hwang, Lee and Kim (2011) showed that the red lighting hue, especially at the high level of chroma purity, was evaluated as'highly displeasure-able', followed by green high chroma purity, then red medium chroma purity, green medium chroma purity, magenta high chroma purity and lastly the blue high chroma purity. Hwang, Lee and Kim's (2011) result is similar to that of the current study which found that the lighting hues with high brightness and less chroma purity were more appropriate for indoor space. White, cyan and yellow were more appropriate and caused ‘less displeasure’ than red, green and blue.

It seems that hotel guest room settings appear more appropriate under high brightness lighting than at the medium level of lighting brightness. They also appear more appropriate under the mixed lighting settings, white, yellow, cyan and magenta, than under the primary lighting settings, red, green and blue at the medium level of lighting brightness. There was a link between the evaluation of the atmosphere of the hotel guest room and how appropriate it was for use. The more positively the room was evaluated, the more appropriate it was for the occupant of the hotel room.There were no differences between what was perceived as appropriate and encouraging atmospheres in the hotel guest room under each of the lighting settings. The study showed an association between the evaluation of how appropriate the lighting for the hotel room was and its evaluationas highly positive, encouraging and appropriate.

9.1.2 The second factor: the negative description of the indoor environment atmosphere

The results of the study show that each of the lighting setting hues at the high level of brightness were evaluated as significantly more negative than those at the medium level of brightness; this effect applied to each of the eight lighting settings.

This result is similar to the results of studies evaluating the white lighting setting at high and low brightness. For example, Van Erp (2008) in his study found that general white light at high brightness was evaluated as ‘less tense’ than at a low level of brightness. The current study similarly found that the hotel guest room’s atmosphere appeared ‘more negative’ with the lower lighting brightness than with the higher level of lighting brightness. Therefore, it would be better to apply different lighting hues at a high level of lighting brightness to produce a ‘less negative’ atmosphere in hotel guest rooms. This result is important as it shows that, not only does the level of brightness of white lighting change the aesthetic evaluation of the atmosphere of the indoor environment, but different lighting hues can also lead to the same result with regard to the hotel guest room atmosphere.

The results also showed that general white was evaluated as significantly less negative than red and green, and significantly more negative than white. There were no

significant differences between the general white setting and yellow, cyan, blue, and magenta. These results applied to both high and medium brightness hues.

The results indicated that white lighting was the ‘least negative’ lighting setting, followed by general white, yellow, cyan, blue and magenta, while red and green were the ‘most negative’ light settings. In this study, the white lighting setting at the high and the medium levels of lighting brightness was evaluated as the ‘least negative’. Both Bronckers’ (2009) and Hwang Lee and Kim’s (2011) studies found similar results, whilst Varkevisser, Raymann and Keyson’s (2011) study had different results.

Bronckers’ (2009) study showed that bright white with high CCT was evaluated as ‘less tense’ compared with low CCT white light. The white lighting hue in general (with high and low CCT) was evaluated as ‘less tense’, ‘less lively’ and ‘more detached’ compared to other lighting hues. Thus, both the current study and Bronckers’ (2009) study found that white lighting settings were evaluated as ‘less negative’. Hwang, Lee and Kim’s (2011) study similarly showed that the white lighting hue was evaluated as one of the lighting hues which can produce the impression of comfort, wellbeing and appropriate communication in the living room space. The Hwang, Lee and Kim (2011) study considered the white lighting setting as a basis for comparing the other lighting hues. The current study also considered the general white lighting hue as a basis for comparing other lighting hues. In general, in this study, the white lighting setting with the wall washer lighting at the high brightness was evaluated ‘less negatively’. In contrast, the Varkevisser, Raymann and Keyson (2011) study carried out in an office space in the Netherlands showed that, at the high level of brightness, the white lighting setting was evaluated as creating ‘high fatigue’, ‘low motivation’ and ‘low valence’. Thus, the bright white lighting hue was evaluated as ‘less negative’ in more than one indoor environment and there were no differences within the hotel guest room.

The red and green lighting settings were evaluated as ‘highly negative’. The red lighting setting was evaluated as ‘highly negative’ in a number of studies: Bronckers (2009); Reisinger et al. (2009); and Hwang, Lee and Kim (2011). For example, in Bronckers’ (2009) study the red lighting setting was evaluated as ‘most tense’. Hwang, Lee and Kim’s (2011) study evaluated the red lighting as creating ‘high displeasure’ at the high and medium levels of lighting chroma purity. In addition, the red lighting setting was evaluated in the Reisinger et al. (2009) study as the ‘most tense’, ‘less active’ and ‘least liked’. This result is in line with the results of the current study.

It seems that the red lighting hue produces negative impressions. The participants may have associated the red light to red traffic lights, danger alarm signals in the workplace, public roads and in public buildings. The aim behind the use of the red light in the current study, and the other studies of Bronckers (2009) and Hwang, Lee and Kim (2011), was to examine the influence of different lighting hues in the indoor environment, not as a tool to alert people in specific environments. Moreover, the red light could correlate with the light of fire flames, which may explain why in Bronckers' (2009) study the red light was evaluated as a warm and cosy lighting setting, as mentioned in Section 2.2.4 of Chapter Two. It seems that the red lighting hue is not one of the most appropriate lighting colours to be used in a hotel guest room. While the red light can give the impression of warmth it does not provide a positive impression for relaxing or for work activities.

The green lighting hue was evaluated as highly negative in the current study at the two levels of brightness, medium and high. Studies by Bronckers (2009), Reisinger et al. (2009) and Nomoto et al. (2014) evaluated the green lighting setting as causing low or average 'tension', thus a different evaluation from the current study. On the other hand, Hwang Lee and Kim (2011) found similar results to the current study. Bronckers' (2009) and Reisinger et al.'s (2009) studies evaluated the green lighting setting as causing average 'tension'. In the same vein, Nomoto et al.'s (2014) study found that the green lighting setting was evaluated as one of the lighting settings that engendered a 'comfort' impression.

The difference in the evaluation of the green lighting hue between the current study and Bronckers' (2009) study may be related to the fact that there had been no furniture in the lighting laboratory to identify the use of the space in Bronckers' study. In the current study, the hotel guest room, where the video was recorded, was furnished. Moreover, the Reisinger et al. (2009) study and the Nomoto et al. (2014) study evaluated the green lighting hue differently from the current study; both studies examined spotlights in a lighting laboratory, while the current study examined videos of a real hotel guest room under the exposure of different lighting settings. Another cause for the difference in the results could be the technique used for examining the lighting setting. In both the Reisinger et al. (2009) and the Nomoto et al. (2014) studies a comparison was conducted between two spotlight hues to evaluate the influence of the light hues. The current study evaluated each of the lighting settings individually. A third factor that may have caused the difference in the results is that the lighting settings were partly different. The current study examined general white, white, yellow, green, cyan, blue, magenta and red lighting hues. The Reisinger et al. (2009) study compared white lighting hue spotlights with blue, red, purple, orange, green, cyan and yellow. Nomoto et al. (2014) compared white, yellow, green, orange, red, blue and pink spotlights also.

Hwang, Lee and Kim’s (2011) study showed that the green lighting hue was evaluated as creating ‘high displeasure’ at the high and medium level of chroma purity secondly, after the red at high and medium level of lighting chroma purity; the current study had a similar result. The similarity in results between the current study and Hwang, Lee and Kim’s (2011) study may be because the latter used a mock-up of a living room in a booth. It is likely that the green lighting hue as a spotlight gives less negative impressions than green lighting observed in identified spaces such as hotel guest rooms and/or living rooms. Therefore, it is better to avoid or limit the use of the green lighting hues in hospitality spaces, as this lighting hue creates a negative atmosphere in such spaces. A negative impression could create negative memories for hotel guest room occupants who may therefore avoid coming back to the same hotel or recommending the hotel to other customers.

The general white, yellow, cyan, blue and magenta lighting settings were evaluated as creating an average negative atmosphere in the current study. Hwang, Lee and Kim’s (2011) results showed a similarity to the current results, as yellow, cyan, blue and magenta lighting were evaluated as creating ‘low displeasure’ at the low and medium levels of chroma purity; however, these lighting hues were evaluated as evoking ‘high displeasure’ at the high level of chroma purity. These lighting settings seem to have low negative influence on the atmosphere of the indoor environment; therefore it is acceptable to apply them in hotel guest rooms without a substantial negative impact on the atmosphere of the room.

The results show there was a gender influence on the negative factor evaluations. Females, but not males, evaluated the high brightness colours significantly less negatively than they did the medium brightness colours.

The female participants showed more sensitivity to the brightness of the lighting settings than the male participants. The results of the current study showed that female participants, but not males, evaluated the high brightness colours significantly ‘less negatively’ than they did the medium brightness colours.

Knez and Kers’ (2000) study also shows that females can discriminate more than males with regards to evaluating the lighting setting either negatively or positively. A study by Yildirim, Akalin, Baskaya and Hidayetoglu (2007) examined the influence of colour and light in a cafe/restaurant; their results showed that females were more precise in their evaluation of the indoor space. Yildirim et al. (2007) gave several reasons for the female evaluations such as anatomy, physiology and psychology. In the current study, females reported more significant discrimination among the lighting setting brightness than males did in their evaluation. The difference could be because the females were more sensitive to changes in their perceived environment. Light and colour are part of the stimulating environment.

In conclusion, the white lighting was evaluated as the ‘least negative’ among the lighting settings, and the red and green lighting hues were evaluated as the ‘most negative’ settings, while the general white, yellow, cyan, magenta and blue were evaluated as moderately negative. The implication, therefore, is that white lighting hues will provide a better impression in a hotel guest room. The implications for the lighting industry are that the lighting hues evaluated in this study as ‘highly negative’ may create a negative impression in the indoor environment; such hues may be useful in spaces where people are not expected to stay for any length of time. Thus, RGB LED lighting is capable of creating both a positive and negative atmosphere in the hotel guest room and may be capable of creating both types of atmosphere in other indoor environments.

Do ratings of the room’s brightness, warmth, appropriateness, and the degree to which participants felt encouraged to return moderate the impact of hue and brightness on negative ratings of the hotel room’s atmosphere

There were no significant main effects for brightness and warmth. There were significant main effects for appropriateness and encouragement to return. Generally speaking, the higher the brightness, warmth, appropriateness, and encourage ratings, the higher the impartial rating. The effect of brightness was moderated by warmth, such that brightness had the strongest effects on negative ratings at moderate levels of perceived warmth.

The lighting setting hues red and green, which were evaluated as ‘highly negative’, were also evaluated as ‘less appropriate’ for use in the hotel guest room. The more negatively the hotel guest room was evaluated under the lighting setting, the less appropriate for use in a hotel guest room. The results also showed that the lighting settings that were evaluated as ‘highly negative’ were also evaluated as less encouraging to a guest to return to the hotel guest room. It seems that both brightness and warmth did not influence how the participants evaluated the atmosphere of the hotel guest room with regards to negativity. The negative factor results show that red and green hues were evaluated as the most negative lighting hues.

In Bronckers’ (2009) study, on the other hand, the red lighting hue was evaluated as the ‘most tense’ lighting hue and ‘highly cosy’. The red lighting in Bronckers’ study was evaluated as one of the more suitable lighting hues for a living room atmosphere, while the red and magenta lighting hues were evaluated as less suitable for an office atmosphere.

Hwang, Lee and Kim's (2011) study was similar to the current study in that the participants evaluated red and green at high and medium level of chroma purity as causing 'high displeasure'. That means these lighting settings were evaluated as 'less comfortable' compared to the other examined lighting settings. Therefore, these two lighting settings were evaluated as least appropriate and least likely to encourage return to the hotel guest room. The implication is that it would be better to avoid applying these lighting settings in hotel guest rooms.

9.1.3 The third factor: the impartial description of the indoor environment atmosphere

The results show that red, yellow and general white were evaluated as significantly higher on the impartial descriptor at the high level of brightness than at the medium level of lighting brightness. There was no significant effect of brightness on the impartial evaluation for green, cyan, blue, magenta and white.

This result is similar to the results for the positive evaluation of the indoor atmosphere, with two exceptions — there was no significant influence from the white and green lighting hues between the high and the medium lighting intensities. This means that the participants could discern the difference in the lighting brightness with long wavelength spectrum colours and these lighting hues were considered more impartial at the high level of brightness than the medium brightness.

The results also show that the difference in the brightness of the lighting with the dominating short wavelength spectrum colours did not have a significant impact on how impartial the atmosphere of the hotel guest room appeared to the participants. This may be because the short wavelength lighting hue has a specific influence on the individual circadian system, as a number of studies show (Glickman et al. 2006; Wright, Black, and Kennaway 2004). The short wavelength lighting hue encourages the human body to suppress melatonin production. The influence of the hue is more important than the level of brightness of the lighting. This was reflected even in the aesthetic evaluation.

The study results for the medium level of lighting brightness show that the general white hue was evaluated as being significantly less impartial than white. Concurrently, general white was evaluated as being equally impartial as cyan. The other lighting settings, yellow, green, blue, magenta and red were evaluated as being equally low impartial.

In this study, the white lighting setting at the medium level of lighting brightness was evaluated as being ‘highly impartial’; a similar result was shown by Bronckers’ (2009) and Hwang, Lee and Kim’s (2011), while the Varkevisser, Raymann and Keyson (2011) study evaluated the white hue lighting setting differently, as creating ‘low valence’ and ‘more motivation’.

In Bronckers’ (2009) study, the white lighting hue was evaluated as ‘least lively’ and ‘most detached’ compared with the other lighting hues. Thus, both the current study and Bronckers’ (2009) study found that the white lighting settings were acceptable for practising different activities. This agrees with Fernandez, Giboreau and Fontoynont (2012), who found that a bright cold white lighting setting in a hotel room was suitable for working or looking in a mirror because such a lighting setting provides clear and comfortable vision in the hotel guest room.

Hwang, Lee and Kim’s (2011) results indicated that the white lighting hue was evaluated as one of the lighting hues which can engender the impression of comfort, wellbeing and appropriate communication in the living room space, while Varkevisser, Raymann and Keyson (2011) found that the white lighting setting was evaluated as creating ‘low valence’ and ‘more motivation’ at a low level of brightness. Thus, it has been shown that the white lighting hue is suitable for use in the hotel guest room, as it was evaluated highly in the AID factor which reflects the ‘impartial’ evaluation and the practicality of the indoor space.

The cyan lighting setting was evaluated as one of the ‘most impartial’ among the examined lighting hues at a medium level of brightness in the current study. Several studies have shown similar results, such as Bronckers (2009), Hwang, Lee and Kim (2011), and Varkevisser, Raymann and Keyson (2012). For example Hwang, Lee and Kim’s (2011) study found that the cyan lighting setting was evaluated similar to the white lighting setting, which was considered the optimum lighting setting for comfort and communication in the living room.

The Varkevisser, Raymann and Keyson (2012) study similarly showed that the cyan lighting hue was evaluated as ‘less fatiguing’ at both high and low levels of brightness. However, it was evaluated as ‘less motivating’ compared with the other examined lighting settings. Varkevisser et al.’s (2012) study also showed that the cyan lighting hue was evaluated as creating ‘high valence’ at the high level of brightness but ‘less valence’ at the low level of brightness. This result was incompatible with the current study, as the cyan at the medium level brightness was evaluated as one of the top ‘impartial’ lighting settings. That may be because of the difference in the use of the space; Varkevisser, Raymann and Keyson (2012) examined the lighting setting in a working environment and the current study examined the lighting setting in a hotel guest room. The other factor that may have caused the difference between the two results is the number of examined lighting hue settings in the two studies; the current study examined eight lighting hues and Varkevisser, Raymann and Keyson examined four lighting hues. The probability of choosing and evaluating one of four is different from one of eight.

In Bronckers' (2009) study the cyan lighting setting was evaluated similarly to the white cold lighting setting as highly detached. This result is somewhat similar to the current study's result. The cyan lighting hue setting, like the white cold lighting hue, is more suitable as lighting for a work environment than for a relaxing environment. This lighting setting gave a strong impression of an impartial atmosphere to the users of the space. Therefore, it seems the cyan lighting hue is suitable for use in the hotel guest room as it was evaluated highly in the AID factor which reflects the impartial atmosphere impressions and the practicality of the indoor space.

Yellow, green, blue, magenta and red lighting settings were evaluated as equally less impartial than white, general white and cyan at the medium level of brightness. This means that the atmosphere of the hotel guest room at this level of lighting brightness is less acceptable for carrying out tasks; there were no significant differences in the evaluation of the room under each of the lighting exposures.

The result shows that, at high lighting brightness, general white was not significantly different in being impartial from yellow and white. Meanwhile, general white was evaluated as significantly more impartial than red, green, cyan, blue and magenta.

As discussed earlier, the white lighting setting was evaluated as 'highly impartial' at both high and medium levels of lighting brightness, similar to the studies of Bronckers (2009) and Hwang, Lee and Kim (2011). The yellow lighting setting was also evaluated as 'highly impartial' at the high level of lighting brightness. A similar result was shown by Varkevisser, Raymann and Keyson (2012) and Hwang, Lee and Kim (2011). However, Reisinger et al. (2009) reported different evaluations of the yellow lighting hue.

The Varkevisser, Raymann and Keyson (2012) study evaluated the yellow lighting hue as having 'high valence' at the high brightness level. The yellow lighting setting was also evaluated as the 'most motivating' lighting setting. This result is in line with the results of the present study, as the yellow lighting hue was evaluated as moderately impartial at the medium level of lighting brightness and highly impartial at the high level of lighting brightness.

Hwang, Lee and Kim's (2011) study showed that the yellow lighting setting was evaluated as a good atmosphere for comfort and communication. At two of the examined levels of chroma purity, low and medium, there were no significant differences other than the white lighting hue, which was considered in Hwang, Lee and Kim's (2011) study as the optimal lighting setting. This result shows that the yellow lighting hue at a high level of brightness, and even with a medium level of brightness, was evaluated as 'highly impartial', as in the current study there were no huge differences in the evaluation of the white and yellow lighting settings.

Reisinger et al.'s (2009) study found that the yellow hue lighting setting was evaluated as 'highly relaxed', 'less active' and 'highly liked' compared with other lighting settings (red, blue and magenta). The result of Reisinger et al.'s study partly agrees with the current study. The yellow lighting setting at the high level of brightness in the current study was evaluated as 'highly impartial', while the yellow lighting hues were evaluated as 'less active'. This could be because Reisinger et al.'s (2009) study was conducted in a light laboratory with no identified space use, and the current study was held in a hotel guest room space. The other aspect which could cause the differences in evaluation between the two studies is the way the lighting setting was evaluated. Reisinger et al.'s study compared pairs of spotlights, while the current study evaluated individual lighting settings, and the hue lighting was directed to the space through the wall washer lighting combined with the white general lighting. The measuring tool could have been another reason for the difference in evaluations. Reisinger et al.'s (2009) study used semantic scales - cold-warm, heavy-light, tense-relaxed and passive-active - while the current study used the modified Atmospheric evaluation model of Vogels. The results of the previously discussed studies show that the yellow lighting hue was evaluated as 'positive' and 'impartial' in more than one indoor environment including the hotel guest room. The yellow lighting hue as background to the general lighting can work well in the hotel guest room for relaxation and performing different activities. The implication is, therefore, that the yellow lighting hue is one of the best lighting settings to be applied at a high level of lighting brightness in the hotel guest room for relaxing and performing different activities.

