Study on Hospital's Smart Lighting System (SLS) Evaluation in Qatar

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Abstract

This research examines the relationship between hospital lighting design and staff preferences with focus on visual performance and reduced energy consumption. A novel approach to hospital lighting design introduced by Philips (HealWell) was studied in a health care facility in Qatar. This Smart Lighting System combines both daylight elements and artificial light in order to maximize the benefit of daylight features, provides satisfactory lighting design solution and minimizes energy consumption.

A mixed research method was utilized, which combines qualitative and quantitative methodologies, to combine both a detailed view of the meaning of the generalization of the concept under study and to enable a variety of techniques to be used in the research. These techniques including statistical analyses to investigate staff preferences for light through the use of surveys, which was followed by field experiments to test the hypothesis, to link it to reviewed literature, and finally provide a detailed analysis of the findings of this case study with conclusions drawn for hospital energy efficient lighting design in similar climates.

The results revealed that when daylight was provided inside the hospital area through this Smart Lighting System, it was possible to improve visual comfort for occupants, and staff performance while increasing energy-efficiency. This solution can thus be considered for health care lighting design, in particular in hospitals that suffer from lack of daylight, i.e. in the countries where daylight is associated with high glare and high heat gain.

Five published papers are included within this thesis in addition to the critical reviews for these published papers with particular attention given to lighting problems in hospitals, such as, visual comfort, energy efficient lighting design and the cost impact of lighting design.

Dedication

I dedicate this work to my parents' soul, my uncle Dr. Sabah and to my wife, Huda, my children, Ali, Sarah and Fatimah; I would like to acknowledge the support I received from many people, especially my family, because their support made the completion of this thesis possible. In particular, I would like to thank my wife, Huda; I cannot thank her enough for being so patient, helpful, inspirational, understanding and encouraging, particularly during the writing of the thesis. Also many thanks to my sister and my brothers Haifaa, Riad, Shatha and Saad, for their unconditional support.

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List of Publications

1. Safaa Alzubaidi, Susan Roaf and P.F.G. Banfill "Study on improving the Energy Efficiency of Buildings: Part 2: Daylight control and Integrated Lighting System" Journal of Light and Visual Environment, 2016, under review by journal Editor.

2. Safaa Alzubaidi, Susan Roaf and P.F.G. Banfill, Raidh Ali Talib, Abdullah Alansari "Survey of Hospitals Lighting: Daylight and Staff Preferences" International Journal of Energy Engineering, Vol 3, no. 6, pp. 287-293., 10.5923/j.ijee.20130306.02, 2013.

3. Safaa Alzubaidi "Cost Impact of Green Building in Qatar –A case study" Proc. Climate Change Technology Conference CCTC 2013 ,Paper Number (1569693237),Montreal, Canada

4. Safaa Alzubaidi and Prashant Kumar Soori "Energy Efficient Lighting System Design for Hospitals Diagnostic and Treatment Room—A Case Study" Journal of Light and Visual Environment. Vol.36, No.1, 2012. Japan.

5. Safaa Alzubaidi and Prashant Kumar Soori "Study on Energy Efficient Street Lighting System Design" Proc. 2012 IEEE International Power Engineering and Optimization Conference (PEOCO2012), Melaka, Malaysia: 6-7 June 2012, ISBN: 978-1-4673-0662-1, 2012, pp. 291-295.

6. Safaa Alzubaidi and Prashant Kumar Soori "Study on Improving the Energy Efficiency of Office‘s lighting System Design" Proc. Of 6th **IEEE** GCC Conference, Dubai, UAE, ISBN: 978-1-61284-118-2, 2011, pp. 585-588.

List of Presentations:

1. Hospital lighting design at GCC Infra - Lighting Concepts Summit, September 2013. Doha Qatar.

2. Cost Impact of Green Building in Qatar –A case study at Climate Change Technology Conference CCTC 2013. Montreal, Canada, May 2013.

3. Overview of Green Development at Construction Leaders Forum Qatar, September 2012.

4. Developing a fully Integrated Green City at 2nd Annual MEP Summit and Awards , May 2012. Doha, Qatar

5. Study on Energy Efficient Street Lighting System Design at IEEE International Power Engineering and Optimization, Conference (PEOCO2012), June 2012. Melaka, Malaysia

Glossary

CCT Correlated Colour Temperature (CCT)

CFL Compact Fluorescent Lamp

CIE The International Commission on Illumination

CRI Colour Rendering Index

DF Daylight Factor

EBD Evidence Based Design

IESNA Illuminating Engineering Society of North America

LED Light Emitting Diode

NHS National Health Service

UGR Unified Glare Rating

IPSS Statistical Package for the Social Sciences

Chapter One: Background on Hospital Lighting Design

1.1 Introduction

Sunlight and artificial light are the main sources of lighting in buildings. These two sources of light exist within an electromagnetic spectrum that contains visible and non-visible spectrums; both of these spectrums have different demonstrated impacts on human health (Boyce, 2009).

Some studies have shown that lighting types have an impact on buildings occupants' behavior (Boyce 2006), mood (Baird, 2010), wellbeing and task performances (Terman et al 1995; Blanks et al., 1991; Kamali and Abbas, 2012), therefore light should be provided inside buildings at a high-quality and the correct type. The relationship between sunlight and hospital design is ancient, since the very beginning, sunlight was the preferred source of illumination for building designers due to its known impact on human health (Boyce, 2009). There are various approaches to designing to optimise this relationship between light, patient and health. The modern hospital faces the challenge of integrating complex building services into spatial designs to accommodate natural light access and its level of control to the major building areas where patients, caretaker and staff spend most of time.

Historically, artificial light sources, such as, candles, oil lamps or gas-based lamps were used as complementary sources of light for night vision or to light deep areas in the hospital where there was no sunlight access. Three problems were associated with these types of lamps. Firstly, in early examples pollution and reduced and quality, then low efficiency of the sources and the high cost of fuels (Wilkins, 1994). When electricity become widely available, the new electric lamps took advantage of this development, and hospital lighting designers start relying on it in different hospital areas. This resulted in reducing the reliance on daylight to light different hospital areas (Belakehal, 2004; Ouahrani, 1993).

Sunlight stimulates the production of vital vitamins and empowers the human body for everyday lives. It improves the body's organ functions and controls the circadian rhythm and body clock which affects eating and sleeping disorders (Brainard et al., 2013).

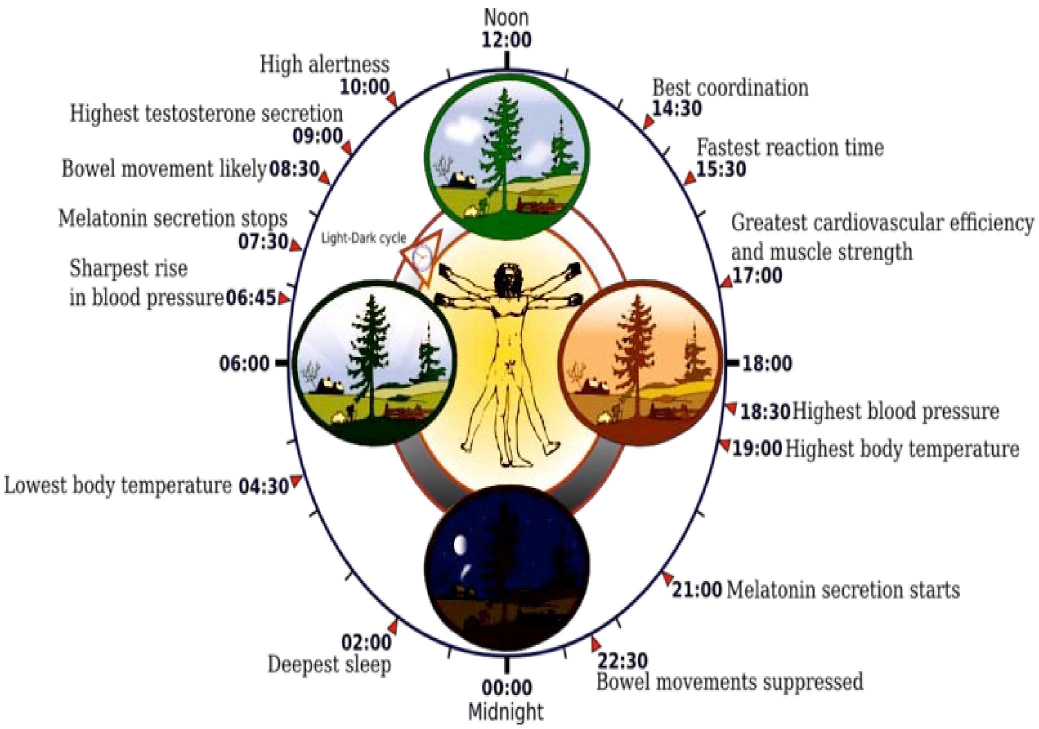

Figure 1 Biological circadian clock of the human (image from Wikipedia source: Brainard et al., 2013)

Sunlight is also powerful in the eradication of pathogens and was widely used in sanatoriums for instance, to kill of Tubercular pathogens, improve recovery rates and reduce rates of cross infection (Mroczek et al., 2005; Mead, 2008). Consequently some researchers have studied different characteristics of light to see which light types and characteristics of them play an important role in helping us maintain healthy bodies and improve productivity with less harmful effects. The wide ranging results of such studies show that different lighting spectrums (visual and non-visual) can affect us in different ways (Wilkins, 1994; Joseph 2006; Rea et al., 2013; Boyce, 2009).

Recently, some researchers suggested that daylight can have a positive effect not only on patients but also on staff and can contribute to improving staff welfare, morale and performance (Rea et al., 2013; Joseph 2006, Kamali and Abbas, 2012). Moreover, it can positively affect patient recovery time, reduce stress and increase patients' satisfaction (Baird, 2010). These suggestions are based on clinical observations and personal opinions. However, further validation and more discussions with the concerned people should take place.

From another perspective, the global concerns about energy efficient buildings and energy consumption lead to focus on the benefits of natural light as a free energy source, which maximizes the use of daylight to light large areas due to its health impacts and as a technique to conserve energy through reducing the use of electric lighting. This approach is widely accepted and many standards and regulators support it, in addition to the green building initiatives that aim to create sustainable hospitals building such as LEED[1] or BREEAM[2] through careful design that integrates lighting both for its visual efficiency and its health effects.

In low latitude countries like Qatar, sunlight is intense and the heat gain from the sun is very high, which makes the building's designer avoid the reliance on the daylight as a main source to light the building (Belakehal, 2004). Despite the known impact of sunlight on staff and patients health in addition to the standards' recommendations to use natural light in modern hospital design, still the use of daylighting is very limited in these buildings due to many obstacles associated with it. For this reason architects rely more on electrical light in these countries as a practical solution (Ouahrani, 1993). Lately, a new lighting system is introduced by Philips as a pilot lighting system[3]; this system is aimed to emulate daylighting through the use of electrical lighting. Due to the importance of daylight for hospital staff and patients, this lighting system will be assessed and evaluated for potential use in Qatar hospitals, once studies prove its similarity as compared to the positive effect of natural light on the hospital staff and patients. On the other hand, artificial lighting is one of the major energy consumption elements in hospitals and therefore the balance between energy efficiency requirements and efficient electrical light design should be considered, and will be studied as part of this thesis.

1 http://www.usgbc.org/leed/rating-systems/healthcare.

2 http://www.breeam.org/BREEAM2011SchemeDocument/Content/05_health/hea01

3 ://www.lighting.philips.co.uk/application_areas/healthcare/healwell.wpd

1.1.1. *Lighting and Health*

To understand the relationship between light and health, the definition of each should be clarified.

1.1.2. *Lighting Spectrum*

Light as defined in physics is the visible portion of electromagnetic spectrum with the wavelength range between 380 to 780 nm or simply the wavelength of radiation detectable by the human eye[4], as shown in Figure 1.1

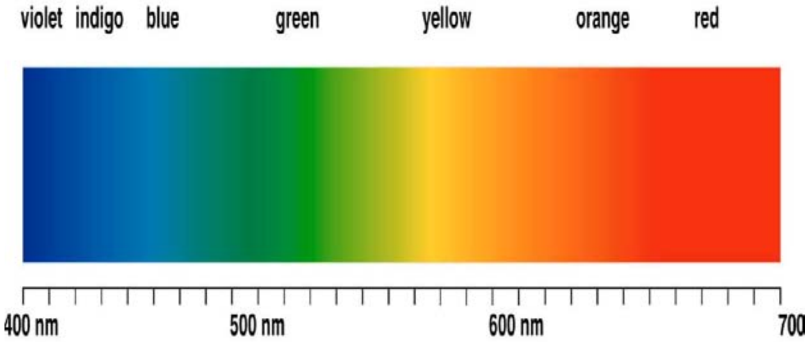

Figure 1.1 Visible Light Spectrum[1]

However, the Sun produces a wide range of electromagnetic radiation including visible and non-visible spectrums. Non-visible radiation lies below and above the visible wave length that includes radiation like ultraviolet UV and Infrared Radiation IR as shown in Figure 1.2 (Akul, 2011). The Sun is not the only light source that produces non-visible radiation, most of today's electrical light is producing this non-visible radiation in addition to the visible radiation[5].

[4] http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

[5] http://imagine.gsfc.nasa.gov/docs/dict_ei.html#em_spectrum

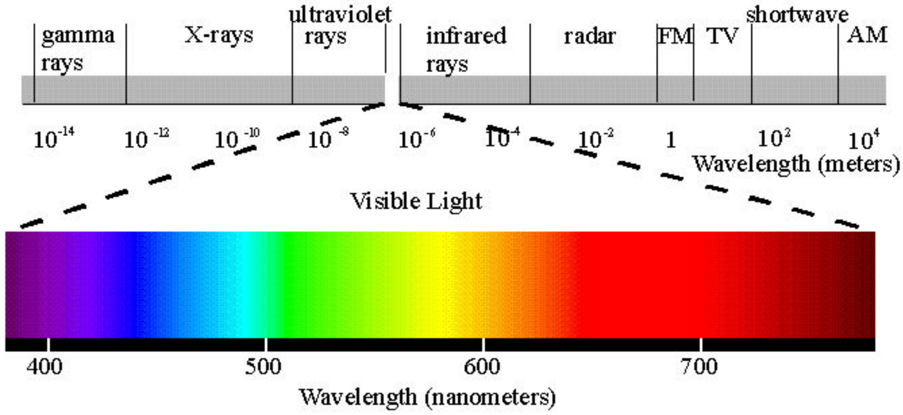

Figure 1.2 Sun Light Spectrum (source Akul 2011)

Radiometric and photometric units are the science of measuring the visible light; for the purpose of this research only photometric aspect of light will be studied. The optic characteristics concerned with the physical measurement of the visible light energy, the psychophysical features of the human response and the physical units of power are defined as Photometry. Photometry measures the light spectrum with respect to the standardized model of the human eye, so that it refers to the human eye sensation of brightness perceived. The light photometry unit of luminous intensity is the Candela (cd). While Lumen (lm) is the unit used to measure the total quantity of visible light emitted by a source . The human eye receptors respond to different visible spectrum in accordance to its wavelength with the peak response at wavelength of 555 nm of the visible spectrum (yellow-green colour); this means light intensity may not have the same effect when coming from two different sources, brightness also may not be seen equally (Sharpe et al., 2005). Another standard light unit used to measure visible light intensity is the Lux (lumen/m2) it is a unit of illuminance and luminous emittance, measuring luminous flux per unit area. It is well defined by the CIE (The International Commission on Illumination – officially known as the CIE from its French title, Commission Internationale de l´Eclairage) in its Standard Observer Curve CIE (1932), The Photoptic curve6 is shown in Figure 1.3.

[6] http://www.cie.co.at/index.php/Technical+Committees

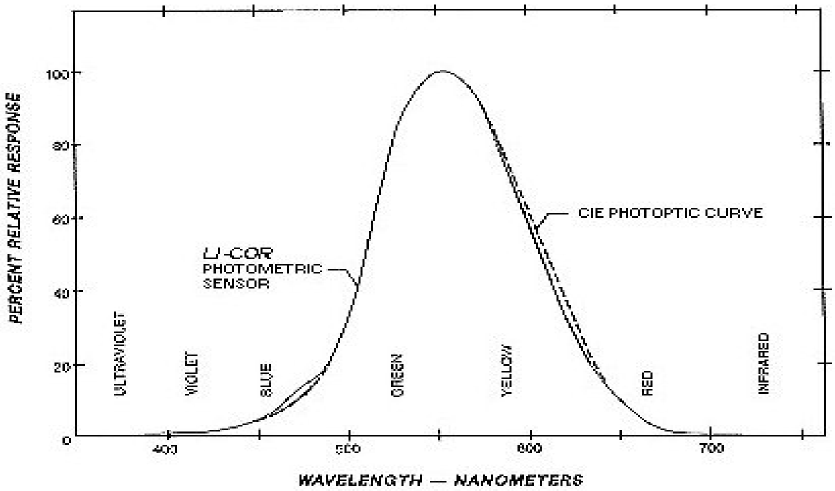

Figure 1.3 CIE Standard Observer Curve (showing peak at 555nm)

1.1.3. *Light Colour Temperature and Colour Rendering*

Light Colour Temperature CT or Correlated Colour Temperature CCT is a characteristic of visible light; it is equal to the temperature used to heat an ideal black body and radiates light with colour identical to the light source. Measured in Degrees Kelvin where colour differs over the visible spectrum wavelength; the light colours of shorter wavelengths correlated with a higher colour temperature and called the cool colours, such as, blue and purple and colours of long wavelengths associated with lower colour temperature and called the warm colours, such as, red and orange as shown in the colour temperature chart Figure 1.4 (Boyce, 2006).

In summary, natural and artificial light have different colour temperatures spectrums, while daylight colours continue to change according to the time of the day and sky condition, the artificial light usually produces constant light colour temperature over the light spectrum. Natural light colour temperature varies from 5000K to over 20000K for sun and skylight (Banu, 2007). Artificial light sources tend to have predefined colour temperatures that are set over a short visible wavelength, for instance candle flame CT is 1850K while metal halide lamp can reach 5000K (Veitch and Newsham,1998).

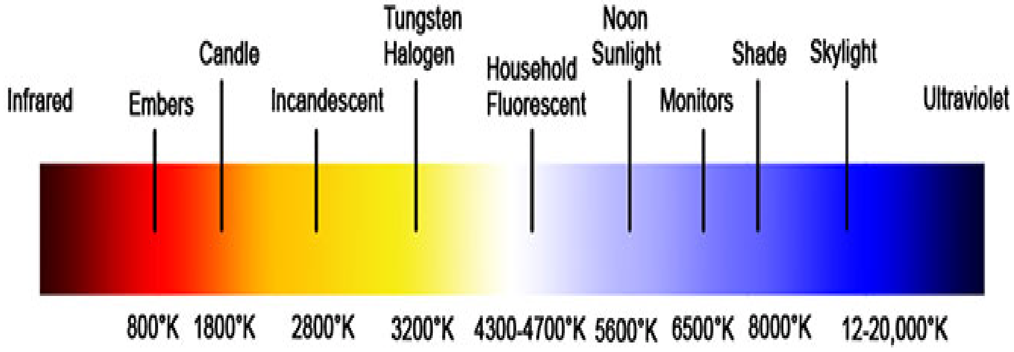

Figure 1.4 Colour Temperature Chart (Boyce, 2006)

Simply, light colour is an important aspect of visible light that enables us to distinguish between different objects' colours; the Colour Rendering Index (CRI) is the tool to measure how well a light source renders the colour of the objects that it illuminates. It is a measurable rating index that refers to the ability of a light source to reflect the realistic colours of various objects in comparison with an ideal or natural light source, which refers to the standard Correlated Colour Temperature (CCT) of eight CIE standard colour samples (Noguchi et al., 2004). For instance, Pritchard (1999) interpreted based on his study of the low-pressure sodium lamp that it emits only monochromatic colour with wavelength peak at 600nm, which results in difficulty in making colour discrimination (Pritchard,1999). Natural light is rated 100 on the scale of CRI according to CIE (1995), so it is an ideal source of light to differentiate true object colours. Generally in hospitals, the patients skin colour is an important factor used to diagnosis the type of illness they have, accurate colour judgment is required and generally CRI should be above 80 (Park et al.,2010). McCluney (1990) suggested that a good lighting source should not cause colour shifts, otherwise it would generate adverse effects of the spectrum of visible light (Noguchi and Sakaguchi, 1999).

1.1.4. *Health and Wellbeing*

World Health Organization defined Health is "a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity". Where the term well-being is defined as, "a good or satisfactory condition of existence; a state characterized by health, happiness and prosperity", as identified by Webster's dictionary. Studying these definitions lead to many possibilities of interpreting health status and making it a complex task to identify healthy people. However, considering the above meaning of health lead to conclude that surrounding environments would induce well-being and health; lighting type and quality is one of these environment elements.

Both lighting types natural and artificial can impact human health in a positive and negative way. However, each one of them has different features and characteristics by which it has certain impacts on humans. There are three ways that light impacts people's health. First, through a visual system, through the circadian system and finally through its effect on the skin. For instance, eyestrain and headaches are one of the common health impacts caused as a result of inadequate lighting, which can harm the visual system. The light impact on health may result in changing the circadian system rhythm by disturbing chemical reactions and influencing sleep patterns. A recent study linked lighting to the development of breast cancer among night shift workers, due to this disturbance of sleep wake cycle (Hansen, 2010). Another study concluded that lighting type is responsible for stimulating serious syndromes such as autism, migraines and Alzheimer (Terman et al 1995; Blanks et al., 1991).

People's health can be influenced by lighting spectrum type, for instance, radiation produced by light sources (in non-visible spectrum of light) can damage both the eye and skin, through both thermal and photochemical mechanisms; it may cause tissue damage, eyestrain and skin aging while visible radiation can heat the eye tissues and damage the retina of the eye causing what is known as Photoretinitis.

On the other hand, lighting can play a positive role with respect to human health as referenced by many researchers (Boyce, 2009; Czeisler, 1988). Boyce (1998) described daylight as important environmental tools that in addition to enabling good vision, it also gives the feeling of connectivity with the environment and that leads to improved mood (Boyce, 1998). Biologically, UV radiation of light works as an essential element to synthesize vitamin D which is critical to the human body; and works as a treatment to other syndromes, such as sleep disorders and rickets (Osmancevic, 2009). Another study found that lighting type improves productivity and morale among employees (Noguchi, 2004).

In short, the impact of light on health is much more than what is listed in this paragraph and there is much to learn about it. However, what we know is sufficient to study this important element and use it to light our buildings and human body.

1.2 **Light Impact in Healing Environment**

Theories related to healing environments are very old. The concept of creating an environment to support healing goes back centuries (Young et al., 2009). The idea to create healing environments suggests a return to the fundamentals living style even if less numinous. Fundamentals living style is all about connecting with the wider world and allowing its healing power to flow through the body and mind even if the individual's focus is inward. What the modern hospital typology lacks is that connection to the world, save a preference for a good view if possible. Ulrich (1984) study endorsed the benefit of view in his research which shows that patients with a bed-side window looking out to a natural setting recovered more quickly (Ulrich et al., 2001). Recently, more attention was given to promote this idea in hospital designs. Healing environment is a combination of many factors that support individuals to promote health and well-being. Lighting is one of these factors.

With diverse users and functions, such as, in hospitals, the type of lighting system design plays a major role (Joseph, 2012); it should be suitable to three groups of users with their different requirements of lightings. Patients as the most important group in hospital lighting and their outcomes, safety and satisfaction may be affected by its lighting design requirements. Patient lighting design requirements should focus on a suitable quality lighting environment (Noguchi, 2004). For patients, their safety and comfort is the priority, Bernhofer et al. (2005) found that hospital lighting regime would have great impact on the sleepiness status and fatigue of the patients (Bernhofer et al 2013), another study by Beauchemin and Hays (1996) found that patients, who stay in rooms with daylight, reduce their stay in hospital. Walch et al. (2005) suggested that light has the power to reduce pain for patients, while Osmancevic et al. (2009) suggest that lighting in some cases were used as tools in treating some patients with psoriasis, herpes and skin disorders. For staff, lighting should be designed to maintain the spirit, mood and performance up to the level required in such professions, and to avoid headaches of other health problems, in addition to help their bodies adjust to night shift work (Joseph, 2012). Type of lighting system can impact staff performance, Fox and Henson (1996), found that a light source used during surgery could potentially cause retinal damage to the surgical staff.

The author et al. (2013) suggest in a recent study that certain lighting design has a great influence on staff perception as they considered it a positive factor that helps staff's performance of daily work.

Caretakers of patients have also lighting requirements different from patients and hospital staff. They need lighting that guide circulation in the hospital and allow for sleep during the night. Therefore, another challenge added to the lighting design regime of the hospitals is the lighting requirements for patients' caretakers. Lighting design in the healing environment is considered as one of the most significant healing factors in hospitals. It can assist staff such as nurses and hospital professionals to perform their daily work and improves their morale. Developing hospital physical settings is therefore an important element to make hospitals more healing, safer, and better places to work. Benedetti et al (2001) study revealed that high light level from artificial lighting cures patients with seasonal depression disorder. While Boyce et al. (2003) pointed that performance on visual tasks increases when indoor light level increases, and suggested that daylight is not inherently better than artificial lighting for the performance of most visual tasks (Boyce, 2009).

Ancient civilization used the world's wider healing power however; complexity of industrialization resulted in isolating patients and disconnected them from the larger natural powers. This change requires architects and engineers to reconsider the typology and settings of hospitals and to endorse an effective design that integrates with the surrounding environment and makes use of these powers.

Light colour is another light characteristic that is affecting the healing environment. It plays a significant role in guiding spatial orientation, enhancing environment and providing information. It assists visitors, staff and patients to get a sense of the hospital spaces and connect with their environment. It helps visitors to establish positive background about their experiences in that specific hospital and improve staff satisfaction in the workplace (Dalke et al., 2006).

1.2.1. *Light Role in Reducing Medical Errors*

Generally, work environment in hospitals is stressful for nurses and physicians (Baker, 1984). They perform a variety of tasks which have a direct relationship to human health; starting by physical inspection to prescribe illness and treatment to patient-care, in addition to completing administering in/out process for patients. Poor lighting design in addition to a hectic environment are expected to cause stress and lead to medical errors. Some studies found that lighting type can result in reducing medical errors (Kamali and Abbas, 2012; Buchanan et al., 1991).

Buchanan et al. (1991) examined the lighting illumination levels effect on reducing medical errors in pharmacies (Buchanan et al., 1991); high level light enhanced medical staff performance and error rates were significantly reduced. Similar results were also confirmed with another study by Boyce et al. (2003). The literature review on this subject shows that further study is needed to look at the impact of different lighting conditions at the nurses' station, and its influence on the task performance.

1.2.2. *Hospital Lighting Design Development (Modern Vs. Historical)*

There is no doubt that health care facilities like hospitals follow architectural trends and engineering design ideas of the time when they are designed. They follow the up to date technologies, social and healing concept requirements. The architectural history of hospitals goes back to the ancient world. Temples with their sacred settings were used in Greece and Egypt as a place to heal sick people (Williamson, 1993), while hospitals of Ancient Rome were built as barracks for military purposes[7]. Healing was based on religious environments and military order, therefore, the design of the building followed the trend of its time. Early civilizations were worshiping the Sun, and therefore the Sun was used widely in the temples for spiritual issues and as the main source of illumination for these temples (Williamson, 1993).Architect designers established these building designs centralized around natural light requirements; this type of light was discussed in one full chapter by Vitruvius (Roman Architect) within his book 'De Architectura, 15 B.C[8].

To capture most of the sunlight, temples were oriented east to house sunlight and illuminate its spaces as in ancient Greece (Williamson, 1993). The type of artificial light used during that time was oil-lamps, mostly used for night lighting and to light the inside building spaces as shown in Figure 1.5, [9]sample of the oil lamp used at Roman Imperial era.

[7] http://www.crystalinks.com/rometemples.html

[8] http://www.vitruvius-pollio.com

[9] http://www.britannica.com/topic/Encyclopaedia-Britannica-English-language- reference-work

Figure 1.5 Terracotta Oil Lamp of the Roman Imperial Era (replica)

Ancient Egyptians used bulbs and the arc light technique in their temples, as shown on the paintings found in one of the ancient crypts: Dendera Temple complex in Egypt, Figure 1.6 (Childress, 2000). There is not much information about other healing factors to consider in these two types of healing places apart from spiritual and natural powers.

Figure 1.6: Dendera Temple Complex in Egypt Light, Showing the Single Representation on the Left Wall of the Right Wing in One of the Crypts.

In the UK, hospital lighting design has changed over the years; its lighting design reflects the innovation of the lighting technologies of its time. Two distinguished design styles were recognized over its history; Victorian hospitals designed before the Second World War and then the modern hospital style after the Second World War. This change was supported by the welfare state emerging, regulating hospital design by government regulations with emphasis on the role of the science to drive this sector.

1.2.3. *UK Victorian Hospital Lighting Design*

Victorian hospital lighting design followed the Nightingale wards design concept which allows much of the sunlight to enter inside the building. The architect's main focus was on the exterior design more than the interior, which meant improvements to the inside environment were ignored including interior lighting design[10]. Nightingale wards are an open space room, with no subdivisions between patients, typically organized on the sideways of the ward Figure 1.7 (Pattison and Robertson, 1996). This type of hospital building allows a lot of sunlight to enter the ward due to its architectural design.

Artificial lighting used before and at that stage includes oil lamps produced by Aime Argand the Swiss chemist (1780s)[11], this type of light is usually mounted as foot lights, chandeliers, or as ladders in the wings. Gas lighting was another source for lighting invented by Scottish engineer William Murdoch in the early 1790s[12]. It was also used at that stage, with combustion gaseous fuels, such as, methane, hydrogen and natural gas. This type of lighting was lit manually, but later with improvements in design it become self-igniting, usually it was mounted footlights or strip lights (Border or Wing Lights), placed between pairs of scenic borders to give the architect more options in design. The ward design of Saint Marylebone Workhouse series which was built in 1730[13], was a good example where these lights were applied; sample ward design of this health care facility is shown in Figure 1.8, the daylight from the top through the use of glazed ceiling (skylights) were designed in the ward and at night it will be lit using two pendent star-burners. This arrangement made the placement of the light out of the inmates' reach for safety issues.

10 http://www.victorianweb.org/art/architecture/hospitals/baldwin.html
11 http://en.wikipedia.org/wiki/Aim%C3%A9_Argand

12 http://global.britannica.com/EBchecked/topic/398073/William-Murdock

13 http://www.workhouses.org.uk/StMarylebone/

Figure 1.7 Ward Design of Saint Marylebone Workhouse, 1867

The two common types of lights (Oil and Gas lamps) were widely used in the design of hospital areas before the inventions of electricity. There were some drawbacks associated with the use of these lights as the oxygen consumption and carbon produced were very high, which at hospitals lead to health complications. The other problem with these types of lights was that the heat generated caused discomfort to the building occupants especially during the summer season. Another drawback associated with these types of lights was the fire hazard of the oil and gas used, which raised the hazard risks to patients and staff. These artificial lights' disadvantages were partially solved with the invention of electrical lamps. Swan (1878), the British inventor, and American scientist, Edison (1879), introduced the famous incandescent electric lamp (Harris 1993). This type of light was known for overcoming the problems of gas lights, as it consumes no oxygen and generates very low heat compared to gas or oil lamps. These electric lamps follow the mounting setup used with gas lamps so that it was installed as footlights, wing-lights or border lights, Figure 1.8 shows the lighting setup with the use of the incandescent lamp design at the dormitory of the St Marylebone new workhouse in 1900 and Kings College Hospital UK (1931) as shown in Figure 1.9, and also reflects the daylight coming from windows during the day time.

Figure 1.8 Dormitory of St Marylebone New Workhouse, 1900.

Figure 1.9. Nightingale Ward at Kings College Hospital UK (1931)

In 1938, there was an important development in the lighting industry represented by the introduction of fluorescent lamps for commercial use (Harris, 1993). General Electric (GE) the giant electrical corporation introduced this type of light as a new invention that is more efficient and powerful compared to the other available lights of that time, another advantage of the fluorescent lamp is that it can be produced in seven colours. These features empower building architects and engineers with more flexibility in their design, the colours introduced were: red, gold (yellow), green, blue, pink, white, and daylight. Hospital designers considered this new light as an opportunity to add a brighter source of light inside health care buildings.

One of the major changes in hospital lighting design after the Second World War, was the establishment of the National Health Service (NHS) in 1948, which was the new regulatory body[14].The aim of this organization was to promote the health care system by making it available for all people and also to improve health services by regulating the hospital development design in the UK as a step towards modernization of this sector after the war.

Since NHS was established, the development of hospital design has followed the findings and requirements of many different endeavours of related research. For that, Hospital Building Notes (HBN) gathered many recommendations and scientific findings in the known publication under Hospital Building Notes (HBN) series, which later become a benchmark publication in 1960s, and its subsequent updates follow in the following years[15]; these publications include the recommendations for Hospital Building Division and designers which highlights major elements, such as, lighting. In these series of guidelines HBN advised recommendations and the best practice guidelines to architects and engineers elaborating on how to design different element in hospital buildings taking into consideration the lighting design as a factor of direct relationship to patient and staff welfare, for hospital renovation and new construction projects.

At that time, Patient Centered Medicine (PCM) was the new trend in health care facility with emphasis to study patient needs and help researchers to better understand the patient and hospital necessities; for that reason, surveys were held to explore the patient's requirements, expectations and actual needs that definitely includes also their lighting requirement[16]. Questions, such as, how we can decrease stress and improve visual comfort were the main focus of this study with the aim to provide a pleasant hospital

[14] http://www.nhs.uk/NHSEngland/thenhs/nhshistory/Pages/NHShistory1948.asp
[15] https://www.gov.uk/government/collections/health-building-notes-core-elements.
[16] http://www.statistics.gov.uk/hub/health-social-care/health-of-the-population/lifestyles-and-behaviours

environment. Greenwich Hospital[17], the modern hospital, post NHS creation, was built as the acute district general hospital in London. It is one of the health care facilities developed in 1963 under the recommendations and guidelines of NHS. The hospital was designed as a single large building with rectangular shape on three floors for different clinical use; and with a service floor separating one from the other; the wards were placed at the building periphery, which enable lots of natural light to enter the building, believing in the natural light power of healing, maintaining comfort and satisfaction of patients. Artificial lighting such as fluorescent and incandescent lamps were used to light deep areas in the hospital which can't receive daylight and as guidance at night.

As discussed earlier daylighting was the primary means of lighting for all types of buildings including ancient forms of hospital, such as, temples. This concept changed in the early twentieth century when electric sources presented themselves as easy to use and to distribute inside the building. Daylighting practice started to decline and become more of architect's preferences however; they worked to maintain daylight inside buildings through the use of continuous horizontal windows knowing in advance that this won't be sufficient to provide daylight to other areas with distance from windows. In addition, the development of architectural modern designs have also reduced the floor height clearance and daylighting design becomes more challenging to achieve; in 1960s, reliance on artificial or electric lighting becomes the main source to supply the lighting during days and nights to all hospitals areas (Harris ,1993). Due to that, less consideration was given to daylight as a functional source, and windowless workplace concept started to appear in factories, and other types of buildings (Fong, 2005).

Moreover, more window to achieve better daylight coverage means more heat to the building and subsequently, less satisfaction of patients; this was another factor in favor to adopt artificial light inside the building and at all times of the day. In the 1970s, the energy crisis and limitations of fossil fuels usage occurred; new ideas leading to reduce electricity use in buildings by reconsidering ways to rely on natural resources like sunlight were rising, and the concept of energy efficient buildings become more sounds

[17] http://www.grenhosp.org.uk/

in building design. Evidence-Based Design criteria were established in reference with the research and field data; NHS has conducted much research on different aspects of healthcare building designs including lighting design. Conducting literature reviews in the existing field, analyzing key results and recommendations, data collection from field site visits, launch surveys to explore subject-matter experts, forecasting the design decision outcomes and focus on the positive effects for design implementation, were all implemented in the research methodology. Determined design methodologies aimed to create a new regulatory document guiding the use of artificial and natural lighting in hospital lighting design, which has been sorely elaborated over the years by NHS published guidelines Health Building Notes[18].

1.3 Review of Hospital Lighting Design: Guidelines, Regulation and Common Practice

In this section, standards and guidelines related to lighting design in hospitals will be surveyed and in particular, the artificial and daylighting design requirement of hospital's wards will be discussed. There are many international standards and guidelines which look at the design of hospital buildings, for instance, searching the British Standard Library for the word hospitals we found more than 800 documents which refer to hospital[19]. These documents mostly deal with architectural specifications and different components of the hospitals such as aesthetic and construction material; lighting design criteria may be considered however, only in the specification document. These guidelines and standards usually give great consideration to the safety and visual task requirements of patients, staff and visitors. Creating visually satisfying environments is another aim of the guidelines which was based on the research and its findings.

Three types of design guidelines are available and it helps architects and engineers while

[18] https://www.gov.uk/government/collections/health-building-notes-core-elements
[19] http://www.bsiglobal.com/upload/Standards%20and%20Publications/shop.html

designing the lighting for hospital buildings; first the designer guidelines identify the minimum acceptable lighting level in each area of the hospital; the aim of such guidelines is to maintain the patient and staff safety through providing acceptable light to do various visual tasks; these are called the mandatory requirements, an example of such guidelines is European standard EN12464-1 for Indoor Lighting. The other type of guideline is the one which presents the good practice solution for system design and usually called code of good practice [20]; these guidelines mostly present new techniques and solutions based on practice of professionals and other disciplines involved in building construction, example of such guidelines is the SLL Code of Lighting (Boyce, 2009) and BREEAM – Energy Limits for Buildings and the Best Practice for Energy Savings[21]. The last type of guidelines is the one that is based on publications; it introduces creative and innovative works of best design, what is known as future codes and may be referred to with Evidence Based Design (EBD) Guidelines (Stankos and Scharz, 2007); EBD basically relies on experimentation study and results approved by professionals in that field.

In North America, Illuminating Engineering Society (IES) is the professional body which sets the standards and recommendations for building lighting design; more than 100 documents have been produced with regard to lighting recommendations and Lighting Handbook 10th Edition 2011 was the most popular[22].