Red, green, cyan, blue and magenta lighting settings were evaluated as equally low for the 'impartial' atmosphere at the high level of lighting brightness. This result is no different from the lighting settings at the medium level of lighting brightness. However, there were exceptions at the medium level of brightness; the cyan lighting setting was one of the top high 'impartial' lighting settings and the yellow was evaluated as low for impartiality compared to the rest of the lighting. At the high level of lighting brightness the cyan lighting switched positions with the yellow lighting setting and became one of the 'low impartial' lighting settings. The implication is that, when a hotel guest room is to be used for office work, red, green, cyan, blue and magenta lighting settings at the high level of brightness should be avoided, as these lighting settings create an impartial atmosphere for the user of the hotel guest room. An impartial atmosphere in the hotel guest room may discourage some hotel guest room occupants who usually use the hotel guest room as a temporary office from staying.

The red lighting hue was rated as significantly more impartial by participants over 41 compared to the younger participants.

The finding that the red lighting hue was rated as significantly 'more impartial' by participants over 41 could have been due to the older participants having less flexibility in their eye lenses; if that were the case, they would have been slower to adapt to the changes in the lighting settings, making it difficult for them to discriminate among the lighting hues. Another explanation could be that the older participants considered the red lighting as more impartial than the younger participants because of their experience with lighting hues. It may be that older age groups' understandings of what an impartial atmosphere is in a hotel guest room are different from those of younger age groups. Similarly, in the study of Kuijsters et al. (2012) there were differences in the evaluations by the different age groups. In the Kuijsters et al. (2012) study the older participants reported that they were actually unhappy with the high saturated lighting hues as these hues presented an unpleasant atmosphere for them. Moreover, Knez and Kers' (2000) study showed that younger participants were more sensitive to differences between the lighting settings than the older participants, hence the difference in the evaluation.

In conclusion the white, cyan and general white lighting settings were evaluated as 'highly impartial' among the lighting settings at the medium level of brightness, and red, blue, green, yellow and magenta lighting settings were evaluated as 'least impartial'. The implication therefore is that white, cyan and general white lighting setting hues will provide more impartial impressions in a hotel guest room. At the high level of lighting brightness the yellow, white and general lighting hues were evaluated as the 'most impartial' among the lighting settings; the rest of the lighting hue settings were evaluated equally as 'less impartial'.

The implications for the hotel industry are that the lighting hues evaluated in this study as 'highly impartial' will create impartial impressions which will leave positive memories for hotel guests who use the hotel room as an office; these memories may encourage them to stay longer in the room or to come back in the future to the same hotel and/or recommend the hotel to other customers. Architects, designers and stakeholders will be able to use this information to make more informed choices with regard to hotel rooms used as work spaces.

Do ratings of the room's brightness, warmth, appropriateness, and the degree to which participants felt encouraged to return moderate the impact of hue and brightness on negative ratings of the hotel room's atmosphere

There were significant main effects for brightness, warmth, appropriateness, and encouragement. Generally speaking, the higher the brightness, warmth, appropriateness, and encourage ratings, the higher the 'impartial' rating. The effect of hue was moderated by brightness such that hue had its strongest effects on impartial ratings at higher levels of perceived brightness.

It seems that both the 'positive' factor and the 'impartial' factor had a similar relationship with how the atmosphere of the hotel guest room was evaluated under the exposure of different lighting settings with regard tobrightness, warmth, appropriateness and encouragement to return to the space.

The evaluation of the indoor atmosphere as 'highly impartial' under the exposure of high brightness lighting settings has been observed in more than one study. Fernandez, Giboreau and Fontoynont (2012) in their study found that bright cold white light was suitable for work and for looking in the mirror in the hotel room. This result partly corresponds with the current study result. Moreover, Park and Farr (2007) and Second (2012) evaluated the influence of brightness and the CCT of lighting and found that the bright warm white lighting setting was preferred for retail and dining environments. On the other hand, Moor's (2009) study found that the warm bright white lighting was 'cosier', 'livelier', 'less tense' and 'less detached' in a lighting laboratory without identified use of space. Bronckers' (2009) study showed that white and cyan lighting hue settings were more suitable for working space than red, magenta, blue, green and yellow hues, while red and magenta were the least suitable lighting hues for an office. Together these studies demonstrated that bright lighting was preferred most of the time and acceptable for use in impartial or task-oriented spaces, while warm lighting settings were preferred by the occupants of the space depending on the use of the space.

It seems that the judgment of what is impartial for the atmosphere of the space is based on the use of the space. The evaluations of the influence of the lighting brightness, CCT, hue and the purity of the hue for work space were different. The evaluation of lighting properties is different for general or public spaces, for retail space or dining space or a work office. Even the level of the degree of formality is different in a multi-purpose space. The evaluation of the living room in a house is different from that for a common room in aged care, as discussed in Chapter Two with regard to the study of Kuijsters et al. (2012), and is different from the hotel guest room.

The evaluation of how appropriate the lighting is, and the degree to which participants felt encouraged to return to the hotel guest room space, are of significance to the financial sustainability and improvement of the hotel and tourism industry. If the clients do not find the hotel guest room's atmosphere appropriate they may leave the hotel, or not return. From the future investment perspective 'encouragement to return to the hotel guest room' is an important point to be considered in order to establish a suitable atmosphere for the client. It is important for the service provider to build a relationship of trust with the client by creating the optimum atmosphere that can fulfil the aesthetic and practical needs of the user through the lighting experiences.

9.2 Chapter Conclusion

It can be concluded from the study that lighting hues do influence the atmosphere in a hotel guest room. At the medium level of lighting brightness, the mixed lighting settings of white, cyan, yellow and magenta created a more positive atmosphere than the primary lighting settings of red, green and blue. At the high level of lighting brightness, the yellow lighting hue was the best lighting hue to create a positive atmosphere in the hotel guest room. The rest of the examined lighting settings created a positive atmosphere but not at the same level as the yellow lighting hue.

It is also concluded from the study that, to create positive or impartial atmospheres the influence of lighting brightnessis more pronounced for the lighting hues with long and medium dominant wavelength spectra than on the lighting hues with dominant short wavelength spectra. In contrast, no significant effects of lighting brightness on the creation of a negative atmosphere were observed.

From the study results it can be concluded that some of the lighting hue settings can create a negative atmosphere in the hotel guest room. For example, at high and medium levels of lighting brightness, red and green lighting settings create a highly negative atmosphere, while the white lighting setting creates the least negative atmosphere.

The study also showed that the most impartial hotel guest room atmosphere was created at the medium level of lighting brightness by applying white lighting. General white and cyan were the second best lighting settings for creating an impartial atmosphere in the hotel room. The other lighting hues engendered a low impartial impression although, at the high level of lighting brightness, white, general white and yellow were the best lighting hues for creating impartial impressions of the hotel guest room atmosphere. Finally, the study showed that the higher the brightness, warmth, appropriateness, and encouragement ratings, the higher the positive and impartial rating; and the lower the appropriateness and encouragement ratings, the higher the negative rating. The next chapter, Chapter 10, provides the overall conclusion for the study and recommendations.

10.Conclusion and Recommendations

This chapter presents the conclusion of the thesis and recommendations. First, the research questions and the objectives of the study are presented, and then the main study conclusions followed by the research's contribution. The significance of this study derived from the three-stage methodology of the study. The conclusions from the structured interview with participants are then discussed. Further conclusions derived from this study aligned with other studies that have examined the influence of lighting hues. The limitations and strengths of the study are discussed; followed by recommendations and future research.

10.1 The study conclusion

The core question of the current study, is to determine in what way the new RGB LED lighting technology, which is capable of emitting different levels of lighting and hues using the same fixture, influences the perceived atmosphere of the indoor environment (hotel guest room).

The following research questions were asked:

1. To what extent does the hue of the RGB LED lighting influence the perceived atmosphere of a hotel guest room?

2. To what extent do the brightness of RGB LED lighting influence the perceived atmosphere of a hotel guest room?

3. To what extent do both hue and brightness of the RGB LED lighting influence the perceived atmosphere of a hotel guest room with regard to brightness, warmth, appropriateness and encouragement to return to the hotel guest room?

Following are the conclusions of each of the research questions drawing from the result of the current study.

10.1.1 To what extent does the hue of the RGB LED lighting influence the perceived atmosphere of a hotel guest room?

It is concluded that: Different lighting hues do indeed have an influence on the perceived atmosphere of the hotel guest room.

It can be concluded from the study that the lighting hues had a positive influence on the atmosphere of the hotel guest room. The mixed lighting settings of white, cyan, yellow and magenta created a more positive atmosphere than the primary lighting settings of red, green and blue. Figure 10.1 shows in the first row the lighting hue setting that was evaluated as highly positive, and in the second row the lighting setting that was evaluated as low positive at the medium level of lighting brightness.

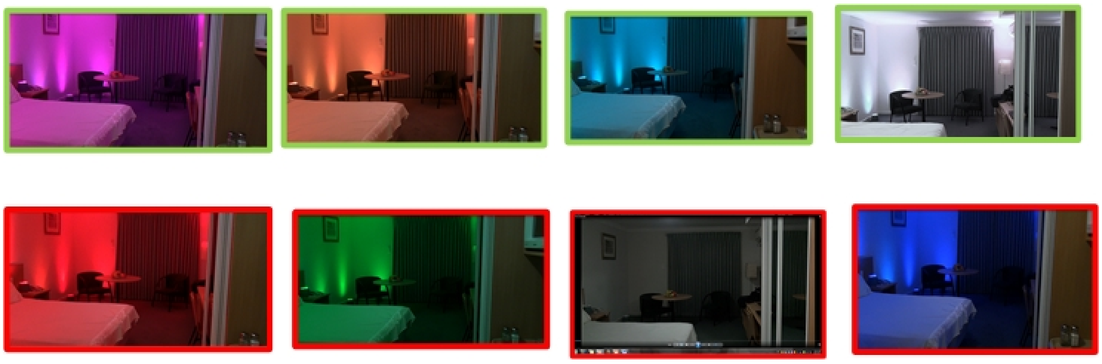


Figure 10.1 The flowchart of the lighting hue setting evaluation at the medium level of brightness of the APD.

Factor One, the atmospheric positive descriptive for the lighting setting at the medium level of brightness. The light green framed images of the first row shows the lighting settings which were evaluated significantly as highly positive, which included white, yellow, cyan and magenta. The red framed images of the second row are the mediation of the general white with no significant difference of red, green and blue.

Figure 10.2 shows in the first row the lighting setting that was evaluated as highly positive, and in the second row, the lighting hue setting that was evaluated as low positive at the high level of lighting brightness.

Figure 10.2 The flowchart of the lighting hue setting evaluation at the high level of brightness of the APD.

Factor one, the atmospheric positive descriptive for the lighting setting at the high level of brightness. The light green framed image shows the lighting settings which were evaluated as significantly highly positive, which included yellow. The yellow framed images are the mediation of the general white with no significant difference between red, green and blue, white, cyan and magenta.

From the study results it can be concluded that some of the lighting hue settings such as red and green can create a negative atmosphere in the hotel guest room. Figure 10.3 shows in the first row the lighting setting that was evaluated as highly negative and in the second row the lighting hue setting that was evaluated as less negative; the third row shows the lighting setting that was evaluated as least negative at both levels of lighting brightness, medium and high.

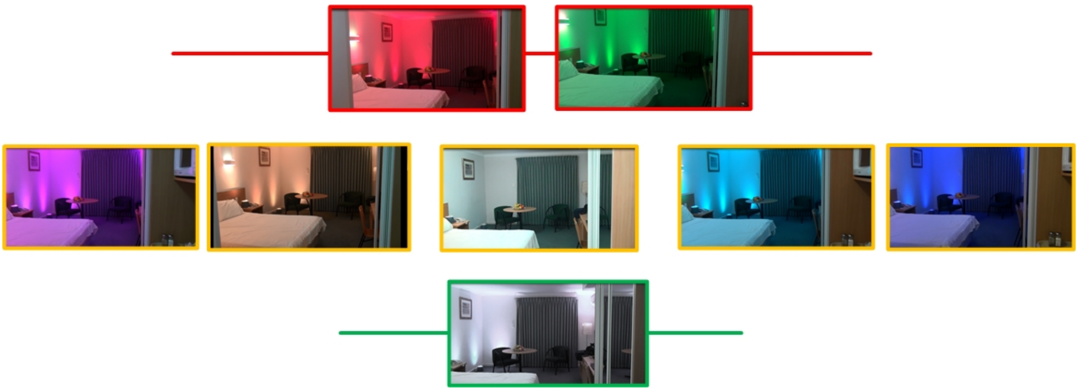


Figure 10.3 The flowchart of the lighting hue setting evaluation at the medium and high level of brightness of the AND.

Factor two, the atmospheric negative descriptive for the lighting settings at the high and medium level of brightness. The red level is the lighting setting which evaluated as significantly highly negative red, green. The yellow level is the mediation of the general white with no significant difference between blue, cyan, yellow and magenta. The light green level shows the lighting settings which evaluated as significantly less negative which included white.

The study also showed that an impartial hotel guest room atmosphere can be created by applying a number of lighting hues such as general white, cyan and yellow.

Figure 10.4 shows in the first row the lighting hue setting that was evaluated as highly impartial, and in the second row the lighting hue setting that was evaluated as slightly less impartial whilethe third row is the lighting hue setting that was evaluated as least impartial at the medium level of lighting brightness.

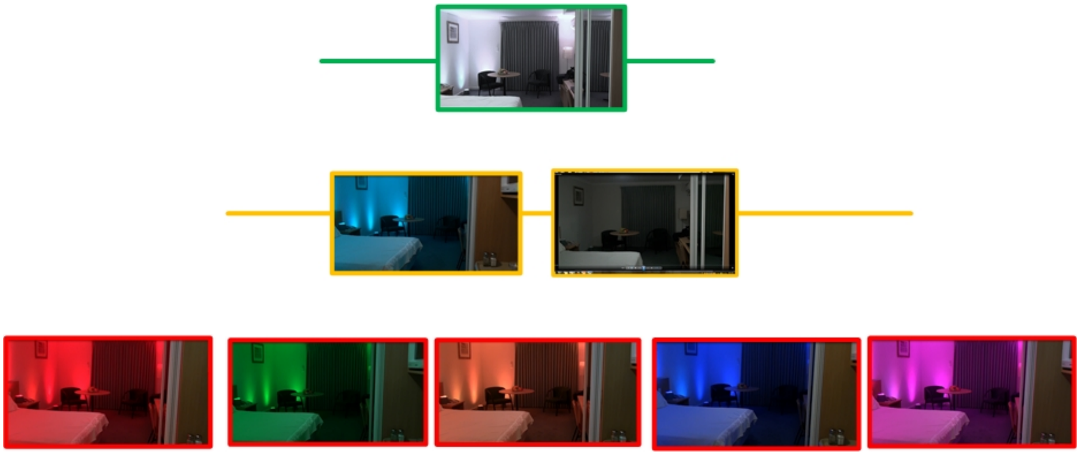


Figure 10.4 The flowchart of the AID for the lighting hue setting evaluation at the medium level of brightness.

Factor three, the atmospheric impartial descriptive for the lighting setting at the medium level of brightness. The green level is the lighting setting which evaluated as significantly highly impartial, the white. The yellow level is the mediation of the general white with no significant difference from cyan. The red level shows the lighting settings which were evaluated as significantly less impartial which included red, green, yellow, blue and magenta.

Figure 10.5 shows in the first row the lighting hue setting that was evaluated as highly impartial, and in the second row the lighting hue setting that was evaluated as less impartial at the high level of lighting brightness.

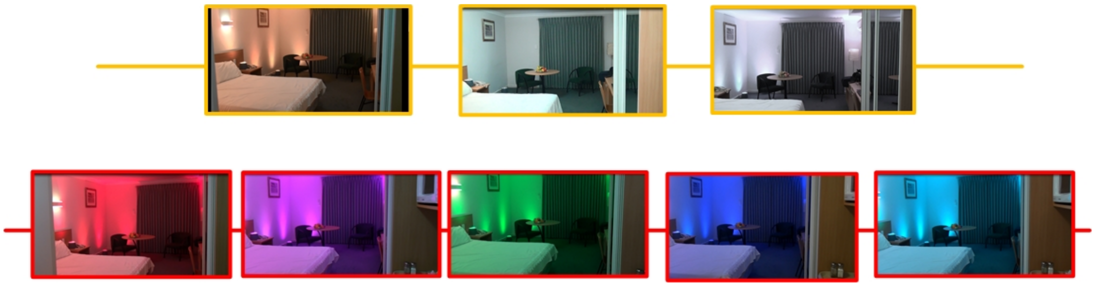


Figure 10.5 The flowchart of the AID for the lighting hue setting evaluation at the high level of brightness.

Factor three, the atmospheric impartial descriptive for the lighting setting at the high level of brightness. The yellow level is the mediation of the general white with no significant difference between white and yellow. The red level shows the lighting settings which were evaluated as significantly less impartial, which included red, magenta, green, blue and cyan.

Moreover, the lighting hues that correlated with daylight, from sunrise to sunset, were the most preferred lighting hues by the study participants. Therefore, there seems to be a link, if only indirectly, in that the lighting hues that are associated with the hues of natural light had an effect on the aesthetic evaluation of the lighting in the hotel guest room.

The current study provides evidence that the hue of the lighting system can change the way the perceivers evaluate the indoor environment. Without any doubt, lighting designers and interior designers can utilize the lighting hues to create the atmosphere that they wish (such as positive, negative and impartial) in the hotel's guest rooms. This means that the designers can use specific lighting hue to create an attractive indoor environment that leaves a likable memory for users of the space to encourage them to stay longer in that space or to come back to the same place. At the same time, the designers can use specific lighting hues to create an indoor repellent environment which encourages the users of the space to leave the space.

10.1.2 To what extent does the brightness of RGB LED lighting influence the perceived atmosphere of a hotel guest room?

It is concluded that: Different lighting brightness do indeed have an influence on the perceived atmosphere of the hotel guest room.

It was concluded from the study that the influence of the lighting brightness was more important for creating a positive atmosphere in conjunction with lighting hues with long and medium dominant wavelength spectra such as red and yellow lighting hues, than in conjunction with lighting settings with dominant short wavelength spectra such as blue and cyan lighting hues. The study also showed that lighting brightness was more important for creating an impartial atmosphere with the long dominant wavelength spectra than with the lighting settings with dominant medium and short wavelength spectra; there were no significant influences of lighting brightness on the creation of a negative atmosphere. Figure 10.1 shows the influence of lighting brightness on different lighting hues of the first factor, the atmospheric positive descriptions.

Figure 10.6 The influence of the lighting brightness on different lighting hues: the first factor, the atmospheric positive descriptions.

In the upper level of the figure, the vertical arrow shows that the lighting setting positivity increases with the increasing brightness of lighting in the lighting hues with high and medium dominant wavelength spectra. In the lower level of the figure, the horizontal arrow shows that there was no significant influence of the lighting brightness on the lighting hue settings with dominant short wavelength spectra in the positive factor.