Safety criteria of indoor artificial lighting highlighted in these guidelines were in line with IESNA Lighting Guidelines[23], which determine the health risk associated with the use of indoor lighting; risks were classified according to the type of radiation emitted from each lighting type, distance from that light source and period of exposure. The emission that comes from light sources, such as, Ultraviolet or Infra-Red radiation was considered as a potential risk that might affect human health. Eight hours was established as the maximum exposure margin where workers would be exposed to these lights without high risk; longer exposure time presents high risk to workers; this standard

[20] http://www.licht.de/fileadmin/shop-downloads/Guide-DIN-EN-12464-1.pdf
[21] http://www.breeam.org/BREEAM2011SchemeDocument/Content/05_health/health.htm
[22] https://www.ies.org/about/what_is_iesna.cfm
[23] http://www.ies.org/

evaluates the task lighting risk only (CIE, 2002), which measures the hazardous lamp from a distance of 20cm only. Similar British Standards were produced (BS EN 60598) and electrical safety take the top priority for all luminaries within the hospital buildings, particularly in patient bed-head luminaries (Wilkins et al., 1989). Standards also specify the class of construction of these luminaries as specialized fittings for hospitals.

On the other hand, while some studies find a relationship between serious disease like breast cancer and lighting (especially with female night shift workers) (Hansen, 2001), a considerable number of standards and international codes look at the risks of artificial light and suggested that working under indoor lighting is safe and have no concern of safety issues. Therefore, there is a need to reconsider these recommendations in light of this study.

Another professional body is the Charter Institute of Building Service Engineers (CIBSE) in the UK, which sets the standard related to building services in the UK and overseas; a comprehensive guideline that deals with many aspects of hospital lighting design. "Lighting Guide 2: Hospitals and health care buildings" were endorsed by the UK Department of Health (DH); it has also been referenced in the published Health Technical Memorandum (HTM) series of documents, in addition to the Health Building Note (HBN), as a reliable source for hospital lighting design criteria. This document provides the guidance for hospital designers related to lighting task requirements, such as, types, colour and illumination levels for various places in hospitals as follows:

1.3.1. *Light Intensity*

The minimum required illuminance depends on the task performed and the details to be perceived. Task accuracy and user's age is another factor that influences the illumination intensity in any place. Edwards and Torcellini (2002) found that older people experience a decrease of the transmittance capability in their eye lenses. Moreover, a minimum lighting level is required to balance between the two lighting setup extremes, such as, move from dim corridors to bright sunlight patches, which can cause adaptation problems with light for older people (Dalke et al., 2005). Guidelines commonly mandate hospital designers demonstrate that the minimum required lighting level were achieved in their design; the architect or the engineer can prove that either by building a mock-up space or conducting light calculations for that area. There are two ways of calculating the required light design to show compliance with standards; the first is to evaluate the average luminance of the lighting design at different locations of the space and the second is to show the maximum lighting level produced. Many lighting calculation software is available and accepted as evidence of design compliance with standards (Nazmiet al., 2008).

As said, the recommendations of the illuminance level depend on many factors, the appearance of the room play an important role in recommending the lighting level. The visual requirements of hospitals are different from other buildings, where elder people are one of the users of this facility and usually have certain vision requirement according to their age therefore; illumination level should consider the minimum level for those aged users as well. The current recommended illumination levels are based on good current practice, it takes into account the visual abilities of sighted individuals with 40 years of average age as shown in Table 1.1 (Dale et al., 2012).

AREAS - ACTIVITIES	TYPE OF WORK	Recommended Lux - (minimum Lux)
Doctors' offices	(General lighting)	150
Doctors' offices	(Working table)	1000 – (500)
Waiting areas		150
Bathrooms	(General)	200 – (100)
	(Mirror)	400 – (200)
Library		500 – (250)
First aid ward	(Localized)	1000 – (500)
	(General)	20000 –(10000)
Corridors - staircases		150
Kitchen		500 – (250)
Laboratory	(Research areas)	500 – (250)
Laboratory	(Working table)	1000 – (500)
Operating room	(General)	1000 – (500)
	(Working table)	40000 –(20000)
	(X-ray ward) adjustable lighting	0 - 100 -(0 - 50)
Dentistry	(General)	500 – (250)
	(Chair)	10000 – (5000)
Maternity ward	(Delivery bed)	10000 – (5000)
	(Deliver area) general	500 – (250)
	(Infant and waiting area)	200 – (100)
Patient rooms	(General)	150
	(Localized lighting: beds)	500 – (250)

Table 1.1 Preferred Light Levels in Hospitals

1.3.2.*Light and Colour*

Light and colour may impact peoples' responses to the environment and their perceptions (Birren, 1978). They also affect patient recovery rate, improve the quality and overall experience of patients, staff and visitors. Background colour and appropriate lighting are also powerful tools for coding, navigating and way-finding; studies shows that the interaction between light's colour design of a task performance and visual comfort level among hospital staff, patients and visitors are complicated (Dalke et al., 2005: Birren, 1978). There are four factors that affect our perception to object colour; the light source colour, the object colour and its background colour and the eye vision capability; any change in these parameters may cause miss-colour judgment (Malkin, 1992). In hospitals, identifying the correct patient body colour is essential to identify symptom, disease characteristic and treatment, which includes correct colour of tissue, eye colour and skin-tone. When an impartial decision of skin colour is required, the background colour should be neutral grey (Birren, 1978); some guidelines have set a colour requirement for certain areas in hospitals based on the professional's opinion and some clinical studies. For instance, the operation theatres are recommended to use green colour, a useful colour to lessen colour after-image from red wounds; in dermatology wards, the blue line is the recommended colour; because it helps minimize the distressing appearance of orange treatment ointments on patients' sheets; while in the maternity ward, the orange is used to give people a feeling of energy during the short stay; other colours such as, yellow was not recommended in the newborn units to be able to detect the new born jaundice earlier (Dalke, et al., 2005).

NHS in the UK relies on the available studies to recommend the suitable type and colour of light for each area and department in healthcare facilities. The publication of lighting and colour for hospital design presents a complete section on lighting and its colour (Dalke et al., 2005); it highlights the colours influence on the medical decision for each task being performed, and this is why NHS recommends standard spectral colours in the selection of lamps to be used.

Colour rendering index requirements is one of the strict standards conditions that hospital light sources must achieve as specified by the Commission International de l'Eclairage CIE (1932). This standard requires most of the hospital areas to achieve a colour rendering index of at least 80, including operating theatre, ward units, and consulting rooms. However, specialized areas such as examination or treatment rooms are required to achieve a minimum colour rendering index of 90. Lighting and colour are important aspects to the development of contemporary hospital design therefore, standards had consider them in many guidelines as an appreciation to this important interrelationship where accurate visual performance especially in hospitals areas is the basic ingredient towards achieving successful visual judgment.

1.3.3. *Daylight and Daylighting*

Demand for artificial lighting and availability of daylight is often linked; savings can be significant when daylight is available to light the building areas with natural daylight; the international standards request architects design hospitals with maximum provisions for direct sunlight. Use of daylighting to illuminate the building is one of the techniques recommended by standards and guidelines to incorporate and achieve this goal; the standards also considered the emphasis of many researches on daylight and its role in promoting wellbeing and other health impacts. The CIBSE standard sets the requirement for daylight in hospitals relying on daylight factor parameter; it requires the hospital designer to consider certain Daylight Factor (DF) allowance; DF is a concept developed in the early 20th century in the UK and represents the ratio between the indoors daylight illumination and the outdoors illumination under overcast skys; later, this ratio becomes more usable in many standards and guidelines (Tregenza and Sharples, 1995). In the hospital, CIBSE Lighting Guide LG10 of daylighting recommends that most of hospital areas should achieve minimum of 3% DF. The standards also recognize that high daylight factors could result in low uniformity value of lighting and have its sub sequential effect on visual comfort; that's why artificial lighting should always be the supplementary lighting source exit to provide the required visual balance. Minimum of 30% uniformity level in hospitals is recommended to be achieved. The green building guidelines such as BREEAM in the UK and LEED in the USA encourage the use of daylight in hospital and set that the minimum of 3% DF in wards and many areas in the hospital should be achieved in order to get the required accredits and green building certificates[24].

[24] http://www.breeam.org/BREEAM2011SchemeDocument/Content/05_health/hea01.htm

1.4 **Energy Savings**

Reducing carbon emissions and greenhouse gas emissions are vital in today's battle against global warming, according to the World Energy Report in 2012, 19% of the world's electricity demand goes to lighting[25]. Hospitals, as they operate 24/7 and by their nature are major consumers of energy, where energy used to serve numerous building occupants, such as, staff, patients and visitors, in addition to the growth in hospital sizes and services, all are factors that resulted in progressive increase of energy consumption[26]. In the U.S, hospitals represent less than one percent of all commercial buildings however, it consumes more than five percent of the total energy used by the entire commercial sector[27]. A survey conducted in the U.S found the healthcare facilities' consumption of electricity accounted for 50% of the total hospitals' energy consumed; analyzing the major elements which consume energy in hospitals lead to find lighting as one of the major elements that consume electrical energy (Baird, 2010). Another report by the U.S Energy Information Administration highlights that energy consumption in hospital buildings reach up to 43% due to lighting[28].

A circular published in Germany by the Environment Science Centre report[29] points out that hospitals' electricity account for 70% of the energy cost. While the results from the UK hospital audit 2012 show that hospital lighting power consumption reach up to 35% of the total electricity consumption[30]. Research done by the University of Chicago Medicine reported that generated carbon emissions from hospitals' energy consumptions are equal to almost 70% compared to those yields from worldwide automobile fleets (Author and Soori, 2012). These reports and studies lead to think in a way to reduce the

[25] http://www.worldenergyoutlook.org/publications/weo- 012/#d.en.26099,2012
[26] https://www.eia.gov/consumption/commercial/reports/2007/hospital-water-data-collection.cfm
[27] http://www.eia.gov/consumption/commercial/
[28] http://www.eia.gov/reports/#/T1089
[29] http://www.carbontrust.com/resources/guides/sector-based-advice/healthcare.
[30] http://www.uchospitals.edu/news/2009/20091110-footprint.html

energy consumption in hospital without affecting the performance of this facility; all these reports and studies established that the lighting is the major factor of energy consumption and could reach up to 40% of power consumed therefore, the challenge is to look for a new methodology to improve the efficiency of the lighting system and reduce energy consumption in this sector. Due to the fact that hospital lighting should work around the clock for guidance and safety of patients and staff, this requirement makes it difficult to rely on manual or automatic lighting control strategies therefore, another approach for energy savings should be followed. Improve energy efficiency is a concept followed worldwide to reduce consumption and increase energy savings (Author and Soori, 2012).

Daylighting is one of these measures that are used to increase energy efficiency, as a natural resource that does not require energy to operate and reduces reliance on artificial light, so it reduces energy consumption. Using the daylight as the main light source in buildings is important to achieve the energy conservation measures due to its capability to minimize the use of electricity for lighting. However, the cost of integrating daylighting in the basis of energy savings is not justified. Many technologies are available to deliver daylight into buildings, some of these technologies are effective and proven; others yet require development to be a reliable source for lighting in the building. Simple technology is appreciated to bring sunlight inside hospital facilities, that includes using windows however, windows are not always effective methods of using daylight due to many factors such as weather and subsequent sky conditions and sunlight intensity change during the day hours.

1.5 Hospitals Daylight Design Obstacles in Hot Climate Region

Supply of daylight to hospital buildings in hot climate regions, such as Qatar is challenging; many considerations should be taken into account when lighting spaces with daylight. Problems such as excess heat and high lighting intensity can result in visual discomfort for staff and patients, in addition to overheating the interior spaces (thermal discomfort) and fading or deterioration of furnishing.

Traditional old buildings design in hot tropic climate countries had followed some techniques which were developed over the years by the architects to let daylight enter the buildings (Karizi and Mendez, 2011). These old techniques created a centre area in the buildings to provide Daylighting, such as, Courtyards shielded oasis, protected from its sides by the structured Iwans (spaces within the building where one side is entirely open to the outdoors) and Muqarnas (dome structures); these treatments resulted in bringing indirect light to those traditional building however, with some exposure to heat (Nabavi and Ahmadi, 2012).

Window is another technique used to bring daylight into the building in hot climate countries; they are typically designed as a small size and located at a high level which can provide daylight only to a small portion of the space (Belakehal, 2004). Glare is also one of the biggest problems associated with the use of windows; studies show that in desert climate countries, glare is a common daylighting issue brought by bare ground or light coloured facades of adjacent buildings (Belakehal, 2004; Saridar and Elkadi, 2002). Most of these techniques were suitable for the old and simple building architecture however, modern hospital architecture have a different form of design that its square footage is much greater, its functions become more complex and should typically be cooled with HVAC systems which means it performs better with a closed building envelope .

1.6 **Research Hypothesis**

Daylight plays an important role at health care facility; it can improve staff performance and patient’s health condition in addition to help patients in their recovery journey; due to many reasons such as change in sky conditions, buildings architectural design and occupant's privacy, the reliance on sunlight becomes difficult. The problem becomes greater in hospital buildings of hot climate regions such as Qatar, where the hot weather and high sunlight intensity makes engineers and architects design the buildings in a way that avoids exposure to sunlight to overcome the discomfort and heat. Since daylight is essential to hospital occupant and there is a limitation relying on the sunlight to lit the hospital different areas all the times , a new lighting system should be the solution for hospitals, which uses electrical lighting and emulates daylight.

Installation of artificial lighting in the hospital and the requirement for day lighting had led to the following hypothesis "since the artificial lighting colour and intensity can be controlled, to emulate daylight in terms of its spectrum and required illumination level therefore this could be the solution for lack of daylight in hospitals to provide the desired daylight to hospital's occupants".

1.7 **Research Aim and Objective**

The aim of this research is to investigate the relationship between lighting type and hospital staff preferences in hot climate region; and to assess staff performance under new smart lighting system (visual comfort, improve performance and energy efficient) proposed by Philips Healwell system .

These aims led to formulate four research objectives as described below:

I. *To explore the relationship between lighting type and hospital staff preferences.*

II. *To review the preferences for smart lighting in the Ward.*

III. *To assess the effect of lighting type, in particular, Healwell lighting system, on hospital's staff performance.*

IV. *To identify the required measures towards achieving energy efficient lighting system design in hot climate region hospitals.*

Chapter Two: Methodology

2.1 *Introduction*

Research objectives identified in the previous chapter will be addressed in Chapter Two however, in different approaches; the approaches need to be designed in advance in order fulfill research objective efficiently. In the field of social science, research framework design was the subject of a wide debate in the literature due to different philosophies and approaches (Muller G and Heemels, 2007). Philosophical research usually guides the plans and strategy of the study approach which is in turn, informed by epistemological considerations. In planning for the research, some considerations play important roles on deciding the approach that should be taken, such as, the researcher's personal experience and available philosophies [Creswell, 2003]. For instant, researchers experienced in the scientific field employs technical methods in their study, such as computer statistical programs mostly to quantify design approach; the approach to knowledge should consider the type of problem, research inquiry type and identify the approach that matches.

There are many philosophies and ways to conduct a study and to reach knowledge (Mertens, 1998). These philosophies are included in every stage of the research. Hence, applying the available theories in conducting research is the first step towards achieving the objective of the research. The theoretical design and framework of the research is related to its philosophical basis, and this link will lead to the practical components of the investigation undertaken (Crotty, 1998). In this chapter, some of the well-known theories for conducting research in social science will be introduced and the reasons behind each philosophy will be explained and justified accordingly. In particular, the philosophies concerned with study framework elements such as Epistemologies, Theoretical Perspective and Methodologies and Methods.

Crotty (1998) concluded that most of those days' studies are results of real-life experiments which usually impose a set of inquiries where hypothesis and objectives are formulated, and the plan for the research methodology and methods are placed. To properly link the theoretical perspective and epistemological a suitable methodology and method need to be in place; those which help the researcher defend their techniques and justify claims of the acquired knowledge. In fact, the author's view of research framework was selected by many researchers (Alalouch, 2011) and Brown (2003) due to its consistent steps and clear methodology approach. Accordingly, the current research was developed and constructed based on these approaches. At the same time, the required improvement to the research design steps shall define the epistemology, set the theoretical perspective, compile facts expressing the problems, formulate hypothesis and set objectives and choose the appropriate methodology and method.

To achieve the research objectives, a combination of research approaches and philosophies were employed to validate the assumption of each objective outlined. This study was divided into three stages: Understanding, Evaluation and Conclusion where four methods are used to implement these three stages. Muller (2007) suggested that research development usually started with creating new ideas, collecting data, analyzing and evaluating, these techniques was found to be a reliable research technique as confirmed by Creswell (2003 These techniques have been adjusted for this study as: Data Collecting, Analysis, Testing New Idea and Conclusion. It is used in response to the first research objective outlined in chapter one; the next technique is the analysis; this technique is used to understand the relationship among the data collected, theory and the results; another technique is Testing, which verifies the tested research hypothesis and links it to a theoretical stance; Conclusion is another technique used in which the main finding discussed and presented are based on the available knowledge, testing results and understanding.

Based on the objective of this thesis, a model to knowledge was developed introducing the use of a rigorous combination of techniques and methodologies. Different research philosophies were used in this thesis to serve the purpose and objective of the study, these included qualitative, quantitative and mixed methods, where despite the differences in philosophy behind each approach, the current research was formed in a logical interlinked basis. The studies were making the use of techniques, such as questionnaires, experiments, case studies and statistical analyses.

2.2 **Theoretical Framework**

This study began with the question of which theoretical framework should the research follow. In the field of research planning, the theoretical structure of research is connected with its philosophical basis, and this link leads to the practical components of the investigation undertaken. Mertens (1998) suggested that the proper plan for the research framework will lead to make the right decision that guides the research process. Wilfried (1996) in his study on research methodology and models, discussed the Deduction and Induction research approaches, he also introduces them as good start points for the research style thinking. The Induction approach starts with fragmentary details to an associated assessment of the situation, whilst Deduction approach looks at the situation from a general view before getting into particulars.

2.2.1.*Deduction Process*

In the deductive process, the researcher starts with broad theories narrowed down to formulate the hypotheses and at the end those hypotheses get tested to be either confirmed, modified or countered (Wilfried, 1996). The theories present assertion on concepts which is usually generated as abstract ideas and form the main core of the theories and hypotheses. According to Wilfried (1996), the first stage is clarification of a set of ideas, which get verified through observation and/or experimentation; prior to going into the experimentation phase of the research, the concepts should be set measurable (operationalized) to confirm its occurrence. At this stage the indicators and measures are generated. Figure 2.1 shows the scientific research process of the Deduction concept.

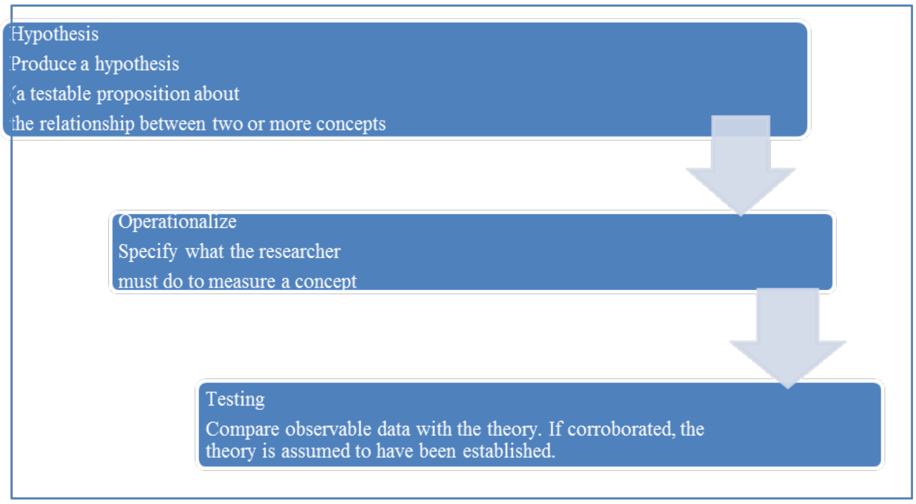

Figure 2.1 Deduction Style of Conducting Scientific Research

2.2.2. *Induction Process*

In the inductive process, data collection is prepared in advance, and then analysed to explore any possible patterns and/or connections identified among variables (Wilfried, 1996). Subsequently the theories or what is known as construct of generalization get established. To summarize, Wilfried (1996) suggested that progress in research following Induction style would head towards discovering a binding principle, and not just relying on the quick conclusions from the merit of available data. Figure 2.2 shows the Induction research style flow chart.

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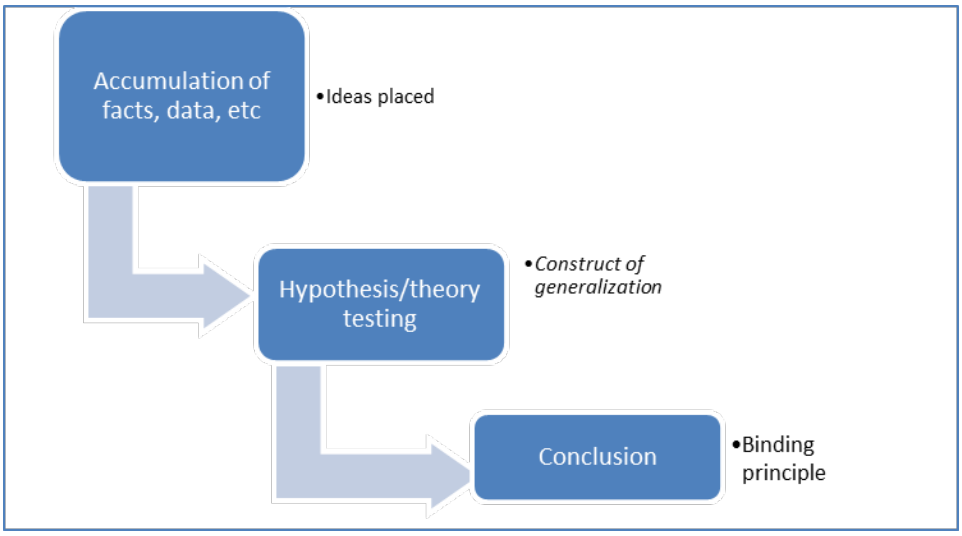


Figure 2.2, Induction Style of Research Flow

Crotty (1998) suggested similar research process introducing a new style however, elaborated more on details in conducting the scientific research and the flow of research from one stage to another; this research style proposed by Crotty (1998) combines both Induction and Deduction research styles in one research style. Dewey (1933) research style cited by Crotty (1998) recommends that the concept of the general paradigm of enquiry should start with a tangible problem; and then it will generate particular inquiries that need to be addressed. The generated queries will lead to formulate hypothesis and represent the start of the research idea. In general, the researcher should try to connect this problem to a theoretical perspective and epistemological (Theory of Knowledge); in this way the assumption made will be justified through the logical research process (Carter and Miles, 2007). Figure 2.3 presents the research style with mixed approach.

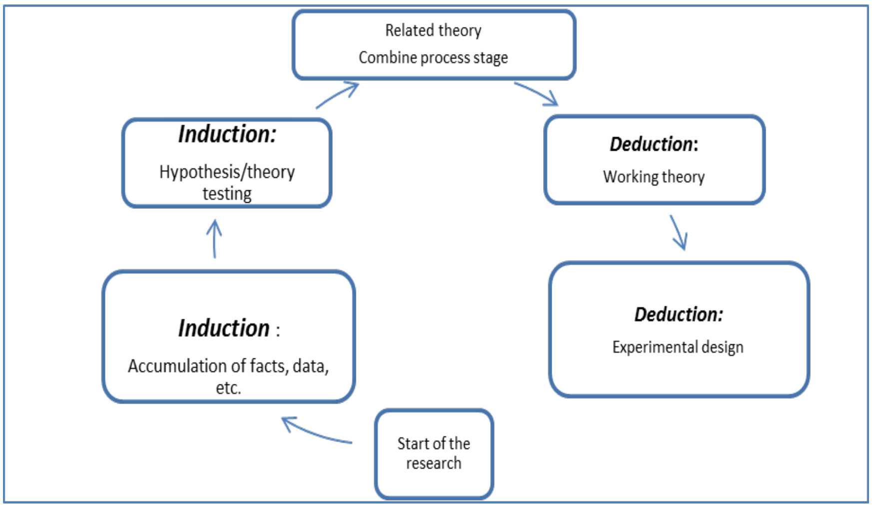


Figure 2.3 Combined Research Style

The author sees the mixed method (induction and deduction) as closer to the current research study style, where identifying the problem was the first stage of accumulating facts and data; and subsequently sets the research objectives (theory to be tested) and the look at the existing theories; where there is an advantage to verify theory through conducting experiments until conclusions are reached based on the results of the claimed knowledge.

2.3 Research Design

Research framework consists of four basic elements; epistemologies, theoretical perspective, methodologies and methods (Carter and Miles, 2007). Carter (2007) suggests that these four facts are the criteria on which research quality should be assessed and evaluated. The relationship among these facts is explained by Carter (2007) in Figure 2.4.

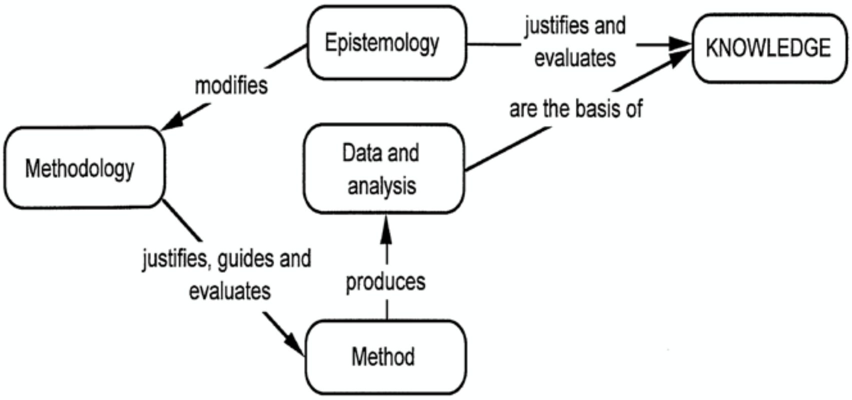


Figure 2.4 Research Elements

The term epistemology was suggested by the Scottish philosopher James Frederick Ferrier, and means the theory of knowledge[31]; Schwandt (2001) elaborated more on the term epistemology and defined it as the "study of the nature of knowledge and justification". Crotty (1998) interpreted the term epistemology as the nature of human knowledge limits.

Methodology was seen as an important factor in the research; it was also defined by Harding (1987) as the analysis or theory on how research should proceed; where this analysis could include elements, such as procedures, justification and explanation or description of methods. In short, methodology in research gives justification for the techniques or methods used in the research. While methodology provides the description for the methods used, the methods represent the techniques and procedures for gathering evidence (Harding, 1987).

[31] http://global.britannica.com/EBchecked/topic/205046/James-Frederick-Ferrier

2.3.1.*Epistemology*

Derived from the Greek word episteme "science” or "knowledge"[32], epistemology is a branch of philosophy concerned with the nature, origin, methods, and limits of humans. Crotty (1998) sees this branch of knowledge as the study of “how we know what we know “, or as Guba and Lincoln (1998) see it as the justification of knowledge (Guba and Lincoln, 1998). Maynard (1994) and Rayner (2011) view it as the science that provides a philosophical basis for the researcher, and to choose kinds of knowledge that is possible to investigate, legitimate and adequate.

Creswell (2003) suggests that Objectivism and Subjectivism philosophies are the main models of epistemologies. Subjectivism defined as subjective ‘truth’ is only true for certain people at certain times under certain conditions (Guba and Lincoln, 1998); simply, that knowledge only exists to certain individual people and is discovered not created by researchers.

Objectivism paradigm is the opposite of Subjectivism; it considers knowledge pending on common sense; and the logical order in gaining knowledge with this approach is the Percepts; it also considers awareness of a specific existent as a result of integration of specific sensations. Second are the Concepts, which refer to the logical organization of the percepts; the mind of groups classified according to their essential features (Hamzaha et al., 2012; Mills et al., 2006). Crotty (1998) suggested that Objectivism is where knowledge exists even if we are not conscious of it. The researchers following this philosophy focused on searching for explanations, causes and effects, in addition to testing theories, predict events and examine hypotheses.

Crotty (1998) suggested another philosophical paradigm that can be added to epistemology styles, which is Constructivism. In his study, The Foundation of Social

[32] http://www.galileanlibrary.org/site/index.php/page/index.html/_/essays/introducingphilosophy/5-epistemology-1-r22.

Research Means and Perspectives the Research Process; Crotty considered Constructivism as an epistemology model rather than being a theoretical perspective.

In simple terms, Constructivism is a problem-based approach that adopts the relativist position and allows for creation and innovative techniques (Guba and Lincoln, 1998). Researchers adopting Constructivism as a way to knowledge had based their research on the practical knowledge that is personally constructed based on real life practice to build knowledge (Crotty, 1998; Mills et al., 2006). The similarity in philosophical paradigms between Constructivism and Subjectivism approach is obvious; these two paradigms are opposite of the Objectivism model of epistemology and seek to understand and describe rather than explain.

Epistemology relies on consistencies rather than simple truths; this is what directed the research in the social world and it is due to the limited capability of the human thinking and not because of existence of truth; and possibly, limitation restricts our capability to capture the truth. In line with this understanding, Objectivism seems more close to the objective and the aim of this study as it is testing the theory and examining the hypothesis in predicable manner.

2.3.2. *Theoretical Perspective*

Crotty (1998) views the theoretical perspective linked with the main philosophical assumption; so that the researcher adopts certain research style considering the social life within the world. In other words, theoretical perspective is a hypothetical way to understand the world with respect to ourselves (Alalouch, 2011). This understanding requires different epistemological paradigm to touch the knowledge. Crotty (1998) set a number of theoretical perspectives that makes a clear path for the designated epistemological positions; the two extreme types with the theoretical perspective are positivism and interpretivism (Chia, 2002). However, between these two extreme views, several approaches have been established e.g. Post-Positivism, Pragmatism, Participatory and Postmodern seen in Figure 2.5.

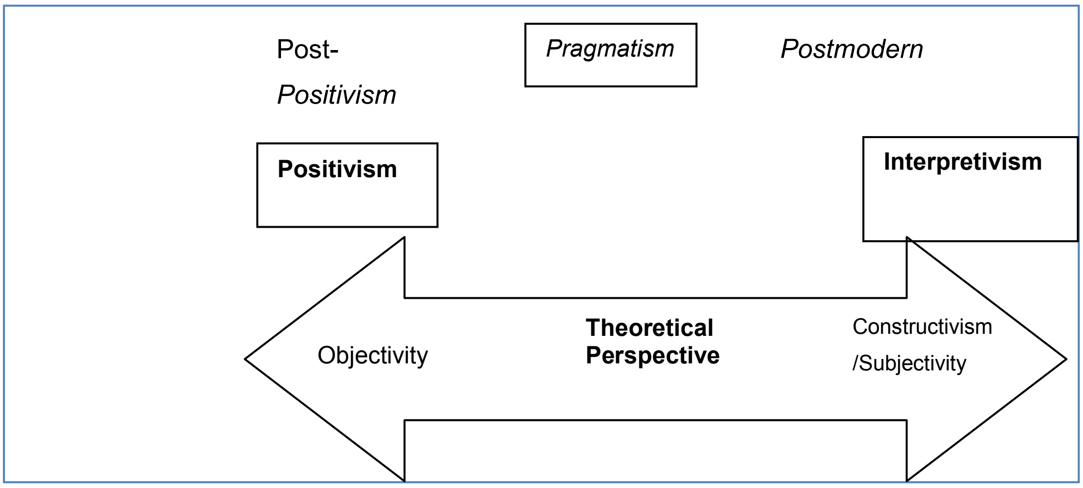


Figure 2.5 Theoretical Perspectives According to Crotty (1998)

The theoretical perspective that is linked to objectivism epistemology is positivism (Carter and Miles, 2007); which claims that the researcher must investigate using scientific inquiry to the existent reality. In the natural science approach, where the objectivist research is linked to the theoretical perspective the following statement becomes viable; ‘‘the researcher is just a collector of facts and considers the truth or objective world as existing regardless of our opinion and it follows the natural laws and can be measured’’. In opposite, constructivism and subjectivism does not believe in the view of human knowledge and sees the truth created by individuals’ interaction with the surrounding world.

Crotty (1998) asserts that interpretivism philosophy is linked to constructivism and subjectivism rather than objectivism; Gia (2000) agreed with this view and considered the researcher as part of this world where his opinion and attitude cannot be isolated from the research perspective.

In the middle of these two philosophies Pragmatism is present; it is a philosophy that is based on the function of thought and not just on representing or describing reality;

instead, it should lead to problem solving (Alalouch, 2011). Moreover, pragmatist believes that any philosophy used should consider the practical uses of perspective instead of the degree of accuracy (Carter, 2007).

The author views the Pragmatism way of research design will result in a reliable conclusion due to its logical style of predicting the solution for a viewed problem and for finding the result from reality; Johnson (2004) proposes that researchers follows the concept of "what works is what is useful and should be used" without considering established methodological or philosophical limits.

2.3.3. *Method and Methodology to Knowledge*

Selection of methods and methodologies techniques is a critical element in answering the research question within the research framework. Methodology represents the process for studying and how we know what we know and at the same time it justifies the knowledge (Creswell, 2003). Hay (2002) defined methodology as the process strategy, design or plan of action, basis that select particular techniques and linking it to the desired study outcomes. Carter (2007) defined the research methods as the research action, procedures or techniques used to collect and analyse data related to research hypothesis questions. The justification to decide on certain methods and methodologies in the proposed research goes beyond just responding to the research inquiries. Crotty (1998) suggests that the justification to the research methodology and method is related to the assumptions and theoretical perspectives placed by the researcher and based on the understandings of knowledge acquired and investigated. Therefore in the theoretical framework factors like hypothetical perspective and epistemology which underlying the research assumption are the key element to disclose the methods and methodology underpinning the research.

Maynard (1994) believes that methods and techniques utilized in the research, establish the approach and strategy for the researcher to carry out the study; in addition, it would determine the quality of the research outcome. Therefore methods and techniques should be compatible with the research objectives. According to Creswell (2003), the research starts with compiled knowledge; this means the researcher is already set on what will be learned and how it will be achieved in the study course and consequently, the research approach will be chosen according to three main methodological approaches for researchers: qualitative, quantitative and mixed method as shown in the following Figure 2.6.

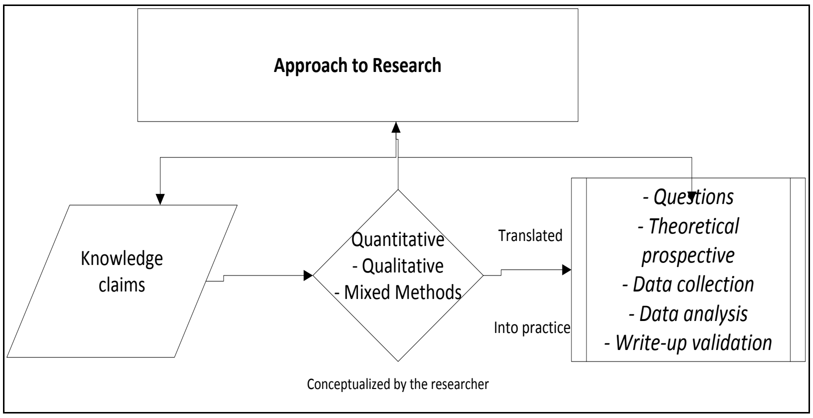


Figure 2.6. Research Methodology, Creswell (2003).

Quantitative methodology approach suggests a different tactic to conduct research, such as, experiment and survey. Experiment is a technique in which the study relies on conducting arranged field tests with subjects; those subjects undergo random assignments, behavior and settings; it also includes a nonrandomized design of quasi-experiment. The other methodology used is Surveys; this technique includes methods, such as, structured interviews or questionnaires that depend on the claimed knowledge; the survey could be either random or with selected groups and then the results spread to a wider population. Researchers adopt the positivism perspective claims where personal opinions could lead to inclined results therefore, to avoid any bias this type of opinion should be avoided in the research (Carter, 2007). Due to that, quantitative data are mostly used with positivists (Brown et al., 2003).

In qualitative approach, there are many strategies utilized such as Grounded Theory and Case Studies; in Grounded Theory the researcher relies on the views of the study participants to ground his abstract theory; while in the Case Studies technique, the researcher investigates in depth a process or an activity. Creswell (2003) and Crotty (1998) suggested that qualitative methodology is mostly used with interpretivism philosophy due to its approach.

Guba and Lincoln (1988) argued that qualitative and quantitative methodologies can't be combined due to different assumptions and epistemological method that each one follows. In contrast, Patton (1998) and Hassard (1993) recognized mixed methodologies as a possible research approach, and the difference in their epistemological method and assumptions are not fixed and unavoidable.

The author views that the mixed method, which combines qualitative and quantitative methodologies, is suitable for this research because it combines both detailed view of the meaning and the generalization of the concept under study.

As stated earlier, the researcher developed his methodological approaches based on pragmatism philosophy; this combines qualitative and quantitative methodologies to enable a variety of techniques to be used in the research including collection and analysis of data through the use of surveys; and test the hypothesis through experiments, utilizing literature reviews and the case study techniques to accomplish the research objectives. Figure 2.7 illustrates the current thesis framework philosophy of approach to knowledge, it provides a detailed description for each techniques used in this thesis; and the validation of use is conveyed in the relevant respective chapter.

framework				
	Epistemology	**Theoretical Perspective**	**Methodology**	**Methods**
Approach	Objectivism	Pragmatism	Combined Qualitative and Quantitative Style	Experiment Survey Case Study Ground Theory
Technique	To test the theory and examines the hypothesis in predicable manner	Due to problem solving style based on practical uses perspective instead of the degree of accuracy	Detailed overview of study concept	Literature review Field test Questionnaire Observations Statistical Analysis Discussions

Figure 2.7 Theoretical Framework of the Study

Research methods used to achieve the thesis objective is summarized below:

2.4 Hospital Lighting Preferences

Light affects people in two ways, visual and nonvisual; these two effects have many parameters and indicators on which we can judge the quality of light. Visual effects of lights had been studied in many researches (Guba, and Lincoln, 1998; Maynard, 1994), and it concluded four main causes of satisfaction about any lighting design which is categorized into the following:

- Visual comfort (Glare, colour, bright…)
- Lighting level
- Lighting direction
- Lighting source preferences

Review for the previous studies was conducted to investigate these factors and in particular, the light effects on human mood and social behavior. Review of the past and current studies, including studies on hospital lighting system technologies, policy and standards was attended to earlier. A comprehensive review of policies and standards was carried out to refine the current criteria of hospital lighting design; these were analysed qualitatively to establish a hierarchy of ward design criteria. Dalke et al (2006) studied light in hospital and determined that there is a strong links between the aspects of light as an element in the healing environment and the way staff and patient response to it.