The brightness of lighting was shown to influence the perception of the atmosphere of the hotel guest room for lighting settings with long and medium dominant wavelength spectra. For long dominant wavelength spectra, the brightness of lightinginfluenced how impartial the atmosphere of the hotel guest room was perceived to be. The hue of the lighting was shown to have an influence on how positive, negative and impartial the atmosphere was perceived to be. Both the brightness and hue of the lighting settings were shown to have an influence on how the atmosphere of the hotel guest room appeared with regard to brightness, warmth, appropriateness and encouragement to come back to the hotel.

The current study provides evidence that the level of brightness of lighting in the indoor environment interacts with the hue of the lighting to create diverse perspectives for the viewed atmosphere which impact on the evaluation of the indoor environment. Lighting designers and interior designers can therefore use both the brightness and hue of the lighting system as a language to express their ideas to create the atmosphere that they wish (such as positive, negative and impartial). It's a language which can give its statement to the perceivers with high eloquence.

10.1.3 To what extent do both hue and brightness of the RGB LED lighting influence the perceived atmosphere of a hotel guest room in terms of brightness, warmth, appropriateness and encouragement to return to the hotel guest room?

The study results also revealed the relation between evaluations of the hotel guest room atmosphere and perceptions of brightness, warmth, appropriateness, and encouragement to return to the hotel guest room. The higher the brightness, warmth, appropriateness, and encourage ratings, the higher the positive rating. The lower the appropriateness and encouragement ratings, the higher the negative rating. The higher the brightness, warmth, appropriateness, and encourage ratings, the higher the impartial rating.

The study can guide lighting designers as it suggests that lighting brightness and hue can be used to create different impressions – positive, negative and impartial – in the atmosphere of a hotel guest room. The implications for the hotel industry are that the control of the brightness level and hue of lighting is a useful tool to leave positive, negative and impartial memories for hotel guests who use the hotel room for different purposes such as temporary workstation, leisure and entertainment space or any other task which usually take place in multi-purpose spaces. These memories may encourage them to stay longer in the room or to come back in the future to the same hotel and/or recommend the hotel to other customers.

10.2 Research's Contribution

Lighting in the built environment is no longer associated only with meeting functional needs by simply fulfilling the lighting standards for comfortable visual purposes. The interaction between users of the indoor environment and their surroundings is another essential factor for creating a comfortable indoor environment. In order to understand this interaction, it is important to know how users evaluate their environment under the exposure of the lighting system.

This study shows how the viewers of the indoor environment evaluate the influence of two properties of RGB LED lighting the (level of brightness and hue) on indoor multi-purpose spaces (hotel guest rooms).

The study is important for both lighting designers and interior architects as it identifies the lighting hues and the level of brightness which can be applied in the hotel guest room to create a positive, negative or practical atmosphere for the hotel guest room.

The empirical approach to examining the RGB LED lighting in the hotel guest room shows without any doubt there is an essential impact of the lighting properties (brightness and hue) on the aesthetic evaluation of the atmosphere of the indoor environment.

The current study methodology proved to be an appropriate choice for this study as it enabled the researcher to obtain a reliable evaluation of the aesthetic influence of the different lighting hue settings on the perceived atmosphere of the experimental hotel guest room using variations of the RGB LED lighting technology.

The modified atmospheric measuring tool - an English version of Vogel's (2008) instrument - was tested and validated and used to assess the responses of selected West Australian users to photographs of five hotel guest rooms. Vogels' model was designed to reduce non-environmental influences on the evaluation process. In the preliminary stage, the numbers of items in the instrument was reduced and categorised in terms of the three factors of the study. This process produced an evaluating tool which was compact, reliable and understandable through three dimensions — Atmosphere Positive Descriptive (APD), Atmosphere Negative Descriptive (AND) and Atmosphere Impartial Descriptive.

The modified atmospheric model may be considered as an effective way to evaluate the influence of the lighting system in the indoor environment for English users.

The 3D video technology was validated as providing an alternative to a live visit to the space, one which allowed the researcher to collect data accurately in a simulated space. 3D video technology simulates the human perceptual experience, as the technology creates a sense of depth in the animated images of the video. The 3D technology also provided the viewers with visual data that enabled them to experience the images of space from different angles and positions in continuous way across the whole examined indoor environment. Also, the 3D video technology reduced the eight minutes of a real visit to two minutes of purposeful, compact visual experiences.

Therefore: the 3D video technology method of this study can be considered as an effective alternative to the live experience in studies which concern in evaluating the built environment from the visual perspectives. This method can save time and reduce the financial demands of the research project. The 3D video technology method also helps researchers in their time management process by providing a flexible and controllable visual environment for the study participants.

10.3 Significance of the study

Because of the nature of the study, it is significant in terms of both its methodology and its findings. As a result, there are three major areas of significance, as follows:

1. the demonstration of the ability to affect the atmosphere in hotel rooms through the control of hue and brightness level of LED RGB lighting;
2. the adaptation of Vogels' research model from Dutch to English allowing a wider application of the reduced emotional evaluation of the effects of lighting in the indoor environment, and
3. the application of 3D technology as a valid research tool in place of real world experience or graphically created virtual experience,

each of which is addressed individually below.

10.3.1 The ability to affect the atmosphere in hotel rooms through the control of hue and brightness level of LED RGB lighting

The primary significance of this study derives from its focus on the aesthetic influence of RGB LED lighting in the hotel guest room. The utilisation of the LED lighting technology in the indoor environment has been widely examined from practical and economic perspectives; however, only a limited number of studies have investigated the aesthetic influence of RGB LED in the indoor environment.

Specifically, at the time this study was proposed, no previous studies had investigated the influence of coloured LED lighting in the hotel guest room. Moreover, for those interested in the hotel industry, lighting industry, lighting design and interior design, the current project will provide useful information about users' evaluations of the hotel guestroom under the exposure of lighting settings differing in hue and brightness.

It was hoped that the results would reveal the users' views with regard to the atmosphere of the hotel guest room under the exposure of RGB LED lighting. A better knowledge of the influence of the RGB LED lighting on the atmosphere of hotel guest rooms can be beneficial for the user and hotel owner as well as the lighting designer. Therefore, the current study can provide a new understanding of the influence of the RGB LED lighting technology in the multi-purpose space of a hotel guestroom which has implications for architects and interior designers in terms of both the functional fitting of such spaces and the colour palette of finishes and furnishings that could respond to changing lighting conditions.

10.3.2 The adaptation of Vogels' research model from Dutch to English

The researcher designed the study to accomplish the research objectives by using a multiple stage methodology, with each stage considered as a basis for the following stage. In terms of methodology, this study was therefore different from other studies in this area. It comprised one survey and two empirical stages, which were described in the literature review chapters. Chapter Two highlighted the role of LED lighting technology in the indoor environment and emphasised the knowledge gap in this field, and also discussed the mathematical models of lighting colour space, which are based on the additive RGB lighting colour theory. The examined lighting settings in the study were designed on the basis of this theory. Chapter Three described the development of an appropriate measuring tool to be used in the study. This chapter also discussed the 'where and how' of examining the influence of RGB LED lighting in the hotel guest room. The findings in this chapter led to the use of 3D video as an alternative to a real visit to the hotel guest room.

After a critical review of the measuring tools for the aesthetic evaluation of the indoor environment, Vogels' (2008) model was chosen as it was designed in such a way that it avoided the non-environmental influences in the evaluation process. However, Vogels' questionnaire model, as mentioned in Chapters Three and Five, was established and tested in Dutch. As the current study was to be carried out in English, the terms used by Vogels were translated and the modified terms tested to establish their validity. Testing of the modified English version of the questionnaire resulted in the current study observing a different factor structure than the original Dutch questionnaire. In particular, the new solution included the three factors that are usually considered in self-report techniques for evaluating an indoor environment, these being the level of comfort, the level of activity and the degree of control of the surrounding environment.

As a result, the study has provided a translated and modified version of Vogels' (2008) questionnaire that has been validated and is available for other English language based researchers who may wish to carry out studies on the effects of lighting on architectural spaces.

10.3.3 The application of 3D technology as a valid research tool

The findings of the first stage of the methodology enabled the researcher to establish a parallel between two comparable visual experiences (visiting real space and watching a 3D video of the same space) as tested in the second stage of the study, which then enabled the researcher to identify differences in perceptions of the atmosphere of the hotel guest room under the exposure of different lighting setting intensities and hues.

In the third stage of this study, a 3D video was used as an alternative to visiting a real hotel guest room as a way of evaluating the atmosphere of the room. A number of factors, discussed in Chapter Six, helped to make this a viable simulation method for evaluating indoor environments. The sequence of the scenes in the 3D video provided a sense of the fourth dimension, time, thus making the visual experience with the 3D video similar to a live visit. The sense of depth in the visual experience of watching the 3D video was another factor which made the experience similar to a live visit to the examined space. Reference to the ways in which individuals explore a new indoor environment enhanced the 3D video production to give the visual impression of visiting an indoor environment for the first time. Care was taken to produce a visual experience for the participants that were free from sharp transitions and sudden movements or vibrations in order to increase the realism of the visual experience.

Moreover, the researcher was able to better manage the environment. The room in which participants viewed the 3D display of the subject room could be controlled thermally and acoustically, there by eliminating potentially confounding variables. The result was that all of the participants 'lived' the same visual experience because they did not have the freedom to move and observe the indoor environment. They all viewed the same video with the same movement path and the same recorded details in exactly the same environment.

Validation of the simulation method using 3D videos was proved to be significant for several other reasons. Firstly, the convenience of being able to allow participants to view a hotel room without needing to visit the room had both time and cost benefits as well as being able to monitor a consistent environment without variations in the temperature and other climatic or environmental factors. Secondly, it provided major time and cost benefits over another proposed method, that of graphically rendering a 3D version of the hotel room. An initial estimate of the time needed to render such an environment for the study was in excess of five thousand hours, whereas the recording of the 3D video and subsequent post-production totalled less than one hundred hours. This also resulted in an equivalent saving in the associated costs, so by utilising the 3D video, expenses were kept to a reasonable level. Thirdly, not only was the use of 3D video more economic compared to conducting the project in real or graphically rendered space, it also provided the flexibility to collect data from participants individually or collectively and the visual experience of the participants was arguably close to reality.

The recorded 3D videos could be kept and used more than once; also, the researcher could view the video records more than once in the analysis process to gain a better understanding of the participants' evaluations. Moreover, the visual materials could be copied and transformed for use in different places. This means that the evaluator does not need to physically be in the space to evaluate. The visual materials could be used in different seasons if there is a suggestion that climate impacts on the aesthetic judgment. The evaluations could be re-conducted with identical visual experience, but with different temporal and spatial environments.

10.4 The conclusions from the structured interview with participants after the main study experiment are that:

The interviews allowed the participants to provide their opinions or perspectives on three major aspects of the study. The first two aspects correlated to the study methodology of the questionnaire and the use of the 3D video, while the third point was concerned with the evaluation of the examined lighting settings.

The interview with each of the participants in the study's third stage, the main study, showed that 24 of the 32 participants thought the instrument measured a combination of their subjective feelings and objective judgements about the environment. Only three of the 32 participants stated that their evaluation of the hotel guest room was objective, and five of the study participants felt their evaluation was a subjective response to the examined atmosphere. This indicates that the study questionnaire was interpreted by those respondents as a mix of atmospheric evaluations and emotional refelctions, not, as it was designed to be, purely an atmospheric evaluation tool.

Although the 3D video technology was suitable for converting the visual experience of visiting a hotel guest room, there was still the possibility that a few of the participants, not being used to the 3D visual experience, could have felt some discomfort. Nevertheless, the 3D video was demonstrated to be an effective way to differentiate the changes which occurred in the atmosphere of the indoor environment under the exposure of various lighting intensities and hues.

The primary lighting hues such as red and blue at a low level of lighting brightness were less preferred than the mixed lighting hues such as yellow, cyan, magenta and white at the high level of brightness. The findings of the three empirical stages conducted in this project highlight the significant influence of the hue and the brightness of RGB LED lighting on the atmosphere of a hotel guest room.

The study was distinct from other studies that have examined the influence of lighting in hotel guest room, as this study examined different hues of lighting in the indoor environment from the aesthetic perspective.

10.5 Further conclusions derived from this study align with those of other studies that have examined the influence of lighting hues:

The RGB LED lighting system can be effectively used in multipurpose spaces such as hotel guest rooms. The use of this system in the current study enabled the researcher to create three different atmospheres: positive, negative and impartial. It was found that this lighting system was not only efficient in terms of energy consumption and had a less negative impact on the natural environment; it also had aesthetic efficiency as it could be used to create different indoor atmospheres.

The aesthetic evaluation in this study showed that there is a relationship among the lighting hues which are evaluated as highly positive and appropriate for use in hotel guest rooms and the daylight hues from sunrise to sunset such as white, cyan and yellow. Other studies have found similarly that there is a relationship between lighting hues, physiology and naturally occurring light.

The lighting hue setting when evaluated in unidentified indoor space can give different results from the evaluation of similar lighting hues in identified indoor space.

The level of lighting hue purity and the level of saturation and brightness of the setting can influence the evaluation of the same lighting hue.

Differences in the number and combination of the examined lighting hue settings in studies examining the influence of lighting hues in the indoor environment can lead to different results.

Using different questionnaire models can demonstrate the influence of the lighting hue from different perspectives.

There is a possibility that the same hue and brightness of lighting settings in the indoor environment have different influences depending on the gender and age of the observer.

10.6 Limitations and Strengths of the Study

The limitation of the current study was the type of sample that was used in the study, as it used a convenient sample of University postgraduate students and staff in the second and third stages. Although all the participants in the study had experienced staying in hotels either for work and/or recreation travel and hence could be viewed as acceptable participants, they nevertheless represented a relatively narrow demographic, meaning that, the results of the current study may not represent a wide range of hotel users. Therefore, this study was designed to answer the specific research questions and its results cannot be generalised.

10.7 Recommendations

Based on the results of this study, it is recommended that:

- The RGB LED lighting system be incorporated in hotel guest rooms, as it provides a variety of choices for the hotel guest.
- The RGB LED lighting system, by controlling the changes in the brightness and the hue of the lighting settings, be used to enable lighting designers and users to easily change the atmosphere of the hotel guest room.
- Mixed lighting hues be applied in hotel guest rooms rather than primary lighting hues in order to produce a positive impression.
- Red and green lighting hues be carefully utilised in hotel guest room as they can create a highly negative atmosphere.
- Three mixed lighting hues of white, cyan and yellow, be used to produce an impartial impression in hotel guest rooms.
- Consideration be given to the needs of females and older individuals, as these two groups (and others) may evaluate the influence of lighting hues differently.
- Utilising the RGB LED lighting technology is more applicable in hotel guest rooms with achromatic walls and furniture as the influence of lighting hues will be clearer than in rooms that have chromatic walls and furniture.

10.8 Future research

Based on the study results, future research is recommended. The results of this study contribute to understanding the influence of lighting hues and brightness on the perceived atmosphere of a hotel guest room. The study shows that lighting brightness and hue have specific effects on the perceived atmosphere. A number of studies, besides the current one, have investigated the influence of lighting hue and brightness on the atmosphere of the indoor environment such as living rooms, work spaces and non-identified indoor spaces (lighting laboratories). It is recommended therefore that:

- The influence of different lighting hues in different spaces be investigated.
- A number of studies have examined how a combination of a number of lighting hues in the indoor environment can enhance or diminish the perceived atmosphere, such

as the studies of Seuntiens and Vogels (2008); Choy Calvin (2009); Van Essen, Offermans, and Eggen (2012). More diverse combinations of lighting hues could be studied.

The majority of studies, including this one, have investigated the influence of additive RGB colour lighting theory using the three primary hues of red, green and blue as well as the secondary lighting hues of yellow, cyan and magenta. Thus for the future it is recommended that:

- Other hues such as orange, pink, aquamarine and violet be examined for their influence on the indoor environment.

As few studies have investigated the influence of different lighting hues in other hotel spaces, it is recommended that:

- Different lighting hues be examined with regard to their influence on other hotel spaces, such as lobby, coffee shop, casino, and restaurant.

As few studies have investigated the influence of the CCT and brightness of lighting in the hotel guest room, it is recommended that:

- The CRI of the LED lighting be examined for its influence in hotel guest rooms.

This study used the 3D video technology to film the hotel guest room only. It is recommended therefore that:

- 3D technology be used to evaluate other indoor environments.

The study used 3D video technology to examine the influence of lighting properties on the perceived atmosphere of the indoor environment. It is recommended therefore that:

- 3D video technology is used to evaluate the influence of other variables and components on the perceived atmosphere of the indoor environment.

One of the participants in the main study indicated that the weather situation could influence the evaluation with regards to the lighting hue setting. It is recommended therefore that:

- The evaluation of the study indoor environment be repeated more than once if there is extreme difference in weather between different seasons around the year where the study is being conducted.

The study did not focus on cultural differences in the evaluation process as most of the hotel services were not offered according to cultural preferences. It is therefore recommended that:

- Cultural differences be considered when evaluating the influence of lighting hue and brightness in indoor environments other than hotel guest rooms to determine whether cultural differences have a significant influence on the evaluation process.

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Position: CONTENT DEVELOPMENT MANAGER, WARC (Publisher of Journal of Advertising Research)

Date: 29/6/2015

Please return signed form to [Insert name and address of research student]

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[Figure 3 in "Color influences on human beings evaluated by nasal skin temperature, by Tota Mizuno · Naoki Nakategawa Yuichiro Kume. (2012)] in Artificial Life and Robotics 16 (4):519-522.DOI: 10.1007/s10015-011-0978-9

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Signed: Hiroshi Tanaka

Name: Hiroshi Tanaka

Position: Professor Emeritus, Tokyo Medical and Dental University

Date: July 28, 2016

Please return signed form to [Insert name and address of research student]

Criterion
Hotel Perth

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[Criterion Hotel Perth photo] ***Published in*** https://www.google.com.au/search?q=boutique+hotels+united+kingdom&biw=1366&bih=659&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiVhobp147OAhVCnJQKHZSWA34Q_AUIBygC#tbm=isch&q=criterion+hotel+Perth+bedroom&imgrc=yWBvYKdc2EzYEM%3A

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I confirm that I am the copyright owner of the specified material.

Signed:

Name: Yesisca

Position: Acting PA to General Manager

Date: 28th July 2016

Please return signed form to [Haider A Abdulrazzak Alseaid]

Tan & Chong Management Pty Ltd (ABN 52 169 505 033) trading as
Criterion Hotel Perth
560 Hay Street, Perth, Western Australia 6000
Tel : (08) 9325 5155 Fax: (08) 9325 4176
Website: www.criterion-hotel-perth.com.au E-mail: criterion@criterion-hotel-perth.com.au

2. Appendix

The first stage questionnaire version number 1

A Pilot Study questionnaire

Finding the correct terms to describe the atmosphere of the hotel guestroom

(Part of a wider study looking at the influence of coloured light emitting diode in the hotel guest rooms)

The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Dear respondents,

The researcher would like to thank you for your cooperation in assisting with the proposed research. The aim of this pilot study is to find the correct Australian terms that describe the ATMOSPHERE of a hotel guest room.

Question No.1 of this pilot questionnaire asks you to evaluate the atmosphere of the room shown in the photo.

Q1. For each expression in the table below please indicate on scale of 1-7 (with 1 being the least applicable and 7 being the most applicable) the extent to which each term accurately describes the atmosphere of this hotel room.

Expression	1	2	3	4	5	6	7
Cosy							
Safe							
Oppressive							
Depressing							
Uncomfortable							
Exciting							
Formal							
Romantic							
Tranquil							
Inspiring							
Intimate							
Cheerful							
Detached							
Lively							
Terrifying							
Luxurious							
Musty							
Mysterious							
Threatening							
Uninhibited							
Restless							
Relaxed							
Personal							
Business							
Cool							
Hospitable							
Spatial							
Pleasant							
Boring							
Tense							
Lethargic							
Stimulating							
Accessible							
Hostile							
Chilly							
Warm							

Q2. How bright do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Bright								Dark

Q3 How warm do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Warm								Cool

Q4.Do you find the lighting condition in the room appropriate.

	1	2	3	4	5	6	7	
Appropriate								Inappropriate

Demographic profile

1. Gender:Female Male
2. Age:

The first stage questionnaire version number 2

A Pilot Study questionnaire

Finding the correct terms to describe the atmosphere of the hotel guestroom

(Part of a wider study looking at the influence of coloured light emitting diode in the hotel guest rooms)

The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Dear respondents,

The researcher would like to thank you for your cooperation in assisting with the proposed research. The aim of this pilot study is to find the correct Australian terms that describe the ATMOSPHERE of hotel guest room.

Question No.1 of this pilot questionnaire asks you to evaluate the atmosphere of the room shown in the photo.

Q1. For each expression in the table below please indicate on scale of 1-7(with 1 being the least applicable and 7 being the most applicable) the extent to which each term accurately describes the atmosphere of this hotel room.

Expression	1	2	3	4	5	6	7
Cosy							
Safe							
Oppressive							
Depressing							
Uncomfortable							
Exciting							
Formal							
Romantic							
Tranquil							
Inspiring							
Intimate							
Cheerful							
Detached							
Lively							
Terrifying							
Luxurious							
Musty							
Mysterious							
Threatening							
Uninhibited							

Restless							
Relaxed							
Personal							
Business							
Cool							
Hospitable							
Spatial							
Pleasant							
Boring							
Tense							
Lethargic							
Stimulating							
Accessible							
Hostile							
Chilly							
Warm							

Q2. How bright do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Bright								Dark

Q3.How warm do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Warm								Cool

Q4.Do you find the lighting condition in the room appropriate?

	1	2	3	4	5	6	7	
Appropriate								Inappropriate

Demographic profile

1. Gender:Female. Male

2. Age

The first stage questionnaire version number 3

A Pilot Study questionnaire

Finding the correct terms to describe the atmosphere of the hotel guestroom

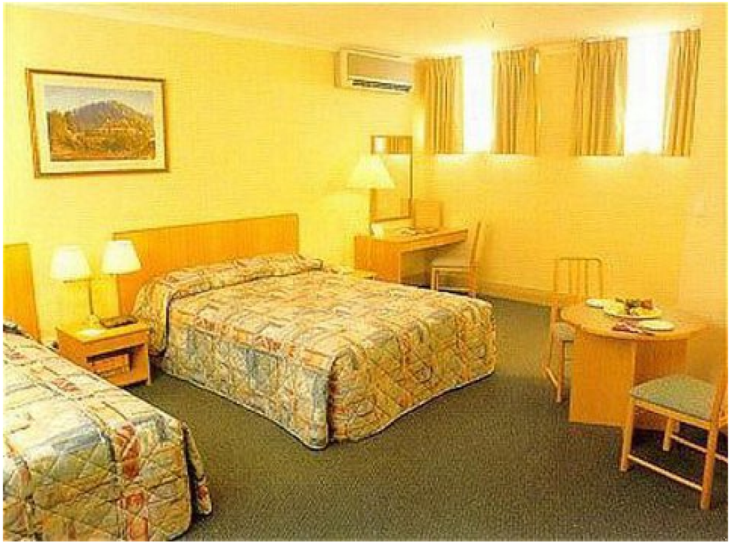
(Part of a wider study looking at the influence of coloured light emitting diode in the hotel guest rooms)

The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Dear respondents,

The researcher would like to thank you for your cooperation in assisting with the proposed research. The aim of this pilot study is to find the correct Australian terms that describe the ATMOSPHERE of a hotel guest room.

Question No.1 of this pilot questionnaire asks you to evaluate the atmosphere of the room shown in the photo.



Q1. For each expression in the table below please indicate on scale of 1-7(with 1 being the least applicable and 7 being the most applicable) the extent to which each term accurately describes the atmosphere of this hotel room.

expression	1	2	3	4	5	6	7
Cosy							
Safe							
Oppressive							
Depressing							
Uncomfortable							
Exciting							
Formal							
Romantic							
Tranquil							
Inspiring							
Intimate							
Cheerful							
Detached							
Lively							
Terrifying							
Luxurious							
Musty							
Mysterious							
Threatening							
Uninhibited							
Restless							
Relaxed							
Personal							
Business							
Cool							
Hospitable							
Spatial							
Pleasant							
Boring							
Tense							
Lethargic							
Stimulating							
Accessible							
Hostile							
Chilly							
Warm							

Q2. How bright do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Bright								Dark

Q3.How warm do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Warm								Cool

Q4.Do you find the lighting condition in the room appropriate.?

	1	2	3	4	5	6	7	
Appropriate								Inappropriate

Demographic profile

1. Gender:Female Male
2. Age:

Please return your copy of the questionnaire to Building 201 at the front desk on Level 3.

The first stage questionnaire version number 4

A Pilot Study questionnaire

Finding the correct terms to describe the atmosphere of the hotel guestroom

(Part of a wider study looking at the influence of coloured light emitting diode in the hotel guest rooms)

The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Dear respondents,

The researcher would like to thank you for your cooperation in assisting with the proposed research. The aim of this pilot study is to find the correct Australian terms that describe the ATMOSPHERE of a hotel guest room.

Question No.1 of this pilot questionnaire asks you to evaluate the atmosphere of the room shown in the photo.

Q1. For each expression in the table below please indicate on a scale of 1-7 (with 1 being the least applicable and 7 being the most applicable) the extent to which each term accurately describes the atmosphere of this hotel room.

Expression	1	2	3	4	5	6	7
Cosy							
Safe							
Oppressive							
Depressing							
Uncomfortable							
Exciting							
Formal							
Romantic							
Tranquil							
Inspiring							
Intimate							
Cheerful							
Detached							
Lively							
Terrifying							
Luxurious							
Musty							
Mysterious							
Threatening							

Uninhibited							
Restless							
Relaxed							
Personal							
Business							
Cool							
Hospitable							
Spatial							
Pleasant							
Boring							
Tense							
Lethargic							
Stimulating							
Accessible							
Hostile							
Chilly							
Warm							

Q2. How bright do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Bright								Dark

Q3.How warm do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Warm								Cool

Q4.Do you find the lighting in the room appropriate?

	1	2	3	4	5	6	7	
Appropriate								Inappropriate

Demographic profile

1. Gender:Female Male
2. Age:

The first stage questionnaire version number 5

A Pilot Study questionnaire

Finding the correct terms to describe the atmosphere of the hotel guestroom

(Part of a wider study looking at the influence of coloured light emitting diode in the hotel guest rooms)

The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Dear respondents

The researcher would like to thank you for your cooperation in assisting with the proposed research. The aim of this pilot study is to find the correct Australian terms that describe the ATMOSPHERE of a hotel guest room.

Question No.1 of this pilot questionnaire asks you to evaluate the atmosphere of the room shown in the photo.

Q1. For each expression in the table below please indicate on scale of 1-7 (with 1 being the least applicable and 7 being the most applicable) the extent to which each term accurately describes the atmosphere of this hotel room.

Expression	1	2	3	4	5	6	7
Cosy							
Safe							
Oppressive							
Depressing							
Uncomfortable							
Exciting							
Formal							
Romantic							
Tranquil							
Inspiring							
Intimate							
Cheerful							
Detached							
Lively							
Terrifying							
Luxurious							
Musty							
Mysterious							
Threatening							
Uninhibited							
Restless							
Relaxed							
Personal							
Business							
Cool							
Hospitable							
Spatial							
Pleasant							
Boring							
Tense							
Lethargic							
Stimulating							
Accessible							
Hostile							
Chilly							
Warm							

Q2. How bright do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Bright								Dark

Q3.How warm do you find the hotel room in the photo rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Warm								Cool

Q4.Do you find the lighting condition in the room appropriate.?

	1	2	3	4	5	6	7	
Appropriate								Inappropriate

Demographic profile

1. Gender:Female Male
2. Age:

3. Appendix

The Second stage the Information Sheet (A) to find a suitable time duration for displaying a 3D video to evaluate atmosphere in an indoor environment

Information Sheet (A)

(Part of a wider study looking at …The title of the study is**: The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Finding a suitable time duration for displaying a video to evaluate atmosphere in an indoor environment

1. The aim of this pilot study is to find out what is a suitable time duration for displaying athree dimension (3D) video in order to evaluate the atmosphere in an indoor environment without becoming bored or distracted. This study will help interior designers to use 3D video as a tool in their work. Discovering a suitable time duration for display of a video will help respondents in another part of this study to evaluate the quality of indoor space.

2. You will be required to answer a questionnaire after you see a three dimensional video of a room. You will be watching a video for one of the following durations (8, 6, 4 or 2 minutes). The questions in the questionnaire are designed for you to evaluate the atmosphere of the indoor space. You will be given five minutes to answer the questionnaire after you have watched the video.

3. The total expected time for your involvement in pilot study is approximately 15-20 minutes.

4. Your participation is completely voluntary; you will be at liberty to withdraw at any time without giving a reason for withdrawal.

5. The proposed research will not involve potential physical or psychological harm. The researcher will take every possible precaution to minimize the participants' discomfort or inconvenience.

The Second stage the Letter of Consent (A) Find a suitable time duration for displaying a 3D video to evaluate atmosphere in an indoor environment

Letter of Consent

(Part of a wider study looking at …The title of the study is**: The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Finding a suitable time duration for displaying a video to evaluate atmosphere in an indoor environment

Dear Reader

Please answer the following questions by circling your responses:

Have you read and understood the information sheet about this study?YESNO

Have you received enough information about this study?YESNO

Do you understand that you are free to withdraw from this study at any timewithout give a reason for your withdrawal?YESNO

Do you agree to take part in this study?YESNO

Your signature will certify that you have voluntarily decided to take part in this research study having read and understood the information in the sheet for participants. It will also certify that you have had adequate opportunity to discuss the study with the investigator and that all questions have been answered to your satisfaction.

Signature of reader:Date:

Name (block letters):

Signature of investigator:Date:

The Second stage the Pilot Study questionnaire (A) Find a suitable time duration for displaying a 3D video to evaluate atmosphere in an indoor environment

A Pilot Study questionnaire

(Part of a wider study looking at …The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Finding a suitable time duration for displaying a video to evaluate atmosphere in an indoor environment

Dear respondents

The researcher would like to thank you for your cooperation in assisting with the proposed research. The aim of this pilot study is to determine the duration time to evaluate indoor environment atmosphere.

Please look the space that you are in and evaluate the atmosphere of it by answering questions 1-4.

Q 1. For each expression in the table below please indicate on a scale of 1-7 with 1 being the least applicable and 7 being the most applicable the extent to which each term accurately describes the atmosphere of the room

Expression	1	2	3	4	5	6	7
Intimate							
Inspiring							
Cheerful							
Personal							
Relaxed							
Lively							
Luxurious							
Cosy							
Tense							
Hostile							
Musty							
Lethargic							

Restless							
Detached							
Business							
Spatial							
Accessible							
Formal							

Q 2. How bright do you find the lighting in the room on a scale of 1-7?

	1	2	3	4	5	6	7	
Bright								Dark

Q 3 How warm do you find thelighting in the room rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Warm								Cool

Q 4.Do you find the lighting condition in the room appropriate?

	1	2	3	4	5	6	7	
Appropriate								Inappropriate

Demographic profile

1. Gender:Female. Male
2. Age:20-4040 and above

The Second stage the Information Sheet (B) to find a suitable time duration for displaying a 3D video to evaluate atmosphere in an indoor environment

Information Sheet (B)

(Part of a wider study looking at …The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Finding a suitable time duration for displaying a video to evaluate atmosphere in an indoor environment

1. The aim of this pilot study is to find out what is suitable time duration for evaluate the atmosphere in an indoor environment without becoming bored or distracted. Discovering suitable time duration for perceiving indoor environment it will help respondents in another part of this study to evaluate the quality of indoor space

2. You will be required to answer a questionnaire after you will be within a space for (8 minutes). The questions in the questionnaire are designed for you to evaluate the atmosphere of the indoor space. You will be given five minutes to answer the questionnaire after you have visit the space.

3. The total expected time for your involvement in pilot study is approximately 15-20 minutes.

4. Your participation is completely voluntary; you will be at liberty to withdraw at any time without giving a reason for withdrawal.

5. The proposed research will not involve potential physical or psychological harm. The researcher will take every possible precaution to minimize the participants' discomfort or inconvenience.

The Second stage the Letter of Consent (B) Find a suitable time duration for displaying a 3D video to evaluate atmosphere in an indoor environment

Letter of Consent

(Part of a wider study looking at …The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Finding suitable time duration for displaying a video to evaluate atmosphere in an indoor environment

Dear Reader

Please answer the following questions by circling your responses:

Have you read and understood the information sheet about this study?YESNO

Have you received enough information about this study?YESNO

Do you understand that you are free to withdraw from this study at any timewithout give a reason for your withdrawal?YESNO

Do you agree to take part in this study?YESNO

Your signature will certify that you have voluntarily decided to take part in this research study having read and understood the information in the sheet for participants. It will also certify that you have had adequate opportunity to discuss the study with the investigator and that all questions have been answered to your satisfaction.

Signature of reader:Date:

Name (block letters):

Signature of investigator:Date:

The Second stage the Pilot Study questionnaire (B) Find a suitable time duration for displaying a 3D video to evaluate atmosphere in an indoor environment

B Pilot Study questionnaire

(Part of a wider study looking at …The title of the study is: **The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room**

Finding a suitable time duration for displaying a video to evaluate atmosphere in an indoor environment

Dear respondents

The researcher would like to thank you for your cooperation in assisting with the proposed research. The aim of this pilot study is to determine the duration time to display three dimension (3D) video films to evaluate the indoor environment atmosphere.

Please look at the 3D video and evaluate the atmosphere of the room shown on the video film by answering questions 1-4.

Q 1. For each expression in the table below please indicate on a scale of 1-7 with 1 being the least applicable and 7 being the most applicable the extent to which each term accurately describes the atmosphere of the room shown on the video

Expression	1	2	3	4	5	6	7
Intimate							
Inspiring							
Cheerful							
Personal							
Relaxed							
Lively							
Luxurious							
Cosy							
Tense							

Hostile							
Musty							
Lethargic							
Restless							
Detached							
Business							
Spatial							
Accessible							
Formal							

Q 2. How bright do you find the lighting in the room shown on the video on a scale of 1-7?

	1	2	3	4	5	6	7	
Bright								Dark

Q 3 How warm do you find thelighting in the room shown on the video rated on a scale of 1-7?

	1	2	3	4	5	6	7	
Warm								Cool

Q 4.Do you find the lighting condition in the room shown on the video appropriate?

	1	2	3	4	5	6	7	
Appropriate								Inappropriate

Demographic profile

1. Gender:Female. Male
2. Age:20-4040 and above

4. Appendix

The main study Information Sheet to evaluate atmosphere of a hotel guestroom under the influence of different RGB LED lighting settings

Information Sheet

The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room

Displaying a 3D video to evaluate atmosphere of a hotel guestroom under different lighting settings

1. The aim of this study is to evaluate the atmosphere of a hotel guestroom indoor environment.

2. You will be required to answer a questionnaire after viewing a (2 minutes) 3D video of a hotel guestroom. The questions in the questionnaire are designed for you to evaluate the atmosphere of the indoor space. You will be given five minutes to answer the questionnaire after you have view the video.

3. You will be required to evaluate fourteen video of the same hotel guestroom under the fourteen different lighting setting.The total expected time for your involvement in the study is approximately 100 minutes.

4. Your participation is completely voluntary; you will be at liberty to withdraw at any time without giving a reason for withdrawal.

5. The proposed research will not involve potential physical or psychological harm. The researcher will take every possible precaution to minimize the participants' discomfort or inconvenience.

Note: the term atmosphere in this document mean the general appearance of space in the video.

The main study Letter of Consent to evaluate atmosphere of a hotel guestroom under the influence of different RGB LED lighting settings

Letter of Consent

The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room

Displaying a video to evaluate the atmosphere of a hotel guestroom environment

Dear Reader

Please answer the following questions by circling your responses:

Have you read and understood the information sheet about this study?YESNO

Have you received enough information about this study?YESNO

Do you understand that you are free to withdraw from this study at any timewithout give a reason for your withdrawal?YESNO

Do you agree to take part in this study?YESNO

Your signature will certify that you have voluntarily decided to take part in this research study having read and understood the information in the sheet for participants. It will also certify that you have had adequate opportunity to discuss the study with the investigator and that all questions have been answered to your satisfaction.

Signature of reader:Date:

Name (block letters):

Signature of investigator:Date:

The main study questionnaire to evaluate atmosphere of a hotel guestroom under the influence of different RGB LED lighting settings

Study questionnaire

The Atmospheric Influence of (RGB) LED Lighting on Occupants of a Hotel Guest Room

Dear respondents

The researcher would like to thank you for your cooperation in assisting with the research. The aim of this study is to evaluate the indoor atmosphere of a hotel Guestroom under different lighting settings.

Please look at the 3D video and evaluate the atmosphere of the room shown on the video film by answering questions 1-6 on a scale of 1-7 with 1 being the least applicable and 7 being the most applicable.

Q 1. For each expression in the table below how well each term describes the room shown on the video?

Expression	1	2	3	4	5	6	7
Intimate							
Inspiring							
Cheerful							
Personal							
Relaxed							
Lively							
Luxurious							
Cosy							
Tense							
Hostile							
Musty							
Lethargic							
Restless							
Detached							

Business							
Spatial							
Accessible							
Formal							

Q 2. How bright do you find the lighting in the room shown on the video?

	1	2	3	4	5	6	7	
Bright								Dark

Q 3 How warm do you find thelighting in the room shown on the video?

	1	2	3	4	5	6	7	
Warm								Cool

Q 4.Do you find the lighting condition in the room shown on the video appropriate for a hotel room

	1	2	3	4	5	6	7	
Appropriate								Inappropriate

Q5.Do you find the space in video encourage you to stay in room?

	1	2	3	4	5	6	7	

Q6.Do you find the space in video discourage you to stay in room?