The non-visual effect of light on human perceptually and physically was studied as well; the reference to the key studies in this field was presented with emphasis on the main findings and recommendations. This review has been reported in Chapter Three.

2.5 Survey: Develop and Launch a Questionnaire

A questionnaire survey was developed as a method to analyse the subjective judgments of the hospital staff lighting requirements and satisfaction. The questionnaire contains many questions designed around human factors in lighting (visual and nonvisual effects of lighting design on the staff) that are in line with the view of Boyce (1981); the surveyed factors are behavioral influences of lighting, psychological aspects of lighting and subjective perception for light. The survey was constructed so that the relationship between lighting type and hospital staff performance is examined; the correlation between lighting type and health is studied as well. The aforementioned questionnaire was administrated with face-to-face interviews utilizing paper form questionnaires. A number of questions using Likert scale response were asked to investigate a wider insight into light impact on hospital staff, from the hospital professional's viewpoint (Carifio and Perla, 2007).

The hypothesis which has been tested is that "The Daylight created by Smart Lighting System in hospitals could positively correlate with staff performance"; qualitative assessment is made through questionnaire data, analysed to test this hypothesis. Hence, if the hypothesis is confirmed, hospital designers and regulation makers should focus on providing more daylight in hospital design rather than governing the energy saving provision in their design. Description of the survey, its question design details and analytical are provided in Chapter Four.

2.6 Analyse Questionnaire Result

Statistical analysis techniques were employed to link the hospital staff behaviors and performance with lighting regime; data collected from the questionnaire will be grouped and analysed using different mathematical methods. These included exploring possible consistencies in answers, analysis common factors; looking for correlations and inherent variances. IBM software Pack (SPSS) was used to carry out the statistical analysis

(Argyrous, 2011). Complete description of the statistical analysis, findings and results presented in Chapter Five.

2.7 **Case Study: New Lighting Solution**

Due to many difficulties, the provision for daylight in hospitals of hot climate countries is not sufficient and this will be explained in this research; an alternative source for daylight is needed to compensate this important factor in the healing environment like hospital. To overcome this fact, new lighting system has been proposed by Philips Company named Healwell Lighting System[33]; this system uses artificial lighting to emulate Daylighting and at the same time provides the required task lighting. However, designing electrical light that simulate the external daylight characteristics, improve staff mood, performance, decrease medical error and at the same time use minimum power consumption could be the new integrated lighting solution for health care facility. Analytical descriptive will be carried out on this lighting system by installing it in one of Qatar hospitals. System features and characteristics were studied and potential problems analysed with proposed solution.

2.8 **Experiment to Evaluate Smart Lighting Functionality**

One of the main objectives of this study was to assess the impact of the Healwell Lighting System on the hospital staff performance. To perform this test, the experiment has been performed based on three scenarios of lighting; Classic Lighting, Daylighting and Healwell Lighting System Scenarios. Thirty male and female nurses from skilled nursing facility staff in one of Qatar hospitals have volunteered to participate in this experiment; an ethical approval was granted prior to conducting the test. The experiment was conducted at evening time to eliminate any contribution of external source of lighting to the test room. The Classic Lighting Scenario installed lighting using the standard fluorescent light and will be referred to as the “Reference’’ Lighting Scenario;

[33] http://www.lighting.philips.com/main/application_areas/healthcare/healwell.wpd

the Healwell Lighting System Scenario, the newly installed lighting scenario (SLS system) will be referred to as “SLS” Scenario; as for the Daylight Scenario, lighting effect will be assessed during the day time with curtains opened and will be referred to as ‘’Daylight’’. The work under Daylight Scenario will be compared to the work under Reference Scenario to confirm that performance under Daylight is better than normal lighting and then ‘’SLS’’ Scenario results will be compared with the Daylight Scenario to see if this new system is competing.

The test was divided into two stages; the first stage is the induction where the participants have been informed about the nature of the study and what is expected to do in each stage; Ten minutes spent in Induction and to allow the participant to adapt to the lighting environment; consent forms were signed during this stage prior to starting the test. Second stage is the Implementation in which the test papers were given to the participants to do the structured test; 30 minutes spent in this stage. The performance test starts with Alertness monitoring test known as Karolinska Sleepiness Scale (KSS) ratings, followed by Freiburg Visual Acuity and Contrast Test (FrACT) (Akerstedt and Gillberg, 1990); this test allows to evaluate a person’s contrast threshold and visual acuity through recognition of correct Landolt-rings on computer screens (Bach ,1996); as suggested by Courret (1999), the experiment should be followed with a paper-based test using Landolt C rings (Courret,1996). The last part of each test was the paper-based questionnaire where each participant shall fill-out to provide their opinion on the lighting regime. Test sequence, participant selection criteria and procedure details were explained in Chapter Five.

2.9 **Hospital and Energy Efficient Lighting System Design**

The impact of using energy efficient lighting design in hospitals has been studied as part of this doctoral thesis (Author and Soori, 2012). Many studies found that lighting in commercial buildings consumes considerable amount of electrical energy (Author and Soori, 2011; Galasiu et al., 2007), and in the healthcare sector it can reach up to 40% of the total consumed power[34]. The shortage in energy resources worldwide necessitates joining all efforts to improve the efficiency of the designed systems and reduce energy consumption. The performance of different types of lighting installations used for hospital lighting system design will be discussed from two perspectives: energy consumption and cost impact. Energy efficient lighting design methodology for hospital is presented in chapter six to achieve optimal and efficient lighting design. Simulation software was used in the experiment to assess the efficient lighting scheme functionality; in addition, mathematical analyses were used to determine the cost effectiveness of each solution. A detailed description of these methods including case studies was presented in Chapter Six.

2.10 **Structure of the Thesis**

This research project was designed in a logical terminology to achieve the specified research objectives. It started with identifying the research aim and objective, followed by literature review and analysis of the appropriate approach towards the knowledge; this was conducted through survey of the available theories and philosophies. Among many methodologies, an innovative research style was chosen to combine mixed style research approach, in a suitable scheme.

The research starts with identifying the current problem of lighting design in hot climate hospitals; special emphasis is placed on the role of daylighting in improving the mood and performance among hospital staff; and understanding the factors affecting lighting preferences, including deeper insight into how the current policies govern such design.

The importance of this study is that it involves the hospital staff in the experiment which gives access to comprehensive insight on the issue being investigated i.e. impact of light

[34] U.S. Energy Information Administration, survey of commercial buildings, EIA,2003.

on hospital staff. This thesis was configured in eight interconnected chapters, so that each section aims to address the research objectives in different methods. Figure 2.8 shows the outline of the research and each chapter overview as follows:

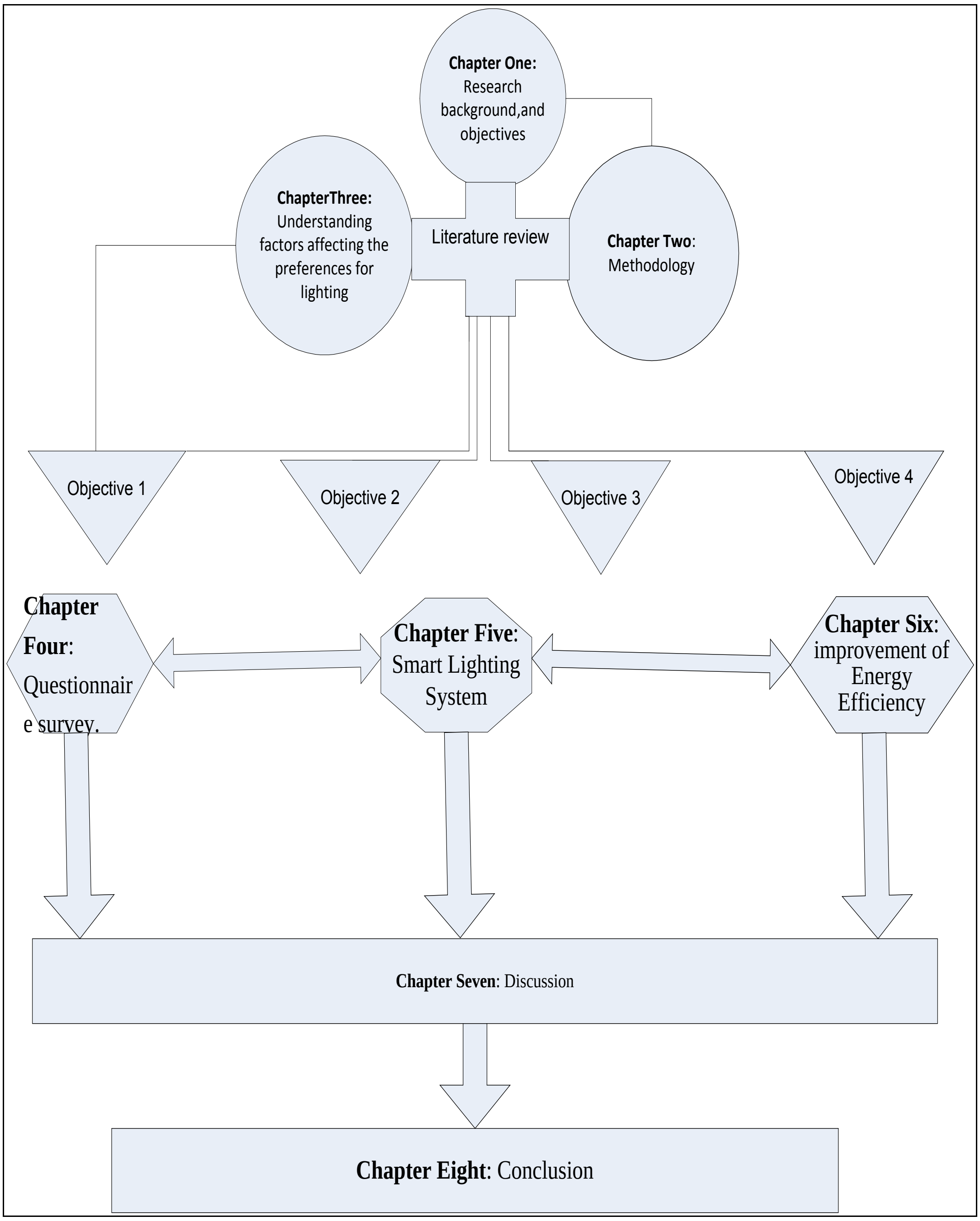


Figure 2.8 Research Structure

2.11 **Thesis Chapters' Outlines**

Chapter One: Background on Hospital Lighting Design. This chapter provides the introduction to the thesis by giving an overview to the research topic; summarizes the literature in terms of the relations between Lighting and Health, and daylight impact in the healing environment. It discusses the hospitals lighting design development (i.e. modern vs. historical). Surveys made on hospital daylight design Guidelines, Regulation, Common Practice and the obstacles of hospitals daylight design in hot climate region. Research question, aim and objective are included in this chapter as well.

Chapter Two: Methodology. In this chapter the approach to knowledge, overview on the existing philosophies and theories and justification to select certain methodology were all discussed; each objective in this research were interrelated to the technique used in this research.

Chapter Three: Understanding Factors that Affect the Preferences for Lighting. In this chapter an understanding of lighting preferences theory and its associated impact on individual's work performance have been discussed in the literature that has been investigated.

Chapter Four: Questionnaire Survey. In this chapter, the paper-based questionnaire technique used in this research is described; how it was developed, its conceptual design, and the structural framework. It also discusses the type of the survey used, questions content, statistics approach and administering methodology. The chapter also provides an overview on the employed analyzing software Statistical Package for the Social Sciences (SPSS) and coding techniques.

In addition to the hospital professional's subjective judgments on lighting preferences, the survey's results were used in numerical method. A statistical framework was applied to combine all of data with the aim to address thesis objectives one and two. Statistical techniques applied were described in details in this chapter. Graphical and Numerical illustration were used to present the findings and results of these analyses before it was discussed thoroughly. Furthermore, the results of staff comfort and staff performance experiment were linked to the measures that need to be taken in order to achieve preferred hospital lighting. The importance of this chapter is to provide data from hospital staff's subjective judgment on lighting in hospitals; this will provide regulation makers and hospital designers with references to the important factors as it reflects the opinion of the hospital professionals and emphasizes the importance of using good daylight in the healing environment. This data is important as well for proposing a new lighting system as introduced in Chapter Five of this thesis.

Chapter Five: Smart Lighting System; this chapter presents the proposed lighting system solution (Healwell by Philips) and the daylight problematic in the hot climate countries hospitals; complete description of the system with key features will be presented; focus on its influence on improving performance and energy efficient technology. The other part of this chapter was focusing on assessing the proposed lighting system visual and performance comfort by conducting an experiment in a mockup room in Hamad Hospital in Qatar; complete description of the experiment methodologies and procedure will be introduced. The assessment results for visual comfort and performance were also discussed in detail to validate the selection of the system.

Chapter Six: Hospital Energy Efficient Lighting System Design; this chapter focuses on proposed measures to achieve energy efficient lighting system in hospitals. It assess the energy performance and lighting power consumption through a case study in the hospital. Cost impact of using such system was assessed as well. Complete experimental configuration and methodology and the main elements utilized were discussed. The results were presented in graphical and numerical forms to show the possibility of achieving energy savings lighting design in hospitals.

Chapter Seven: Discussion. This chapter discusses the findings of this thesis with analysis of the efficacy of the proposed new system in relation to provide higher quality lighting in low latitudes.

Chapter Eight: Conclusion. This chapter summarized the findings and what has been achieved in relation to the research objectives; discuss the limitations and potential implementation of the achieved results in different areas; it also provides comprehensive conclusion for this thesis.

Chapter Three: Understanding Factors Affect the Preferences for Lighting

3.1 Introduction

Generally, good quality lighting systems will help users do different tasks in a comfortable and efficient manner. Through evaluating the efficiency of the lighting systems, it not always easy as it is connected to other factors such as visual and non-visual elements playing important roles in judging how well the lighting is environmentally performing.

Visual preferences of lighting include many elements such as visual comfort, glare free, colour comfort, brightness level, illumination level, lighting direction, controllability of lighting and availability of daylight and the way it is it is been controlled; these factors were the subject of many studies as main driving factors in determining peoples' preferences for light (Boyce et al., 2003; Linhart and Scartezzini (2011) Rae (2000); Author et al. (2013); Boyce (2014).

Nonvisual factors that have great impact on users of lighting systems includes factors such as sense of visual clarity, feeling of spaciousness, impression of relaxation, impressions of pleasantness, perception and attitude towards lighting and uniformity of luminance; these factors will be studied and discussed to see its effect on hospital staff preferences of lighting system. The other factors that affect users' preferences for light include user age, type of facility building and task being performed.

Considering all these factors and the wide range of elements that each one leads to different results and opinions, the imposed upon question is about whether there is a definite factor/s that the lighting system is affected by? Although it is hard to define however, there are two main factors in common; first is the lighting system ability to provide adequate illumination that satisfies the occupants, where the effectiveness of a lighting system would seriously degrade with inadequate illumination level, second is the colour of the light source in conjunction with the building's architectural elements.

Most buildings and in particular healthcare buildings utilize a combination of daylight and electric light to illuminate different spaces in the building however, these two sources of light and notwithstanding seem to be an ideal solution but still absolute satisfaction is not achieved (Boyce, 2014). We learned from the previous chapter how these two sources of light type's impact human health and performance. In this chapter the factors that are affecting occupant preferences for light will be studied and analysed.

3.2 **Relation between Light, Work and Performance**

Most people spend a great amount of their time doing some kind of work. They rely on the lighting to provide the required visual level at workplaces to enable seeing properly and do their work accurately, quickly and easily. There are many studies which explored the environmental factors that impact people's work performance; lighting condition was appreciated as one of these factors which have considerable impact on the worker performance as cited by Boyce et al. (2003), Joseph (2006): Kamali and Abbas (2012); Linhart and Scartezzini (2011) and Author et al. (2013).

Most of these studies can be classified into three groups: first group is the real-task research, which is primarily focused on investigating the individual's performance under real tasks (Manav, 2007; Linhart and Scartezzini, 2011), the second type of research is the subjective judgment studies, this group evaluates the individual's subjective judgment of light setting considering work performance through surveys and questionnaires (Galasiu and Reinhart, 2008; Kamali and Abbas 2012; Boyce et al., 2003; Author et al., 2013) while the third group was looking into the theoretical aspect of this relation through abstract research (Boyce et al., 2006; Dalke et al., 2006; Dale and Tiller, 2012).

There are many differences between these three groups, the main and the crucial one is the validation and generality, Boyce (2014). For instance, in the real task research individuals are asked to do a specific task, then the researcher appraises the performance based on that task, the only variable within the room space is the use of different lighting conditions, usually light setting is selected because it is easy to be monitored and controlled, example of that is the task lighting illumination level (Kamali and Abbas, 2014), change of the lights source colour (Kwallek et al., 1990: Fairweather et al., 2000) and variation in the light distribution of the luminaries validation (Saunders, 1969). The issue with this type of studies is that, it relies on measurements that are taken either through a real task in the field or using the simulation scenario of that task at a smaller scale, such as, in the laboratory. This type of studies was criticized for having high face validity, but only for specific task (Boyce, 2014), mostly if it is conducted in the field however, the results will lack generality on the conclusion.

The generality requires wide use of the experiments and the results beyond the specific task with lighting installation used (Schunn and Anderson, 1999). The use of different combinations of lighting system along with a specific task could lead to variation in the motivations among people and the effect it creates on the visual system and would produce different arrangements of visual components (Author et al., 2013), therefore it is not easy to generalize the results found in a certain research area or task to another one. Despite the expansive amount of the research that investigate certain actual tasks, researchers such as Boyce et al. (2003) suggest that we are still far from a generalization of the overall pattern but, the findings of this research are offering enough to knowledge and believe that changing in lighting settings can change task performance. The other difficulty with the field studies is the experimental control degree utilized is not easy to be maintained under control (Hartnett and Murrell, 1973; Akashi and Boyce, 2006). In the ideal field test there are many elements which should exist to control lighting settings and its characteristics, the way of installation, other elements, such as, room architecture, its wall colour, size of doors, windows, time of the experiment, the methods participant involved.All of these elements are not simply to be controlled and to be fixed over a wide range of studies. An example of field experiment that can be considered is the Buchanan et al. (1991) study; in their experiment they studied the impact of increasing the illumination level in the pharmacy on the staff, considering the error rate of prescription dispensing. They found that changing the light has resulted in a substantial decline in error rate; the study utilized considered examination of more than 10,000 prescriptions. How we judge on the field studies authentication is not easy, it should be cautiously studied to be able to rely on result and to consider that the conclusions are justified. This result would not be reliable without getting sufficient information about the experiment and its conditions, the way the test is done, the method of gathering the data and how the analysis was statistically presented. Researchers such as Boyce et al 2006 tend to consider the experimental field test results as assertions not statements of fact to avoid over evaluation of the outcome.

The second type of research is those which involve gathering the information from a sample of individuals relying on their subjective response of questions related to light setting and considering work performed (surveys and questionnaires). This type of research technique utilizing surveys is popular due to its generalizability, relatively quick, efficient and versatile administration. Efficiency of this method is represented by the many variables that can be measured without noticeably increasing the cost or time, depending on the survey design (Author et al., 2013), the popularity of this research method as generalizability is gained due to utilizing a wide range of subjects and subgroups to be sampled. On the other hand, the possibility of error and getting wrong results is high due to the simple method usually used to carry out the survey or questionnaire that could be implemented by organizing a form with questions and asking random participants to answer these questions. The good results could be obtained when the surveys are well organized and designed (Cook et al., 2005; Andersen, 2009).

The third group focuses on the abstract studies, which best describes the research that makes use of a task visually simple and usually is not common work that most people will never do for a living (Boyce et al., 2003). The primary goal of such research is to understand how the lighting conditions influence the subjective visual performance under a simple task (Linhart and Scartezzini., 2011). The results of such research are generally represented by a mathematical model, which provide a prediction of the performance of the task under other lighting conditions that is not being studied, this is done through thorough investigation of the influence of many tasks on thevisual system, with this type of model simulation researchers should be able to predict the performance of any task under different lighting settings.

While these three groups of research methodologies are different and interdependent, the results of the real task studies can't be understood without reviewing the results of the subjective judgment and the abstract studies. At the same time, we can say the abstract studies can't yield valuable results without considering the results of subjective judgment studies and the real-task studies.

3.3 Lighting Quality

There is no firm definition that describes the lighting quality, however alternative approaches were suggested to describe this term (Loe and Rowlands, 1996; Bear and Bell, 1992; Boyce and Cuttle, 1998; Veitch and Newsham 1998; Boyce, 2003). Veitch and Newsham (1998) gave definition through the level that the lighting design meets the limitations and intentions agreed by the customer and the designer; then the lighting quality in this case is associated with the intents such as improving the performance of related works or tasks, producing the required impressions, making preferred configuration of behavior and making sure the visual comfort is met, similar description were adopted by Boyce et al. (2003).

Traditionally, whether the lighting system is designed to sufficiently illuminate spaces for different tasks and activities been judged in terms of illuminance level measured at that place; this methodology was adopted by many standards and writing bodies Chartered Institute of Building Engineers (CIBSE), the Illuminating Engineering Society of North America (IESNA) and the International Commission on Illumination (CIE), which set the recommended illuminance levels for different types of work. In the UK, CIBSE lighting recommendations are particularly important for workplaces, as these regulations have been endorsed by many legislative bodies (CIBSE 1997, NHS 2000).

The lighting requirements vary from place to place depending on many parameters such as purpose of usage and activities done within that area.

Currently, the methodology used to determine the lighting quality and the complaints about lighting is to determine if the measured illuminance meets the specified standard (Boyce 2006). For instance, when the measured illuminance meets a specific standard, then we conclude that the lighting system quality is good and no reason for the complaint. Obviously, this is not always the case; studies show lighting level is only one parameter that addresses one aspect of a very complex problem (Jones, 1996; Boyce. 2003; Author et al., 2013).

Another important aspect that provides better understand of light quality includes parameters, such as, the contrast of the object against its immediate background; the object's size, which is calculated in reference to the point of view of the observer; the observer's age, where Jones (1996) found that a person of 60 years-old would need almost double or triple times the lighting need of a person of 20 years-old, and that for a person at 86 years-old would need five times of that lighting in order to achieve the same sharpness of lighting level. Veitch (2001) sees that the different lighting need is associated with age because of age clouding the lens and the decline in retinal ability. The other factor is the adaptability, which means adaption of the light over the view field, adaptation are neural and physiological responses to the light, in which our visual system altered with a lighting system which might be different from the one being exposed to an immediate preceding period; elderly persons' eyes could take a longer time to adjust to the light level changes (Veitch, 2001). These four parameters represent the constraints that would affect the visibility of an object and would therefore impact the lighting quality when viewed from personal judgment.

In general, light is needed to enable people to see, however it is not totally accurate to say that illuminance is the stimulus for vision. It is accurate that light represents a transporter for visual information which carries to the observer's eyes and then it passes through the nervous system to analyse the visual data.

Evidently, the main two factors in determining the light quality are the understanding of the nature of the work itself and the visual system capabilities of the subjects, which is an important aspect in assessing the lighting quality compared to the current method that determined the illuminance level on the working plane. Veitch and Newsham (1998) suggested that we can assess the human’s visual system capabilities by conducting surveys combined with field tests.

3.4 **Visual Preferences of Lighting**

Visual preferences of light differ from person to another, it would be almost impossible to find that all people agreed on the same lighting parameters (Newsham et al., 2005). Veitch (2001) and Brunnström (2004) see person age and type of work performed playing an important role in determining the visual judgment of lighting systems in any place, Boyce (2003), in his book, Human Factors in Lighting, examined the ways people interact with lighting and presented age as one of the factors which impact lighting preferences. Perlmutter et al. (2013) suggested that older people need more light than younger people to see objects well; that they receive less light at the back of their eyes, the reason is that with age pupils get smaller and thicker lens inside the eye will be developed. Charness (1999) highlighted elder eyes need to absorb more light to be satisfied with the lighting environment. Eldred (1992) confirmed that the advance in age results in scattering most of the light entering the eye, which creates unclear vision and forming what is known as "luminous veil" and affect the elder person's capability to see objects clearly.

There are many ways to understand people's preferences for light, surveys, experiments and interviews are the most common ways of gathering information from people on the most preferred type of lighting system. A study conducted by Rae (1991) suggested that there are many elements that affect the person's judgment on the lighting regime in any place that includes visual comfort, lighting level, lighting setup, ability to control the light and availability of daylight. There is no doubt understanding peoples' preferences for a lighting system is neither easy nor a simple question; we need to look at many factors, including the visual performance required to perform that task, the amount of illumination level and other light characteristics (Veitch, 2011).

3.4.1. *Light and Visual Comfort*

Visual discomfort caused from a number of lighting related factors, Veitch and Newsham (1997) found that discomfort could occur when there is glare and Hoffmann et al (2008) sees the light colour would have a great effect on person mood and comfort. Veitch and Newsham (1998) see bright or dimmed light, non-uniform distribution of lighting, too much variation in luminous distribution and presence of veiling reflections are all factors that impact visual comfort and should be considered for visual comfort. Boyce (2003) suggested that there is no easy and straight-forward path to follow when developing visually comfortable luminous environments and suggested the combinations of many factors. Winterbottom and Wilkins (2009) presented spacious and brighter light as the elements involved in promoting discomfort and impairing task performance; these factors could have a major effect of visual comfort and hence recommends that all light characteristics be considered when designing light systems. Glare is defined by CIE as the "condition of vision in which there is discomfort or a reduction in the ability to see" however, it is not easy to be measured due to the fact that light perceived is subjective and it is related to the other factors, such as, person age and task preformed (Author et al., 2013). The common way to address glare problem is to follow the international lighting standards and lighting committees, such as (IEEE, EN, IESNA and CIBSE); these regulatory bodies provide lighting recommendations for a Glare limits for different tasks that can be considered as visual comfort in different types of rooms and activities. These guidelines on light represent the best practice of lighting design in a space, provided that the lighting design would not exceed the glare limitation range. The main purpose of these guidelines and recommendations are to reduce or eliminate any visual discomfort that might be caused because of the lighting setup, however the lighting designer's job is not only to reduce visual discomfort but to provide visual comfort.

Another factor impacting visual comfort is the lighting colour; lighting can have considerable effect on peoples' perceptions and responses to the environment (Birren, 1978) and also affect patient recovery rates, improving the visual quality and overall experience of patients, staff and visitors (Tregenza, 2011; Author et al., 2013). Lighting Colour are also powerful tools for navigating, coding and wending, while Correlated Colour Temperature (CCT) and the Colour Rendering Index (CRI) are used to describe the colour of the light. To simplify the concept of light colour and CCT colour selection the lamps that have a CCT of 2700 K, its light colour is called yellowish colour and in general perception it is described as warm white; where a lamp with CCT of 6000 K seen as having bluish appearance and its light is called cool light (Author and Soori, 2011).

Previous research on colour preference revealed that people have preference of some colours more than others (Taylor et al., 2013). Other researchers (Hurlbert and Ling, 2007; Palmer and Schloss, 2010) found that people are favoring blue colour more than yellow, proposes that the preference of colours is connected to the objects that are associated with that colour. In other words, people dislike dark greenish yellow because it was associated with entities such as rotten food, dirty water and bile, while blue colour was preferred because it was linked with liked objects, such as, clean water and clear skies, as referenced by Palmer (2010) in his survey. Recent study by Miller (1998) suggested that the lighting colour temperature preferences are based on peoples' culture and driven by climate-related preferences; in line with this study suggestion Ayama et al. (2002) established that climate has a significant effect on lighting colour selection and how people prefer it.

Boyce and Cuttle (1990) proposed that people preferred to use low CCTs when associated with low illuminance level and high CCTs are preferred when high illuminance is needed; this might indicate that the type of work being done has a strong relation with people preferences and each workplace should have its own lighting colour. On the other hand, a study by Davis and Ginthner (1990) suggested that the light colour is an element that people can adapt to when they spend certain time in a space. In more recent research, it has been suggested that light in a blush colour (above 6000K) could increase human alertness.

A key concern for medical staff is to be able to alerted and be able to identify correctly the changes that might occur in the patients' skin colour, which usually is accompanied by physiological changes inside the body (Joseph 2006, Author et al., 2013). An example of such colour change is when a patient's skin turns yellow, which might indicate some liver problems, while blue skin colour might be a sign of breathing problems or red colour skin refers to skin problems (Leavitt and Leavitt 2011; Author and Soori, 2012). In contrast, changes in skin colour may be a sign of an improvement in a patient's health over time. These facts are essential to identify the patient's skin colour and in order to do that, the lighting system should be designed to provide the medical staff with the ability to easily recognize and differentiate any changes in the skin colour. Researchers believe that more research is needed to confirm the effect of lighting colour on staff comfort (Joseph 2006, Boyce et al 2003; Taylor et al., 2013; Winterbottom and Wilkins, 2009).

3.4.2. *Lighting Arrangement Preferences*

The association between lighting arrangement and visual capability had been studied in many research (Durak et al., 2007; Rae 2000 and Baumstark, 2008); these studies suggested that the direction that we view a light source from has a profound effect on how the objects in a scene will appear and on its perception; its design technique usually used as an environmental stimulus that has a significant effect on visual comfort, perception and preferences.

Decide on the lighting design direction of each space is important since it will have a significant deal of impact on how the space scene will appear, and what kind of emotions the image will convey. Lighting studies suggested that lighting direction is a factor that affects people and product evaluation (Obermiller and Bitner, 1984,) and it can significantly enhance or hinder the purpose of place design atmospherics (Areni and Kim, 1994). Previous research present some evidence where the type of lighting influences impressions (Ornstein, 1989b); this concept was confirmed by the research of Flynn, Spencer, Martyniuk and Hendrick (1973), which found that using the same room with different lighting arrangements result in different impressions of friendliness, spaciousness and pleasantness among the building occupants. Similarly, Martyniuk, Hendrick (1973), Spencer and Flynn (1977), confirmed through conducting experiments that a room with different lighting arrangements impact people's impressions of friendliness, spaciousness and pleasantness; this research confirmed that when use a wall lighting arrangement it will result in a positive impressions of spaciousness, friendliness and pleasantness, compared to the overhead diffuse lighting.

The Illuminating Engineering Society of North America (IESNA) introduced lighting arrangement recommendations for many areas based on their usage and work being performed; however this recommendation needs more studies to support these selections.

A recent study by Durak et al. (2007) explored the relationship between lighting arrangement and the perception of the same space using three types of lighting arrangements, general lighting, wall washing and cove lighting; the study revealed that different lighting arrangements could be used to enhance the clarity, spaciousness, relaxation, privacy, pleasantness and order of a roomAstudy conducted by Rea (2000) suggested that even small spaces, such as, fitting rooms in retail stores need thorough investigation to decide on the best lighting arrangement. People's opinions and preferences are taking the most priority within this space in addition to its effects on the overall function of this room; that dressing room in retail shops would have to achieve a good perception for buyers to use horizontal (overhead) and vertical (frontal) lights in certain arrangements, similar lighting arrangements have confirmed its impact on users through the study (Mang, 2008).

Front lighting, side lighting and overhead lighting are the most common types of lighting installation; each type of light is placed to serve as a type of viewpoint; for instance front light is placed directly behind the viewer point of view, such as, those used by the flash photography, where side light can be used in corridors or even in rooms and the other type is the head lighting, which is the most common type in commercial and health care facilities. A study by Baumstarck (2008), Baumstarck and Parks (2010) suggested that personal appearance could be influenced by lighting direction, and that facial appearance of a person could be seen well in overhead lighting compared to frontal lighting, which can help reduce harsh shadows.

Despite the huge resources that has been allotted to design a building physical shape with emphasis on the suitable selection of the lighting colour and conditions, there is still a shortage in the scientific evidence that support these selections; Dalke (2006) sees that there is a lack of information and guidance to assist the development of a hospital’s visual environment, proposing more research in the field of lighting arrangement to focus on different elements of lighting that effect staff, patients and visitors.

3.4.3. *Controllability of Lighting*

A study by Moore et (al. (2002) was conducted to explore the importance of personal adjustments in office lighting, Post Occupancy Evaluation has been considered through getting the feedback of 55 office users divided into two general groups, expert and professional users' and all have been interviewed by pre-arranged questionnaires. The researchers also carried out some tests to quantify the effect on the users when they are able to change the illuminance to their satisfaction level, and to distinguish the effect of "control" from the effect of illuminance change itself. The study concludes that Brightness, Glare and Natural Lighting are commonly considered by the two participant groups as a very important aspect of office lighting, the study highlighted that lighting adjustment is not common in the office; despite that the majority of participants believe it plays an important role in the office lighting (Author and Soori, 2011).

Veitch and Newsham (1998) study gives good reference for the role of lighting adjustment in the office lighting design from the visual point of view. As far as Post Occupancy Evaluation (POE), the study did not quantify the acceptable adjustment lighting level, which building users should be able to quantify in the office by making adjustment applicable for the general lighting or just for task lighting. Veitch (2001) demonstrated in her research that people who rated the lighting as of higher quality (using higher illumination level) considered the space to be more attractive, were happier, and had better health and well-being in the form of less discomfort and greater satisfaction with their environment and their work; this finding confirms Kasof (2000) study, which sees that the lower level of light could provide more behavioral discomfort, highlighting the need for light level control and adherence to one's dietary standards. Early studies by Gergen et al.(1973), Page and Moss (1976), Mann (1981) and Melbin (1987) see that the dimly lit environment could encourage the different counter-normative behavioral expression that are not shown with the use of brighter lighting, and suggests further study and investigation are needed in this field.

3.4.4. *Daylight Preferences*

People generally have a preference to live and work in a space having windows rather than windowless spaces (Wetton, 1986, Shepley et al., 2012). This preference suggests that daylight makes the interior more satisfying and pleasant than the one which is illuminated only by electric light; it is easy to see that people close the windows and give up daylight if it is accompanying thermal or visual discomfort or a loss of privacy (Alalouch et al., 2009), evidence that clearly overrules the common thought of the presence of windows that would improve mood. A study by Boyce et al (2003) found that windows are appreciated because they provides daylight and view to the outside, set as proof of daylight preference.

A study by Hoffmann et al (2008), Author et al. (2013), Golec (2012) shows that utilizing different electric lighting settings can participate in changing people's mood with the space, so the obvious question to study is (what is the extent of the daylight that can impact the individuals feel with their workspace?). A survey of Cuttle (2002) and Veitch et al.(1993) found that the primary source of illumination that people preferred is daylight over electric lighting. Heerwagen and Heerwagen (1986) in their survey presented that the majority of office occupants prefer daylight suggesting that it is better to work for different purposes.

An interesting finding by Begeman, Beld, and Tenner (1997) regarding the lighting level suggests that people today prefer a higher indoor lighting level than the stipulated standards and this is seen as connected to the biological stimulation activities. Begeman et al (1997) believe that our visual, lighting requirement is not similar to the biological lighting requirements, and without sufficient light our biological stimulation activities could be affected and would result in health and performance problems. This finding is significant for night shift workers, as well as for staff who work during the day shift in the case of no exposure to daylight for a long time.

Recent studies by Heschong Mahone Group (2003), Author et al. (2013), acknowledge the link between daylighting and worker performance; these studies suggests daylighting as a factor that can help improve office worker productivity, this research highlights field experiment that daylight can impact the worker productivity positively or negative based on the way it is been applied, also it revealed that daylighting designs with minimal glare, low heat gain and even illuminance distributions could have positive impacts on performance. Some argument might arise here for the missing proof for the product itself, and if we can really measure it, otherwise these studies can be explained by “Hawthorne Effect", where the subjects (people) might adjust their performance only because they are being witnessed (under test conditions).

In hospitals, some researchers found that daylight can contribute to improving staff’s welfare, morale and performance (Author et al., 2013; Huisman et al., 2012, Lusk and Lash, 2005). In addition, it can affect patients’ recovery times, reduce stress and increase patients’ satisfaction. A study by Lusk and Lash (2005) suggested the light is an important element in the healthcare facility, which can improve staff mood and reduce stress; as it is well-known that in 19th century sanitaria sunlight was used as a cure treatment for Tuberculosis (TB), that a TB’s microbe is destroyed upon five hours exposure to sunlight (Mead, 2008). Huisman et al. (2012), in their study reviewed previous studies on healing environments and the factors that impact the physical environments and users; they found that the daylight is one of the important factors that impact the visual comfort and have important effects on people; access to daylight in the healthcare facility has a significant impact on patients as well as on staff. Preference for daylight is increased in hospitals that some researchers presented the daylighting as a factor that influence the recovery of patients based on clinical findings (Walch, 2005, Beauchemin and Hays 1996; Choi and Beltran, 2004).

A study by Alimoglua and Donmez (2005) conducted at a hospital in Turkey found that nurses who have access to sunlight during work felt more comfort and less stress. Another study by Mroczek et al. (2005) carried out in the healthcare facility to explore the natural light impact on staff comfort, revealed that forty percent of the staff, who have been surveyed see that the natural light can have positive impact on their work. In addition, some studies (Benedetti et al., 2001; Beauchemin and Hays, 1996) see a specific relation between sunlight and patient curing period, which implied that daylight play a significant role in reducing the length of patient's stay in the hospitals. To better understand the impacts of the daylight on the human body, it is important to know the emotional impact the lights have on our body. Studies by Boyce et al. (2003) and Veitch (2001) show that there are three areas where the daylight affect people, these are:

1. Physiologically: Küller (1987) suggest that daylight plays an important role in stimulating the human circadian system in addition to the human visual system, this effect was confirmed by Kasof (2002), when daylight enters the eye a complex process begins to stimulate the human body endocrine system and autonomic responses from inside.

2. Psychological: A study by Lusk and Lash (2005) suggested that sunlight improves the immune system and mood by making the patient feel more comfortable and at ease, another study by Walch et al. (2005) revealed that sunlight can be used to help patients use less pain killer drugs, which is confirmed in one of the retrospective studies on two types of patients. In the first case the patients stayed in the bright rooms with access to sunlight and others in dimmed rooms, the result of this experiment show patients, who stayed in brighter rooms experienced less pain and as a result they used less analgesics, proposing their stress level is less.