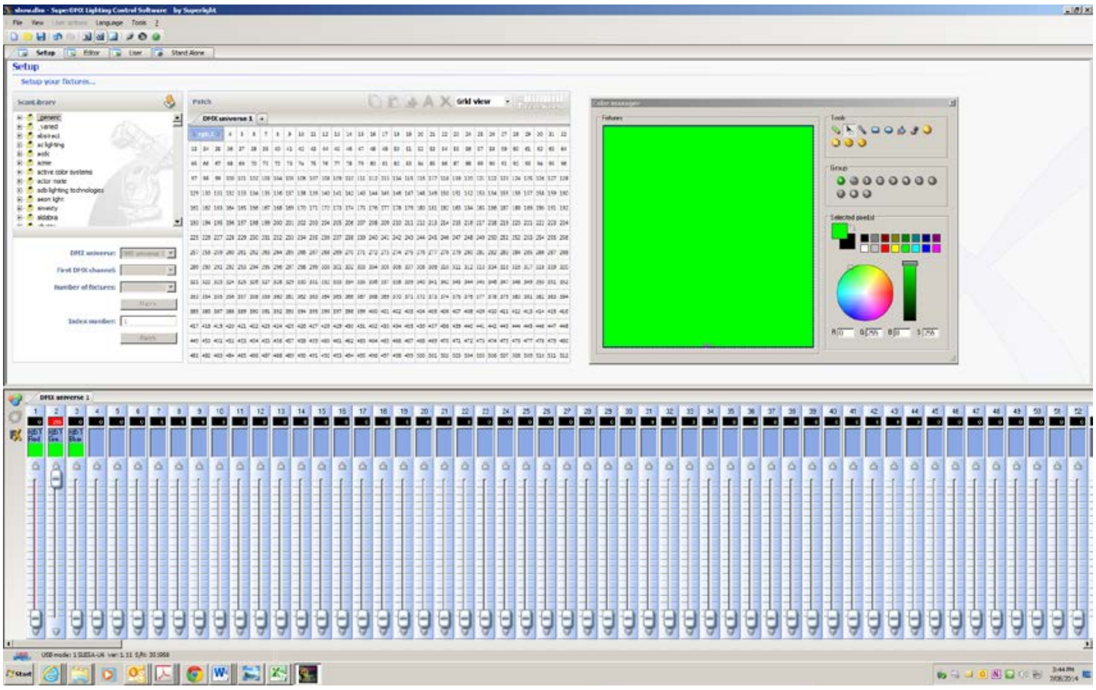
	1	2	3	4	5	6	7	

Demographic profile

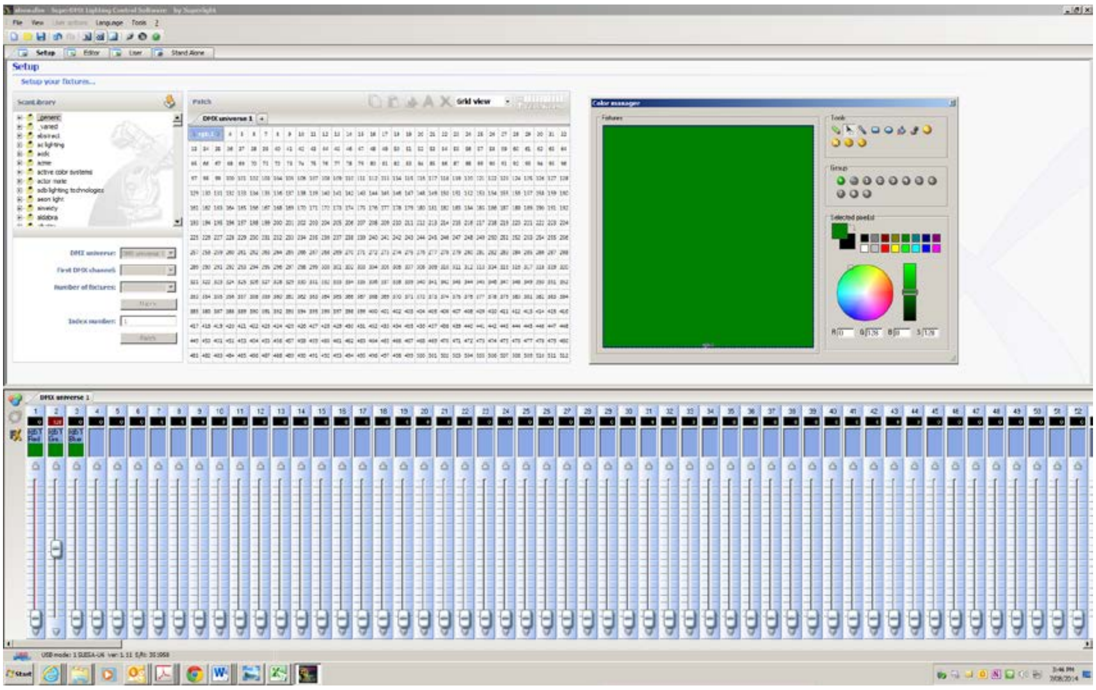
1. Gender:Female. Male
2. Age:20-4040 and above

5. Appendix

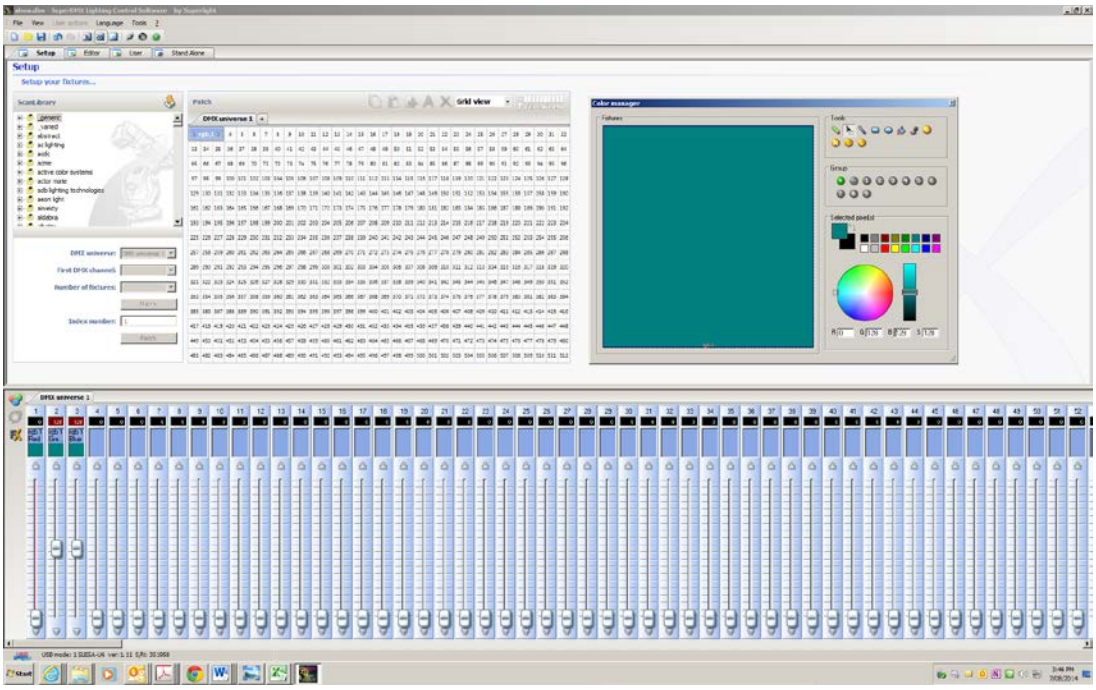
The reading of the DMX512 for the wall-wash green High lighting setting



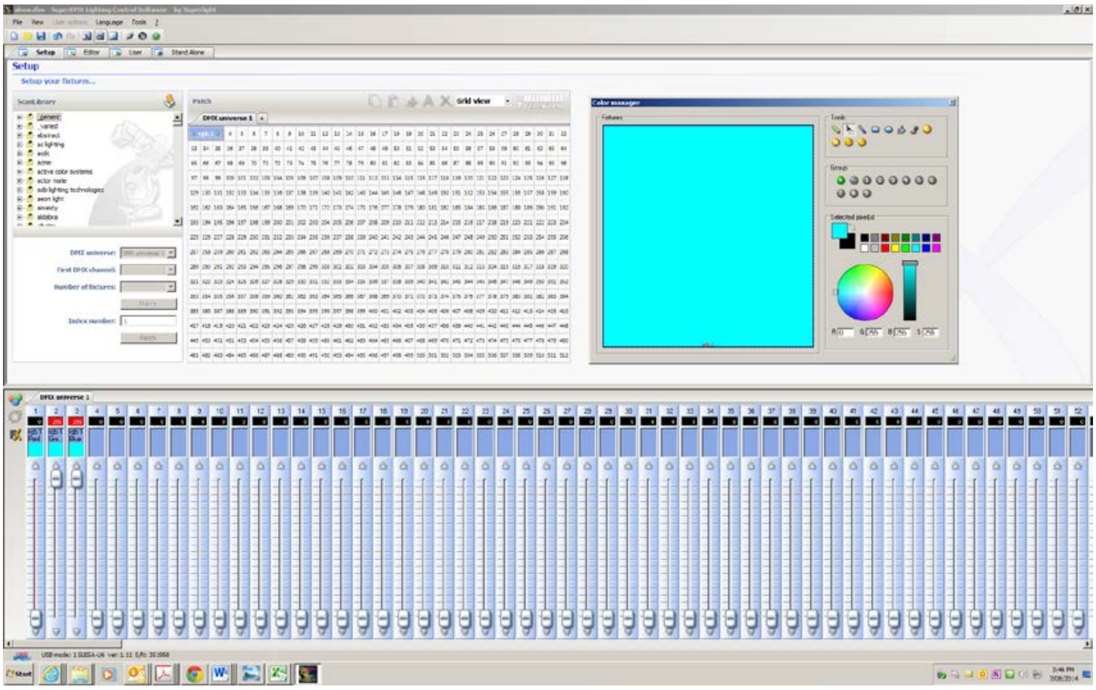
The reading of the DMX512 for the wall-wash green low lighting setting



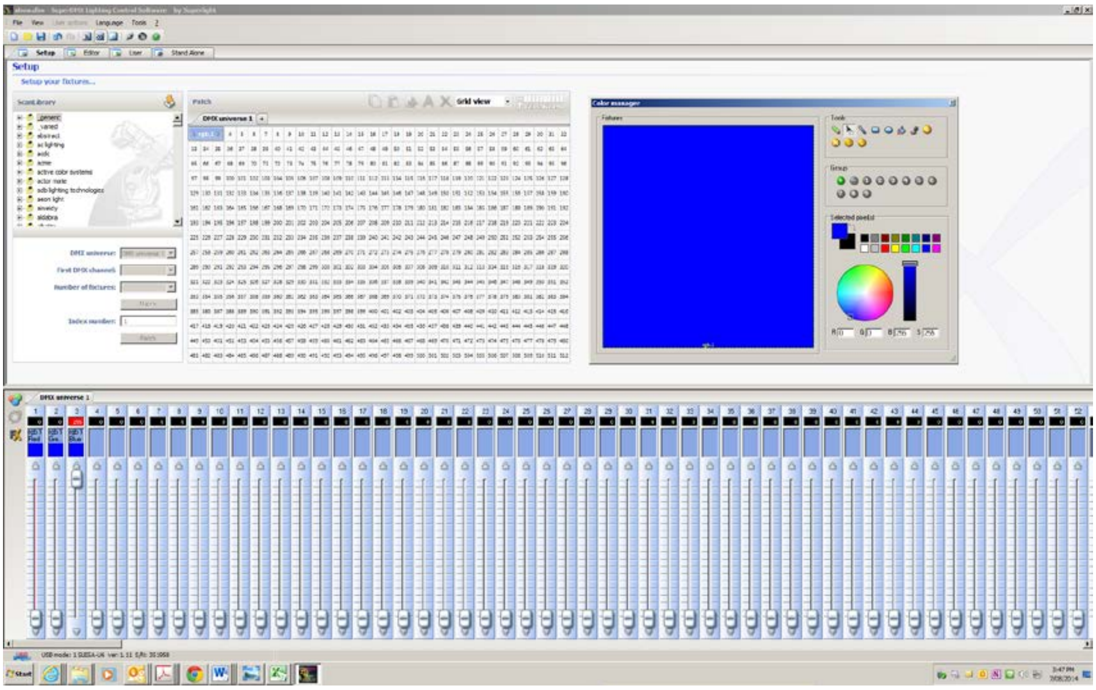
The reading of the DMX512 for the wall-wash cyan low lighting setting



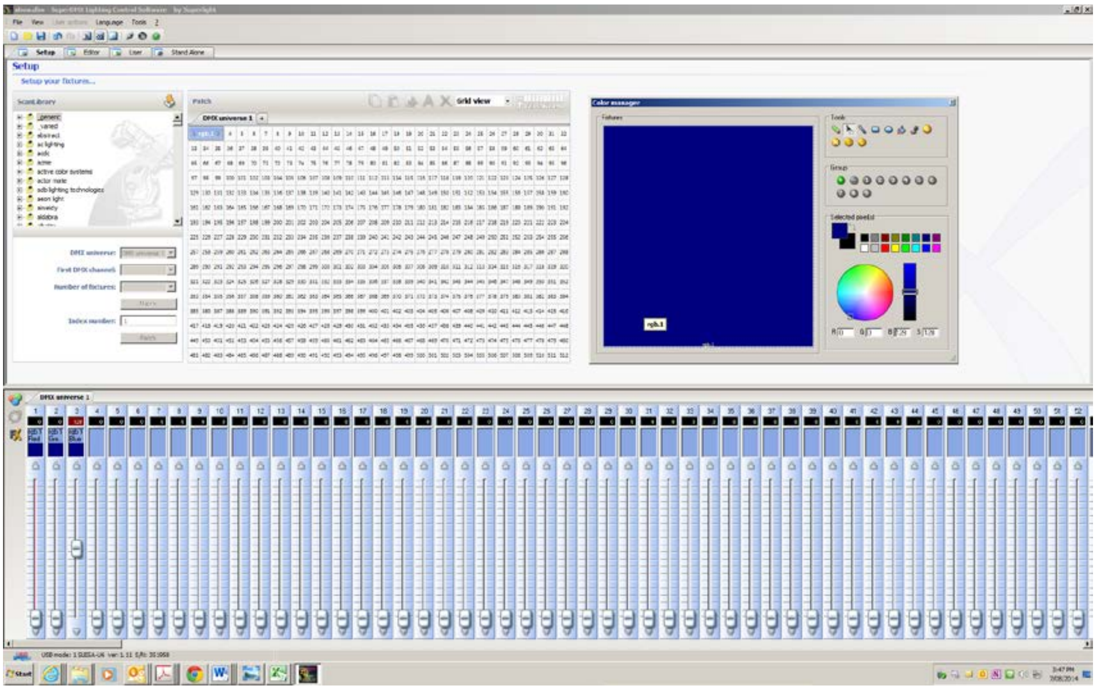
The reading of the DMX512 for the wall-wash cyan high lighting setting



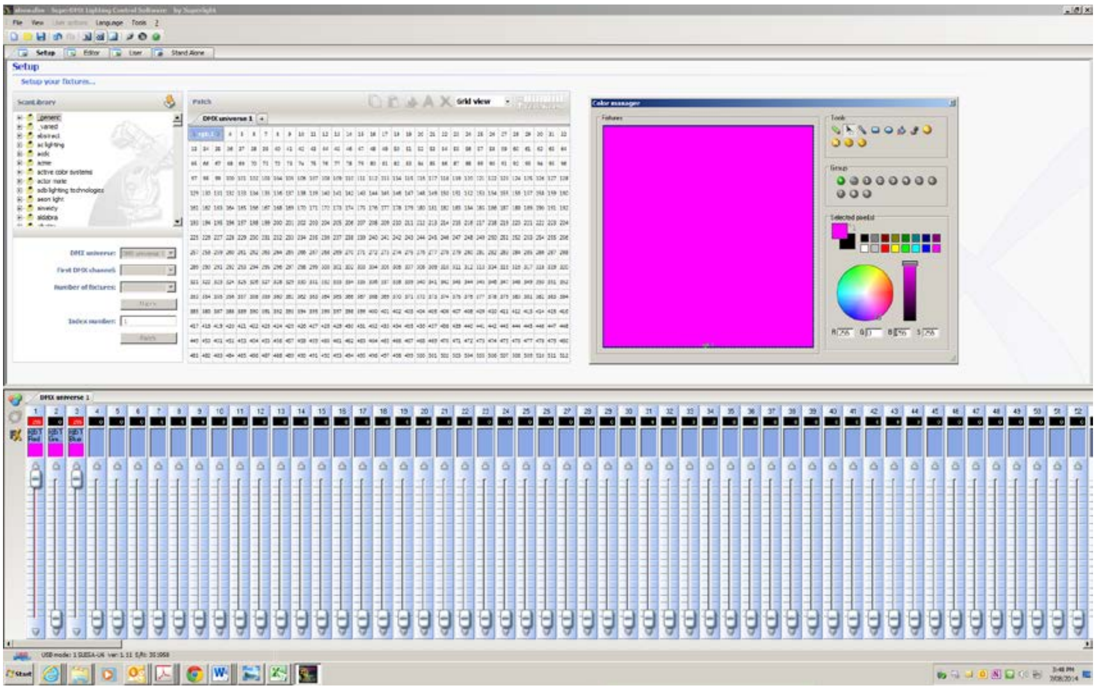
The reading of the DMX512 for the wall-wash blue high lighting setting



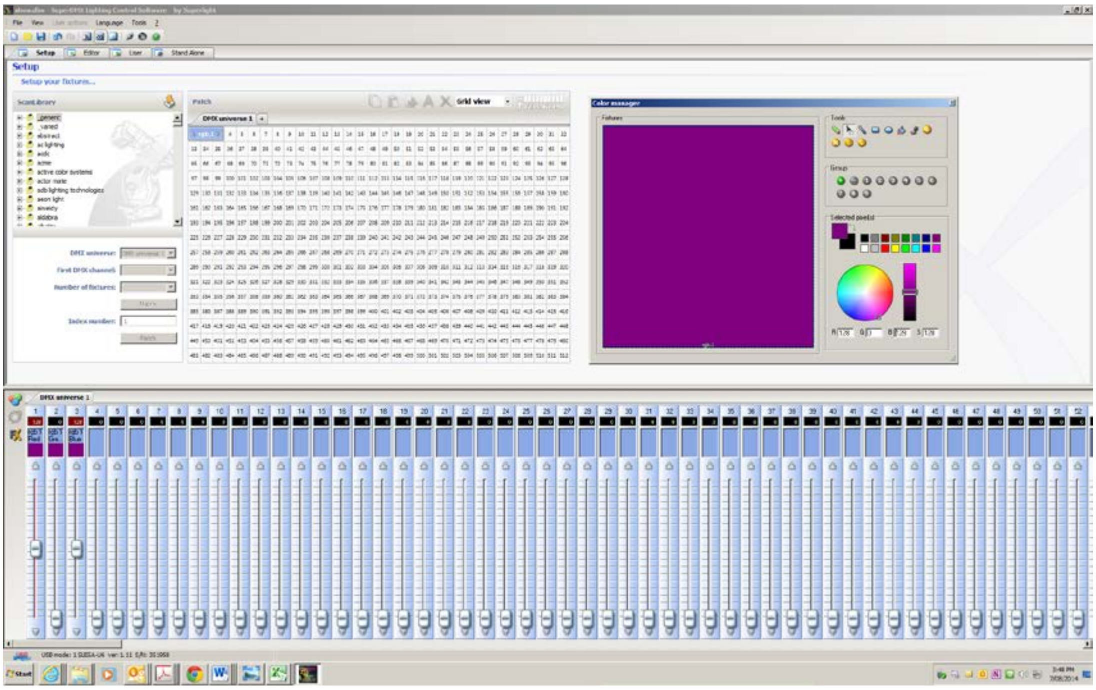
The reading of the DMX512 for the wall-wash blue low lighting setting



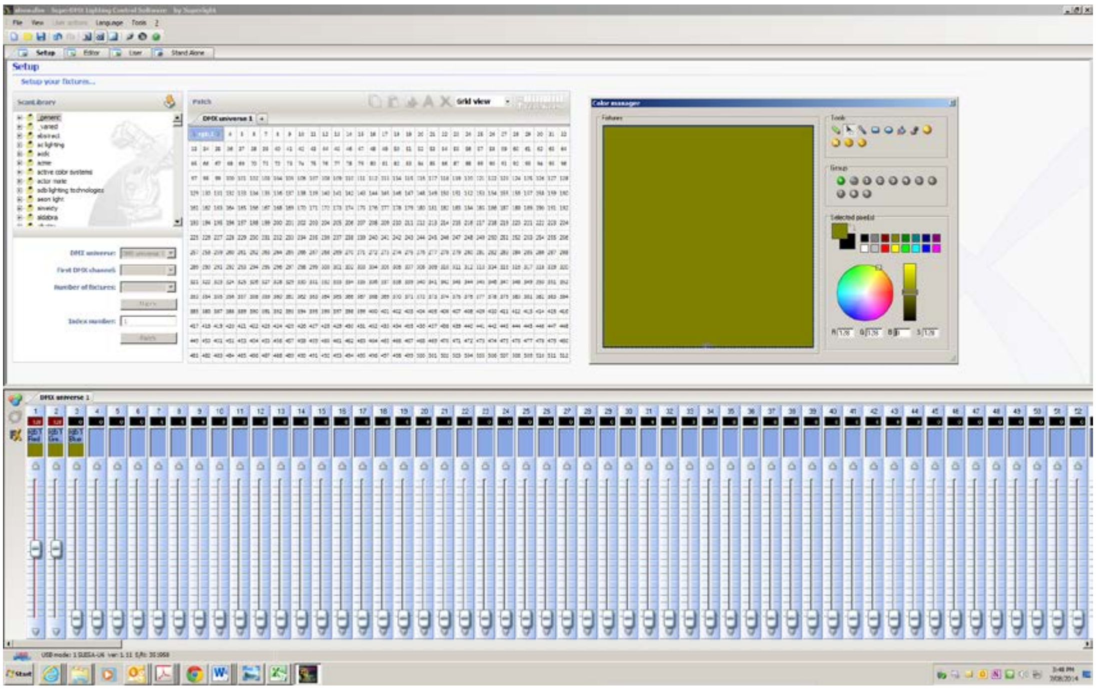
The reading of the DMX512 for the wall-wash magenta high lighting setting



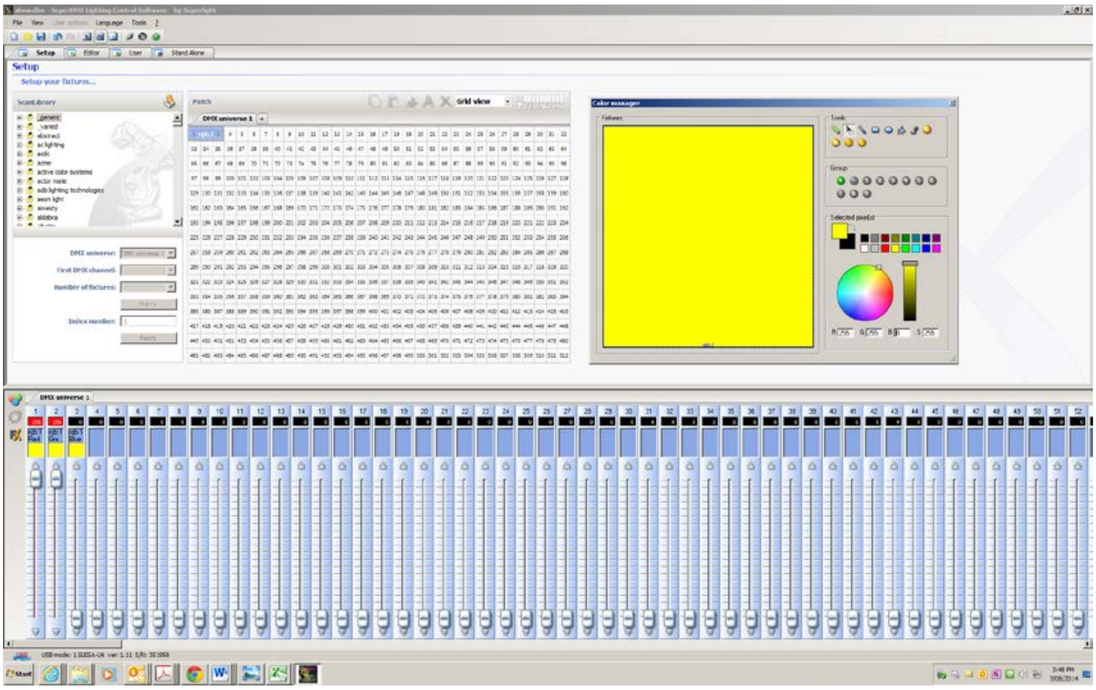
The reading of the DMX512 for the wall-wash magenta low lighting setting



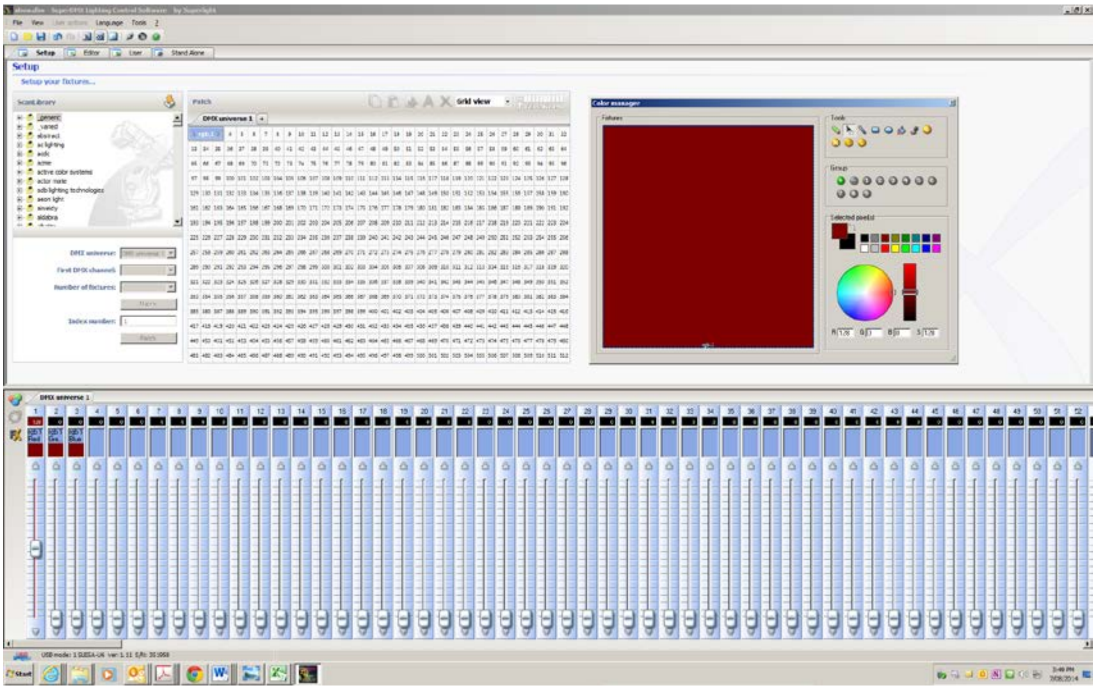
The reading of the DMX512 for the wall-wash yellow low lighting setting



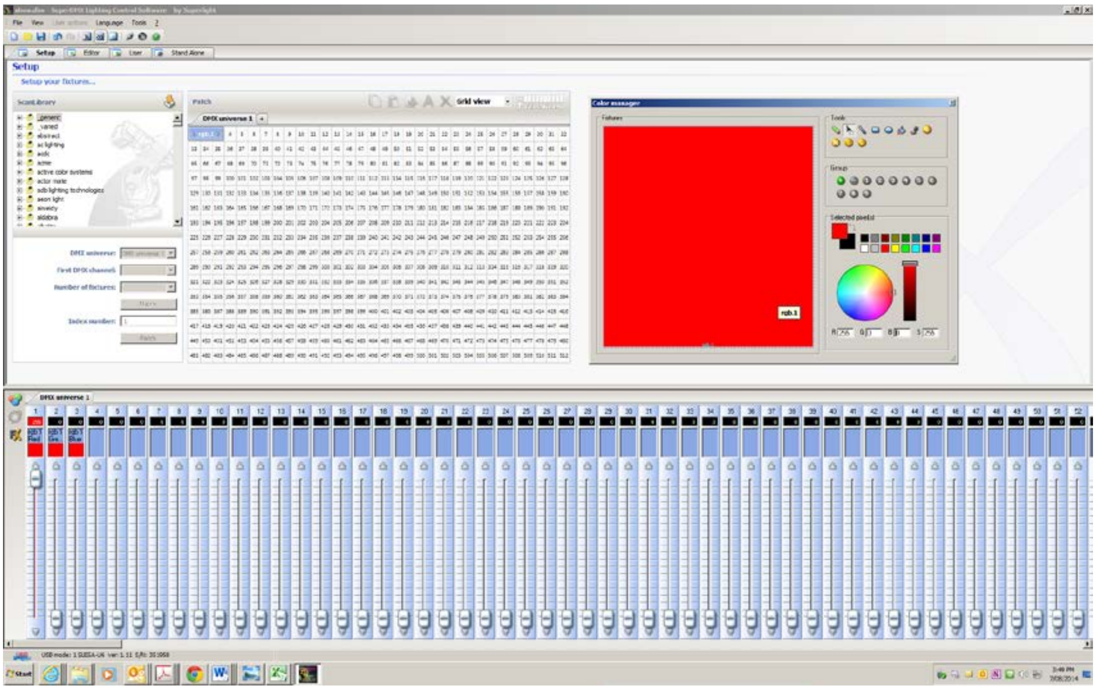
The reading of the DMX512 for the wall-wash yellow high lighting setting



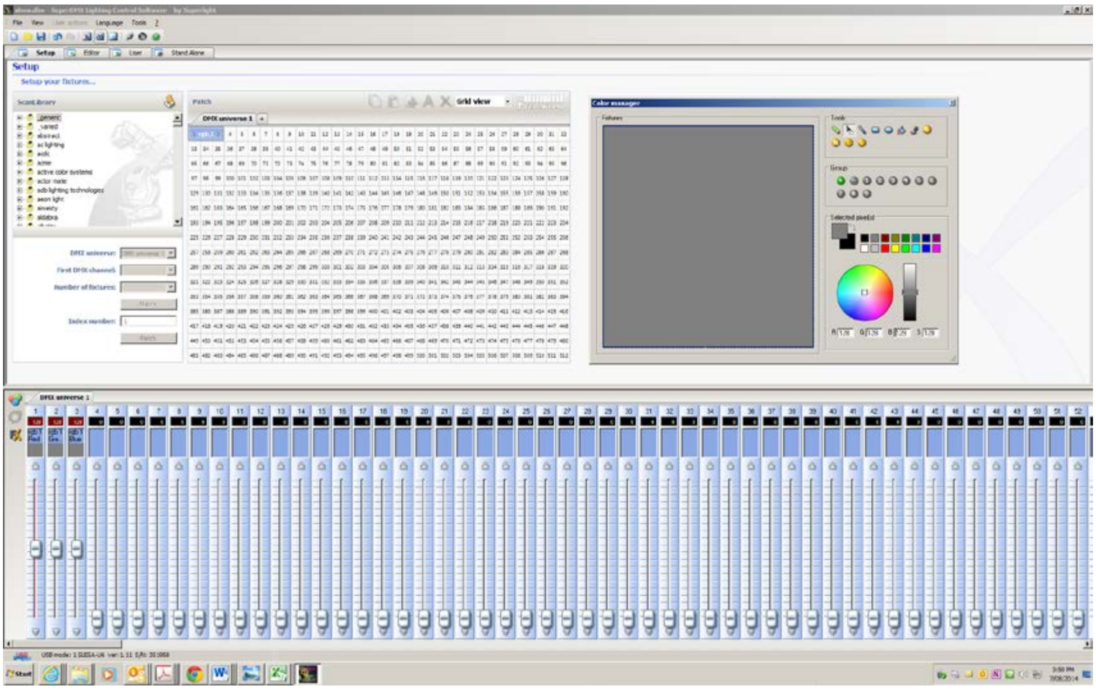
The reading of the DMX512 for the wall-wash red low lighting setting



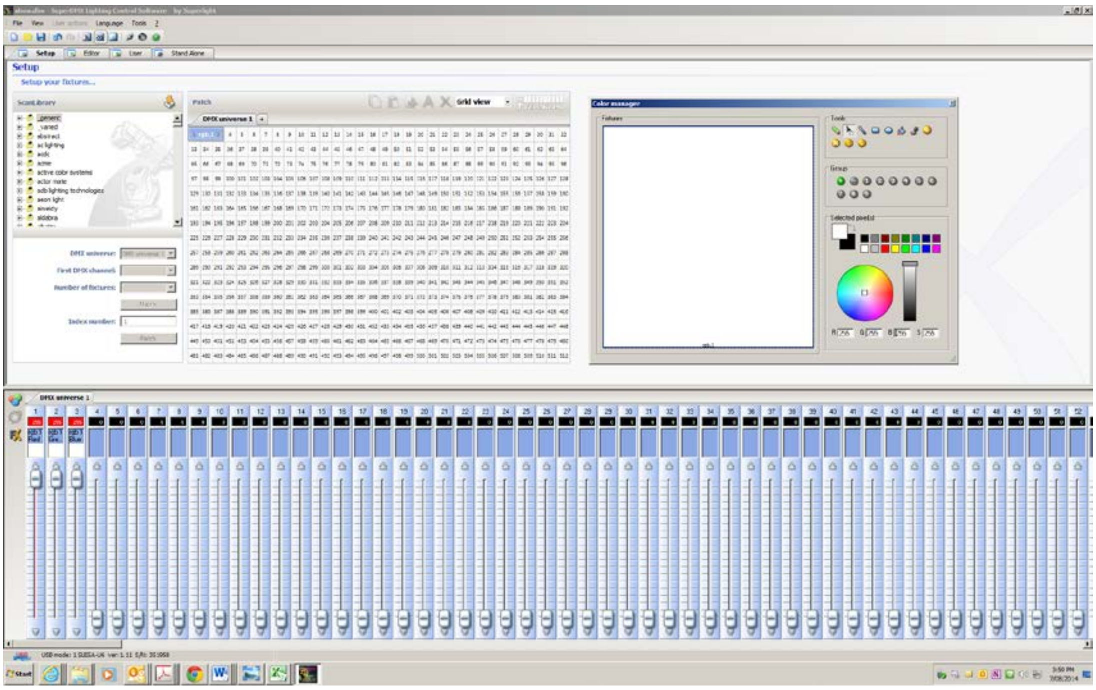
The reading of the DMX512 for the wall-wash red high lighting setting



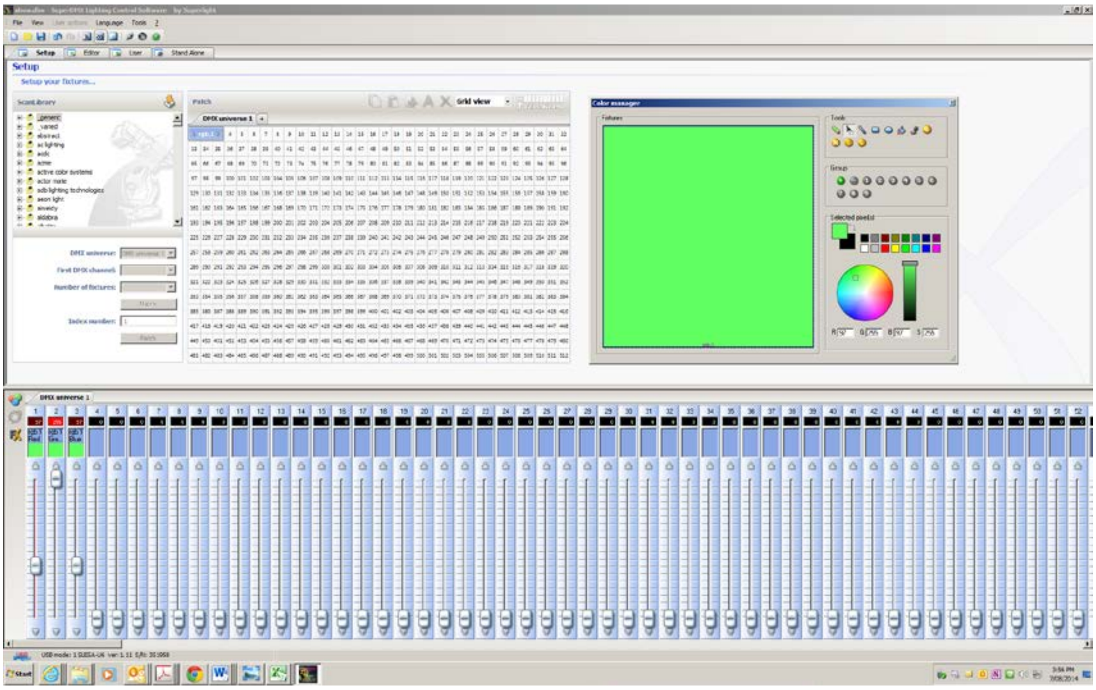
The reading of the DMX512 for the wall-wash of RGB white low before the white balance with the general white lighting