3. Sociability: Patient's emotional and behavioral responses are affected by lighting. A study by Wardono et al. (2012) and Shepley et al. (2012), demonstrated daylight impact on the patient's perceived behavioral sociability and emotion.

Today, modern hospital buildings have become more complicated in their design and structure compared to historical hospital design, where daylight was used largely due to their simple design, and daylight has become difficult to reach deeper areas in the building. In hot climate countries, the building design including hospitals has experienced lack of windows in their designs (Persson, 2006), even when it is been included in the building design we found it small in size and therefore captured less daylight (Boyce, 2003), this is basically due to glare and the high heat gain effect generated at these areas, where sunlight creates an uncomfortable workplace. In many hospitals, nurses' workstations lack the exposure to daylight, and we found studies which surveyed the daylight impact on staff mood or while performing specific task in hospitals are very few, this triggers the need for further research to understand the significance of the daylight on hospital staff performance and mood.

3.5 **Review of the Non-Visual Factors of Lighting**

Recent study sees the eye as merely an entrance to our visual system, like a camera (Boyce, 2014). Regardless of the fact that light is first observed through the eyes which collect the environments' luminous, the information will be processed in the brain, Boyce et al. (2006). Therefore judgment on the light scenes will be related to expectations and references, researchers found that light has effects beyond the use of mere vision; it synchronizes the biological clock in humans and the external time (Boyce et al. (2006), Veitch, Newsham (1998). Other studies by Abbas (2005) and Brainard et al. (2001) see light as a major synchronizer for biological rhythms of the body's internal clock, that in darkness periods human body makes melatonin, which initiates the tired feeling and helps us to fall asleep (Abbas, 2005) on the other hand, light in particular the blue spectrum reversals the melatonin discharge, which keeps us alert and able to concentrate.

The influence of light on human biological performance is not yet very well known. Researchers (Veitch, 2001; Veitch, Newsham, 1998) believe there is a need for more research work to understand the non-visual effects of light to be able to consider them in lighting design and practice. It is suggested that the research work is required to improve our understanding of different aspects of lighting and its effects on our behavioral visual tasks and how these biological effects interact with our preferences and responses. Research on the mechanism by which light affects our non-image internal activities, were all theories was not conclusive until Berson (2002) found how light is processed by intrinsically photosensitive retinal ganglion cells (ipRGCs) which mediate numerous nonvisual phenomena a photoreceptor in the retina that work as the first light-sensitive cells in the retina(Daniel et al., 2005) that stimulates the non-visual reaction in our bodies (called third receptor in addition to rods and cones) which was considered as the missing relationship between light and the biological effects of light and dark cycle, " They may also have a role in vision distinguishing patterns or tracking overall brightness levels and they seem to enable ambient light to influence cognitive processes such as learning and memory (Lok, 2011).

This finding inspired some researchers to understand other non-visual effects, Dacey et al. (2005), Duffy and Wright (2005) presented some evidence on the effect of light on alertness and mood, which suggested that light in specific conditions is preferred to augment alertness, not only these effects where observed because of light, but it extends to depression, stress symptoms, and increased fatigue. Dr John Flynn was considered as the pioneer in investigating the lighting psychological impact, Durak et al. (2007). In his works (Flynn 1973, 1977, 1979) classified the influence of light on our impressions into five areas: relaxation, privacy, clarity, pleasantness and spaciousness. These areas which influence the non-image preferences of people were the subject of many other researchers; Mehrabian and Russel (1974), Nuckolls (1983), Erhardt (1985), Tiller and Veitch (1995), Veitch and Newsham (1998) and Manav and Yener (1999) are among the important studies regarding these aspects. Review of these studies lead to conclude that despite the coherence in the research approach and findings, contradiction can also be noticed among the results. The psychological aspects of the light and the generated impressions in the space is not introduced as a firm consensus among the lighting researchers and designers, further investigation and exploration are needed to see how different lighting arrangements and illuminance would influence peoples' impressions of the space. Studies show that lighting can influence work through the non-visual forming system. However, there are many aspects of this system, which still need to be studied, until these aspects are fully investigated, their effects on people performance will stay at potential more than factual.

The known aspect of light non-image effect on the individual performance is the circadian rhythm. Sleep–wake cycle is the best at describing the effect of light on our circadian timing system; this effect is well known however, there are many other variations on hormones over a day that affects our work and performance. A study by Dijk et al. (1995) suggested that light influences our work performance and can be understood when looking through the circadian timing system, and such understanding might be used to improve the work performance; the exposure to bright light at specific times was proposed as to control the phase-shifting cycle in which we can delay or advance the circadian timing rhythm. Campbell et al (1995) confirmed that the suppression of the hormone melatonin at night would increase alertness. Scheer and Buijs (1999) see that the work performance during the day can be enhanced by manipulating the cortisol hormone concentration; where Rugger et al. (2006) established the evidence that cortisol concentration would be increased if exposure to high light level occurred soon after awakening.

In summary, the Nonvisual Effects of Lighting are another area that affects the lighting and can satisfy subtle psychological and aesthetic ends. Moreover, the Nonvisual Effects of light have been assessed as qualitative and psychological effects of lighting that have been infrequently compared to the research on visibility; further investigation is needed to confirm the effect of the light on work performance.

3.6 Sense of Visual Clarity

Visual clarity has been claimed to be one of the light spectrum perception elements. Researchers such as Flynn (1973), Aston and Bellchambers (1969) were among the pioneer researchers, who suggested that the clarity of visual performance is related to a combination of light elements, such as Colour Rendering (CR), colour preference, colour discrimination and brightness; where high Colour Rendering Index (CRI as identified earlier in this research) were found to be associated with a higher degree of space clarity if associated with appropriate brightness levels Boyce (1977). This relationship between colour and brightness of light, were the focus of some researcher, who tried to understand the relation between visual clarity and subjective judgment; these studies employed subjects in their experiment, setting observers in prearranged rooms and requested those to indicate the visual clarity scenario in different lighting setups. In previous experimental studies, Fotios and Levermore (1997), Boyce (1977) and Bellchambers and Godby (1972), asked the subjects to select a lighting arrangement that would assure their satisfaction with lighting scenarios in terms of visual equality; the results show higher illuminance were selected when a lamp with a colour rendering of moderate value (CRI = 55–65) was used, this provided similar visual clarity preferences when a lamp with light colour rendering properties (CRI = 92) was used, the reference illuminance were selected to be similar to the average office lux level of 500 lx. The results couldn’t be established as a reference for future studies because in each experiment, the methodology used were similar but resulted in differences due to the different criteria used (Boyce 2003). Despite the vagueness of the term, light visual clarity shows a strong relation for many observers' clarity and what it means for each subject; results from previous research show balance between brightness and colour rendering in terms of the light clarity impression however, there can be little doubt that the illuminance ratios provide a measure of the clarity and space impression. The argument is whether that impression is created due to the perception of clarity, brightness or something else, which presents another difficult question regarding clarity. There is a real need for more studies to elaborate about how light influences the perception of clarity.

3.6.1.*Feeling of Spaciousness*

How the light influences our impression about the surrounding space is still a mystery. What makes it difficult to understand is that lighting installations that provide a perception of greater or smaller spaciousness have several different features that include lighting level, lighting direction and other architectural elements in the space. Boyce (2003) suggested that many elements contribute to forming our impression with spaciousness dimensions; lighting arrangement is one of these factors that stimulate our perception in any space. Bean and Hopkins (1980), Rolland and Hentschel (1987) see that the light distribution across the surfaces of the room would influence the subjective judgments of the users and how they appreciate the lighting quality. Ooyen et al. (1987), Tregenza et al. (1977) in their studies found that people prefer lighting arrangement that lit all the room with levels less than that on the working desk, proposing different levels yield better space perception.

An example of the effect of light on our perception is the lighting arrangement that provides light only on the office desk at a low illuminance would result in forming impressions with room as small and cramped (Linhart,2010), while lighting arrangements that provide illumination to all of the room (walls, floor and office desks) would create an impression of a large spacious room (Boyce, 2006). These two examples suggested that, lighting designers need to give more attention to the lighting arrangement because it influences the user’s impression of a room, whether it is clear, spacious or unpleasant, the first example showed a small unpleasant room fit for the task, while the second example room gives an impression of clear and spacious. These two experiments can provide some information to the lighting designer on the effect of different lighting arrangements on the space perception; however the basis of the decision of each scenario is not clear. Boyce (2006) suggested that rating scale preferences would provide a better source of information that it eliminates criticisms over the correlation procedure.

Another significant perception influence of light is that, it assists in orienting individuals within the place; Boyce (1974) show that people preferred to follow the direction of the higher illumination, brightening their way; this result supports the opinion which sees that the light can be used as a directing element into a space and would lead to aid circulation. Providing an appropriate sense with space as if large, small, long, short, spacious or cramped is important for the building occupant, because this non visual feeling will affect their preferences for that place and its importance will be greater if this place is their workplace.

3.6.2. *Impression of Relaxation*

The sense of relaxation is important for the building user, this importance increases when the lighting installation is used in a stressful environment like hospitals (Bailey 1980). Earlier studies by Benedetti et al (2001) and Beauchemin and Hays (1996) presented the impact of light on the length of stay among depressed patients, suggesting that the lighting installation in hospitals affect patients' moods, such as, feeling of relaxation or stress; another study suggested that exposure to light may be linked to clinically non-depressed patient's length of stay as well (Lusk B, Lash 2005). At hospitals' Intensive Care Unit, a study of myocardial infarction patients, who were treated in two different setup rooms; first room was a sunny room and the other one was a dull room; it revealed that in the sunny room patients stayed 2.3 days which is a shorter time compared to 3.3 days in dull rooms (Beauchemin and Hays, 1998); moreover the study explored the mortality rate in both scenarios and revealed that it was less in the sunny rooms compared to the patients staying in dull rooms (21/293 sunny, 39/335 dull). Another study by Federman et al. (2000) conducted at the Veterans Health Administration Medical Centre in the summer time, reach a conclusion that the patients stay a shorter time when compared to their length of stay at the same hospitals in the winter and fall, suggesting a link with light availability.

Some studies had explored the influence of artificial brightness and the impression of relaxation; in a study by Satlin et al. (1992), he suggested that older adults who were exposed to bright white light had experienced substantial changes in sleep quality, moreover sleep efficiency and waking time between sleep were improved. Someren et al. (1997) in their study, demonstrated that the rest and relaxing activity rhythms were improved among dementia patient having been subjected to bright light; and that daily monitoring of those patients who were exposed to a high daytime illumination level in different areas of the hospital units showed increases in the relaxation and rest-activity rhythms (Someren et al., 1997).

Mann, et al. (1986), Blackburn and Patteson, (1991) and Miller et al. (1995) in their studies regarding the relationship between relaxation and light level at night in newborn Intensive Care Units reach a conclusion that the reduction of the night lighting level results in improved sleep, suggesting that light level has non visual effects on the feel of relaxation.

In a study conducted at a domestic facility, the residents show high level of anxiety when exposed to low light levels (Sloane and Colleagues, 1998). Another study by La Garce (2002) explored the influence of different lighting elements on agitated behaviors of Alzheimer's patients; her study presented that some patients felt more relaxed and displayed less distressing behaviors living under constant light levels in contrary to living under varying light levels, which showed a higher stress level. A study by Lovell et al. (1995) explored the effect of exposure to high light levels (above 2500lux) on patients with dementia; it found that exposure to bright light lead to the reduction of patient's agitation. Empirical Studies, which explored the influence of light on the perceived relaxation in healthcare settings, are few. Alimoglu and Donmez, (2005) in their study at the healthcare facility examined the effect of exposure to sunlight on 141 nurses; upon surveying the nurses' opinions they stated that they experienced less stress and felt more relaxed when they work in areas where daylight is available. Mroczek et al. (2005) conducted a survey at the hospital facility to explore the effect of daylight on staff satisfaction; where more than thirty percent of the staff have confirmed the positive impact of light on their work life; this study sees the need for more studies to explore the significance of light (natural and/or artificial light) on the hospital staff and patients.

3.6.3. *Impressions of Pleasantness*

Light quality can be judged on the basis of the pleasantness and what impression of the visual environment it creates, and enables adaptation to the spaces we live and the activities we do. This psychological aspect of light influences our preferences for light. Ashby et al. (1999) suggested the positive effect concept, establishing that the production of a positive response towards surrounding environment is important seeing that pleasant feelings generated by circumstances or commonplace will lead to influencing a social behavior and cognition. The study suggested as well that positive effect improves the individual's efficiency of work, judgments and performance. Early study by Isen and Baron (1991) suggested that factors which determine what is the positive affect are both wide and small; lighting part of the physical environment and small changes with light conditions can stimulate the change in mood and then change in performance; changes in lighting settings could include changes in conditions such as the correlated colour temperature and illuminance level; this variation has shown influence on people's mood and behavior as confirmed by McCloughan et al. (1999), this effect was perceived as in line with positive affect (Baron et al., 1992). Obviously, the light is not the only element that influences mood and motivation, and that when we eliminate the visual discomfort and consider it at preferred levels, this small factor can contribute to the changes to our performance.

The logical question about the positive effect of lighting and the evidence that impact work performance when task visibility is held at a constant level during the day, Boyce (2006) sees that there is no firm answer to this question and most of these assumptions are hypothetical and requires further validation. Veitch and Newsham (1998) conducted field experiments to reveal the impact of lighting quality on worker performance at the office by producing a complicated arrangement of small effects that may or may not have been associated with differences in visibility which sees the variation in lighting elements that could result in change in mood and some behaviors.

A study conducted by Eklund et al. (2000) explored the effect of applying different light distributions on task performance that couldn't confirm significant effect on that task, despite controlling the light level of the work. Another study by Fostervold and Nersveen (2008) presented that small changes in lighting setup, such as, lighting direction can generate some effects on office workers cognitive performance. Boyce et al. (2006) presented in their study, the benefits of providing good lighting quality on the individual's work place; in their experiment, which was conducted in a laboratory setup to simulate standard office work and lighting design, asking workers to do different work under different lighting scenarios which reflect a better quality of lighting design is generating pleasantness impact on the workers. The light colour has shown significant effect on the users pleasantness perception; a study by Boyce et al. (2002) conducted at an office room utilizing two types of lights colour with the same illuminance level; one light was cool light with a CCT of 6500 K while the other test was done under light with warm to cold colours and had a CCT of 3500 K. With the same illuminance distribution in the test space, the light that have cooler colour (CCT of 6500 K) show perception of greater brightness create a pleasant environment. To confirm if the light CCT has a significant effect on the users, a study by Hu et al. (2006) found that there is no big difference in perception between participant when changing the light colour; similarly a study by Boyce and Cuttle (1990) established that the level of the illuminance influences the building users feeling for pleasantness more than using different CCTs.

The results of these studies show that the light illumination level has a big effect on the users appraising of the space, whether its pleasant or not; and the colour temperature shows lower effect, however still this small effect of light colour can change our perception of place (CIE, 2004c; Fairchild, 2005), and further investigation is required in this field (Vidovszky-Nemeth and Schanda, 2012).

3.6.4. *Perception and Attitude toward Lighting*

Boyce et al. (2003) in their study suggested that people's preferences and expectations may influence their response to different lighting settings, and that people's perception and moods are motivated by the conditions of different lighting types, that it likely can cause variations in mood, which would lead to affect performance and behavior at work. On the other hand, changes in mood do not have the same attitude among different people even when the same lighting conditions are utilized. Boyce, Hunter, and Howlett, (2003) see that with the same lighting settings, a person's preferences, discomforts, gender, and expectations influence changes in mood. Heerwagen and Heerwagen (1986) found that individuals prefer daylight over artificial light sources for work, suggesting daylight is perceived as a more comfortable source; in their study they explored the office employees preferred type of light source, the results show that daylight was chosen over electric lighting for many reasons including pleasantness, psychological comfort, and work performance. There are many attempts to understand how lighting conditions would affect human performance by looking at the changes in motivation and circadian timing rather than visible effect; the role of exposure to light on the circadian timing system has been the subject of much study, however the effect of light on mood is still in need of further studies. Kwallek and Lewis (1990) conducted experiments to explore the effect of different light colours (red, green and white) in an office environment and on the employees' mood and productivity; the study revealed that the subjects working under the red colour office show stress, tension andmade the fewest errors in proofreading. While the subjects who worked in a white office experienced a higher rate of errors. The other interesting finding of this study is that females performed better in the proofreading test, and showed more tension than males in the test. At the same time the participants agreed that the red colour office were more distracting than working in the white office; making the white colour office as the preferred colour for work environments and appropriate for an office. The study suggested that the white environment may not be the ideal colour for work as it is believed.

Leather, et al. (1998) see a significant link between sunlight and job satisfaction and that it had been related to improving work performance and mood, yet this relation has not been proven.

3.6.5. *Uniformity of Lighting*

Uniformity of lighting in space can be desirable or less desirable depending on the function of the space and type of activities. A study by Veitch and Newsham (1998) see that people are do not prefer to have a space completely uniform, while Eissa and Mahdavi (2001) see the extreme non-uniform lighting in any space as cause for distraction and discomfort. For this reason the lighting designer's recommendations usually refer to the uniformity of lighting space as the best practice to follow (BSI, 2011a).

Lighting standards and codes such as EN12464-12002, CIBSE 1997, IESNA 2000 usually provide recommendations for illuminance uniformity ratios in different places, to match the task areas and its surroundings. Loe et al. (1994) see the lighting design in any space as based on providing certain levels of illuminance come out of the light source, while the people visual system deals with the light reflected from the space. Room surface reflectance is an important part of a lighting system and affects both the uniformity and lighting. Tiller and Veitch (1995) found in their study that individuals prefer to work in a room with lower uniformity and used a dimmer to match the room illuminance level. Saunders (1969) explored the preferences for illuminance ratios in rooms through asking subjects sitting in the room for a long time how they appreciated the variation in the lighting ratio; the study revealed that the uniformity ratio, which was set as minimum/maximum illuminance, the preferred ratio was found to be below 0.7.

IESNA 2000 recommended having average illuminance uniformity of the task area 0.4 to 0.7, however this ratio can vary based on the application. Slater et al. (1993) confirmed this finding in a windowless room. Another study by Moore et al. (2002) see variations in the lighting ratios on office desks is preferred and the acceptable light uniformity ratio is about 0.7, which was appreciated without complaints especially when individuals were able to switch or dim the lighting from time to time. This might show that the space non-uniformity of light is traded for another benefit, such as, to create the feeling of the outside and lighting uniformity requirements can be perceived as a relaxation issue.

Clearly, most of the lighting recommendations (CIBSE 1997, IESNA 2000, EN12464)about the illumination uniformity focuses on the distribution of illuminance. While the visual system sees only the pattern of luminance. Slater and Boyce (1990) see that the standards and common practice do not have this as problematic in the workplace lighting and that the intention of the designers is to create a working environment of uniform reflectance, the variations in reflectance being introduced by the materials placed on the work surface, and that different settings lead to marginally changing the outcomes however the trends are constant. In brief, reducing illuminance uniformity make the light setting for most people acceptable, specifically, when dealing with a minimum illuminance uniformity ratio of about 0.7.

Rea et (al. (1990) see that even with achieving the minimum illuminance uniformity recommendation the probability of creating an uncomfortable environment due to the low reflectance desk surface is still there. Wibom and Carlsson (1987) surveyed more than 400 employees who worked under certain standard uniform illuminated desks to explore the eye-discomfort level, In most lighting standards, the famous "1:3:10” rule of thumb is often quoted; the result shows that when the luminance ratio was greater than 15:1 many of the participants reported eye discomfort.

Clearly, form the above, we can deduce that the recommended uniformity ratio that is shown by the standards should only be taken as a guidance and consider the other parts of the room to come up with a complete satisfactory light design and that high luminance uniformity is not always good for vision, and that illuminance uniformity achieved in any workplace is not the only factor that should be considered. In order to conform to EN 12464-1 the luminance from the room's surfaces must be relative to the luminance from the working plane. For example, when using low luminance luminaires and downlights, there is a risk that the tops of the walls and the ceiling may be too dark.

3.7 **Summary and Conclusions**

In this chapter an understanding of lighting preferences theory and its associated impact on individual's work performance have been discussed in the literature that has been investigated. Evidence from many studies show a strong relationship between light and critical human functions, and that lighting settings can influence task performance through three routes: the visual system, the circadian rhythm and mood. Lighting conditions can impact the visual system and therefore individual's visual performance. In healing environments such as the hospital, this can be a benefit to patients as well as to staff in healthcare. Good quality lighting settings are crucial for visual performance of tasks by hospital staff, and poor lighting environments show potential medical errors. A significant association was found also between type of light source and task been performed and that it had been related to improved work performance and mood. Light with its visual and nonvisual elements have great impact on users' opinions with lighting settings, the factors that are affecting occupant preferences for light can be classified according to its areas of influence, such as, sensation of visual clarity, feeling of spaciousness, impressions of relaxation, impressions of pleasantness, perceptions and attitudes toward lighting and uniformity of luminance, the other factors that affect users' preferences for light include user's age, type of the facility building and task being performed, these factors were the subject of many studies to see its effect on users, hospital staff were one of those users who had been the subject of many studies due to the important role they play in our lives and that their preferences for lighting system reflect professional judgment (Author et al., 2013). Lighting quality is an important aspect of delivering light to any space, previous study suggested that light quality is an element that is influenced by people's anticipations and previous experiences with light sources, for instance, people who live in villages and use elementary basic light might not have the same judgment on light quality like workers in the modern office (Boyce et al., 2003), also we learn that judgment on light quality vary from one person to another in terms of comfortable lighting conditions based on individuals' cultural regional differences. Two factors were established to determine the light quality in any space, these are understanding the nature of the work itself and the visual system capabilities of the subjects (Veitch, 2001).

Veitch and Newsham (1998) see many factors that have potential contributions to achieve lighting quality and users' satisfaction that include, e.g., lighting uniformity, light distribution, luminance and glare. These are important aspects of light quality, which should be assessed properly in any area lighting compared to the current method that determined the illuminance level on the working plane. Moreover, Veitch and Newsham (1998) suggested that we can assess the human's visual system capabilities by conducting surveys combined with running actual field tests on subjects, thus we can evaluate the complaints about lighting and we can determine if the measured illuminance meets the specified theatrical assumption.

Recent studies suggested that daylight can have a positive effect on staff and can contribute to improving staff's welfare, morale and performance (Joseph, 2006; Kamali and Abbas, 2012, and Author et al., 2013). Moreover, it can affect patients' recovery time, reduce stress and increase patients' satisfaction, these suggestions are based on clinical observation and personal opinions. However, further validation and more discussions with the concerned people need to be done. Another positive effect of daylight was referenced by some studies in particular suggesting that daylight in hospital could positively impact medical staff performance and could reduce medical errors. The question here is whether daylight can help hospital staff do their work in a more comfortable and better way. The question, which was the subject of many research, is how the light affects us, are there any conclusive results, and can the lighting setting influence our mood and performance. The answer to these two questions is that we are aware that the light has visual and non-visual impact on our physical and psychological activities, but still further investigation and confirmation form field studies is needed to establish more assertions and establish science based on a rigid theory, controlled field study and well-designed subjective opinion of the light users. Obviously, the important goal of such research will be to fulfill human needs for proper lighting design and to guide the building designer to provide an accepted lighting quality environment.

Studies that investigated the lighting influence on human mood and performance can be classified into three groups, these are the real-task research, the subjective judgment studies and abstract research. These three types of research are exploring lighting effects from a different methodology than from theoretical, field test and user satisfaction. By combining these three methodologies into one research, we can reach a more acceptable result on lighting quality. The majority of research that investigated the impact of lighting conditions on individuals' performance has focused on exploring the relation between the visual system and work; most of these studies were based on field research. These studies were criticized for their lack of validity and focuses only in one direction that increasing light level would improve task performance. The findings of these studies are limited due to lack of generality and reliance in the experiment on specific tasks. Subjective judgment studies based on controlled surveys and questionnaires gave some understanding of what individuals preferred and what can help them do their work is an important methodology in determining the adequate quality of light, however this methodology should consider the results from field tests and theoretical analysis.

3.8 Field Test and Experiment

In the next three chapters the research objective will be tested and the lighting preference among hospital staff will be explored. In chapter four, an investigation into the views of hospital professionals was carried out; a questionnaire survey was developed and launched with the aim to evaluate the hospital staff lighting regime preference. Survey results have been analysed and compared to the thesis pre-set factors affecting lighting design.

Based on the survey results, a new lighting solution was proposed to overcome the problem of lack of daylighting in hospitals as detailed in chapter five; innovative solution was based on the hospital professional's preferences and the identified effects of lighting design. In one of the Qatar hospitals, this proposed lighting type is subjected to test to prove its visual comfort and performance. In chapter five, light energy efficient design is another factor been selected to verify the proper selection of lighting design, and to achieve further improvement towards Energy Efficient Lighting System Design in hospitals.

Chapter Four: Questionnaire Survey

4.1 Introduction

This chapter presents the outcomes of the paper-based survey questionnaire deployed during this study. The questionnaire framework and its design concept were detailed according to chronological order and structure. The concept of pilot questionnaire and the reason for choosing this type of technique to gather information is discussed, pilot questionnaire design, description and administering is provided. Main questionnaire questions will be subjected to detailed analysis utilizing SPSS software, the key questions of the survey will be reported with focus on the key element for this study, and this will follow the original questionnaire questions order. Last part of this chapter will discuss the survey findings and discuss the results.

The development of this survey went through many stages, starting with literature review of past work in this filed, as demonstrated in the first three chapters; Methodology and framework then had been formed, pilot questionnaire prepared to study the participant's understanding of the survey questions, the feedback from the pilot survey then studied and modifications were carried out to produce a final version of the survey in consultation with a psychologist, so we have solid and clear questions that participants received, this lead to forecast the outcome of each question during the development of this questionnaire. Then the questionnaire went through lengthy approval process since it involved interaction with human subjects, approval from hospital management including ethical and risk assessment reports, similar approval was required from Heriot Watt University prior to conducting the survey with hospital staff at the hospital premises. Upon getting the required consent the next stage was implemented, which includes administrating the survey to staff, study the suitable ward, identify the required sample size and allocate space and time for each participant, get the feedback and gather the results.

The main purpose of this survey is to explore hospital staff satisfaction and preferences to lighting regime, Subjects were asked a number of questions to evaluate their opinions of the current lighting in hospital wards, where they work, and they've been asked specific questions related to their preferences and opinions as users, they need to rate their satisfaction with different light scenarios based on different scales used, such as, if they are: Not at all satisfied, Slightly satisfied, Somewhat satisfied, Very satisfied, Extremely satisfied or N/A, or rating their preferences, such as, :Strongly agree, Agree, Neither, Disagree, Strongly disagree. Straight answers were included as way of getting fast and clear results (Yes or No), guided answers were also made available to the participant.

The main questions were about the lighting at the workplace in areas such as lighting quality, lighting comfort and the preferences for the light source (daylight vs. electrical source), these questions were asked to explore the hospital staff preferences for light in workplace to see the light factor that affects staff performance in better and effective way. The survey questionnaire as subjective judgment along with literature review from the previous chapter will form the foundation for the analysis in the next chapter to address the objective of this study. These subjective judgments on lighting influence on hospital staff performance is appraised through the survey that is explained in this chapter.

In addition to the significance of these groups of questions for this study, other questions have been added with the aim to get a broader understanding on lighting factors in improving staff performance and work efficiency in the hospital. The outcomes of the questionnaire along with the logical analyses provided through IBSS software for these questions will be discussed with respect to the literature review presented in Chapter Three.

4.2 Survey Development

The development of this questionnaire went through six main stages starting with design of the survey, approval stage, launch of the survey, gather the data, analyses the results and discuss the outcome, as shown in Figure 4.1 Survey Development Stages.

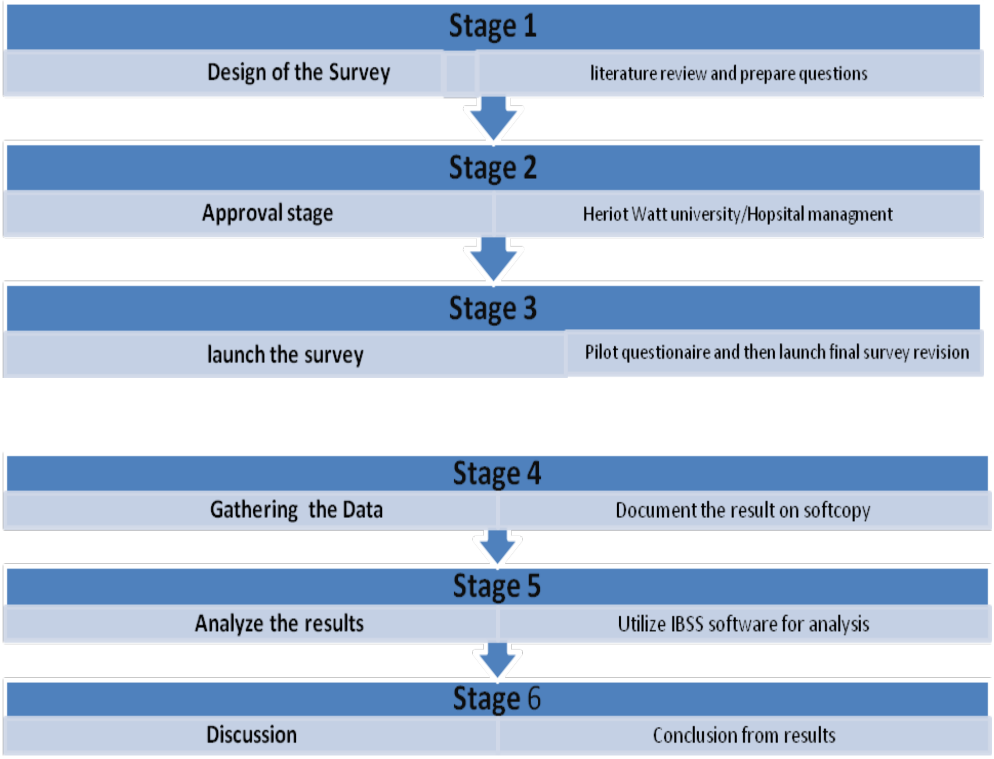


Figure 4.1 Survey Development Stages (source author)

4.2.1.*Design of the Survey*

In the design stage, a literature review was conducted to investigate the past theories in the field of light and human factor with emphasis on hospital staff performance linked with lighting, understanding the psychological impact on people and the expected response with respect to each question were studied with the help of the psychologist hired from the University's staff. At this stage, the preliminary questions were prepared for the survey, with the intent to explore the participants' responses at the early stage (pilot survey), to assess the participants' understanding of the survey and to ensure the precision of the question. The questions in the survey considered lighting factors impact on staff preferences, the questions were in line with Tregenza (2011) in his book "Daylighting: Architecture and Lighting Design", which established the dependent correlation between environment and people, similarly Speller (2000) sees that the surrounding environmental space has acquired meaning as a result of a person's interaction with the space. Also it considered Veitch (2001) for people psychological and lighting quality theory, Boyce's (1973,1977) understanding of illumination and visual performance and preference for people, human conception and physical attributes; in addition to include Veitch (2012) in her review report on lighting effect on people Physiological and Psychological:

- *Illumination Comfort Preferences*
- *Lighting Quality and Psychological Factor*
- *Light Visual Performance*
- *Light Source Preferences*

These areas have been covered in a series of questions through four main sections. Background information data about the participants were collected as well as to get a clear understanding about the results and preferences, these personal data questions were asked at the beginning of the survey to ensure that the participants meet the selection criteria for survey's participation. The Survey covered topics are: Personal Information and Work Information, Lighting Preferences at Workstations, Lighting Comfort, Daylight Comfort and Preferences and Perception and Attitude toward Lighting. The Illumination Comfort Preferences were investigated throughout Section Two, in Lighting Comfort and Preferences for Daylight Comfort. The purpose of splitting these questions into two different sections was to get a better response from participants. The Illumination Comfort Preferences questions were targeting the hospital staff professional, such as, doctors and nurses who spend most of their time in a hospital; this was confirmed by work information questions. In addition, the questions about the hospital's different area lighting comfort were intended to be answered by all participants. In order to avoid any ambiguities with written question, we invited a specialized psychologist to screen the questionnaire questions with the aim to ensure we had used appropriate phrases and words in describing the lighting scenarios. The specialized terms such as uniformity were made easy to be understood and it would not convey hidden meanings. To make the questions more comprehensive guiding questions multiple-choice questions were not included. The person to person interview methodology which was adopted in the survey helped in understanding how the participant comprehended the question and followed a certain order of questions covering different aspects of light preferences. Lighting Quality and Psychological Factor were tested in Section Four, in Section Two questions on Lighting Visual Preferences at the staff workstation were explored including the staff preferences for the type of lighting set up and the preferred lighting colour at their workstation, in Section Three, questions about the Light Source Preferences for work were focused on the relationship between work type and lighting preference.

A specific code was generated for each question and answer, in order to make it easy to gather different variables and to quantify it by numerical and percentage. Section One which gathered the background data about the participants were coded using IBM SPSS Statistics Software to study numerically the relationship between different background information and preferences for light, other sections which deal with the perception towards lighting design were gathered under a different code to form the psychological effect of light variables.

An important element of the surveys is the rating scales; these scales provide quantitative tools to measure the behaviors and opinions of respondents in a mathematical method, it can increase validity and reliability, support data reduction (Alalouch 2010), in addition scales would give a common method for the questionnaire results collection, which would make it be easily understood (Neuman, 2003). Diverse scales were used to measure the hospital staff satisfaction and preferences, that includes scales, such as, those introduced by Likert (1932), Agreement Scales (Strongly Disagree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree) and Satisfaction Scales (Extremely Satisfied, Very Satisfied, Satisfied, Somewhat Satisfied, Neither Satisfied nor Dissatisfied, Not at all Satisfied). The main reason to include the different range of scales is to allow the participants to express their opinion and preferences for specific light issues in that scale.

Since the scale does not ask the respondent to give direct answers, such as, Yes or No answers, it helps the participant to be comfortable in his stand point for that question or about a particular topic; this makes responding to the survey question stress-free on the respondent.

The other point is it gives them room for respondents to provide neutral or undecided feelings of participants (Likert, 1932). The other important feature of the survey scaling helps the researcher gather the survey information results without running the risk of having bias or negatively impacting the results. O'Muurcheartaigh, Krosnick and Helic (1999) and Narayan and Krosnick (1996) see that choosing the midpoint of the scale, such as, "Neither Agrees/Disagree" in general as a valid response, while Fowler 1995 see the response of "strongly" can be confusing for the emotional component for the thought agreement task. The structure of the survey design is shown in Figure 4.2.

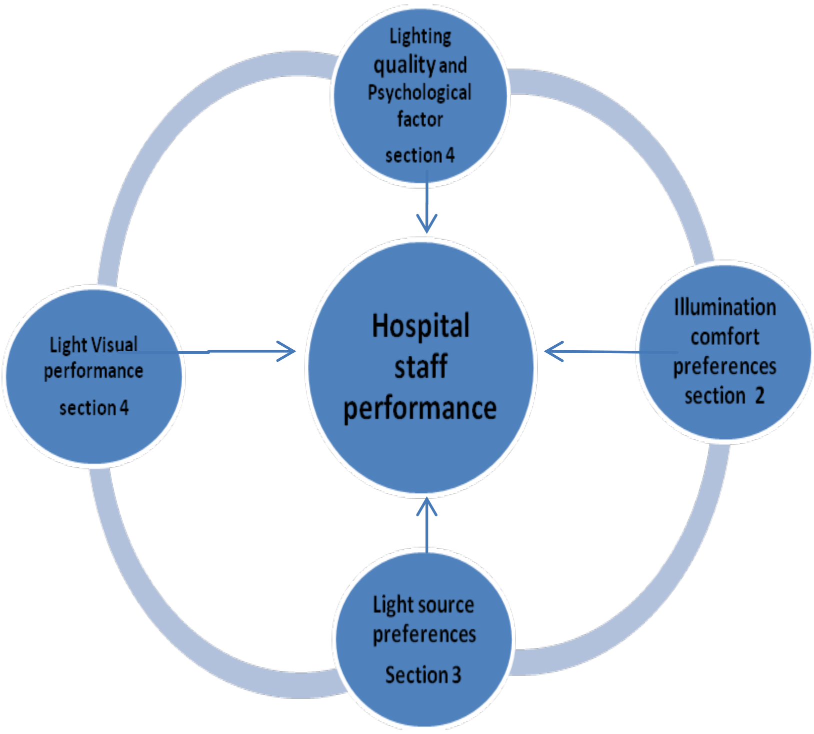


Figure 4.2 Survey Design

4.2.2.*Survey Structure and Questions (Paper Based Questionnaire)*

The survey was designed following the concept that workers such as hospital staff are affected by surrounding environmental factors, lightings is one of these factors which has significant impact on staff.

Lighting in workplace will impact staff physically and psychologically. A questionnaire was drafted with the goal to explore the connection between hospital staff preferences for lighting systems and the current lighting standards; the questionnaire contained twenty-eight questions and focused on two groups of hospital staff, nurses and doctors.

4.2.3. *Personal and Work Information*

This section asked the participant seven different types of questions (open/closed-ended), for personal information questions it covered the subject's ethnicity, age, gender and visual conditions. While for work information it covered work shift time, profession (occupation) and where mostly he/she spends his work time. The response to these questions were categorized in groups, so participant's ethnicity were categorized based on cultural groups as Western, Indian, Arab, Asian, African, the reason to gather the cultural background information from the respondents has been supported by the theory that suggested that the differences in cultural backgrounds would lead to different reactions to lighting (Kuller, 2006), ages were categorized in four sets, 21-30, 31-40, 41-50 and +50, gender categorized into male or female, and visual/eye conditions were also considered as part of selection criteria for the participant, e.g., if he/she require the use of glasses, contact lens or other aids.

Work information was collected as well, information such as work shift (dayshift or night shift), the profession that participant is doing in the hospital (classified into four main groups, such as, doctors, nurse, auxiliary staff and admin/cleaning staff, each of these professions has different visual requirements and also the place where the participant spent most of his duty time has been explored to link it to the activity and preferences for light.

This classification provided more room for investigation on the relationship between lighting setting and participant's performance with relation to age, gender, cultural background on staff preferences under different light settings in the hospital.