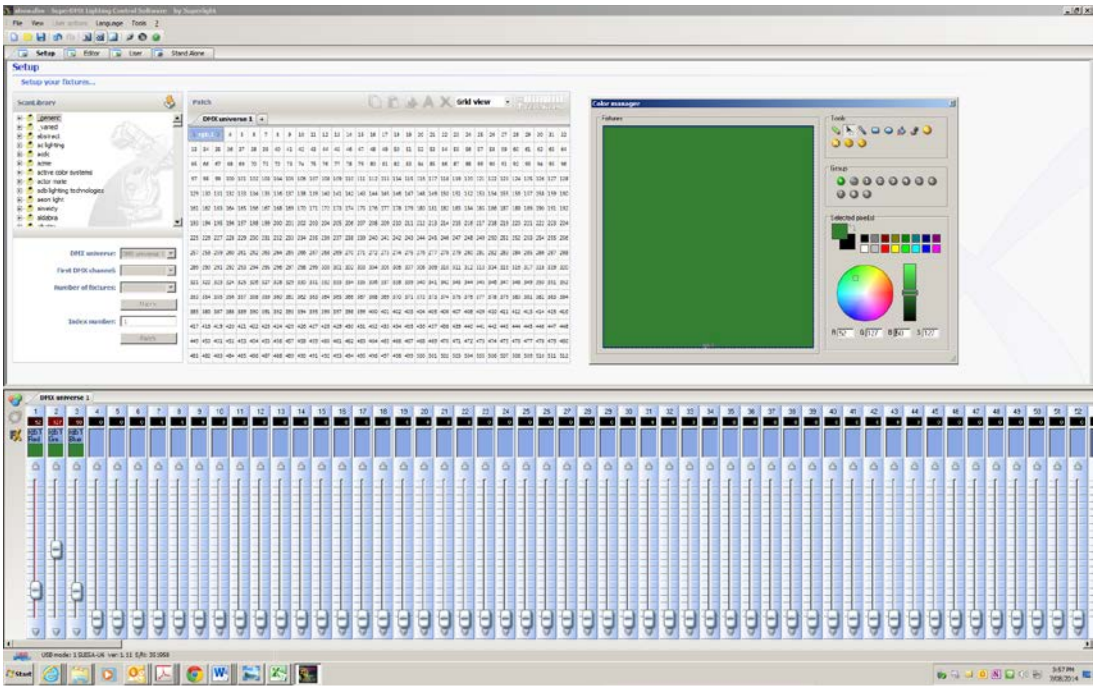
The reading of the DMX512 for the wall-wash of RGB white high before the white balance with the general white lighting



The reading of the DMX512 for the wall-wash of RGB white high after the white balance with the general white lighting



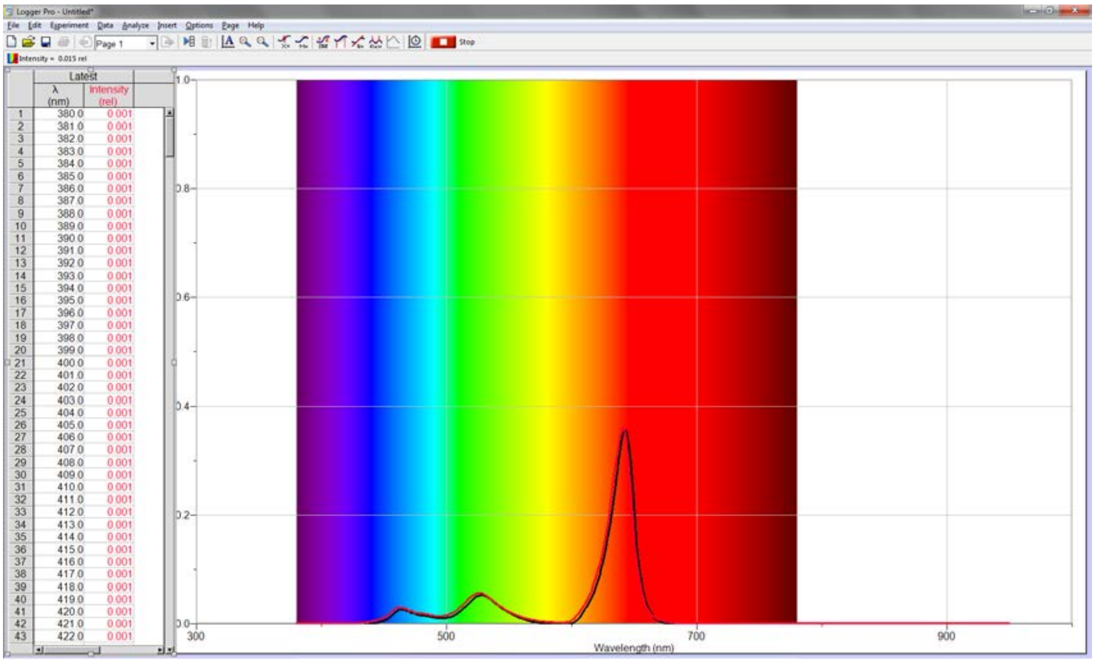
The reading of the DMX512 for the wall-wash of RGB white low after the white balance with the general white lighting



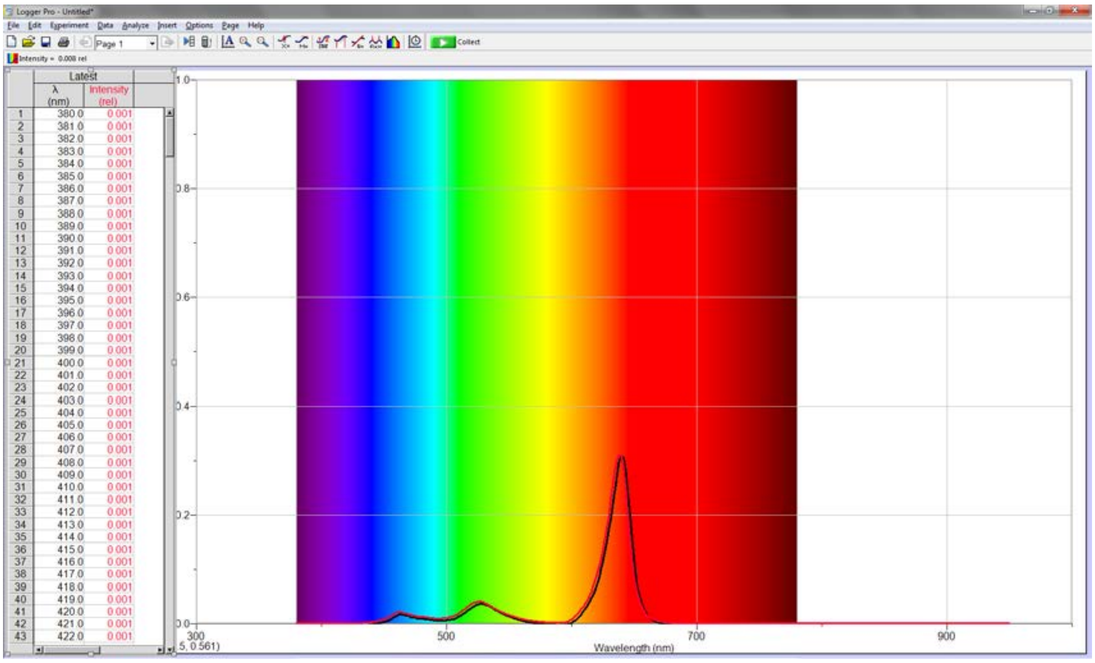
6. Appendix

The reading of light spectrum distribution using the Ocean Optics Red Tide USB 650 spectral light reader and the Vernier - Logger Pro V 3.7 software

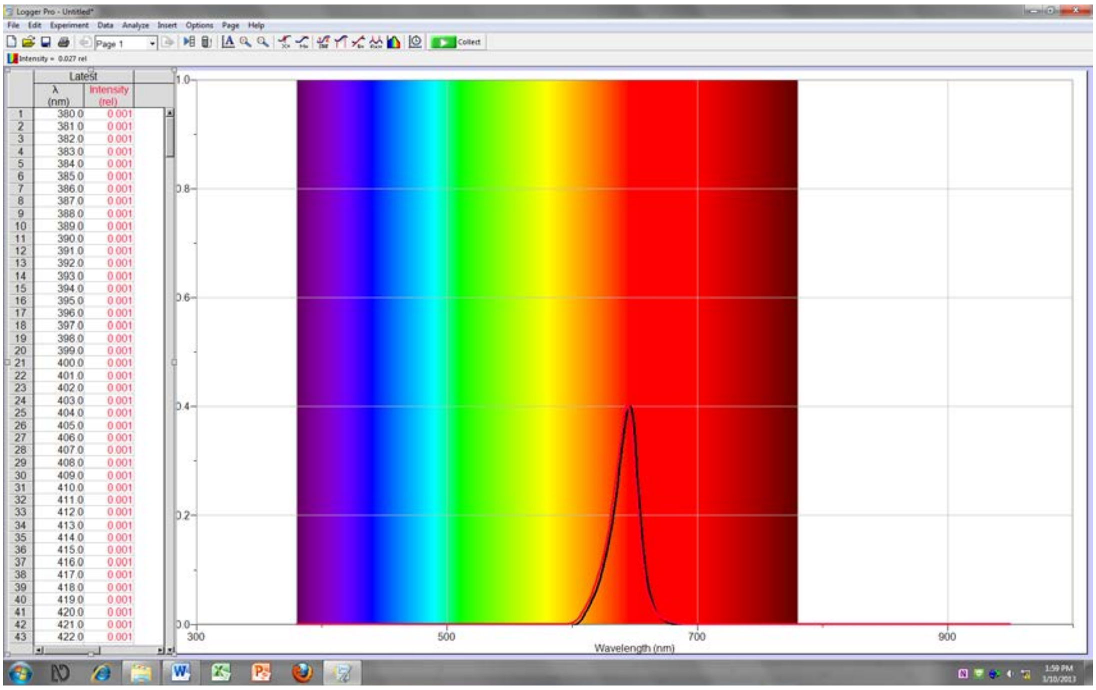
The reading of RGB White High spectrum distribution



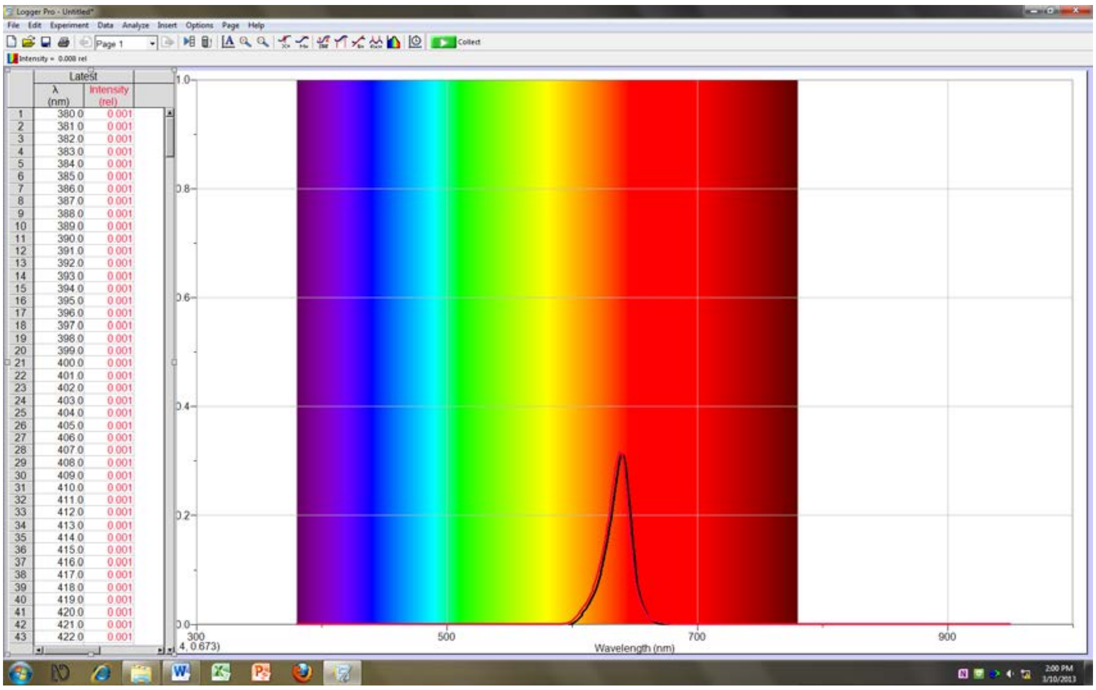
The reading of RGB White medium spectrum distribution



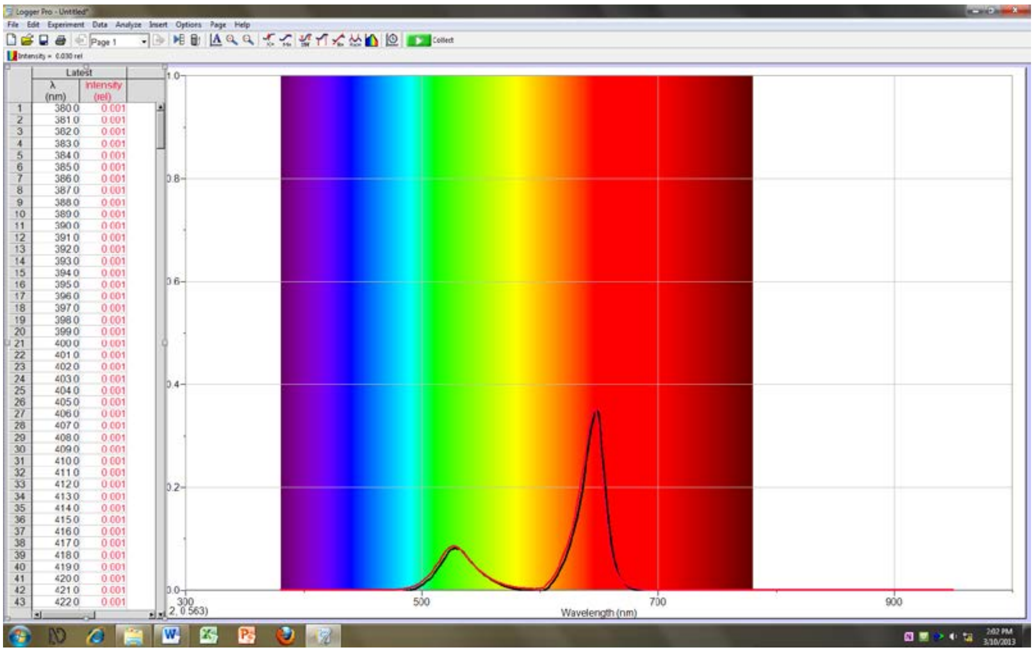
The reading of the Red high light spectrum distribution



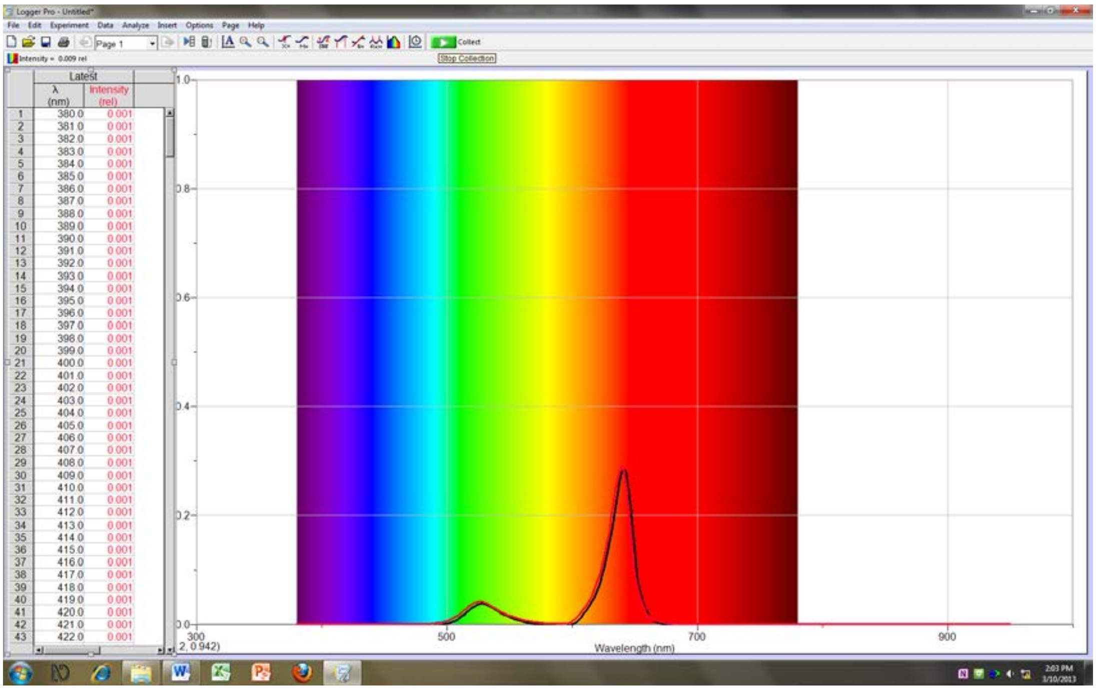
The reading of the Red medium light spectrum distribution



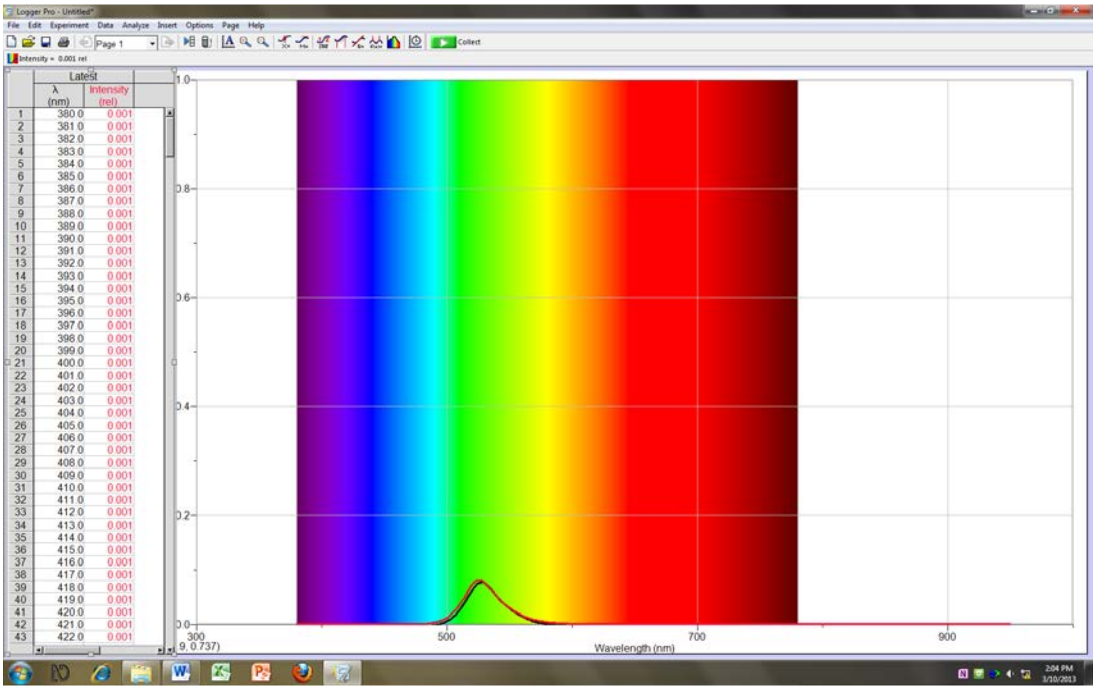
The reading of the yellow high light spectrum distribution