4.2.4. *Lighting Comforts*

As clarified earlier the questionnaires were clustered in many sections to collect as much information as possible from the participant on their lighting preference in connection with their performance. In the first section, lighting comfort for the participants were explored through five questions; four closed-ended and one open-ended. This section investigated staff preferences for light in different hospital areas in terms of comfort level. The elements which had been investigated are:

-Lighting level, participant staff were asked to rate their satisfaction with the lighting level in different hospital areas, such as, doctor’s office, private patient rooms, shared patient rooms, nurse’s desk.

- Brightness level, participant staff were asked to identify the bright areas in the hospital.

-Light sufficiency is another question which was asked to explore light comfort, the key reason for this question is to ensure all aspects of lighting comfort is covered in sense of light level and sufficiency.

- Glare as one of the lighting elements that cause discomfort was explored in this section. Participants were asked to identify areas in hospital, where they considered causing glare from light.

-Light reflection, participant were asked if they consider any areas of the hospital, where having light reflections prevent them from working properly or accurately.

One of the main research questions was located in this section. This research aims to explore hospital staff preferences for lighting; therefore the questions about the lighting comfort reference and the question about the discomfort elements of the light represent key questions in this survey.

4.2.5. *Lighting Preferences in the Main Workstation*

Hospital staff preference for light in the workplace is an important aspect of this research, as explained in the previous chapter, to understand these preferences and relate it to staff performance; four questions were presented in the second section of the survey. The first question asked the participants about the preferred light source setup (mounting), four common lighting setups were introduced to answer this question, including direct on walls, direct on ceiling, indirect hidden (cove light) and indirect on wall, the direction of wall has impact of users comfort as referenced by many research (Author and Soori 2012).

The other question was designed to explore the staff preferences for the preferred light colour at their workstation, light colours in hospitals were seen as an important factor impacting the staff and patients as referenced by Author et al. (2013), Author and Soori (2012): light colour introduced in four scenarios as all white or yellow or blue, or natural (daylight) and last scenario as a mix of white and yellow light sources, the point behind each selection of light were studied in the previous chapter, which linked each light colour with different reaction in sense of comfort and to help to do specific tasks. Participants from staff were asked if they switch off the lights of their workstation during the day.

In question number three of this section, this is to explore if there is enough daylight in their workstation to do their various activities, which implied their preference for only daylight or need for additional light source light. In question number four, survey participants were asked if they currently have control over your levels of lighting at their main workstation, the purpose of this question is to explore the need to adjust light with each task performed and link it to work performance.

The answers of the first and second questions in this section are connected later to the new light system proposed (in Chapter 6) and the staff choice for the new improved lighting design, which are described in this chapter.

4.2.6. *Daylight Comfort and Preferences*

In this section, daylight preferences were explored among hospital staff who participated in the survey, daylight which literatures links to improve worker performance as detailed in previous chapters. Activities carried out at doctor's office, private patient rooms, shared patient rooms, waiting areas and nurse's desk were considered and evaluated in reference to daylight availability. It consists of six questions split into three sub-questions.

In this section, the satisfaction degree of participants were measured on a six-point scale (Not Satisfied, Slightly Satisfied, Somewhat Satisfied, Very Satisfied, Extremely Satisfied to N/A, the Not Applicable choice was to allow the participant to opt out of a question that does not apply to them, this will help in eliminating wrong answers and reduce the bias in the data. The second question asked the participants about their satisfaction with amount of daylight at their workstation in closed/open-ended style and if they prefer to have it. While the third question explored the staff preference for workplace illumination source such as daylight, artificial (electrical) light and a mixture of daylight and artificial light, this question is linked to section two of the survey questions about lighting source preferences. The relationship between work performance and daylight were explored, questions, such as: Do you think it is easier to treat patients in a room with daylight? were aimed to get professionals' opinions on the lighting as a factor that might help them do their work easier, the five-level Likert rating scale was used, including Strongly Agree, Agree, Neither, Disagree, Strongly Disagree, to record the answers, in the fifth question in this section subjective opinions were explored through asking staff about daylight capability in helping them diagnosis patients, such as, any changes in patient skin colour (due to change in health status as explained in previous chapters), six-point scale was used to record the answer (Strongly Agree, Agree, Neither, Disagree, Strongly Disagree, N/A), the last question in this section request the participant to confirm if he needs to lower the sunlight at his workplace or not, and what time they do so, this question is to investigate if the participant works under excessive sunlight or not and at which time of the day.

4.2.7.*Perception towards Lighting and Work Performance*

In this section, staff were asked a series of questions that aimed to explore their perception towards daylight, specifically its effect on their work performance, patient recovery, relaxation and uniformity of light. In the first question, staff were asked to identify any area in the hospital where the colour of the light makes them feel unconformable, this question aimed to link participant responses with the light colour using closed-ended questions (The dichotomous question with Yes/No answer), the second question was repeating question number five in the previous section but with different wording, this will provide better analyzing tools to validate each answer through statistical methods. The third question explored the daylight impact on patients to recover faster, from the view of hospital professionals and to confirm previous literature outcomes, this question uses five-level Likert rating scale (Strongly Agree, Agree, Neither, Disagree, Strongly Disagree). The scale was used to measure these responses and will provide better statistical analyses tools to filter significant information. In the fourth question, different lighting designs were presented to the staff with the aim to explore the lighting setup that would help patients feel more relaxed, which would help them eventually do their job in a better environment, the presented scenarios were:

- *Ward with white light and sunlight with the room painted blue or green*
- *Ward with white light and sunlight with the room painted white*

- *Ward with yellow light and sunlight with the room painted blue or green*
- *Ward with yellow light and sunlight with the room painted white*

Each of these scenarios and light colour were selected based on consideration and review of previous studies that link light colours to hospital staff and patient's preferences (Author et al 2013; Author and Soori 2012; Boyce 2006), the aim is to provide better understanding of the link between light colour on hospital staff. Question five was similar to question one but with different wording, to ensure a consistent answer was given regarding the impact of daylight on patients, the same five-levels Likert rating scale (Strongly Agree, Agree, Neither, Disagree, Strongly Disagree) were utilized. The last question in this questionnaire was to explore light comfort through inquiry about the uniformity of light in the doctor's office and ward; this is to verify if there is any observations that were missing concerning lighting comfort.

4.2.8. *Sample Breakdown*

Although it is not uncommon to have different views as to how to calculate sample size, the techniques used should be described, allowing acceptable judgment on the assumptions and procedures. Having said that, calculating approximately the necessary sample size is the most essential part of the survey's recruitment process (Bartlett, Kotrlik, and Higgins, 2001). To be confident that the study result is acceptable, it is very important to have a large number of participants in the survey, the question is; how many survey participants are needed to make the results sound and acceptable.

Before launching the survey, it is important to determine the required sample size to show a scientific important result, inadequate, inappropriate or excessive sample sizes will impact the accuracy and quality of the study. For example, a too small sample size to identify differences could result in studies considered as wasteful or unethical (ethical codes should be followed and adhered to so that allowances can be considered for potential declinations from some participants who are not willing to participate), so the study might need to be adjusted to count for this refusal rate. Moreover, a small sample size can yield ambiguous results. For instance, the outcomes may demonstrate that there is no difference between groups or between variables, when actually there is an association or a difference. In contrast, a too large of a sample size might lead to needless effort, time wasted and finance. To answer this question of how large a number is needed we need first to know what is the accepted percentage that could be considered acceptable, study by Niles (2006), established that the results need to be utilized to get a 95% confidence level.

The table which was developed by Bartlett, Kotrlik, and Higgins (2001) illustrated the estimation of the error margin for different sample sizes, i.e., sample sizes from 10 to 10,000, Table 4.1.

Sample Size (*N*)	**Margin of Error (fraction)**	**Margin of Error (percentage)**
10	0.316	31.6
20	0.224	22.4
50	0.141	14.1
100	0.100	10.0
200	0.071	7.1
500	0.045	4.5
1000	0.032	3.2
2000	0.022	2.2
5000	0.014	1.4
10000	0.010	1.0

Table 4.1 Error Margin Table Developed by Bartlett, Kotrlik, and Higgins 2001

As shown in Table 4.1, a survey that employed 10 participants wouldn't be considered reliable, because 32% margin of error is very high and it will bring into question the study's outcome, for example, if 7 out of the 10 participants (70%) express their satisfaction with the job environment, then the actual proportion of the workers who are satisfied with the work environment might vary by ±32%. Which means we have results that might vary as low as 38% (70 - 32) and as high as 100% (70 + 32). This range is very high for a survey to have a weighty outcome.

By selecting a sample size of 100 persons the margin of error will drop to 10%. So for 70% of the participants reported their satisfaction with the job environment would be 95% likelihood that between 63% and 77% of the total population are satisfied with the work environment.

Studies by Niel (2006) and Argyrous (2011) show that many factors influence the selection of sample size, including the required precision level for results, the main survey aims and expected response rates. In the current study the group of randomly surveyed hospital staff were selected from a wide range of diverse hospital professional groups who work in the hospital, this is to ensure that the study gather most of the opinions from as many of the working staff in the hospital as possible. As explained earlier the optimal size for the surveyed group, the work of Niles (2006) of a suitable confidence interval has been considered as per Equation 1:

$$K = 1/\sqrt{N} \quad \text{……….……………………………………….1}$$

Where: K is the confidence interval
N is the number of participants or sample size

In this study, 134 subjects were selected to ensure an acceptable margin of error. The participants from the hospital staff sample were selected from a wide range of staff as much as it was possible and varied in age, gender, education level and cultural background. Sample groups were represented by nurses, doctors, administrators, technicians and Auxiliary staff.

Nurses represent the highest percentage of participant professionals as they represent the majority of the working staff in the hospital. The percentage of the groups who participated in the survey is shown in Table 4.2:

Group	Frequency	Percent
Administrators and Technicians	11	8%
Auxiliary Staff	17	13%
Doctor	10	7%
Nurse	77	57%
Technician	19	14%
Total	134	100%

Table 4.2. Survey Participants Percentage by Groups

In total, 134 subjects answered the survey questions, of the subjects, 57% (77 participants) were nurses, 14% (19 subjects) were technicians, and 7% (10 participants) were doctors, and 13% (17 participants) auxiliary staff.

The participants' ages ranged between 21 and over 50 years with mean age between 21-30 years. Participants were: 17.2% (23 participants) between 21-30 years-old, 34.3% (46 participants) between 31- 40 years-old, 41.8% (56 participants) between 41-50 years-old and 607% (9 participants) above 50 years-old. Gender wise, the participants were, 77.6% (104 participants) were male and 22.4% (30 participants) were female. Finally the ethnicity of the participants varied between five groups, 30.6% (41 participants) were from Arab countries, 3.7% (5 participants) were from Western countries, 26.9% (36 participants) come from India, 33.6% come from Asian countries (45 participants) and 5.2% from African countries (7 participants). A table 4.3 shows the sample breakdown.

Age				
	Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
21-30	***23***	***17.2***	***17.2***	***17.2***
31-40	**46**	**34.3**	**34.3**	**51.5**
41-50	**56**	**41.8**	**41.8**	**93.3**
50+	**9**	**6.7**	**6.7**	**100.0**
Total	**134**	**100.0**	**100.0**	

Ethnicity				
	Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
African	**7**	**5.2**	**5.2**	**5.2**
Arab	**41**	**30.6**	**30.6**	**35.8**
Asian	**45**	**33.6**	**33.6**	**69.4**
Indian	**36**	**26.9**	**26.9**	**96.3**
western	**5**	**3.7**	**3.7**	**100.0**
Total	**134**	**100.0**	**100.0**	

Gender				
	Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Female	**30**	**22.4**	**22.4**	**22.4**
Male	**104**	**77.6**	**77.6**	**100.0**
Total	**134**	**100.0**	**100.0**	

Table 4.3 Survey Participants Breakdown per Age, Gender and Ethnicity

Researchers believe that the selection of a wide range of samples is necessary to provide better investigation tools to study the effect of respondents from different demographics on the preference for lighting setup (Author et al., 2013; Alalouch, 2010).

4.2.9. *Approval Stage*

The second stage in the survey development was to get the approval from the Hospital Research Department and Hospital Management, that is including, preparing complete study proposal, attaching the survey and method of conducting it, specifying the criteria for selecting the survey participants, completing the ethical forms, developing risk assessment report, reporting and signing confirmation letters to adhere to Hospital Regulations and Codes of Conduct, Appendix A shows the approval for this research from the Hospital Research Department and Hospital Management and Appendix B shows the approved questionnaire template submitted for Hospital Management's approval. University approval was another process in the survey development, which included applying for approval on conducting research with human subjects as per University Code and Regulation, ethical form was completed along with risk assessment report, as shown in Appendix C. Then, the second stage was to select the survey participants and choose the hospital place to interview the participants, this followed the Alalouch (2010) methodology of selecting random respondents to get better results and better understanding of staff preferences.

4.3 **Launch the Survey**

4.3.1. *Piloting the Survey*

The need for pre-testing the survey is crucial for the survey and an important step before launching the questionnaire on a large scale, such that the draft questions were made by a specialist but not really used in actual interviews to predict the response or understanding. Teijlingen and Hundley (2001) suggested many reasons for piloting the questionnaire, as it is not easy to judge whether the desired results will be achieved from the initial drafted questions. The pre-tests of the questionnaire were conducted on small groups of participants before going with the larger group. The main objective of this pilot questionnaire was to correct any misunderstandings or mistakes at the early stage. The other advantage of the pre-testing of the questionnaire is to see whether the given instructions to participants are clear and that the questions' wording give the required results, also to verify if the questions are achieving the same understanding level by different participants or if we need to modify some questions. A group of ten respondents were selected for the pilot study. The selected respondents for the pre-test of the questionnaire represented most of the types of respondents who will be recruited or interviewed in the main survey. Some researchers established a procedure for pre-testing the surveys (Peat et al., 2002; Polit, Beck, and Hungler, 2001) recommending some techniques for successful pilot studies that would help validate the questionnaire, and these include:

• Apply the same method of interview and questionnaire as it is would be conducted in the final survey with pilot subjects.

• Explore the pilot study opinion about the questions clarity and comments.

• Test the required time for the main study through this pilot study.

• Revisit the questions to ensure the questions are clear and understood by the participants.

• Evaluate the response from the pilot study participants to verify their understanding of the questions.

• Establish that replies can be interpreted in terms of the information that is required.

• Verify which questions take a long time to respond to, and if so, can it be broken down to smaller questions.

• If it deemed necessary eliminate ambiguous questions to remove any confusion.

• Make the questions short and to the point.

In a study by Baker (1994), it is established that for a successful pilot study a sample size of 10% of the targeted final study sample size would result in a worthy understanding of the participants' behaviors and reactions to the study. Baker (1994) also sees that pilot study may not guarantee the success with the research, but it can increase the likelihood of good results. In this study and after completing the questionnaire design, a pilot study represents a mini version of the main study carried out with fifteen participants who have been selected to participate in the pilot study, each one of the hospital staff participants was interviewed individually, a copy of the questionnaire was presented to them, and asked to fill it, time to complete the survey were recorded and comments were considered.

Each of the hospital staff was asked to give overall impressions of the survey, such as, long, short, difficult and any other feedback. Upon completing the pilot survey, analyzing the response and getting the feedback to follow-up with corrective action taken with respect to the final revision of the questionnaire:

- Questions which took a long time to understand have been rephrased and simplified
- Questions that are ambiguous and not clear have been removed.
- Some typing errors were found and corrected in the revised version.

Upon completing the analysis of the pilot survey, the final draft of the survey was formulated including instructions and questions as shown in Appendix E. The pilot questionnaire survey template is shown in Appendix F.

In addition, time was recorded during the launching of the pilot survey and getting the feedback. There is no doubt face-to-face interviews were considered a very expensive method of administering a survey rather than using a web based or postal questionnaire, these survey questionnaires were administered following the face-to-face interviews, this is due to the effectiveness of this method to get direct feedback from the respondents and ensure getting a higher rate of response, rich content and more detailed as compared to other types of surveys. However researchers should note that, time and preparation expenses must be well-thought-out in the case of face-to-face interviews, Denscombe (1998) sees one of the major drawback of this type of surveys is the time spent in organizing long meetings, coordinate with different entities and administrating a large number of interviewees. This was carried out from January 2013 till April 2013 by the author.

4.3.2. *Administrating the Paper-Based Questionnaire*

In this study, a structured interview technique was followed to gather the data from the hospital professionals, in person interviews (face-to-face) were selected to explore the hospital staff preferences and satisfaction with hospital lighting. During the interview, survey questions were read as written on the paper-based questionnaire without clarification or explanation. The survey was conducted from January 2nd till April 2013.

The questionnaire was designed to explore the hospital professionals' opinions, who do different type of activities in the hospital, one hundred and thirty-four volunteered staff participants participated in answering the twenty-eight survey questions. The study was conducted at a central healthcare facility in Doha Qatar, Hamad General Hospital (HGH). These hospitals comprise of 603 patient beds and provide diverse health support departments, such as, pediatrics, emergency medicine, specialized surgery, laboratory medicine, critical care, radiology services and specialized medicine. They offer health care services to over 600,000 people.

The main focus group comprised of nurses, doctors, administrators and auxiliary staff, their subjective judgments was assessed by the means of a questionnaire. The qualitative professional judgments of staff used as the reference indicator, surveyed in the study for a range of types of work, as daily observations in different patients' rooms. Following a verbal introduction to the nature and purpose of the survey and acquiring the background information about the participants, the subjects were then asked to rate their satisfaction with the questionnaire questions.

4.3.3.*Gathering Information*

In this study Microsoft Excel was used to compile the responses from the participants. With the purpose of entering the compiled data from the survey into the computer to carry out the statistical analysis, the responses were reduced to a simplified numerical format and responses were encoded and uploaded into an excel file to be studied using Statistical Package for the Social Sciences (SPSS). The SPSS Statistics software was used to get the descriptive analysis of the staff responses to the survey questions. The SPSS software was developed by IBM and is used mainly for the management of the data, administration of statistical analyses and producing graphs or tables to summarize the results and findings. Its features include the range of the tools in it and the capability to deal with different variables at the same time. Earlier studies considered using SPSS as satisfactory for use with the survey database analysis and table production (Niles, 2013). In this study it helps due to the functions it contains for recoding, graphing, tabling, data entry and adding many new variables.

4.3.4. *SPSS Questions Coding and Data Analysis*

In total, 134 hospital staff participated in the questionnaire to answer twenty-eight questions; dedicated names were specified to each question of the questionnaire. In general, each question was labeled with a 6 digit symbol to create a unique code for each question and to enable smooth process for examining the responses. The first two digits denote the section of the survey, trailed by two digits indicating the question number and the other two digits designating the question description. The question coding were sampled as follows in Figure 4.3:

Section	Question Number	Question Description
XX	**00**	**XX**

Figure 4.3 Question Coding Template

The survey was divided into five sections and two subsections:

1. Personal Information (PI),Work Information (WI)
2. Lighting Comfort (LC)
3. Light in Workstation (LW)
4. Daylight Comfort (DC)
5. Perception and Attitude toward the Light (PA)

Question Category	***Variable Names***
Personal Information	**PI01ET**
	PI02AG
	PI03GE
	PI04VC
Work Information	**WI05WS**
	WI06PR
	WI07TS
Lighting Comfort	**LC08LD**
	LC09LP
	LC10LS
	LC11LN
	LC12LB
	LC13IL
	LC14GA
	LC15LR
Light in Workstation	**LW16LM**
	LW17LC
	LW18SW
	LW19CL
Daylight Comfort	**DC20LD**
	DC21LP
	DC22LS
	DC23LW
	DC24LN
	DC25LW
	DC26LS
	DC27TP
	DC28SC
	DC29CL
Perception and Attitude toward the Light	**PA30FU**
	PA31SU
	PA32RF

	PA33FR
	PA34PC
	PA35UD
	PA36UP

Table 4.4 – Coding of All Questions Variable Names

4.4 Analyse the Results

The responses from the survey participants were analysed using the statistical package SPSS, descriptive analyses techniques were used to report the relation between different variables and to create the graphs shown below. The responses were arranged following the original survey's section order:

4.4.1. *Illumination Comfort Preferences*

The illumination comfort was tested through two aspects; Lighting comforts level and daylight comfort for the lighting comfort level Question 1 was asked:

Q1- How do you rate the Lighting level in the following areas of the hospital?

a) Doctor's Office
b) Private Patient Room
c) Shared Patient Room
d) Nurse's Desk

This question is related to the recent debate on the preferred lighting level for work and the Illumination Comfort Preferences; visual surveys were made for these areas in advance to getting understanding of staff preferences for light levels, which was discussed in Chapter Three. Of the four different locations selected for this question mixed results have been obtained, however lighting level at the Nurse's Desk was shown a higher satisfaction among other locations in the hospital, the light at the Nurse's Desk was higher compared to other locations in the hospital due to the access of daylight to the area. The results are shown in Figure 4.5.a, Figure 4.5.b, Figure 4.5.c, and Figure 4.5.d

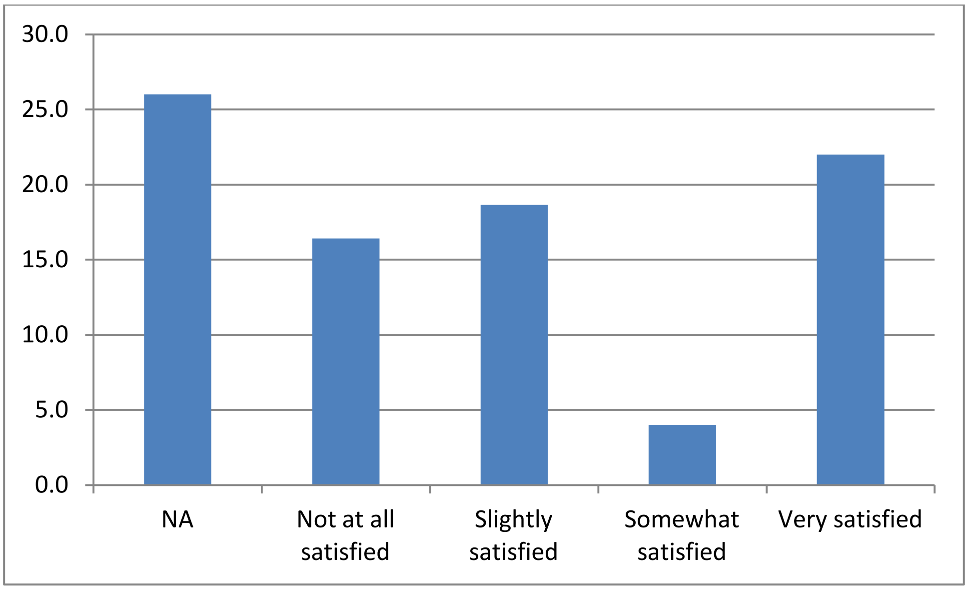


Figure 4.5.a Preferences of Light Level in Doctor's Office

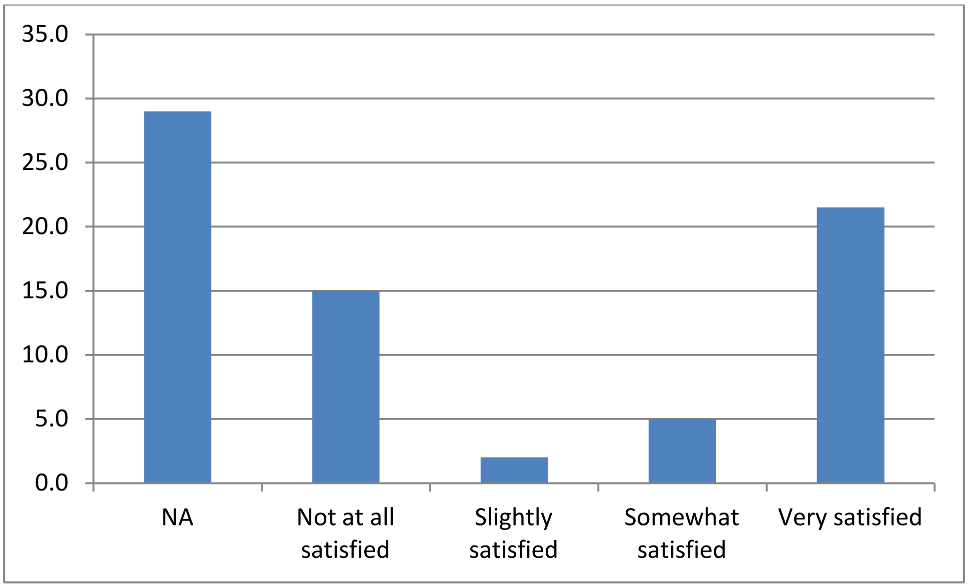


Figure 4.5.b Preferences of Light Level in Private Patient Room

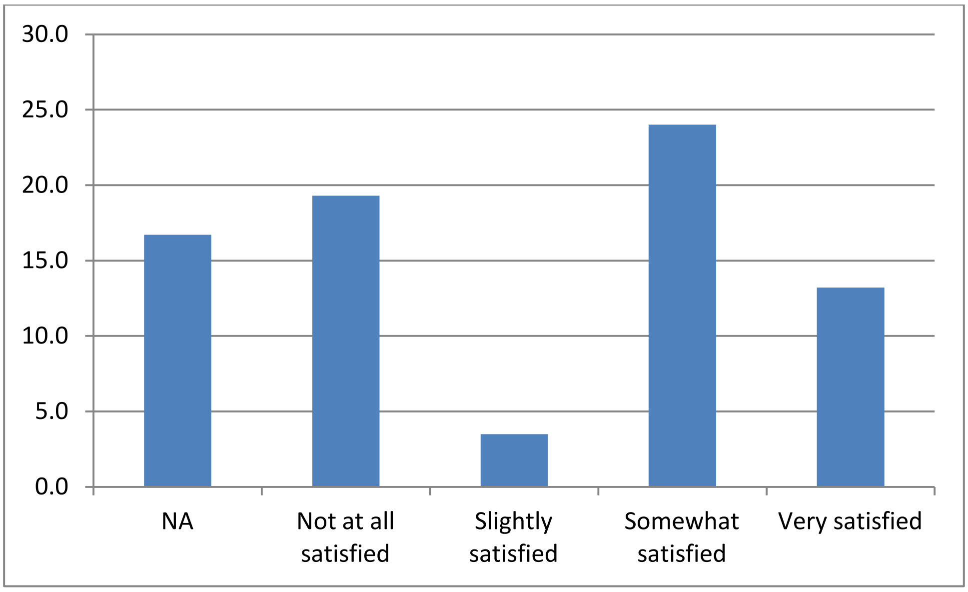


Figure 4.5.c Preferences of Light Level in Shared Patient Room

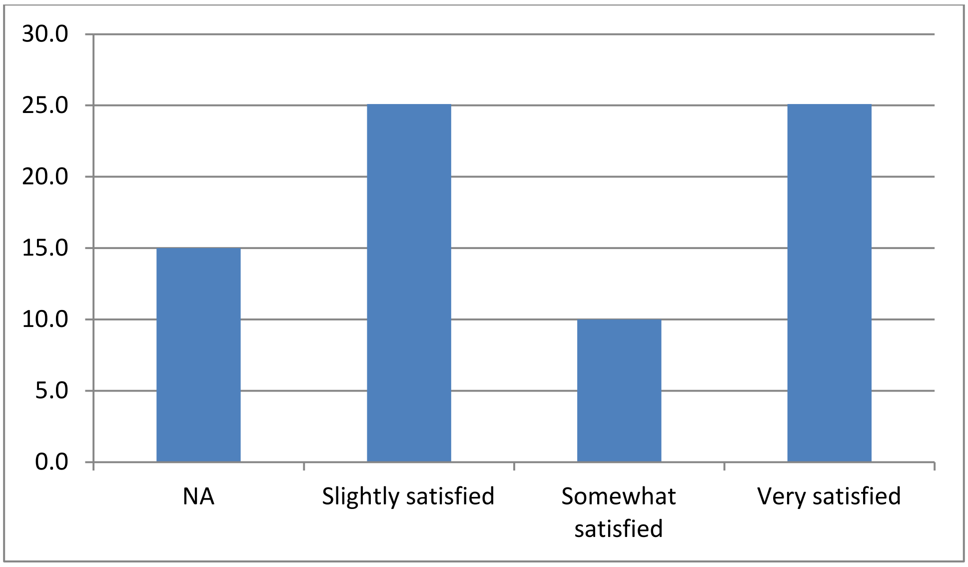


Figure 4.5.d Preferences of Light Level in Nurse's Desk in the Hospital

In spite of the common comfort light level preference in work places, it was found that a significant proportion of hospital staff prefers to work under higher light levels as shown from analysis to the responses with respect to question one regarding the hospital staff satisfaction with light level at different location in hospitals (Figure 4.5.a, Figure 4.5.b, Figure 4.5.c and Figure 4.5.d). This outcome is consistent with the results suggested from the previous studies, which illustrate higher lighting level is associated with the task being performed (see Chapters Two and Three). Further research is needed to identify the factors that contribute significance to the differences between those who prefer higher light levels in work places and those who prefer lower light levels in work places. This variation in light level preferences may relate to personal age, cultural properties and/or task performed (Kamali and Abbas2012; Lawson and Phiri, 2003).

Another question was asked to explore the comfort with daylight (Question 2):

Q2-Are you satisfied with the Daylight level in the following areas?

a) Doctor's Office
b) Private Patient Room
c) Shared Patient Room
d) Nurse's Desk

The results show the area which receives daylight had perceived higher hospital staff satisfaction; this is in line with previous literature which suggested that daylight has the potential to positively impact occupants (Edwards and Torcellini, 2002). This question allows the investigation of the influence of daylight levels on hospital staff's preference of light comfort. The results are shown in Figure 4.6.a, Figure 4.6.b, Figure 4.6.c, and Figure 4.6.d.

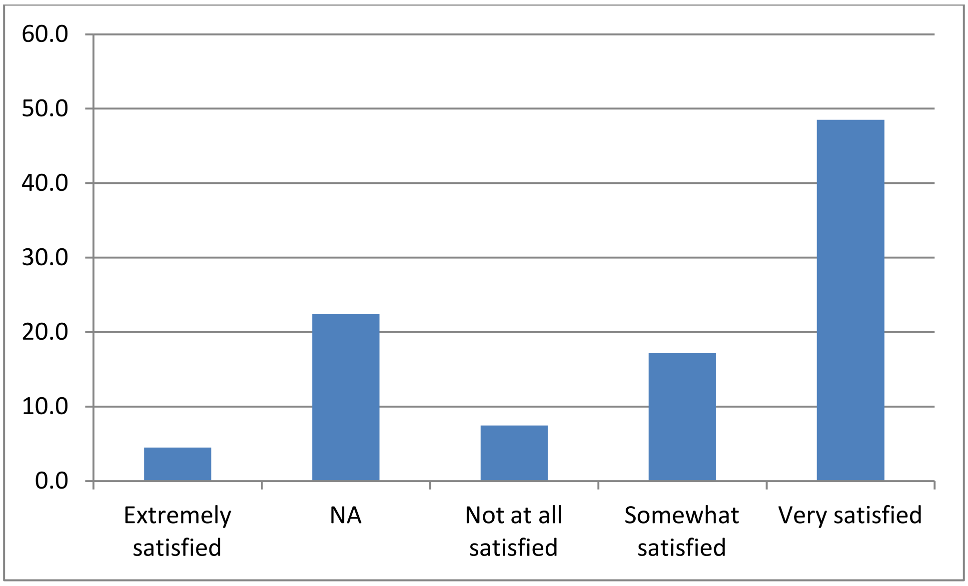


Figure 4.6 a Preferences of Daylight Level Doctor's Office

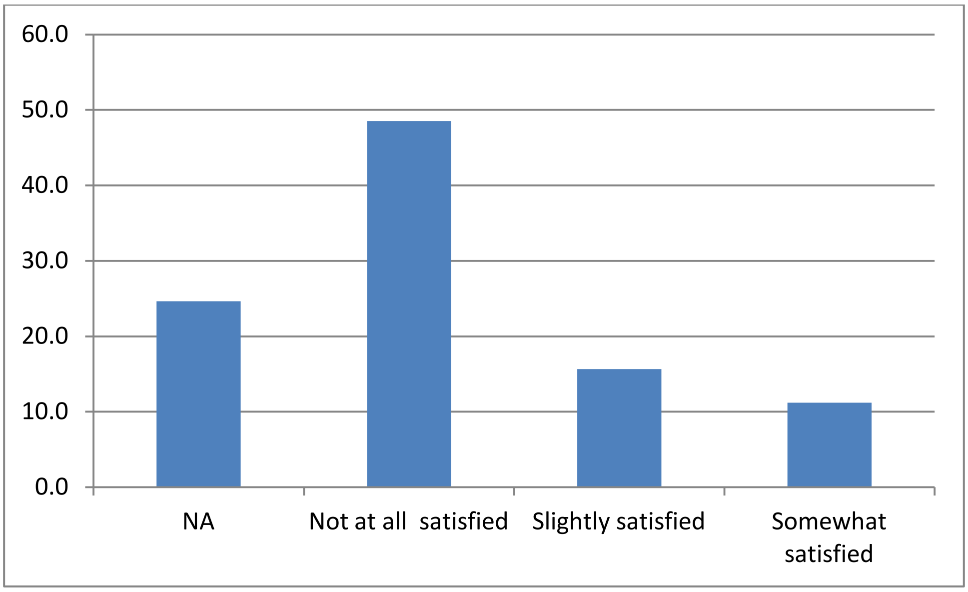


Figure 4.6.b Preferences of Daylight Level Shared Patient Room

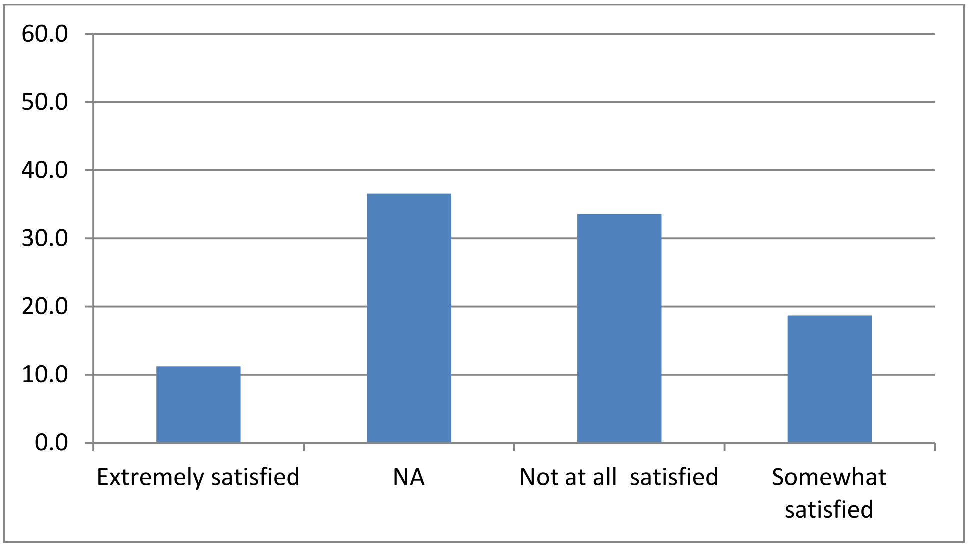


Figure 4.6.c Preferences of Daylight Level Private Patient Room

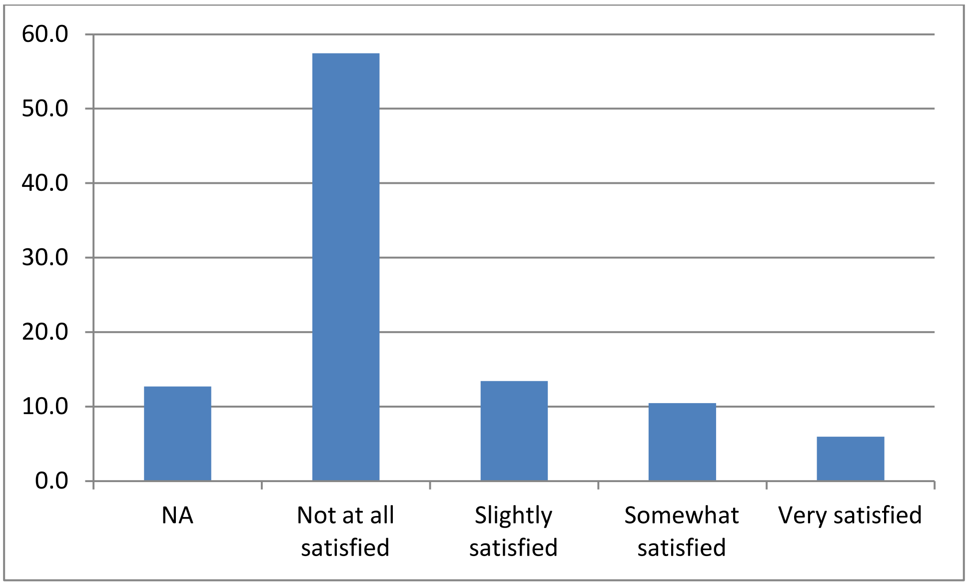


Figure 4.6.d Preferences of Daylight Level Nurse's Desk in the Hospital

Daylight appeared to be the main reason for light comfort preferences among the hospital staff and that reflects two things, firstly, it highlights the importance of daylight for hospital staff and its impact, which has been reported widely in the literature. And secondly, it demonstrates that staff perceived the importance of daylight in the workplace, as explained in earlier research (Edwards and Torcellini, 2002). This question allows the investigation of the influence of daylight levels on hospital staff preferences of light comfort. Despite these findings, it seems that the current daylight provisions in hospitals do not meet staff expectations for daylight. The healing environment setting plays an important psychological role in improving the main purpose of the hospital, which is healing the patient in a faster way, daylight was seen to cause fast recovery for the patients due to its positive psychological influence in making patients feel more comfortable and at ease (Beauchemin and Hays, 1996; Choi and Beltran. 2004, Schlangen 2013). This study has confirmed that hospital staff perceives daylight to have a strong comfort, health and diagnostic benefit for staff and patients in hospital wards. This study provides clear evidence of the subjective judgments of the hospital staff showing (Author et al., 2013):

- Seventy-nine percent of the participants see the daylight in patient's rooms as an element assisting them to do their work more easily.

- Seventy-seven percent of the surveyed staff claimed that daylight is an important element in patients' rooms to aid in reviewing patients' recoveries through recognizing and interpreting changes in patients' skin colour.

- When it comes to patient comfort ninety-two percent of the surveyed staff stated that patients preferred to stay in rooms with access to daylight as it makes them feel comfortable.

- Seventy-eight percent of hospital nurses and all the surveyed doctors believe that daylight has many health benefits including faster recovery and reduced length of stay for patients.

4.4.2. *Lighting Quality and Psychological Factors*

Recent studies have led to an understanding of some psychological factors that influence the patient recovery in a healing environment, such as, hospitals (Beauchemin and Hays, 1996; Choi and Beltran, 2004]. Daylight is suggested as one of these factors due to its visual and non-visual impacts on the human body (Choia et al., 2012). Anjali (2012), in her study "The Impact of Light on Outcomes in Healthcare Settings", suggested there is a need to have studies that survey the impact of daylight on mood or specific task performance in hospitals, suggesting that there are very few studies that explore these findings, which trigger the need for more research in this field.

The following question has been asked to the hospital staff with the aim to explore the Psychological Factors related to light that might affect patients:

Q3-Do you think Daylight helps patient recover faster?

☐ ***Strongly Agree*** ☐ ***Agree*** ☐***Neither*** ☐***Disagree*** ☐***Strongly Disagree***

The agreement among the surveyed professionals shown in Figure 4.7 reveals that the importance of having certain types of light (daylight) in the healing environment, eighty-two percent of the participants have concluded from their experience with patients that rooms with daylight result in faster recovery of the patients, eighteen percent of the participants were unsure of this statement's applicability when linked to patient recovery time.

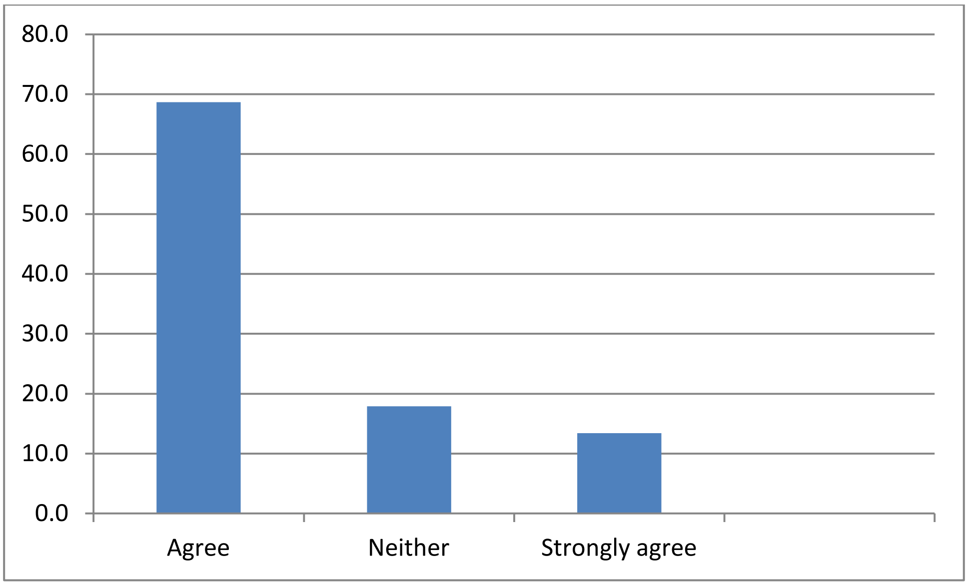


Figure 4.7 Response to Survey Question, Does Daylight Help Patient Recover Faster

Question 4 was to explore the psychological aspect of light, which was:

Q4- In your view, does room with daylight help patients feel more comfortable and at ease?

☐ ***Strongly Agree*** ☐ ***Agree*** ☐***Neither*** ☐***Disagree*** ☐***Strongly Disagree***

The results of the question examining whether daylight makes patients feel comfortable are shown in Figure 4.8.a, high percentage (ninety-two percent) of the hospital staff agreed with this statement highlighting the need for hospital designers to take this fact on board. This finding also confirms the results of previous research on the positive psychological impact of daylight (Beauchemin and Hays, 1996; Choi andBeltran, 2004; Schlangen, 2013). The results show that majority of staff (ninety-four percent) supported the idea of the positive psychological influence of daylight in making patients feel more comfortable; this means staff were able to observe the effects of daylight on patients and how it makes them feel comfortable. One percent of the surveyed staff disagreed with this option; this disagreement might be connected to other causes such as the nature of patient's illness, the nurse’s work, i.e. those who may have sensitivities to sunlight or working in Intensive Care Units (ICU) who do not have access to daylight. The results of the groups’ replies are shown in Figure 4.8.

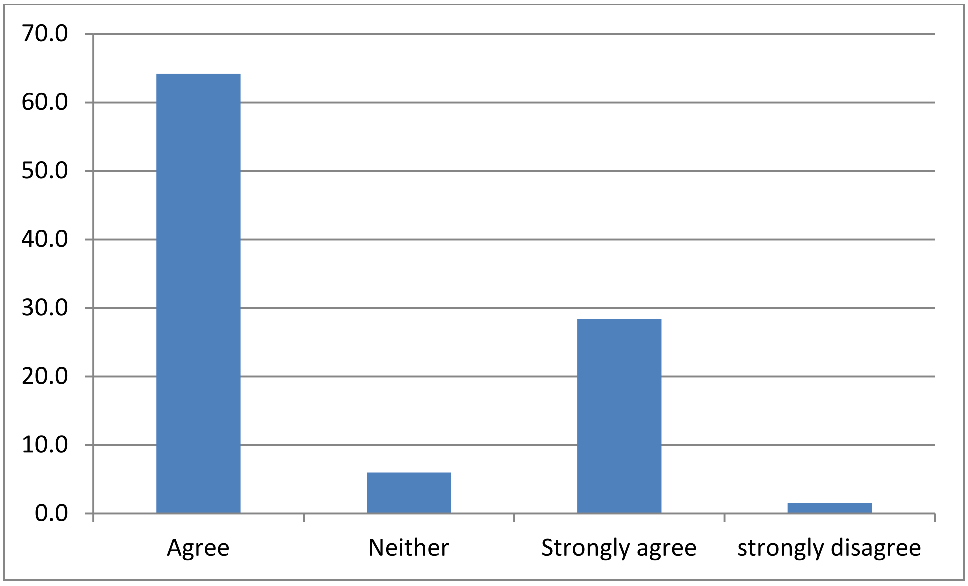


Figure 4.8 Result to Survey Question about if Daylight Help Patients Feel More Comfortable and At Ease

4.4.3. *Light Visual Performance*

Previous survey questionnaires have been conducted to explore the relationship between employee performance in relation to psychological factors and these surveys look at the relationship between light and staff performance (Kamali and Abbas, 2012). In this study, the following Question 5 was asked to hospital staff to explore their experience with the influence of light on their performance

Q5-Do you think it is easier to treat patients in a room with daylight?

☐ ***Strongly Agree*** ☐ ***Agree*** ☐***Neither*** ☐***Disagree*** ☐***Strongly Disagree***

A five-point scale was used to measure the outcome from the respondents, it shows that seventy-nine percent of the staff considers that daylight in the patient's room help them do their work more easily, including diagnosing and treating patients' health and monitoring their recovery. This is an important finding, especially because it comes from people who spend most of their working day inside the hospital and are thus well versed in the relative merits of daylight versus artificial light. After going through the answers of the open-ended questions we found nineteen percent of respondents expressed their uncertainty in responding to this statement. Two percent of the participants disagreed with this statement as they do not consider daylight as an important factor that can make their work easier.

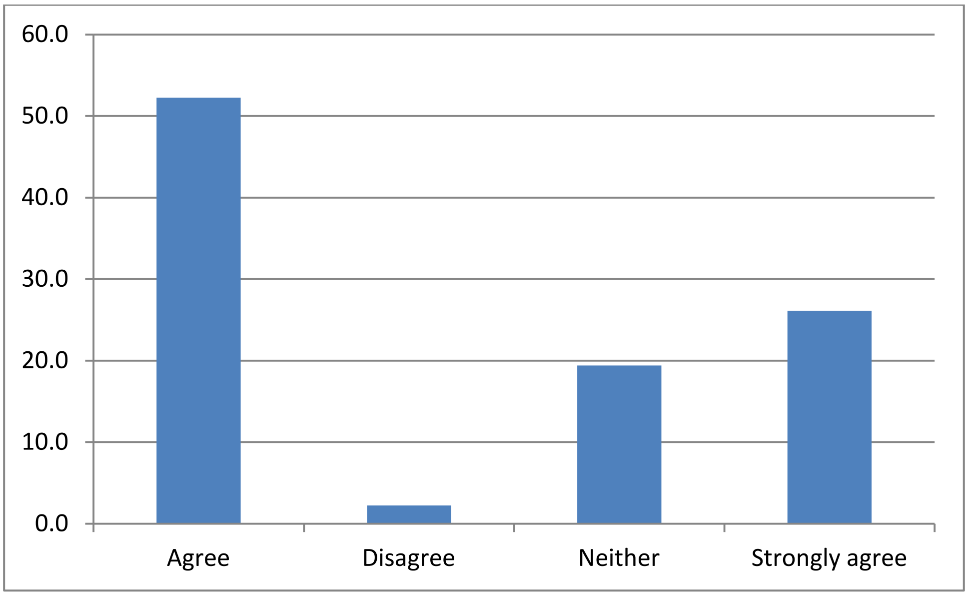


Figure 4.9   Result to Question About Daylight Effect on Staff Performance

4.4.4. *Light Source Preferences*

Literature suggested that the lighting installation type and light source impact user preferences and psychological comfort (Author and Soori, 2012), in this survey two questions were asked to evaluate the participants' preferred light source setup (mounting) and type. In order to clarify the relationship between hospital staff preferences for light source location in wards and staff, respondents were asked to choose in Question 6, among four common lighting setups the preferred light mounting, including light source direct mounted on walls, direct mounted on ceiling, indirect mounted (hidden/cove light) and indirect on wall, as follows:

Q6-Which type of light setting up (mounting) do you prefer?

☐***Direct (Wall)*** ☐***Direct (Ceiling)*** ☐***Indirect(Hidden/Cove)*** ☐***Indirect (Wall)***

The results show that eighty-three percent of hospital staff preferred light installation that is direct mounted on the ceiling, eleven percent preferred light installation that is direct mounted on walls and four percent preferred light installation that is indirect mounted on walls as shown in Figure 4.10.

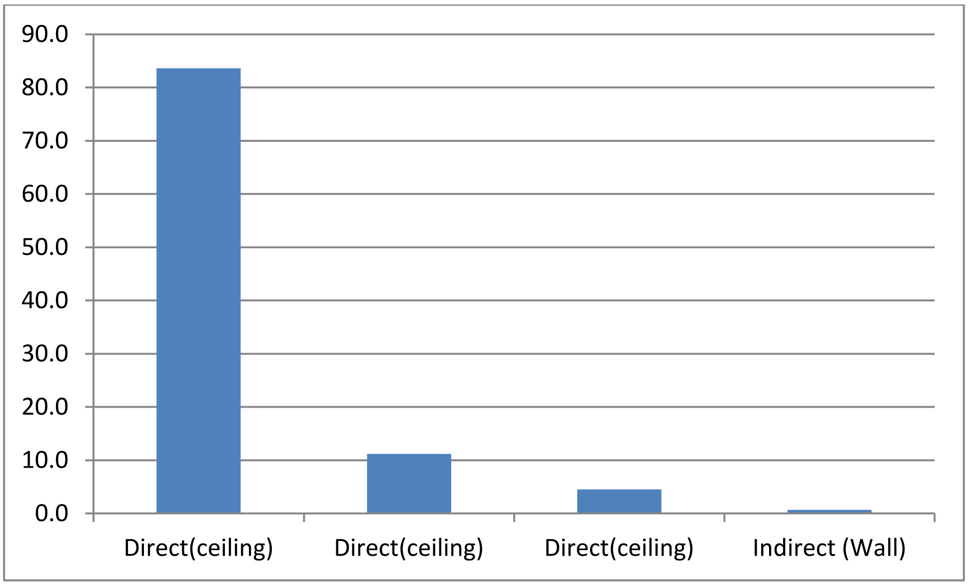


Figure 4.10 Results to Question About Light Setup Preferences

The other question was designed to measure respondents' preferences for the preferred light source at staff workstations, light source in hospitals were seen as an important factor that impacts the staff and patients as referenced by previous studies (Author et al., 2013; Author and Soori, 2012): the three selected types of light source were daylight, electrical light and a mix of daylight and electric light. The point behind each selection of light were studied in the previous chapters, which introduced people's reactions to each light source in relation to do specific tasks. Participants from staff were asked direct questions for the preferred source of light for their workplace, as in Question 7.

Q7-Do you prefer to have the workplace illuminated mainly with:
a) Daylight ***b) Artificial (Electric) Light*** ***c) Mixture of Daylight and Artificial Light***

The analysis revealed that the majority of staff (seventy-one percent) supported the idea of the using mixed type of light sources, i.e. electric light and daylight, suggesting that they complements each other and help staff do necessarily work routines. Not surprisingly daylight was supported by twenty-eight percent of staff as the preferred source for light as staff was able to observe the effects of daylight on patients and how it makes them feel comfortable. The results of the groups' replies are shown in Figure 4.11.

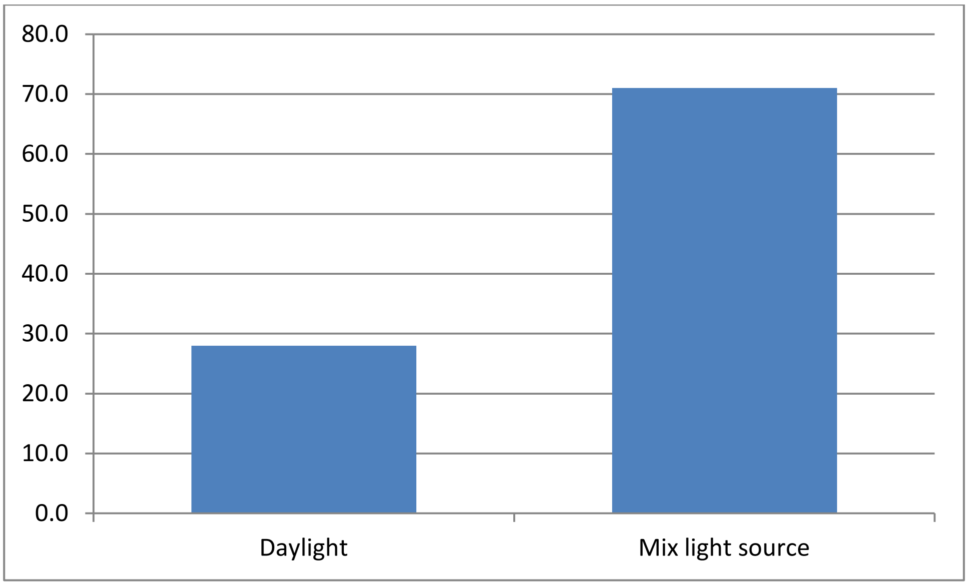


Figure 4.11 Result to Question about Preferences for lighting Source

4.5 Discussion and Conclusions

In this chapter, the outcomes of the paper based survey questionnaire were presented, survey development and stages were discussed in details, the main purpose of this survey was to explore hospital staff preferences to the lighting regime in particular to its effect on performance, randomly selected staff were asked to respond to the questions in the survey regarding the lighting elements in the hospital wards. The randomly selected participants were the professional groups in the hospital including doctors, nurses, auxiliary staff, administrators and technicians, who were asked to participate voluntarily in this survey. The results of the paper based survey questionnaire deployed during this study were presented in this chapter, the data had been collected and analysed, it indicates a range of significant outcomes, and can be summarized as follows:

- The relationship between hospital staff performance and light were explored in this study, staff expressed higher agreement with regard to the influence of light on their performance, specifically light can help them treat patients easily in a room with daylight.

- Lighting installation type and light source impact have been studied throughout this survey to explore user preferences and its psychological comfort (Author and Soori, 2012), higher agreement of hospital staff preferred light installation that is direct mounted on ceiling, while a small percentage of staff preferred light installation that is direct mounted on walls and indirect mounted on walls. While for the preferred light source at staff workstations, light source in hospitals were seen as an important factor impacting the staff and patient as referenced by previous studies (Author et al., 2013: Author and Soori, 2012), majority of staff (seventy-one percent) supported the idea of the using mixed type of light source, i.e. electrical and daylight, suggesting that they complement each other and help staff do necessarily work routines. Not surprisingly daylight was supported by twenty-eight percent of staff as preferred source for light as staff were able to observe the effects of daylight on patients and how it makes them feel comfortable.

- The results suggested a universal preference for light setting in hospitals over different culture, age and gender.

The investigation of the lighting elements factors that affect hospital staff performance provides a better understanding to plan for the next stage of the study. The next chapter reports the statistical analysis carried out in order to explore this relationship.

Chapter Five: Smart Lighting System

5.1 Introduction

In the previous chapter, the opinion of the hospital staff revealed that their experience of the positive impact of daylight on their own comfort and performance in the workplace. However due to many reasons explained in this research, such as, the availability of daylight in buildings limited by weather conditions (overcast, cloudy), atmospheric conditions (dust, pollution) and varying light levels with the diurnal passage of the sun from dawn to dusk as well as by restrictions from the building design itself. Hence, it is not feasible to rely on daylight as a universal lighting solution, and inevitably alternative sources of daylight are needed in hospitals. To overcome this fact a new lighting system has been proposed by Philips Lighting, HealWell, which uses artificial lighting to emulate daylighting and at the same time provide the required lighting levels for the full range of tasks required.

This chapter looks at the installation of this artificial lighting system in the case study hospital and reviews of the extent to which the local requirements for daylighting are met and investigates the extent to which the installed artificial lighting system can be controlled (colour and intensity) to mimic the daylight in terms of its spectrum and required illumination levels to improve the health benefits of the artificial lighting, while at the same time delivering the desired daylight effect. The concept of embedding specialised, health related, daylighting characteristics within available electric lighting technologies employed in hospitals creates a new challenge for the lighting industry. Many designers and manufacturers have proposed different lighting solutions that mimic the patterns and rhythms of daylight. However, the offered lighting focuses on the dynamics of daylight indoors that lighting change colour and intensity during the day. Philips, one of the best known names in the lighting industry, is one of those companies who introduced lighting products that claim that it is able to mimic daylighting spectra, changing the colour temperatures from warm to cool white, and at the same time psychologically and physiologically impacting building occupants in a similar fashion to daylight.

One of the appreciated features of daylight that was highlighted in the survey responses of hospital staff in the last chapter is that is appears to have the ability to improve mood and performance, as was found also in studies by Lumiversal (2010). However there is very limited research on the effects of the use of electrical lamps that emulate daylight on the mood and performance of people (Linhart, 2011). Some lighting manufacturers have claimed that certain lighting design setups can result in improvements in productivity for employees. For instance, West Bend Mutual Insurance claimed increased productivity levels by 2.5% (Kroner et al., 1992) and this issue is explored in the chapter below.

5.1.1. *Overview on Smart Lighting System*

In this chapter, the installation of a 'Smart Lighting Solution', HealWell by Philips, is introduced and evaluated to interrogate the potential of a new lighting technology that mimics the daylight characteristics to improve the hospital staff performance in their workplace. HealWell Lighting System is new lighting system that aims to improve the visual environment in hospital wards through emulating daylighting features through the use of electrical light fixtures.

5.2 Configuration of Experimental Patient's Room

The artificial daylighting solution was set as a test facility in a patient room at the Skilled Nursing Facility in the Hamad Medical Corporation Hospital in Doha Qatar[35]. The test room was rectangular in shape, 3.7m wide, 4.5m long, and 2.8m high as shown in Figure 5.1.

[35] https://www.hamad.qa/EN/Pages/default.aspx

Figure 5.1 The Experimental Patient Room showing HealWell Lighting

The lighting system controller is located above patient's bed in the middle of the room, while the lighting fixtures were installed above the patient's bed in the ceiling. The installed light was a 4x Smart Form 500x500mm, Savio TBS770 each one of them equipped with TBS471, 5x14W 827/855 HFD AC-MLO, the light installation is shown in Figure 5.2.

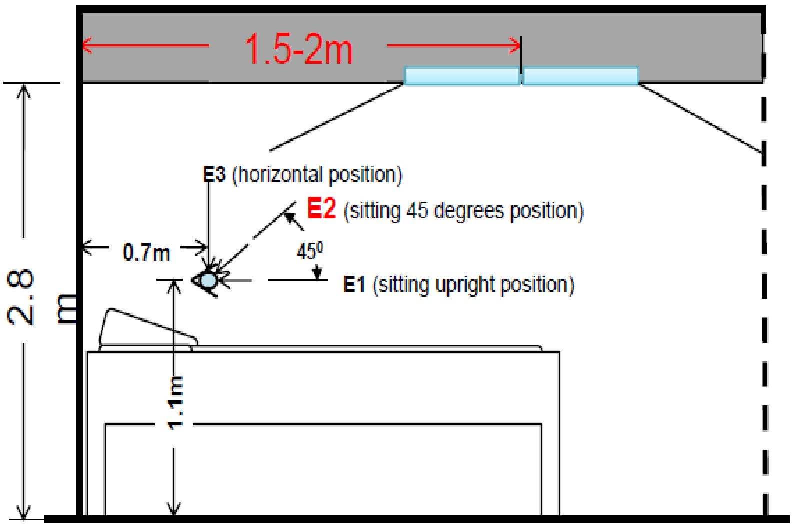


Figure 5.2 HealWell Light Installation Details in Patient Room

The lighting system is designed to mimic the natural daylight and track circadian rhythms, with varying light levels from 0 lux to 2000lux and with the ability to change the colour of the light from warmer to cooler light according to pre-settings. This system is basically designed to improve patient and staff satisfaction through the fine-tuning of adjustable lighting levels to suit personal preferences and help to organize patient day and night time experiences through the control of rhythms of light colour and **light levels**

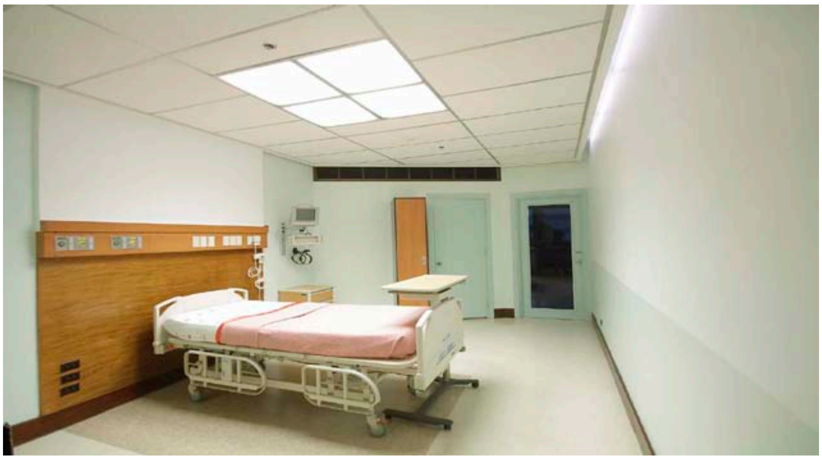


Figure 5.3 Typical HealWell Lighting System in Patient Room

5.2.1. *Visual Comfort and Staff Performance under HealWell Lighting*

In Chapters One and Two, the conclusion was reached that daylight has considerable effect on the hospital staff, including demonstrable improvement of performance. However, daylight is not available all the time, neither in the test room, nor in all areas in the hospitals depending on factors such as time of day, weather, pollution and building orientation. Thus different areas of the hospital will need more of less daylighting for shorter or longer periods (Esther et al., 2013; Dalke, 2005). There is little information on the performance of the type of daylighting system to be tested here, other than what is available from the manufacturer's recommendations. In this chapter, the visual comfort and performance of hospital staff are investigated working under HealWell daylight lighting solution and then also with the room equipped with standard hospital electrical lighting. The two test conditions are assessed using the criteria of staff comfort and visual performance and user satisfaction assessment. Both subjective and objective assessments were carried out through the experimental procedure done as part of this study. The visual performance of the staff were tested through computer-based and paper based tests, while the subjective visual comfort of the staff was done through paper-based a questionnaire survey (details of the experiment procedure will be discussed in detail as part of this chapter)

5.2.2. *Description of the Experiment*

This experimental study was designed to compare staff performance under current hospital lighting as compared to their performance under newly developed lighting system, HealWell; the experiment involved thirty young hospital staff (22 females, 8 males). The mean average age of respondents recruited for the study was 25.55 ± 2.1 years. The experiment was scheduled so that each participant completed the test over two days (only one test per day).

Thirty nurses (male and female) were randomly selected from the Skilled Nursing Facility staff and were volunteered on behalf of the management to participate in the study. It was conducted from December 01, 2013 to February 22, 2014. The screening criteria to select the participants were:

- The participant does not have visual problems, to avoid any potential other factor that might influence the performance

- Age constraint between ages 25-35 years, young enough to be comfortable to sit for the whole experiment

- Good computer knowledge required, as the experiment involved using a computer

-Working in the same hospital, to ensure suitable time slots for the experiment can be scheduled and the subject is familiar with the hospital.

- The experiment was conducted during the evening to eliminate any contribution of sunlight sources of lighting in the test room.

The standard hospital lighting installation using normal fluorescent lights will be referred to as “Reference Lighting Scenario” (RLS), and the newly installed lighting scenario referred to as “Smart Lighting Scenario” (SLS). The work under the RLS (normal lighting) will be compared to the work performance under SLS, and the results are then discussed and analysed to see if this new system can achieve the expected positive effect on staff performance.

5.2.3. *Experiment Room Arrangement*

The experimental room in which the experiment was held is a single patient room with dimensions of 4.2m x 3.1m x 2.8m, the room is illuminated by fluorescent light tubes installed in direct position on the ceiling. During the RLS scenario assessment the room was illuminated with TL5 fluorescent light tubes 4x 18 watts in each of the 500x500mm enclosures, provides 500Lux with CCT of 4000K.

In the SLS scenario, the room was illuminated with the similar light fixture so that the participant would not feel the difference but the lamps where different it was 4x Savio light with dimensions of 500x500mm. Savio enclosure is equipped with TL5 lamps of 4x14W, provides 1000Lux with CCT at 6000K as shown in appendix F.

5.3 **Methodology**

The experiment was done on structured stages, starting at preparation and completing at survey stage, as shown in Figure 5.4.

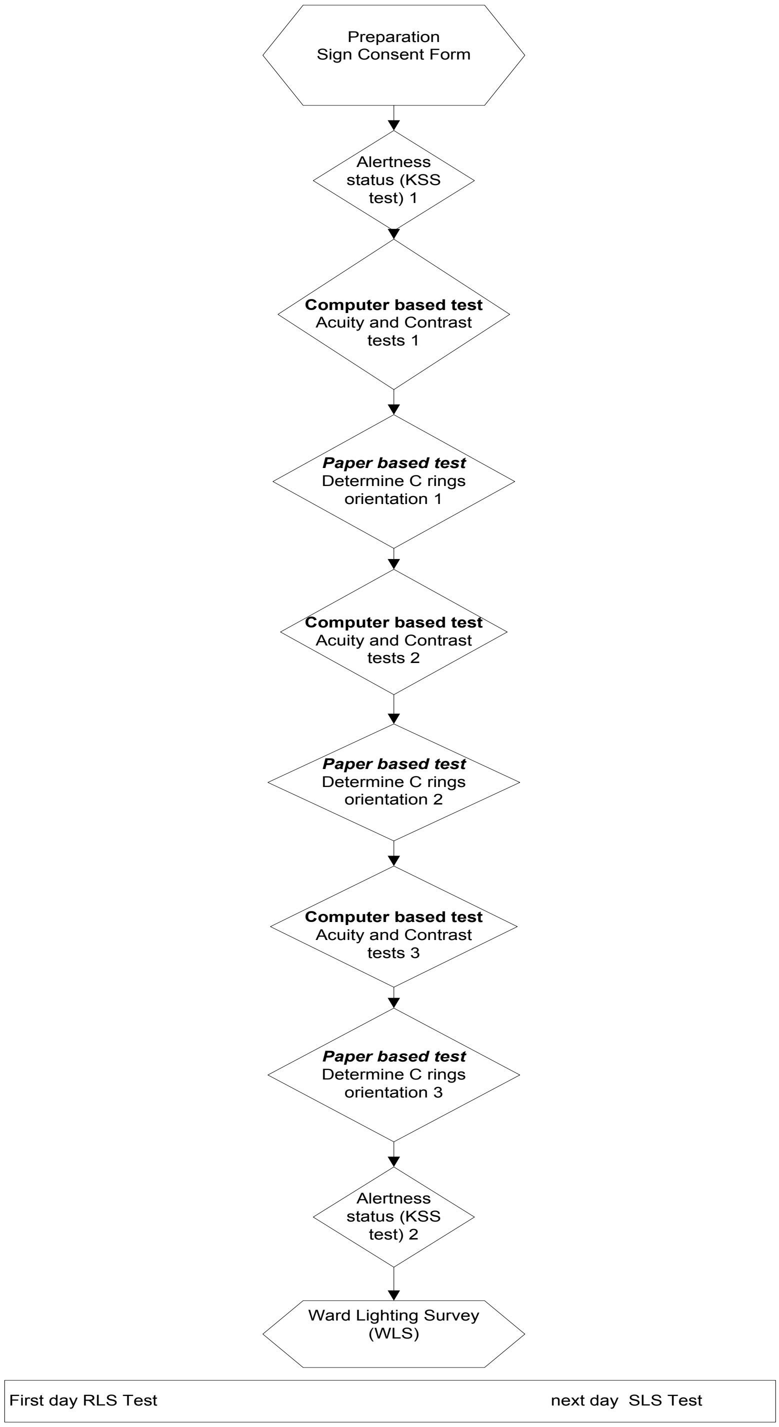


Figure. 5.4 Experiment Schedule – This figure illustrates the complete schedule of the experiment applied for RLS and SLS.

5.3.1. *Detailed Experiment Description*

The experiment was designed so that each of the thirty participants were asked to attend the test room around 7 PM (two hours after sunset) for both the SLS and RLS scenario tests, to ensure no sunlight from outside could interfere with the lighting setup in the ward, moreover all curtains were closed for the same reason. The tests were divided into multi-stages. During the first stage the nature of the study is explained to the participants and what they are expected to do at each stage. This induction stage takes approximately ten minutes during which the participant adapts to the lighting environment and consent forms are signed during this stage prior to start of the test.

In the second stage, participants were asked to do the first Acuity and Contrast Test on the computer prepared for this purpose placed one meter above the floor at a height similar to patient bed level. Upon completion of this computer test the participants take the first paper-based test to determine the number of C rings with each orientation. To ensure that the participants become tired they were asked to carry out the complete test without break times or rests in-between. Immediately following, participants did the acuity, contrast and paper-based tests two more times, this stage were completed in an average of 40 minutes. Upon completing the paper and computer tests, participants are required to state again their alertness status through the Karolinska Sleepiness Scale (KSS) Test. Following completion of their tests the participants were asked to take a two minute break and then complete the questionnaire survey which summarizes their overall experience with the lighting environment under which they did the tests. Breaks between tests were withheld to ensure that the participants are emulating actual everyday workplace situations when they are working in wards where there is no break time during the daily schedule in the urgent patient nursing wards, as is reported by observing staff from the hospital.

Exactly the same testing procedure was repeated next day for the other lighting scenario for each of the participating staff members. The reason for not completing the other lighting scenario on the same day was to allow the participant to come in fresh, not exhausted, to the test, as was the case for the first scenario tested in order to ensure that the results are really comparable.

The complete performance test sequence which started with preparation, signing consent form, providing alertness status, completing a computer based a Freiburg Visual Acuity and Contrast Test, then a Landolt C Rings Paper-Based Test was done in 60 minutes, this is including the computer and paper-based tests that were repeated three times to ensure that the participants get tired, mimicking actual work routines in hospitals and then finishing with the paper-based questionnaire.

5.3.2. *Alertness Monitoring*

Prior to start the experiment the participants were to confirm they had enough sleep before come to the experiment. During the whole duration of each experiment, the participants' alertness was monitored, utilizing the Karolinska Sleepiness Scale (KSS) (Kosuke et al., 2006). Participants were required to state the level that best indicates their psycho-physical status in the last 10 minutes of the tests, it is a subjective rating that participants need to state their alertness level on a scale from 9-stages starting with "extremely alert" (= 1) to "fighting sleep" (= 9). This scale is used as a reliable test tool by many researchers to assess the subjective sleepiness of participants (Shamsul et al., 2013; Linhart, 2010). The reliability of the KSS Test was validated by researchers (Kaida, 2005; Putilov and Donskaya, 2013; Akerstedt and Gillberg, 1990), and found to be an acceptable tool to judge the alertness status of the tested subjects. In this study, participants were asked to record their alertness level on scales of nine stages starting with “extremely alert” as (1) and to (9) as “very sleepy, as illustrated in Figure 5.6.

Rank	Status
1	Extremely alert
2	Very alert
3	Alert
4	Rather alert
5	Neither alert nor sleepy
5	Some signs of sleepiness
7	Sleepy, but no effort to stay awake
8	Sleepy, some effort to stay awake
9	Very sleepy, great effort to keep awake, fighting sleep

Figure 5.6 Karolinska Sleepiness Scale (KSS), used in this study to measure participant alertness status

5.3.3. *Computer-Based Task, Visual Acuity and Contrast Test (FrACT)*

To assess the impact of the two lighting scenarios (SLS and RLS) on the performance of the participating staff the Freiburg Visual Acuity and Contrast Test (FrACT) was used as a tool to determine both visual acuity and contrast threshold (Kosuke, 2006). The Visual Acuity and Contrast tests are automatic computerized procedures that relied on personal judgments to verify a person's contrast threshold and visual acuity by identifying correct recognition of Landolt-rings on a computer screen, as shown in Figure 5.7.

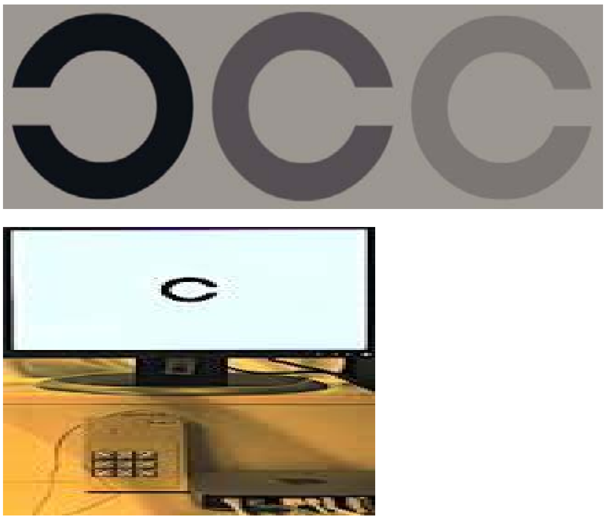


Figure 5.7 The Freiburg Acuity and Contrast Test. A Computer-based test used in the experiment.

It is set either in four or eight orientations as selected by the test administrator (test is available free of charge from *www.michaelbach.de/fract*). In this test, eight orientations of Landolt-Cs configurations were used as shown in Figure 5.7. The participants were asked to press one of eight PC number buttons to indicate the spatial arrangement according to the positions of the Landolt-Cs opening shown on the screen (8=top, 9=top right, 7=top left, 2=down, 3=down left, 1=down right, 4=left, 5= right).

Figure 5.8 Freiburg Computer Test Keypads

In the acuity test, a set of three different sizes and eight orientations of Landolt rings were displayed on the PC screen. The key task for participants is to recognize the C ring orientation by clicking on the PC direction button as quickly as possible. Each participant did the "Acuity" test three times under each of the lighting scenarios. The participants were asked to record the test result on the given papers to record as it is shown on the screen and continue to the next test, a 50cm distance was kept between screen and participant, with 8 choices and 18 trials, each trial allowed 4secs for completion in the software settings. For each sequence of total rings, a performance indicator þ was created as suggested by Münch et al. (2011), as follows:

ă= δ / ť…………..(1)

Where δ is the total number of correctly identified Landolt rings direction per sequence and ť is the total duration of the sequence (in this test, four seconds were set for each orientation).

To complete the visual test a Contrast Threshold Test was included in the computer test (repeated after each Visual Acuity Test). In this test, the Landolt C rings were kept with the same size but the contrast between PC screen background and the rings changed automatically during the test and accordingly the participants were requested to determine the correct orientation of the Landolt C rings while there is a change in the screen contrast for every sequence. In order to have performance indicators on the contrast visual performance assessed the three contrast tests trial were averaged and the recorded as follows:

$¢_{Performance}$ = (Ã+Ä+Å)/3 …………….(1)

Where $¢_{Performance}$ is visual contrast performance indicator

Ã Contrast threshold A,

Ä Contrast threshold B

Å Contrast threshold C

5.3.4.*Paper-Based Task*

In this task participants were asked to determine the orientation of the Landolt C rings lightly printed on white paper. This test was originally suggested by Courret (1999) and validated by Linhart and Scartezzini (2011) and Shamsul et al. (2013). In each paper test there were ninety-six C rings with different orientations and distributed on eight rows by twelve columns, printed with weak contrast to make the task difficult. Sample paper-based test is shown in Figure 5.9. Participants were asked to do this task within five minutes and without marking the C rings on the paper, they are required to write only the final number of each of the four C rings' orientations at the bottom of the test paper. Three different combinations of ring orientations were developed during the test to ensure participants do not remember the total number of each C ring orientations counted at each step in the light scenarios test. The performance indicator for the paper-based tests determines the number of wrong answers to the total number of C rings under each light scenario.