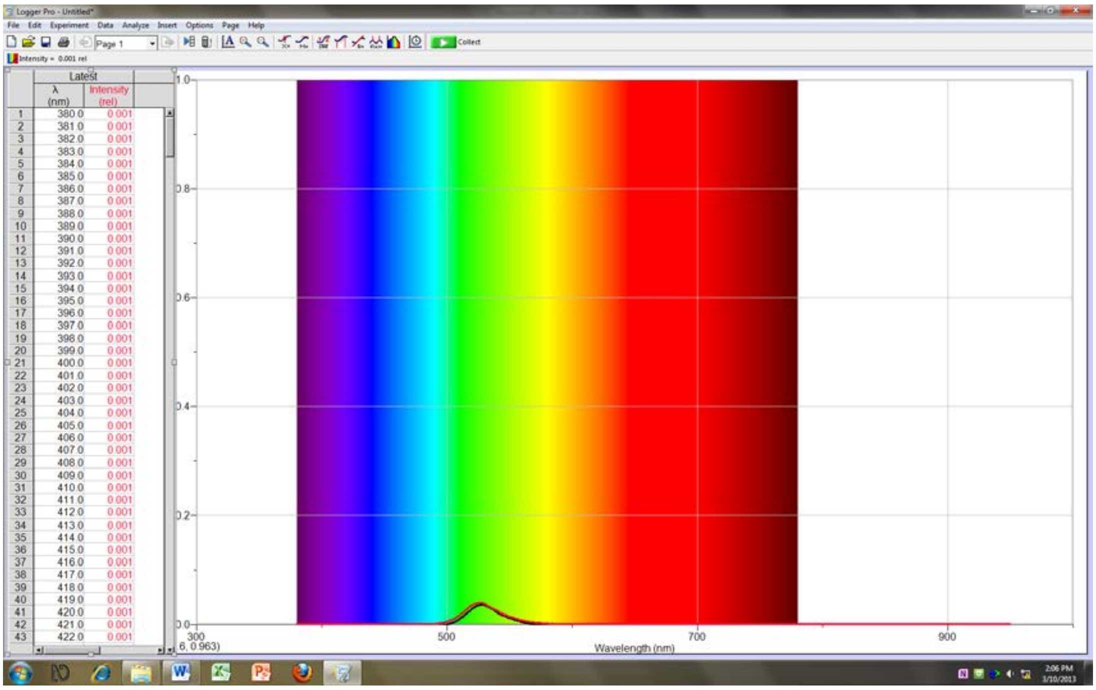
The reading of the yellow medium light spectrum distribution



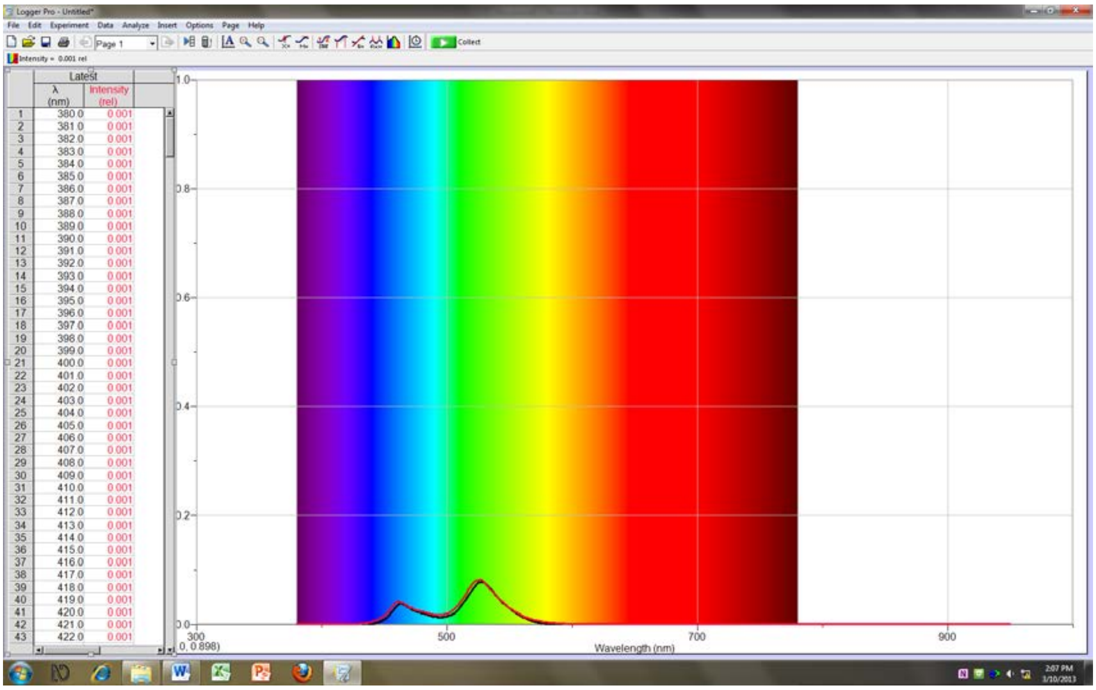
The reading of the green high light spectrum distribution



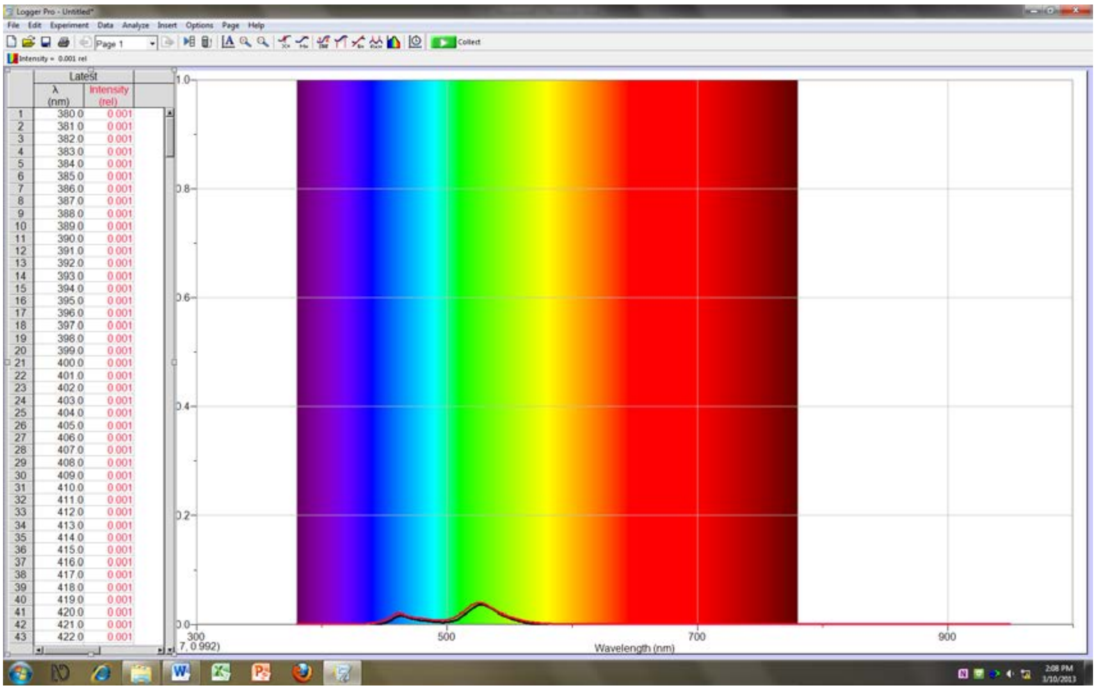
The reading of the green medium light spectrum distribution



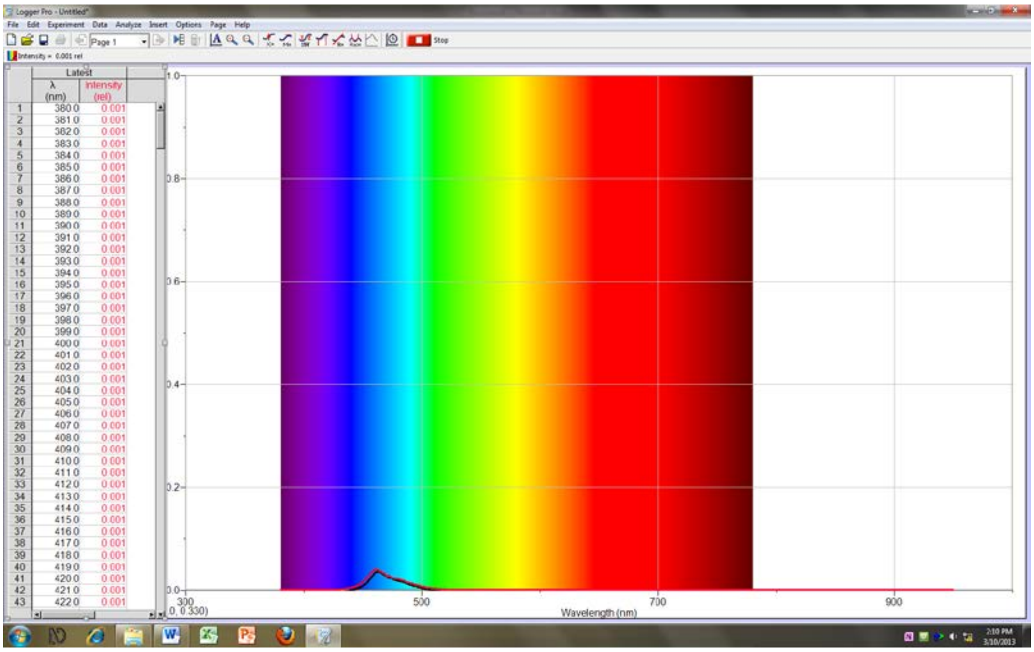
The reading of the cyan high light spectrum distribution



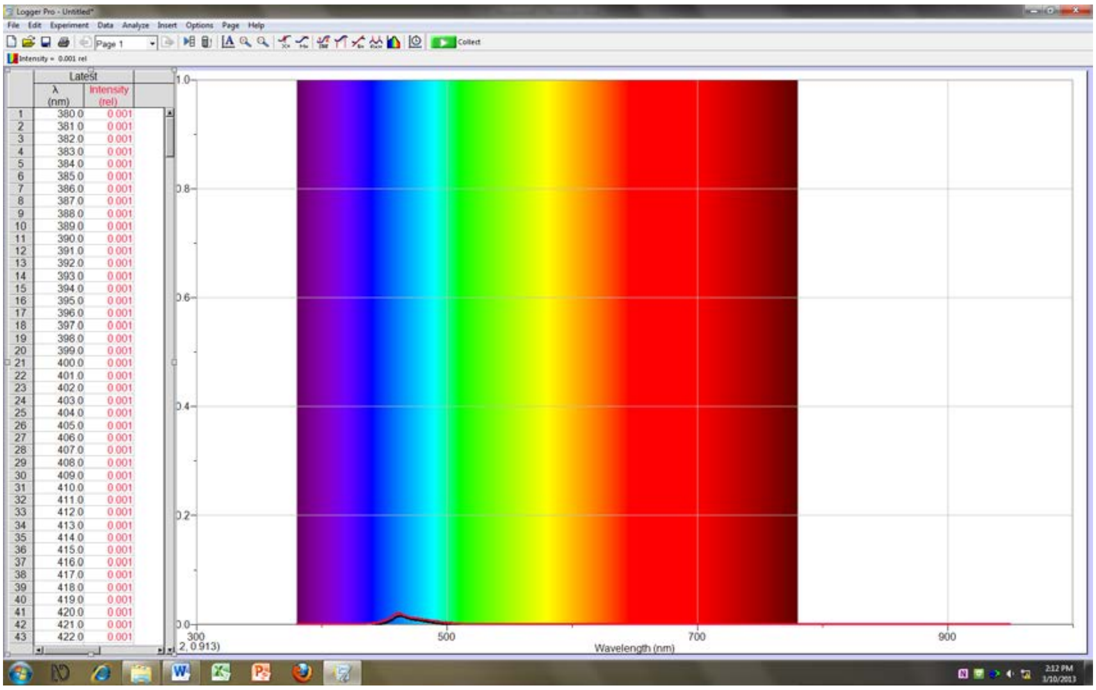
The reading of the cyan medium light spectrum distribution



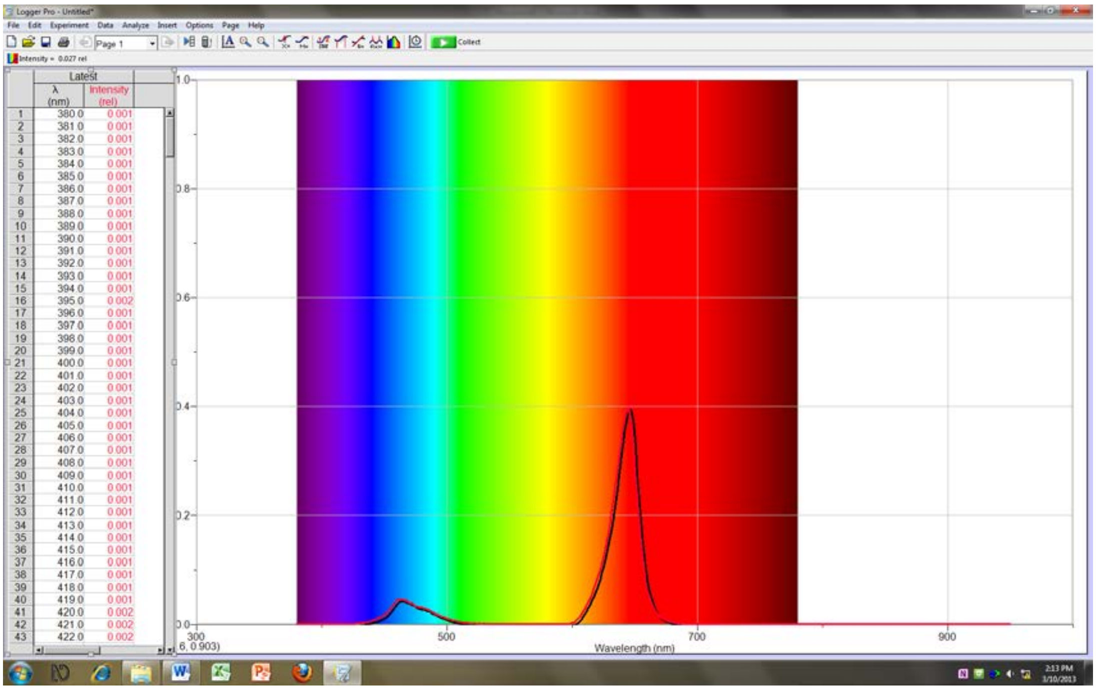
The reading of the blue high light spectrum distribution



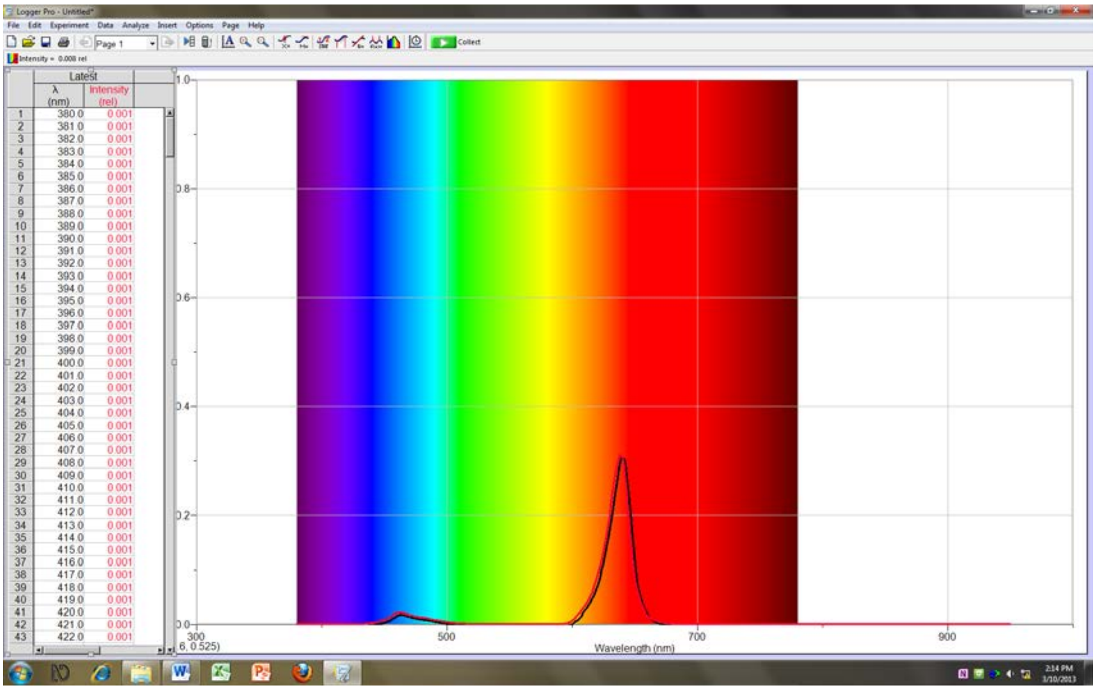
The reading of the blue medium light spectrum distribution



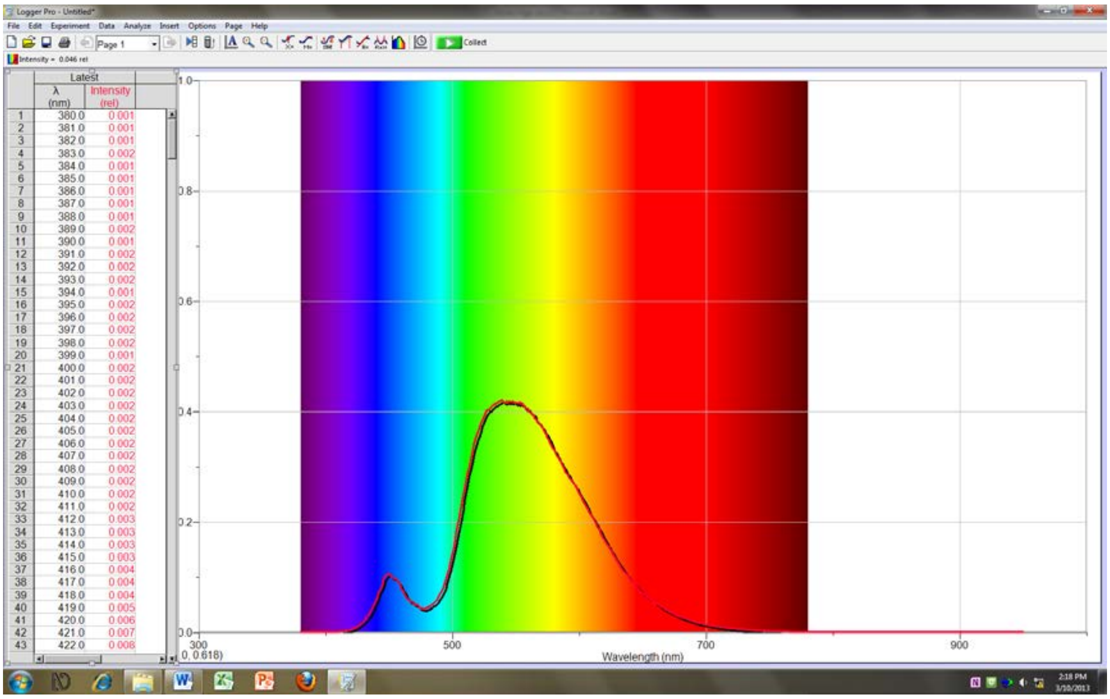
The reading of the magenta high light spectrum distribution



The reading of the magenta low light spectrum distribution



The reading of the General White light spectrum distribution



7. Appendix

The sixteen examined light hue and brightness settings