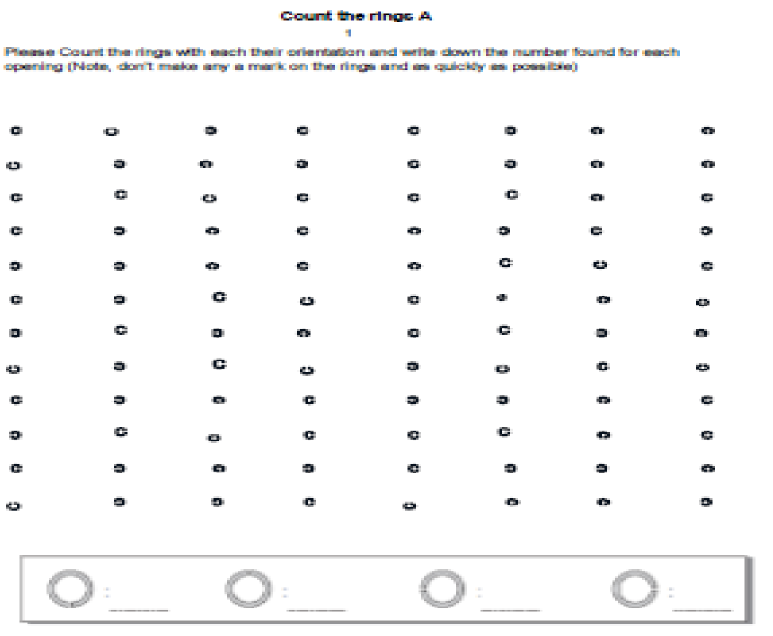


Figure 5.9 Paper-Based Landolt Ring Task. – This test was suggested by Courret (1999),in which participants are asked to count the number of rings for every orientation as quickly as possible

5.3.5. *Visual Comfort Assessment*

At the end of each test questionnaire, a survey was used to explore the participant's satisfaction with each lighting setup. The Ward Lighting Survey (WLS) was designed to contain two groups of statements: firstly to collect the staff member's satisfaction with the lighting environment and secondly to see if any problems were perceived as associated with each lighting regime during the test. Participants were required to locate their responses within five options (Strongly Agree, Agree, Neither, Disagree, Strongly Disagree) so that they could locate their degree of agreement with each statement. Sample of the Ward Lighting Survey (WLS) is shown in Figurer 5. 10.

Ward Lighting Survey (WLS)

Please state your agreement with the following statements:

1. I like the Lighting colour in this ward
   ☐*Strongly agree* ☐*Agree* ☐*Neither* ☐*Disagree* ☐*Strongly disagree*
2. The lighting in this ward is pleasant
   ☐*Strongly agree* ☐*Agree* ☐*Neither* ☐*Disagree* ☐*Strongly disagree*
3. I feel comfortable working under this light
   ☐*Strongly agree* ☐*Agree* ☐*Neither* ☐*Disagree* ☐*Strongly disagree*
4. This ward seems too bright
   ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*
5. This ward seems too dark.
   ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*
6. There is no enough light to examine patient or give medicine in this ward
   ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*
7. Do you think it is easier to treat patients in a ward with this light
   ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*
8. My skin colour looks unnatural under this light
   ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*
9. The lighting in this ward create shadow
   ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*
10. I feel eye strain working under this light
    ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*
11. I have difficulties in seeing object s on the screen
    ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*
12. The lighting in this ward makes me feel sleepy
    ☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*strongly disagree*

Figurer 5.10 Paper-Based Questionnaire used in the Experiment, Ward Lighting Survey (WLS)

In order to get a clear result from the WLS, scores were assigned for each question asked as shown in Table 5.1:

1.	Questions	Score
Preferences	I like the lighting colour in this ward	+3 =Strongly Agree +2 Agree +1= Neither 0 = Disagree 0 = Strongly Disagree
	The lighting in this ward is pleasant	
	I feel comfortable working under this light	
	This ward seems too bright.	
	This ward seems too dark.	
	There is not enough light to examine patient or give medicine in this ward.	
	Do you think it is easier to treat patients in a ward with this light?	
	My skin colour looks unnatural under this light.	0=Strongly Agree 0=Agree 0= Neither +2 = Disagree +3 = Strongly Disagree
	The lighting in this ward creates shadows.	
Indicators	I feel eye strain working under this light.	
	I have difficulties in seeing objects on the screen.	
	The lighting in this ward makes me feel sleepy.	

Table 5.1 Assessment criteria used to assess answers from WLS

Preferences for the light setup were assessed based on the responses to Questions 1 to 9, while the visual comfort level was determined from the responses to Questions 10 to 12. The scores were given as follows:

A. Questions 1 to 7 (if positive statements), scores were:

- +3 points were given if ‘Strongly Agree’ was the selected response,
- +2 for ‘Agree',
- +1 for ‘Neither’
- 0 for ‘Disagree’ and 'Strongly Disagree'.

B. For Questions 8 to 12 (negative statements), scores were:

- +3 points were given for, Strongly Disagree
- +2 for 'Disagree'
- +1 for ''Neither'
- +0 for 'Strongly Agree ' and 'Agree',

5.4 **Statistical Analysis**

To analyse the experimental test results and responses from the thirty participants, a range of statistical analysis methods were used including:

- Descriptive statistics (mean, percentage and standard deviation) were used to describe the socio-demographic distribution of the population.
- Comparison of visual comfort level, subjective preferences, visual task performances, and typing performance were performed usig SPSS software
- T-test Paired-sample were used to measure alertness level before and after experiment, Statistical Package for Social Sciences (SPSS) has been utilized, version 19, was used in all analyses. Statistical significance (p-value) is determined at $p<0$.

5.5 **Results**

Participants' performances under the two lighting scenarios were analysed using different statistical methods. The results will be explained as follows:

5.4.1.*Alertness Status Test*

The subjective sleepiness scale results were analysed for the two scenarios through analysing the drowsiness of participants before and after tests by using paired-samples t-tests (through the Statistical Package for Social Sciences software known as SPSS).

In the reference scenario, results shown in Figure 5.11 suggested that the subjective alertness status before and after tests lower than the case of SLS scenario, where SLS scenario shows a better response than the reference scenario ($p<0.05$). Further analyses were conducted to compare the alertness's level across the two scenarios, and confirmed that the pre-test alertness level was slightly changed in the RLS reference scenario compared to the post-test alertness level, average KSS rating of respondents in the SLS scenario was found to be considerably lower (more alert) than the reference scenario. The two-tailed P value for both scenarios is less than 0.0001, the difference is considered to be extremely statistically significant.

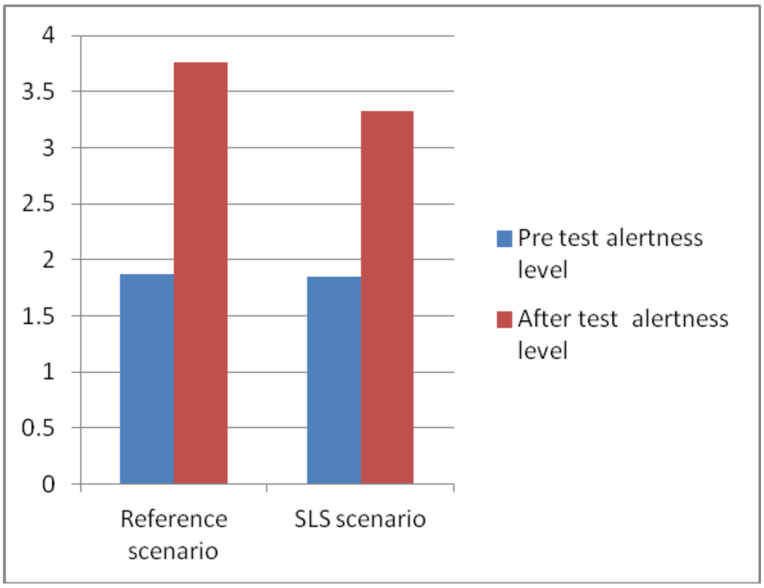


Figure 5.11 Evaluation of Staff's Alertness Level before and after the Test under Reference and SLS Scenario

5.4.2. *Computer-Based Task, Visual Acuity and Contrast Test (FrACT)*

The results of the computer-based task for the two scenarios are shown in Figure 5.12. The differences between the two scenarios show up clearly at $p<0.05$. Comparing the performance under the SLS scenario with the performance under the RLS scenario show significant difference in favor of SLS scenario with $p < 0.001$.

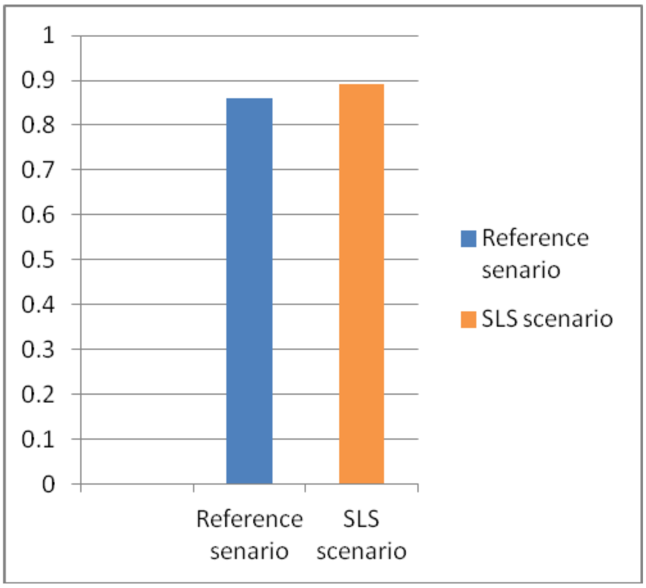


Figure 5.12 Average Correct Decision per Second Obtained from the Acuity Test

The results of the contrast threshold tests show that the average performance in these tests under the two scenarios (reference and SLS) was within 0.53% to 0.58%. Despite the difference we got in the raw mean score, as shown in Figure 5.13. The statistical significant differences between them were not observed with $p > 0.05$.

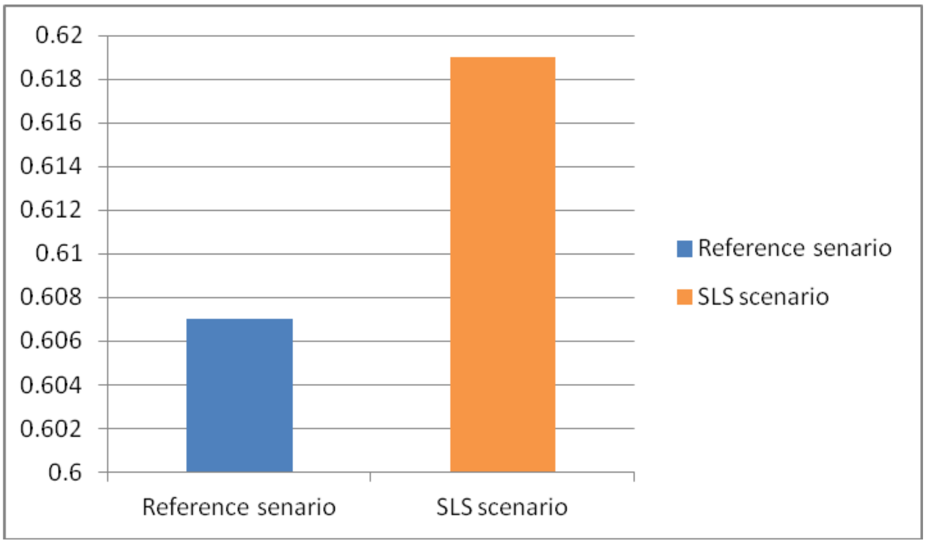


Figure 5.13 Average Correct Decision per Second Obtained from the Contrast Threshold Test

5.4.3. *Paper- Based Task*

Participants' performances under the paper -based tasks were assessed. In each scenario the average number of incorrectly identified orientation of the rings were estimated and compared between scenarios. The best results scored with a mean of 2.55 errors found under the SLS scenario, while for the reference scenario the mean error was 2.8. However, the differences between these two scenarios were not statistically significant with $p > 0.05$. The result was assessed only for the third round of the tests.

5.4.4. *Visual Comfort Assessment*

In terms of visual comfort, preferences under the two scenarios were assessed using the Ward Lighting Survey (WLS). The results show that working under SLS was mostly preferred in preference to the reference scenario. SLS participants scored 13.434 points, while reference scenario respondents scored 12.085 points. Figure 5.14 shows the symptom observations highlighting that SLS scenario produced the least negative impacts on participants associated with each lighting regimes.

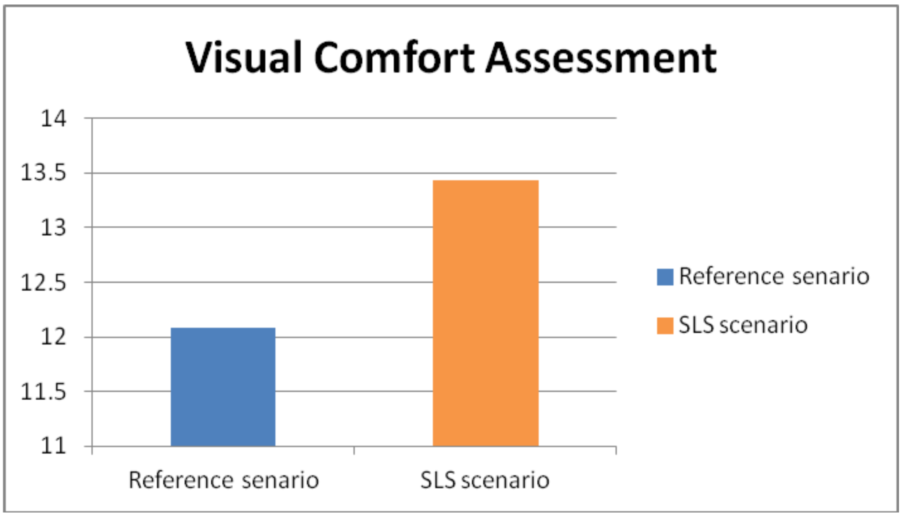


Figure 5.14 Visual Comfort Preferences Results

5.6 Discussion

Overall, hospital staff who participated in the study preferred the new tested light, SLS, over the reference scenario, RLS. Their performance in the paper-based task was notably better under the SLS than under the RLS. No significant differences in the computer-based tasks under the two different lighting scenarios were found. There was no significant decrease in the staff's alertness status, over the entire duration of the experiment for the reference scenario or new SLS. The results provide a good foundation for understanding the lighting performance in the test ward as perceived by hospital staff undergoing a standard test regime under the two lighting scenarios. In terms of the subjective preferences of participants undertaking visual comfort, alertness and task performance tests, the SLS lighting design proved more appreciated than the reference lighting design.

The reported preferences of participants from this one hospital test facility are indicative of a trend but cannot be deemed to provide comprehensive conclusions because of the sample size limitations of the study. Further limitations of the study include the relatively short test times involved of less than two hours of focused work, and the artificialness of the test conditions using one specific test ward in the hospital to do the test, and the non-standard hospital conditions under which the tests were taken. The test conditions were not designed to closely replicate the working routine of the staff, a factor that could lead to biased opinions that impact the reliability of reported scores and measurements. The Hawthorne effect is another factor that might affect the results, in which observer of the effect can influence participants in the experiment, as participants tend to modify or improve an aspect of their performance in reaction to their knowledge of it being part of an experiential procedure.

5.7 Conclusion

The results of the described tests on the perceived subjective visual comfort and visual performance under the two lighting scenarios led to several interesting conclusions, especially that the test was conducted in a facility that was close to a normal working location within the hospital that they are familiar with.

First of all, the results show that the two tested lighting scenarios, simulated daylight and standard reference lighting conditions are comparable in terms of subjective visual comfort. Overall, majority of the study's participants from the hospital staff (90%) prefer the Smart Lighting Scenario (SLS) over the Reference Lighting Scenario (RLS). In addition, their performance under the paper-based tasks was significantly better under the SLS lighting scenario than under the reference scenario.

The above results from the experiment, despite the limitations of its experimental design, do indicate when working under an artificial lighting regime that mimics daylight conditions, even during the limited test period of the evening hours, the positive impact on staff performance is significant. This experiment also revealed that no significant differences were found in the computer-based tasks under the two lighting scenarios. This conclusion of a minimal effect in these tests calls into question the degree that lighting environment effects staff performance when doing computer work compared to their performance undertaking paper-based tasks.

In general, it is concluded that new lighting design systems like the SLS, which can imitate the daylight without jeopardizing performance and visual comfort, could provide a good future solution to the lack of daylight in hospitals, particularly important in very hot regions. The results of the tests described in this chapter illustrate that better visual performance and better visual comfort can be gained by using such daylight mimicking Smart Lighting Systems.

Further work might usefully cover the long-term effects of a range of Smart Lighting

Systems and approaches on visual comfort and performance of hospital staff. Another question that needs further study is whether the light exposure during the normal working day influences performance and visual comfort in the evening. Recent study on Hospital Ward Design suggested that, amongst other factors individual exposure to sunlight during the day need to be taken into account during hospital lighting design (Alalouch, 2010).

Lastly, this preliminary experiment has highlighted the large potential that exists to improve working conditions and performance through enhancing the daylight-like experience of the artificial lighting environment within a hospital. The results of this study are sufficiently encouraging to inspire larger scale roll-out usage of such systems at a hospital scale to achieve better hospital lighting design that can help reduce the problem of lack of daylight in enclosed hospital environments and help improve overall staff performance. In the next chapter different type of electrical lighting design in hospital will be explored to reach the efficient lighting design in hospitals that provide positive effects on staff performance and at the same time improve energy efficiency.

Chapter Six: Energy Efficient Lighting System Design for Hospitals

6.1 **Introduction**

The impact of using energy efficient lighting design in hospitals has been studied as part of this doctoral thesis (Author and Soori 2012). Design of energy efficient lighting systems is not a simple process and the complexity increases when the design involved an important place, such as, a healthcare facility where lighting is seen as one of the factors that can improve the healthcare experience functionally and environmentally, as explained in the previous chapters. Many studies suggested that lighting consumes considerable amount of electrical energy in commercial buildings (Galasiu et al., 2003; Author and Soori, 2011), and in healthcare facilities it can reach up to forty percent of the total power consumed[36].

In the previous chapter, the new electrical lighting system (HealWell Lighting System) shows that enhanced visual performance and better visual comfort can be gained by utilizing electrical Smart Lighting Systems, that emulate daylight and provides preferred lighting type in the hospital, on the other hand the shortage in energy resources worldwide necessitates joining all efforts to reduce energy consumption and improve the efficiency of the designed systems.

In this chapter, the performance of different types of lighting installations used for hospital lighting system design will be discussed from two perspectives: the energy consumption and cost impact associated with each selection. Proposed design methodology is presented to achieve optimal efficient lighting design. In addition simulation software is used to assess the efficient lighting scheme visually and functionally.

36 http://www.eia.gov/consumption/commercial/

6.2 Overview of Lighting Energy Consumption in Hospitals

According to the World Energy Report in 2012, nineteen percent of the world electricity demand goes to lighting[37]. Hospitals by its nature is a major consumer of energy, that it is working 24/7 where energy is used to serve numerous buildings' occupants such as staff, patients and visitors, and these factors in addition to expansion in hospitals sizes and services have resulted in steadily growing the energy consumption[38]. In the United States of America, hospitals represent less than one percent of all commercial buildings however, it consumes more than five percent of the total energy used by the entire commercial sector[39]. A Survey conducted in U.S healthcare facilities found that electricity consumption account for fifty percent of the total hospital's energy consumption, analyzing major elements which consume energy in hospitals lead to find lighting to be one of the major elements that consume electrical energy[40]. According to Energy Information Administration in the U.S.A., energy consumption in hospital buildings can reach up to forty-three percent due to lighting. In Germany, a report published on hospital points out that hospitals' electricity account for seventy percent of the energy costs, as suggested by the Environment Science Centre Report[41]. The results from the UK Hospital Audit in 2012 show that hospital lighting power consumption reach up to thirty-five percent of the total electricity consumption[42].

The University of Chicago Medicine School has conducted research that estimated the carbon emissions generated from hospitals and found that the energy consumptions are equal almost to seventy percent compared to that resulting from the worldwide automobile fleet[43]. The above referenced reports and studies lead to think of ways to reduce the energy consumption in hospitals without affecting the performance of this

37 http://www.worldenergyoutlook.org/publications/weo-012/#d.en.26099,2012
38 http://www.uchospitals.edu/news/2009/20091110-footprint.html
39 https://www.eia.gov/consumption/commercial/reports/2007/large-hospital.cfm
40 http://buildingsdatabook.eren.doe.gov/ChapterIntro3.aspx
41 http://www.carbontrust.com/resources/guides/sector-based-advice/healthcare
42 http://www.carbontrust.com/resources/guides/sector-based-advice/healthcare
43 http://www.uchospitals.edu/news/2009/20091110-footprint.html

facility, seeing that lighting is an important factor and reaches up to forty percent of power consumed, therefore the challenge is to look for methodologies to reduce energy consumption and improve the efficiency of lighting systems in this sector. Due to the nature of hospital lighting that it should work around the clock for guidance purposes and safety of patients and staff, these requirements make it difficult to rely on manual or automatic lighting controls strategies and then another approach for energy savings should be followed.

6.3 **Proposed Design Procedure for Hospital Lighting System**

In previous studies a design procedure was proposed to achieve efficient lighting design in different facilities, in this study a new energy efficient light design methodology will be introduced for hospitals and will be verified based on the previous studies (Author et al., 2011; Author et al., 2012).

6.3.1.*Lighting Design Requirements*

The first step in achieving efficient lighting design in any facility starts with identifying the application for which the design is proposed, which starts with defining the lighting requirements for the designated area, these include understanding the function of the designed area, colour requirement of lighting and the recommended lux level; the recommended lighting level (lux level) can be acquired from international standards and professional organizations, which represent good references for the minimum design recommendation originations, such as Chartered Institution of Building Services Engineers (CIBSE) or Illuminating Engineering Society of North America (IESNA), Table 6.1 shows CIBSE recommended lighting level in hospitals which will be adopted in this study .

Area	Illuminance in lux	Limiting Glare Index	Minimum Colour Rendering
General Lighting	100	19	80
Waiting Rooms	200	22	80
Corridors: Day Time	200	22	80
Corridors: at Night	50	22	80
Day Rooms	200	22	80
Staff Office	500	19	80
Ward Rooms	500 (1000lux inspection)	19	80

Table 6.1 Recommended Hospitals Lighting Requirements[44]

6.3.2.*Luminaries Selection for Energy-Efficient Design*

Deciding on the best fit for the purposed lighting is an important step toward achieving efficient lighting design. This should be done with consideration to the place of use (indoor or outdoor), field of application type, such as, healthcare, commercial, industrial or residential facility and the lighting characteristics. Light characteristics include four basic elements, Luminous Intensity, Luminance, Luminous Flux, and Illuminance, representing its performance that the lighting designer should choose carefully. Luminous Intensity which refers to the emitted amount of visible light emitted per unit time and measured in Candela Cd. Luminance is a term used to indicate how bright the surface is seen, it is measured in Candela Cd per unit area (Cd/m^2). In addition, Luminance can be calculated from Equation (1) (Author et al., 2012),

44 http://www.cibse.org/Knowledge/CIBSE-LG/Lighting-Guide-02-Hospitals-and-Health-Care-Buildi

$$Li = \frac{d^2\ \text{ø}}{\text{d}\tilde{\text{A}}\text{d}\Omega\ \cos\Theta} \quad \ldots\ldots\ldots..(1)$$

Where Li is the luminance (cd/m^2),

ø is the luminous intensity (Cd/m^2)

θ Is the angle between the surface normal and the specified direction

Ã is the area of the surface (m^2), and

Ω is the solid angle (radian).

Luminous Flux is another characteristic of lightwhich should be considered during the selection of the light fitting. Table 6.2 presents common lamps used in lighting system design along with their luminous efficiency and lamp service life, it is one of the reference used by the designer to select appropriate lighting fitting:

Type of Lamp	Lumens per watt	Average lamp life in Hours	Colour Rendering	Luminous Flux
Incandescent	8-25	1000-2000	100	1700
Fluorescent	60-600	10000-24000	82-95	2800
High Pressure Sodium (HPS)	45-110	12000-24000	83	26000
Low Pressure Sodium (LPS)	80-180	10000-18000	25-80	25000
Metal halide	60-100	10000-15000	87-93	40000
LED	28-79	25000-100000	40-85	400

Table 6.2 Characteristics of Common Light Sources Light, Source (Table and Lighting Description Courtesy of Deep Sea Power and Light)

6.3.3. *Lighting Calculation*

Determining the required number of light fixtures can be done either manually through mathematical calculation, i.e. using lumen method as in Equation (2) (Boyce and Raynham 2009),

$$NF = \frac{Lux \times A}{(LDL \times UF \times MF)} \qquad (2)$$

NF The required light fittings
A The overall working plane area in m^2
LDL Lumens produced by each lamp
UF The utilization factor
MF The maintenance factor

Another way to produce the lighting calculation is by computer simulation software, such as, Dialux, which is a reliable professional tool easily used to predict the lighting design scene with the designed light fitting and provides three dimensional graphics for the illuminated space (Author et al 2012).

6.3.4. *Overview of Lighting Design Configuration*

Installation setup and direction of lighting fitting will impact the outcome of each lighting design, to achieve the most favorable design for the lighting system and to deliver a uniform illuminance at the required working plane suitable positioning of lighting should be carefully selected, i.e. direct, indirect, ceiling suspension or wall mounted. Room elements and their reflectance should also be considered, if the used material are standard then the following table is applicable, otherwise each material reflectance should be given per manufacturer.

Surface	Reflectance
Ceiling	0.7 or higher
Walls	0.5-0.7
Partitions	0.4-0.7
Floor	0.1-0.3
Furniture	0.2-0.5
Window blinds	0.4-0.6

Table 6.3 Typical Reflectance Value for Room Elements[45]

To achieve visual comfort and avoid glare effects in patient rooms or any other examination rooms in hospitals the common viewing angle for patients need to be toward the ceiling and to the front facing walls, therefore lighting design should achieve the balance by providing good visibility and avoid glare from these room walls and surface. For the purpose of standardized glare impact Boyce and Raynham (2009) recommended Glare Index for each application and the Unified Glare Rating (UGR) is used to quantify the Discomfort Glare in any lighting installation as suggested by the International Commission on Illumination[46], the formula used to measure UGR measures the luminance of a lamp with respect to the background of visible luminance from the room can be expressed as in Equation (3) :

$$\mathrm{UGR} = 8\log\frac{0.25}{\mathrm{Lb}}\sum L^2 s\frac{\omega}{p^2} \ldots\ldots\ldots (3)$$

45 http://www.cibse.org/Knowledge/CIBSE-LG/Lighting-Guide-02-Hospitals-and-Health-Care-Buildi
45 http://www.cie.co.at/index.php?i_ca_id=781

L_b is the background luminance (cd/m^2), excluding the contribution of the glare sources.

L_s is the luminaire's luminance (cd/m^2)

ω is solid angle subtended at the observer's eye by the luminaire (radians)

P is displacement from the line of sight (Guth Position Index)

According to Boyce and Raynham (2009) the recommended UGR values for visual comfort fall between 13 and 30, where higher value refers to discomfort[47] .

UGR value	Discomfort Glare Condition
13	Just perceptible
16	Perceptible
19	Just acceptable
22	Unacceptable
25	Just uncomfortable
28	Uncomfortable
30	Uncomfortable at all

Table 6.4 Typical Unified Glare (UGR) Values for Lights, from SLL book[48]

6.3.5. *Lighting Power Density (LPD)*

47 http://www.cibse.org/knowledge/cibse-lg/sll-lighting-handbook
48 http://www.cibse.org/society-of-light-and-lighting-sll/lighting-publications

Lighting power requirement is a criteria used to assess the efficiency of the design, it is identified by many standardization bodies and organizations in Canada and the U.S.A., it follows the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)[49], the American National Standards Institute (ANSI)[50], and the Illuminating Engineering Society of North America (IESNA)[51]. In the UK the applicable lighting code follows British Standards (BS) and the Chartered Institute of Building Services Engineer (CIBSE)[52]. Lighting Power Density (LPD) is a term used to describe the lighting power load in any defined area; it utilizes the watts per square metre unit to measure the lighting equipment. American standards, such as, ANSI/ASHRAE/IESNA recommend efficient design power density for hospital areas, such as, emergency rooms to be designed for 27 watts per square metre, while for recovery rooms allowed 8 watts per square metre[53]. CIBSE guidelines on the other hand recommend 25 watts per square metre for treatment rooms[54].

6.3.6. *Review of Cost Analysis, Whole Life Cycle Cost Analysis (WLCCA)*

To assess the cost-effectiveness of the different lighting designs in any area a Whole Life Cycle Cost Analysis (WLCCA) can be carried out (Kats, 2003), in this study WLCCA has been used to assess the cost impact for different lighting systems, which categorized the cost associated with them into three sections: First, the Light Fitting Cost (LFC), second, the Lamp Replacement Cost (LRC) and third, the cost associated with power consumption (Author 2013). Capital cost includes the design and lighting installation costs (Author 2013). Maintenance costs include lamp replacement and operation costs, which estimates the utility bill for energy consumption. Power consumption cost can be estimated from Equation (4).

49 https://www.ashrae.org/
50 https://www.ansi.org/
51 http://www.ies.org/
52 http://www.cibse.org/
53 https://www.energycodes.gov/sites/default/files/becu/lighting07.pdf
54 http://www.cibsedesigncompass.org.uk/lighting

₵=KYP ……………. (4)

Where ¢ is the power consumption cost

K utility tariff

Y total operating hours (8760 hour/year)

P total power consumption

6.3.7. *Design Validation Methodology*

The design methodology used has been to validate the design throughout analysis, compare the overall design against the technical requirements, architectural requirements for lighting features, standardization and energy efficiency of the design (energy saving and the associated costs). We have applied the above design methodology to lighting design of commercial and community facilities and found them to be an effective and acceptable approach to achieve a visual comfortable and energy efficient design (Author et al., 2011; Author and Soori, 2012a; Author and Soori,2012b). In the next section, the above design process will be utilized to study the efficient lighting design in hospitals.

6.4 Experiment Results

To begin with, walkthrough inspections were conducted in four hospitals in Qatar[55], that includes Hamad General Hospital (HGH), Al Wakra Hospital (AWH)[56], Heart Hospital and Reemela Hospital in Qatar[57], to identify the common lighting regime used, upon analyzing these lighting designs comparable LED lightings instead of Fluorescent and conventional tungsten light sources in the hospitals were proposed. Dialux lighting software was used as a tool to simulate lighting design that can best fit the requirement of each area in terms of energy efficiency and cost effectiveness, three lighting scenarios were presented for this purpose in typical diagnostic and treatment room in HGH.

The above design procedure was applied in a model room in HGH, which is a diagnostic and treatment room selected for the study; this room is located in Hamad General Hospital (HGH) in Qatar. The room is located on the first floor of the hospital, a rectangle shaped room with dimensions of ten metres wide, ten metres deep and four metres high. The room is designed to accommodate multiple patient beds, sliding curtain walls were used to separate the beds. The reflection coefficients (in this test it is assumed diffuse) of the rooms are shown in Table 6.5.

Location	Value
Walls (ρ_{wall})	0.5
Floor (ρ_{floor})	0.2
Ceiling ($\rho_{ceiling}$)	0.7

Table 6. 5 Reflection Coefficients for the Experiment Room

55 http://hgh.hamad.qa/en/about/about.aspx
56 http://wakra.hamad.qa/en/welcome.aspx
57 https://www.hamad.qa/EN/Hospitals-and-services/Heart%20Hospital/Pages/default.aspx

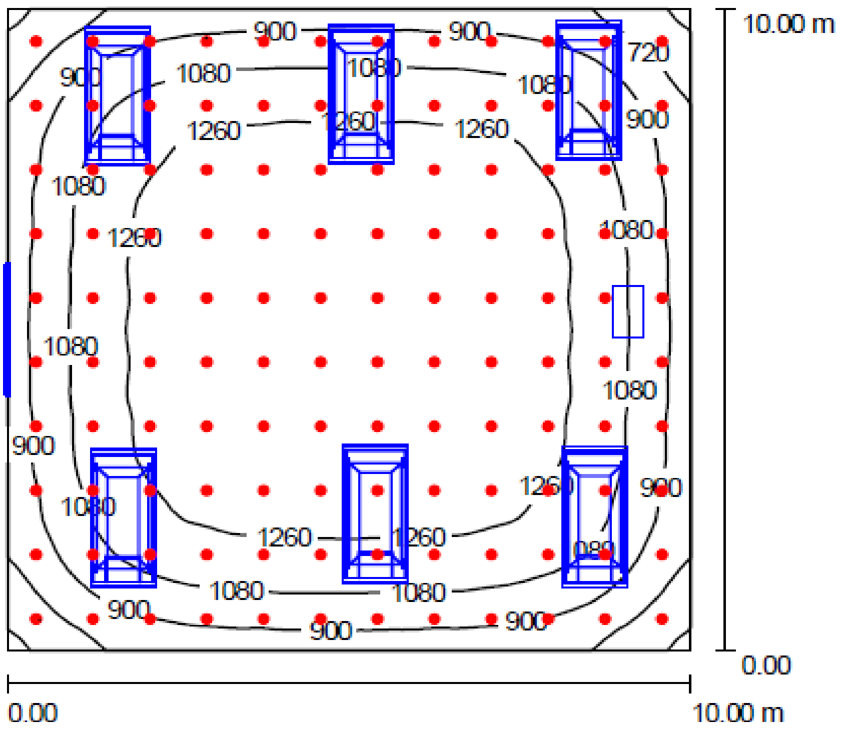
According to CIBSE guidelines, the recommended lighting level in these types of rooms should be 300-500 lux and for examination rooms should 1000 lux, as shown in Table 6.1, as this room will be considered as an examination room then this design will consider 1000lux as the general design level with capability to control the lighting level. Illumination measurements were assessed on 0.85m from floor level (which is bed height) and on 32 by32 grid points to seek many points in room for light level evaluation. Lower UGR were selected (19 and below) to reduce glare and achieve the required visual comfort as recommended by the CIBSE code of practice[58]. The utility in Qatar is owned by the Qatari government and it is subsidized, and that explains the low prices of the power consumption tariff, the rate which is set by the utility provider for hospital energy consumption is 0.10 $ for each one kWh energy consumed[59]. For the purpose of this study three basic lighting installations were selected to choose the optimum energy efficient light design, the power consumption of each lighting scenario was estimated with the use of different types of lamps like incandescent, LED and Compact Fluorescent Lamp (CFL). As in most large hospitals the working hours is 24 hours a day, seven days a week. The analysis of for each scenario was assessed with the use of the simulation software DIAlux 4.8[60].

6.4.1.*Scenario One: Utilize Incandescent Lamp*

In this scenario, The test room used Incandescent Lamp for lighting design, ERCO lighting, which is one of the recognized manufacturer in the lighting industry, is used [61], the selected lighting from ERCO product was Quintessence

58 http://www.cibse.org/Knowledge/CIBSE-Publications/CIBSE-Codes-of-Practice
59 http://www.km.com.qa/en/customer/pages/rateinformation.aspx
60 http://www.dial.de/DIAL/en/dialux.html
61 http://www.ercoworldwide.com/

Down Light 1×QT12-ax100 W, used along with ERCO lamp (ERCO 46012000, lamp100 W). Illumination distribution values for 32 points in the room is shown in Figure 6.1 and Figures 6.2, 6.3, 6.4,6.5 show the Light Photometric Data, 3D Rendering, False Colour Rendering and Value Chart.



Height of Room: 4.000 m, Mounting Height: 4.000 m, Maintenance factor: 0.80

Values in Lux, Scale 1:129

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	1134	511	1406	0.451
Floor	20	914	65	1382	0.072
Ceiling	70	216	180	250	0.834
Walls (4)	50	386	142	678	/

Workplane:
Height: 0.850 m
Grid: 64 x 64 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.348, Ceiling / Working Plane: 0.191.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	120	ERCO 46012000 Quintessence Downlight 1xQT12-ax 100W (1.000)	2200	100.0
		Total:	264000	12000.0

Specific connected load: 120.00 W/m² = 10.59 W/m²/100 lx (Ground area: 100.00 m²)

Figure 6.1 Lighting Distribution Values in Lux(Utilize Incandescent Lamp)

120 Pieces ERCO 46012000 Quintessence Downlight
1xQT12-ax 100W
Article No.: 46012000
Luminaire Luminous Flux: 2200 lm
Luminaire Wattage: 100.0 W
Luminaire classification according to CIE: 100
CIE flux code: 83 100 100 100 58
Fitting: 1 x QT12-ax 100W (Correction Factor 1.000).

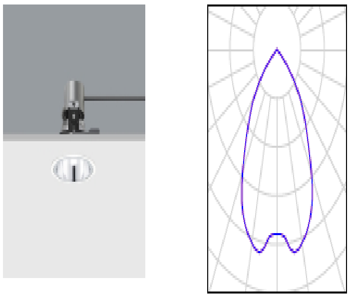


Figure 6.2 Light Photometric Data(Utilize Incandescent Lamp)

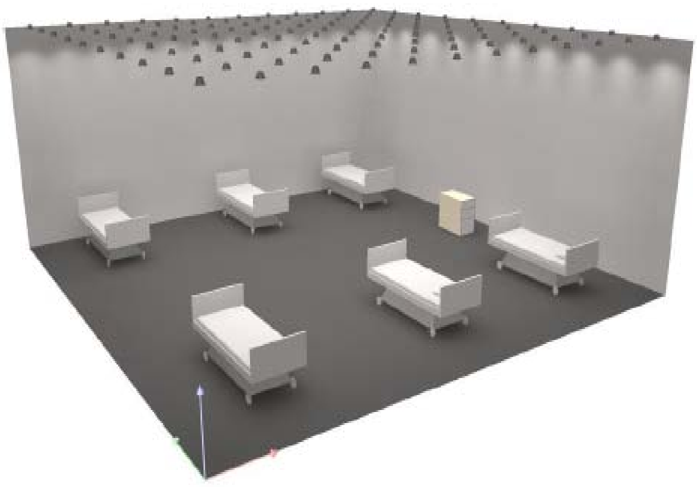


Figure 6.3 3D rendering(Utilize Incandescent Lamp)

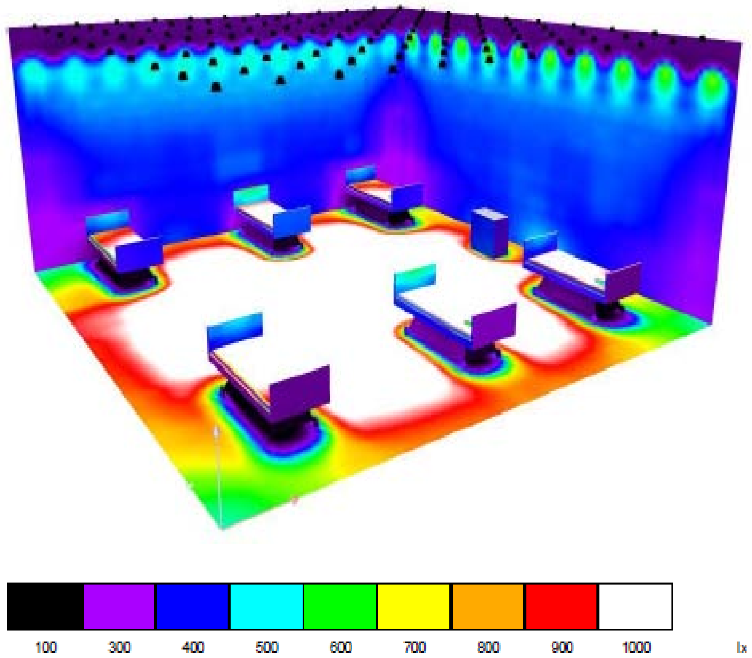
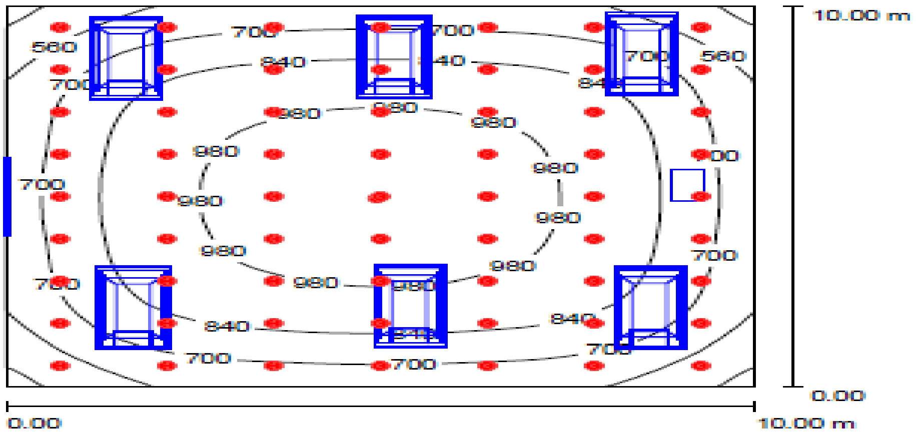


Figure 6.4 False Colour Rendering(Utilize Incandescent Lamp)

Figure 6.5 Value Chart(Utilize Incandescent Lamp)

6.4.2. *Scenario Two: Utilize Compact Florescent Lamp*

Compact Florescent Lamp (CFL) was used in this scenario to illuminate the test room, same brand was used in all of the three scenarios to ensure same quality and financial impact, same lighting setup and installation, all scenarios used recessed down light. In this scenario, ERCO 46608000 Quintessence was chosen from the CFL family (TC-TELI26W with ERCO lamp CFL 2x26 W). Lighting distribution was illustrated in Figures 6.6, 6.7, 6.8, 6.9, 6.10, which includes Lighting Distribution Values in Lux, Photometric Data, 3D Rendering, False Colour Rendering, Value Chart for this scenario.



Height of Room: 4.000 m, Mounting Height: 4.000 m, Maintenance factor: 0.80

Values in Lux, Scale 1:129

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	814	386	1062	0.474
Floor	20	650	54	1011	0.083
Ceiling	70	160	137	176	0.856
Walls (4)	50	308	112	623	/

Workplane:
Height: 0.850 m
Grid: 32 x 32 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.386, Ceiling / Working Plane: 0.197.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	127	ERCO 46608000 Quintessence Downlight 2xTC-TELI 26W (1.000)	1800	26.0
		Total:	228600	3302.0

Specific connected load: 33.02 W/m² = 4.06 W/m²/100 lx (Ground area: 100.00 m²)

Figure 6.6 Lighting Distribution Values in Lux(Utilize Compact Florescent Lamp)

127 Pieces ERCO 46608000 Quintessence Downlight 2xTC-TELI 26W
Article No.: 46608000
Luminaire Luminous Flux: 1800 lm
Luminaire Wattage: 26.0 W
Luminaire classification according to CIE: 100
CIE flux code: 71 100 100 100 50
Fitting: 2 x 2xTC-TELI 26W (Correction Factor 1.000).

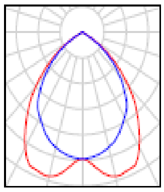


Figure 6.7 Photometric Data(Utilize Compact Florescent Lamp)

Figure 6.8 3D Rendering(Utilize Compact Florescent Lamp)

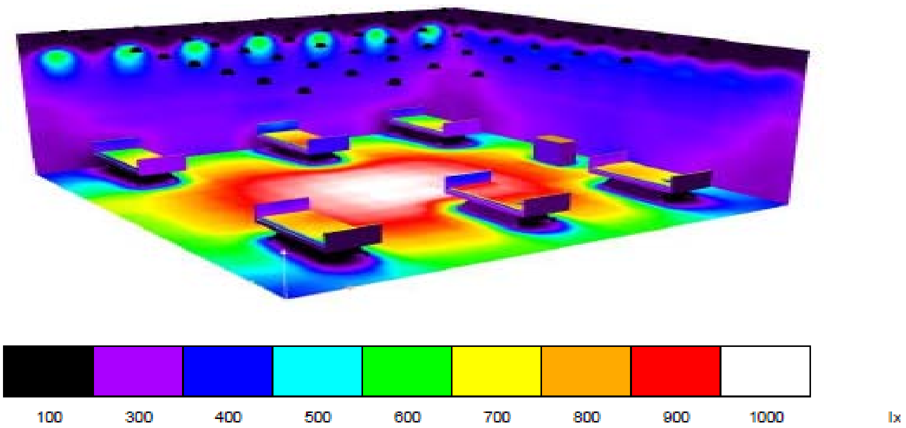


Figure 6.9 False Colour Rendering(Utilize Compact Florescent Lamp)

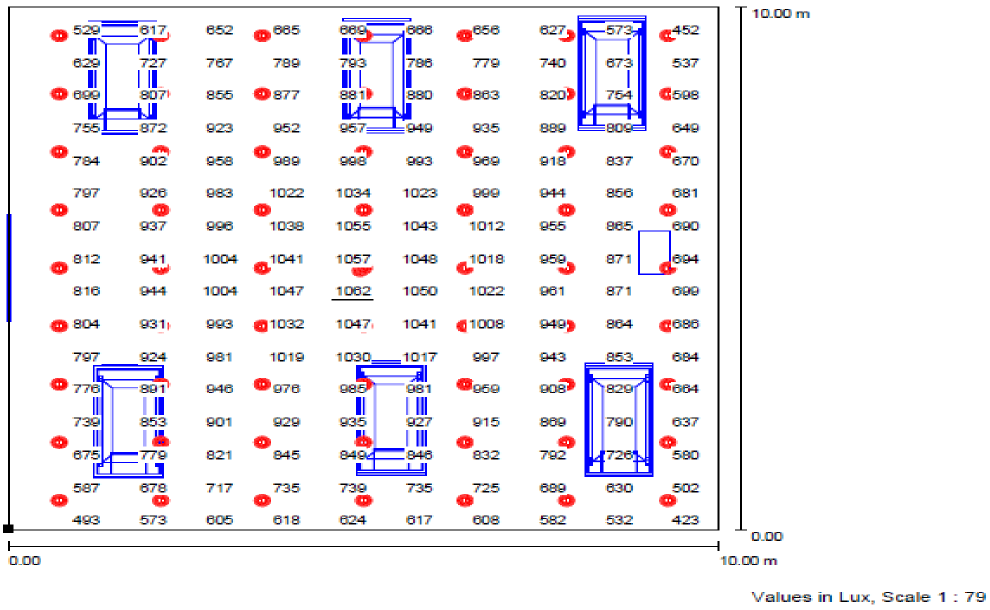
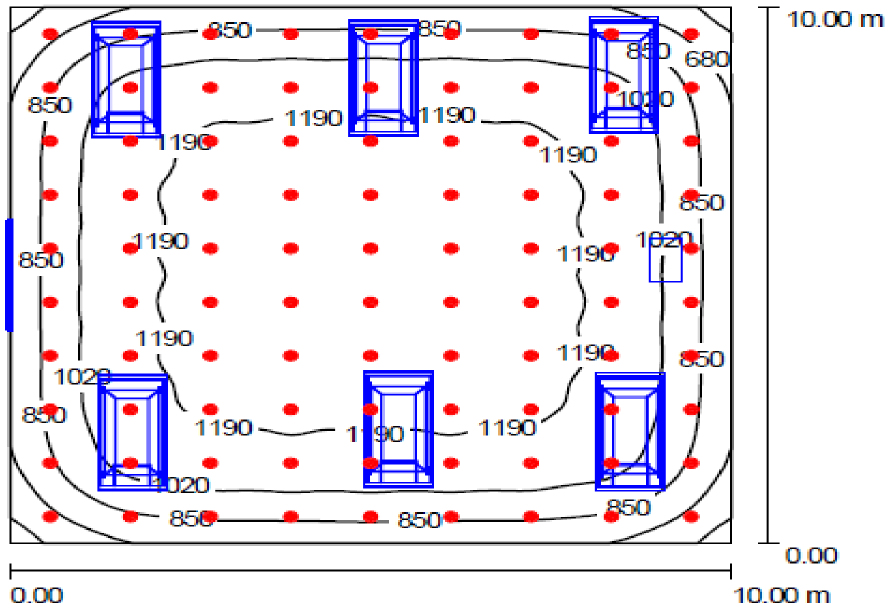


Figure 6.10 Value Chart(Utilize Compact Florescent Lamp)

6.4.3.*Scenario Three: Utilize LED Luminaire*

The lighting design used in this scenario utilized LED luminaire, ERCO product was selected (ERCO 46815000 Quintessence Down light LED 28 W daylight white) equipped with 28w LED lamp in the luminaire. Figures 6.11, 6.12, 6.13, 6.14, 6.15 show different lighting design data, such as, Lighting Distribution Values in Lux, Photometric Data, 3D Rendering, False Colour Rendering and Value Chart for this scenario.



Height of Room: 4.000 m, Mounting Height: 4.000 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:129

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	1045	436	1237	0.417
Floor	20	853	51	1234	0.060
Ceiling	70	185	147	210	0.794
Walls (4)	50	303	126	457	/

Workplane:
Height: 0.850 m
Grid: 64 x 64 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.294, Ceiling / Working Plane: 0.177.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	90	ERCO 46815000 Quintessence Downlight 1xLED 28W daylight white (1.000)	2160	28.0
		Total:	194400	2520.0

Specific connected load: 25.20 W/m² = 2.41 W/m²/100 lx (Ground area: 100.00 m²)

Figure 6.11 Lighting Distribution Values in Lux(Utilize LED Luminaire)

90 Pieces ERCO 46815000 Quintessence Downlight 1xLED 28W daylight white
Article No.: 46815000
Luminaire Luminous Flux: 2160 lm
Luminaire Wattage: 28.0 W
Luminaire classification according to CIE: 100
CIE flux code: 92 100 100 100 71
Fitting: 1 x LED 28W daylight white (Correction Factor 1.000).

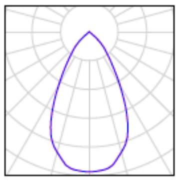


Figure 6.12 Photometric Data(Utilize LED Luminaire)

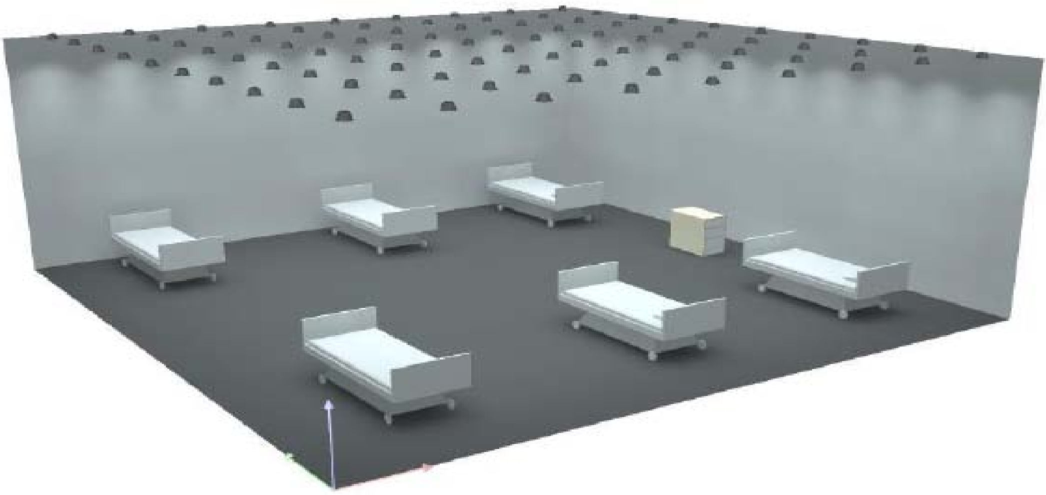


Figure 6.13 3D Rendering(Utilize LED Luminaire)

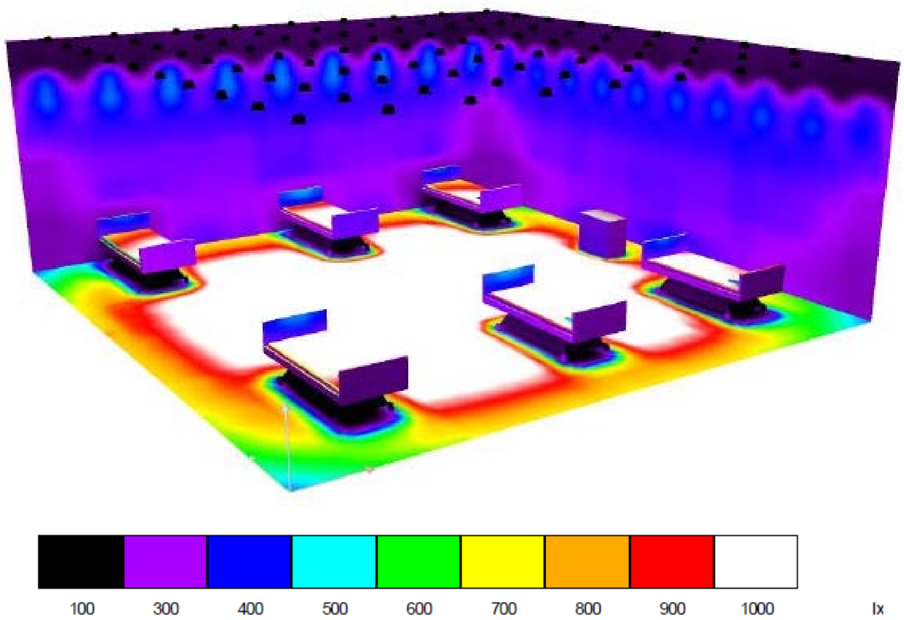


Figure 6.14 False Colour Rendering(Utilize LED Luminaire)

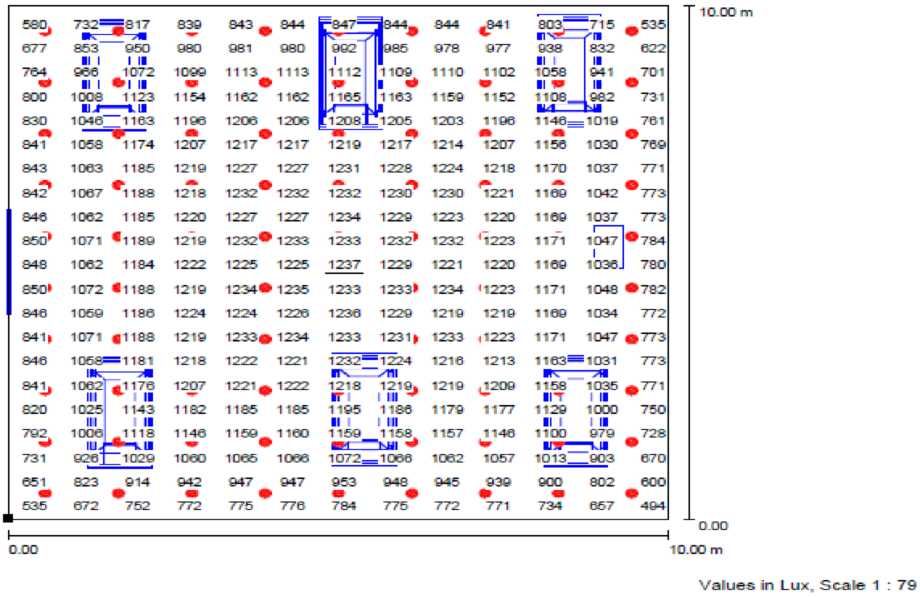


Figure 6.15 Value Chart(Utilize LED Luminaire)

6.5 **Discussion**

In the first scenario, incandescent lamps were used with overall power consumption of 12000W to achieve the design required lighting level of 1000 lux. This design had a resultant power distribution of 120 W/m2 or simply called Power Density (PD) (room area of 100 square metre), this value is a very high PD when compared with the recommended power density for such applications (Boyce and Raynham, 2009).

In the second scenario, the test room where designed utilizing Compact Florescent Lamp (CFL), the lighting design achieved by installing 127 CFL fittings to provide the design lighting levels. When comparing the deign using CFL with Incandescent Lamp we found the efficiency of this design in terms of power savings achieved 55% compared to the design with incandescent lamps. However, the power density is still higher for this selection at 66.04 W/m2 compared to the standard recommendation. In an efficient lighting design, the recommended lighting power density for hospital lighting shall be in the range of 25 W/m2.

In the third lighting scenario, LED lights were studied in which more than seventy-nine percent savings in power was achieved compared to the incandescent lighting design . In addition, the power density for the design is 25.2 W/m2, as the preferred value for PD in hospital areas. Table 6.6 shows the three scenario design results where the power consumption and power density for each type of light are presented.

Type	**Number of Lamps**	**Power Consumed P (W)**	**Power Density (W/m^2)**	**Average Illumination Level (Lm)**
Incandescent lamp	120	12000	120	1134
CFL	127	6604	66.04	814
LED	90	2520	25.20	1045

Table 6.6 Summary of the Experiment Results for the Three Lighting Scenarios

6.6 **Whole Life Cycle Cost Analysis (WLCCA)**

The cost for each lighting scenario along with expected average rated lamp life[62] is shown in Table 6.7.

Type	Number of lamps	Unit Price ($)	Light Fitting Cost (LFC) in $	Lamp Cost $	Lamp Life
Incandescent lamp	120	225	27000	1	1000
CFL	127	400	50800	50	10000
LED	90	1000	90000	10	50000

Table 6.7 Summary of the Cost for each Lighting Scenarios

When investigating the maintenance cost we can see the lamp is the only part in the light fitting that needs regular replacement based on its life span. In the first scenario, the cost of one incandescent lamp was one dollar per lamp based on the quotation from the manufacturer, and for an average of one thousand hours life time of operation for 120 lamp fittings, the yearly cost of replacing these lamps was estimated over twenty years of operation and found to be $19,200. In the incandescent case the estimated running cost (¢) over the twenty years was $210,240.00. In the case of the CFL installation, two lamps were used per light fixture each of 26 W, the lamp price as per manufacturer price is $10 each and the lamp average operating life is 10000 hours for the 127 fittings, yearly cost of replacing these lamps was estimated over twenty years operation and found to be $25,400 and the estimated running cost (¢) over the twenty years was $115,702.08. LED lamps in the third scenario cost $50 each, for 50000 hours of operating life (90 lights), the yearly cost of replacing these lamps was $13,500 estimated over twenty years of operation, the estimated operation cost (¢) over the twenty years was $44,150.40 . Figure

[62] http://www.bulbs.com/learning/arl.aspx

6.16 presents the result of the replacement cost for each scenario, Figure 6.17 illustrates the power consumption over twenty years for all installations and the whole life cycle costs over twenty years of operation for the three scenarios are shown in Figure 6.18.

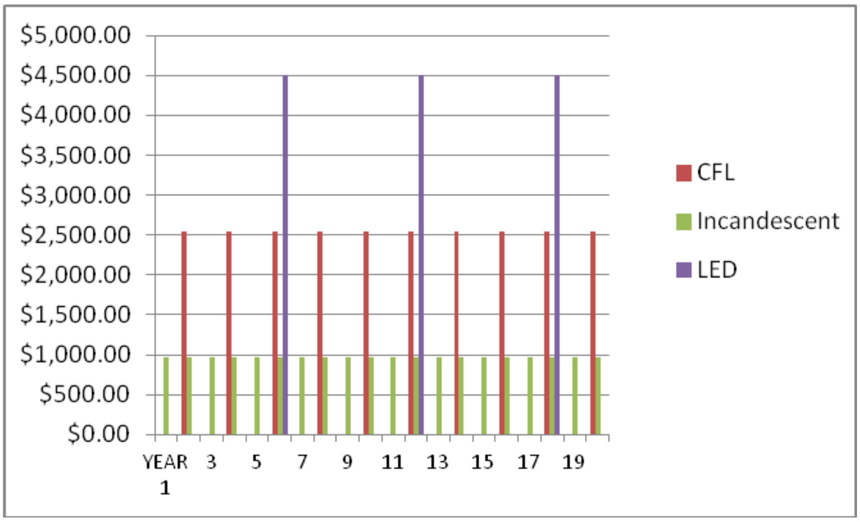


Figure 6.16 Replacement Cost for each Lighting Scenario

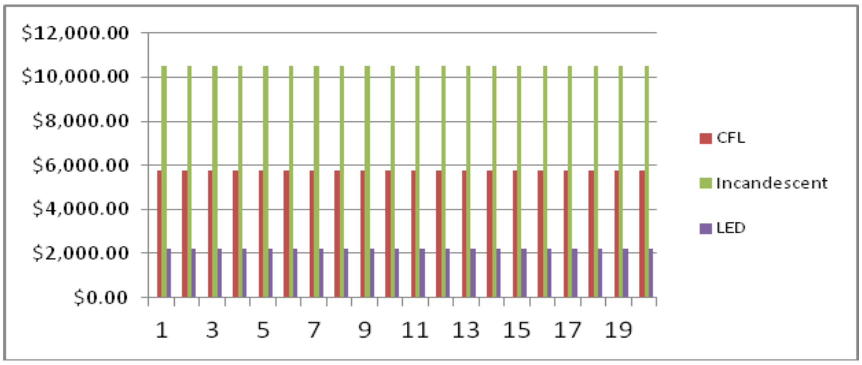


Figure 6.17 Power Consumption Cost for each Lighting Scenario

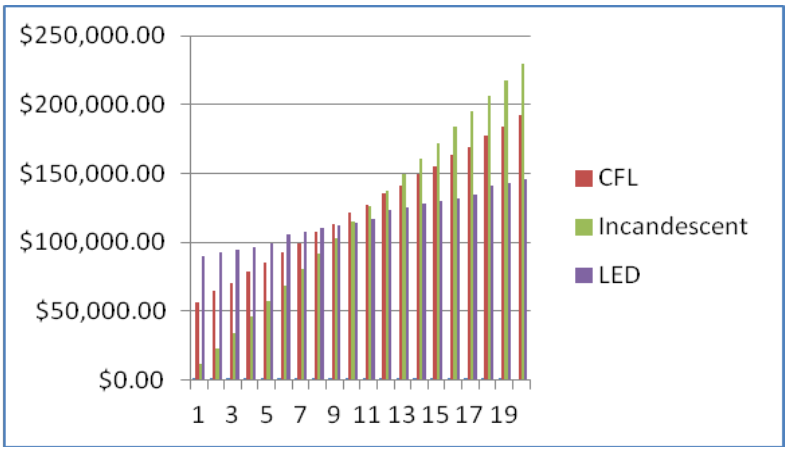


Figure 6.18 Overview of Cost Analysis (Whole Life Cycle Cost over 20 Years).

6.7 Conclusion

Energy efficient design is not a simple and straight forward process, the procedure to achieve all the required design parameters from comfort to energy efficiency and economic viability should be considered. In this chapter common types of installations in hospitals have been studied from energy efficiency and economical aspects, a case study in the hospital test room is presented following predefined design procedures, which lead to a suitable design structure. Three design scenarios in the hospital simulated test room were applied; the designs were assessed in terms of energy and economical aspects. The design with LED light had achieved significant savings in energy (up to 80%) compared to CFL and incandescent lighting designs. It can be concluded from this experiment that despite CFL being a very common lighting selection in the hospitals, their efficiency in terms of power savings is not optimal, LED can be considered as the best suited solution in terms of the energy efficient lighting system design for the hospital.

When comparing the cost of operation of these lighting scenarios the results of the design with CFLs show they cost almost forty percent less than incandescent, while LED achieved eighty percent savings in cost. Whole Life Cycle Cost (WLCC) is calculated using Equation (4) and the results confirm the economic value of the LED design selection. Payback Period (PBP) analysis was performed to study the required time to cover the high capital cost of LED lighting (Author 2013), and the results revealed that costs can be recovered after seven years to replace incandescent lighting with LED and nine years when replacing CFL with LED. Hence, as far as the monetary decision is concerned the design using LED is a better choice despite its high initial cost as compared to the design using incandescent lamps and CFLs. The conclusion from the above is that hospital lighting design using LED light is an energy efficient lighting design from energy saving prospective and monetary concern.

Chapter Seven: Discussion

7.1 Introduction

This doctoral thesis examined the relationships between the lighting design and hospital staff preferences and needs in hospital settings with focus on the effect of the Smart Lighting System (SLS) on hospital staff performance.

Studies show that lighting types (daylight and artificial light) have an impact on building occupants' behaviors, mood, and wellbeing and task performances. As illustrated in the previous chapters, daylight can contribute to improving staff's welfare, morale and performance. In addition, it can affect patients' recovery times, reduce stress and increase patients' satisfaction.

In the past, hospital building designs were simple and daylight can reach to most areas in the hospital. However, modern hospital buildings become more complicated in their design and the structure compared to historical hospital designs where daylight becomes difficult to reach deep areas in the building. Moreover, sunlight problems, such as, visual discomfort and heat generated are concerns in today's energy efficient buildings. This is why most building designers rely on achieving the minimum required daylighting in hospitals following lighting design recommendations and International Standards. Where most of today's standards identify the minimum daylight that buildings should have based on the depth of the building room that can be lit by daylight, which is dependent on the size and head height of the window. In other words, bigger window areas can receive more daylight. Bigger windows mean many problems in hospitals, such as, visual discomfort, more heat comes into the buildings and privacy issues where patients in hospital require privacy and that leads to windows being closed with blinds most of the time. This chapter discusses the main findings of the previous chapters and links them to the main objectives of the thesis.

7.2 Hospital Daylight Design in Qatar

Utilizing big windows to bring daylight into hospitals represent a complicated problem in hot climate areas like Arabian desserts, where the sun is near the equator and creates a great amount of heat with high sunlight intensity. Big windows mean excessive heat comes into the building. More thermal insulation is needed and it is a less energy efficient building in addition to high visual discomfort coming from high sunlight intensity through the windows. Thus the balance between daylight, visual comfort and thermal comfort becomes a real concern. The common practice for the designer always comes in favoring of achieving the thermal comfort rather than bringing more daylight into buildings, due to expenses and other factors. Studies show hospital as a healing environment require plenty of daylight for the staff and patients and it is clear that recent hospital daylighting design had failed to achieve the required daylight and visual comfort, despite many innovative designs to bring sunlight into the hospitals. There are still many obstacles to achieve the required daylighting from the sun in hospitals.

Since there is a difficulty to rely on sunlight as a main source to provide the required daylighting inside buildings and the need for daylighting is essential to hospital staff and patients, then a new lighting system is proposed for hospitals, which uses electrical lighting and emulates daylight. Prototype artificial light system named HealWell was installed in one of the Qatar hospitals to emulate the actual daylight from the sun and overcome the problem of visual discomfort, thermal effect of sunlight or privacy issues. This system combines both daylight elements and artificial light in order to maximize the benefit of daylight features and provide a satisfactory lighting design solution.

This research had examined in particular the relationships between hospital lighting design and staff preferences with focus on visual performance, and reduced energy consumption. Staff performance under artificial daylighting and standard electrical lighting has been studied to validate if the new electrical system can achieve the required daylight effect on staff performance in the healing environment.

7.3 Understanding Factors That Affect the Preferences for Lighting

To understand light preference in hospitals a combination of different methods were used to study alternative source for daylighting in hospitals, which include:

7.3.1. *Literature Review*

In this study, an understanding of lighting preferences theory and its associated impact on individual's work performance has been discussed in the literature that has been investigated. Evidence from previous studies show lighting setting can impact individual's visual and task performances. In healing environments such as hospital, good quality lighting settings are crucial for visual performance of tasks by hospital staff, and poor lighting environments show potential medical errors. A significant association was found also between type of light and job satisfaction and that it had been related to improved work performance and mood.

The factors that are affecting building occupants' preferences for light can be classified according to its area of influence, such as, sensation of visual clarity, feeling of spaciousness, impressions of relaxation, impressions of pleasantness, perception and attitude towards lighting and uniformity of luminance, these factors should be studied along with other factors such as users' ages, type of the facility building and task being performed, these factors were the subject of many studies to see its effect on users, hospital staff were one of those users who had been the subject of many studies due to the important role they play in our lives and the their preferences for lighting system reflect professional judgment (Author et al., 2013).

Lighting quality was found to be an important aspect of delivered light to any space, previous study suggested that light quality is an element that influenced people's anticipations and previous experiences with light source (Boyce et al., 2003), judgment on light quality may vary from person to person in terms of comfortable lighting condition based on individuals' cultural regional differences. In order to determine light quality in any space two factors were suggested to be considered which are:

a) The nature of the work itself and
b) The visual system capabilities of the subjects (users)

Another important finding from recent studies is the positive effect of daylight on improving staff's performance and reducing medical errors (Joseph, 2006; Kamali and Abbas, 2012; Author et al., 2013). However, further validation and more discussions with the concerned people need to be done. The question which was the subject of many research is how the light affects us, are there any conclusive results, and can the lighting setting influence our mood and performance. The answers to these two questions are that we are aware that the light has visual and non-visual impacts on our physical and psychological activities, but still further investigation and confirmation from field study is needed to establish more affirmation and establish science findings based on rigid theory, controlled field study and well-designed subjective opinion of the light users.

Studies that investigated the lighting influence on human mood and performance can be classified into three groups these are the real-task research, the subjective judgment studies and abstract research. These three types of research are exploring lighting effect from various methodologies of theory, field test and user satisfaction. By combining these three methodologies in one research, we can reach a more acceptable result on lighting quality. The majority of research that investigated the impact of lighting conditions on individuals' performances have focused on exploring the relationship between the visual system and work; most of these studies were field research. These studies were criticized for their lack of validity and focus only in one direction that increasing light level would improve task performance. The findings of these studies are limited due to lack of generality and reliance on the experiment on specific tasks. Subjective judgment studies based on controlled survey and questionnaire gave some understanding of what individuals preferred that can help them do their work is an important methodology in determining the adequate quality of light, however this methodology should consider the results from field test and theoretical analysis.

7.3.2. *Qualitative Measures*

It was suggested that the human's visual system capabilities can be assessed by conducting surveys combined with running actual field tests on subjects, thus to evaluate the complaints about lighting and to determine if the measured illuminance meets the specified theatrical assumption. To get a clear understanding about effect of light on hospital staff a questionnaire for hospital staff was developed with the aim to verify visual comfort by exploring hospitals' staff preferences for lighting and daylighting in a hot climate area (Qatar), a statistical analysis was conducted to analyse the results.

7.3.3. *Quantitative Measures*

A new lighting system has been proposed by Philips Lighting (HealWell) which uses artificial lighting to emulate daylighting and at the same time provide the required lighting levels for the full range of tasks required. Hospital staff performance under the normal electrical lighting was assessed through a field experiment at Hamad General Hospital in Qatar and compared to their performance under new lighting system (HealWell). The results of the performance tests were analysed and discussed in detail.

7.3.4. *Cases Studies*

Since artificial lighting is responsible for a large part of a hospital building's electricity needs, an energy efficient lighting design procedure for a hospital was introduced. LED light technology design has been presented as one of the cases studied during this doctorial study.

7.4 **Discussion on Lighting Survey in Hospitals**

The first objective of this research was to explore the relationships between lighting type and hospital staff preferences, despite the previous conclusion of the literature review in the field of hospital lighting design, as well as the findings of this research, it seems that there is no framework or design guidelines that link the daylighting design of hospitals and hospital staff performance, nor information about architects' understanding of the importance of daylight's availability in the hospital workplace. This led to the formulation of the thesis' first objective which was as follows:

I. *To explore the relationship between lighting type and hospital staff preferences.*

The concept of daylight and its role in improving hospital staff performance is complex, in particular when included within overall design of hospital space, this creates exceptional methodological problems for the researcher. The type of methodologies traditionally employed in research related to lighting preferences, i.e. survey and questionnaire. In this research a survey was conducted to get a better understanding of hospital staff on the preferred lighting regime in the hospital and the result of the paper-based survey questionnaire conducted during this research to explore hospital staff preferences to the lighting regime, in particular to its effect on the performance, indicates a range of significant outcomes, and can be summarized as follows:

Higher light level was found to be preferred by hospital staff in their work places. This outcome is consistent with the results suggested from the previous studies, which illustrate higher lighting level is associated with the task being performed (see Chapters Two and Three). Further research is needed to identify the factors that impact worker under different tasks, factors such as age, cultural properties and/or task performed (Kamali and Abbas, 2012; Lawson and Phiri, 2003). Considering different lighting scenario presented to hospital staff, it appears that daylight obtains higher comfort preferences among the hospital staff and that highlights two things, first, it highlights the importance of daylight for hospital staff as a tool to help them do their work more efficiently in their workplace. And second, it demonstrates that staff is appreciating the daylight and its impacts on the healing environment, as explained in earlier research (Edwards and Torcellini, 2002). Despite these findings, it seems that the current daylight provision in hospital does not meet staff expectations for daylight. This study has confirmed that hospital staff perceives daylight to have a strong comfort, health and diagnostic benefit for staff and patients in hospital wards. Also it provides clear evidence of the subjective judgment of hospital staff (Author et al, 2013). The other findings that have been highlighted in the survey are:

- Majority of the survey participants (more than 90%) see the daylight in patient's room as an important factor in assisting them do their work more easily.

- Daylight helps staff monitor patient recovery through improved recognition and interpretation of changes in patient skin colour.

- Hospital staff confirmed from their daily work observation that patients preferred to stay in rooms with access to daylight as it makes them feel more comfortable, this is another reason to focus on providing daylight inside the hospital.

- High agreement was found among hospital staff with regard to the influence of light on their performance, specifically that light can help them treat patients easily in a room with daylight.

- Mixed types of light source (daylight with electrical light) is the preferred source of light in hospitals, which highlights that daylight and electric light complement each other and help staff do necessary work routines.

These particular findings seem to have direct implications for the architectural design of hospitals, such that the preferences of the hospital staff for lighting regime in hospital revealed their experience of the positive impact of daylight on their own comfort and performance in their workplace. These findings, which were reported on in Chapter Four, could be used by decision makers, such as, architects to aid in the design process of hospital lighting. In addition, international regulatory authorities, such as, CIBSE, ASHRAE and IESNA ought to consider these finding in the building codes for hospital lighting requirements.

However, due to many reasons previously explained in this research, such as, the availability of daylight in buildings, weather condition limitations (overcast, cloudy) and varying light levels with the diurnal passage of the sun from dawn to dusk as well as by restrictions following from the building design itself, it is not feasible to rely on daylight as a universal lighting solution, and inevitably alternative sources of daylight are needed in hospitals.

7.5 Effectiveness of the Proposed Lighting System in Qatar Hospitals (Smart Lighting System)

The findings from the series of analyses in Chapter Four, that involved investigation of the lighting elements' factors affecting the hospital staff performance provides better understanding to plan for the next stage of the study, which focused on evaluating a novel lighting design that utilizes Smart Lighting System (SLS). This system combines both daylight elements and artificial light in order to maximize the benefit of daylight features and provide a satisfactory lighting design solution. The new lighting system has been proposed by Philips Lighting (HealWell), which uses artificial lighting to emulate daylighting and at the same time provide the required lighting levels for the full range of tasks required, which was installed in a patient room at the Skilled Nursing Facility in the Hamad Medical Corporation Hospital in Doha, Qatar. Structured experiment was designed to test the effectiveness of the new system, and the experiment was explained in details in Chapter Five and it confirms the following:

- In terms of the subjective preferences of participants undertaking visual comfort, alertness and task performance tests, the new SLS lighting design proved to be more appreciated than the reference lighting design. This could be understood as it emulates daylight and daylight was the preferred type of light by hospital staff as explained in the previous survey conducted within this research framework.

- Secondly, working under an artificial lighting regime that mimics daylight conditions, even during the limited test period of the evening hours, revealed significant positive impact on staff performance, which could provide a base for further investigation on the impact of lighting environment effects on staff performance., This preliminary experiment has highlighted the large potential that exists to improve working conditions and performance through enhancing the daylight-like experience of the artificial lighting environment within a hospital.

The results of this experiment is encouraging to conduct larger scale roll-out usage of such systems at a hospital to achieve better hospital lighting design that can help reduce the problem of the lack of daylight in enclosed hospital environments and help improve overall staff performance. However, the opportunity to use such new lighting design as part of the hospital lighting design is related to the available regulations and guidelines that are associated with hospital design, which are usually written by experts in the related subject based on professional experience, experiment and tested theories. Accordingly, the second and third objectives of this thesis were:

To review preferences for smart lighting in the Ward

II. *To assess the effect of lighting types, in particular, Healwell Lighting System on hospital's staff performance.*

7.6 **Energy Efficient Lighting System Design for Hospitals**

Design of efficient lighting in hospitals should not focus only on helping improve hospital staff performance it should also focus on achieving an energy efficient lighting system, since hospitals by their nature are major consumers of energy, which are working 24/7 with the energy used to serve numerous buildings' occupants, such as, staff, patients and visitors. These factors in addition to the expansion of hospitals sizes and services has result in steadily growing energy consumption. The efficient lighting design in hospital is not a simple process and the complexity increases when the design involved important places such as healthcare facilities, where lighting is seen as one of the factors that can improve healthcare experience functionally and environmentally.

Given the earlier findings and the literature review findings in Chapter One, which suggested healthcare facilities account for high energy consumption; the fourth objective of the thesis was formulated as follows:

IV. *To identify the required measures towards achieving energy efficient lighting system design in hospitals.*

In order to achieve the efficient lighting system design, a design procedure was proposed to achieve efficient lighting design in different facilities. In this study a new energy efficient lighting design methodology was introduced for hospitals and verified based on previous studies' effectiveness of the proposed lighting system in Qatar hospitals.

A common type of installation in hospital had been studied from energy efficient and economical aspects. A case study in a hospital test room is presented following predefined design procedures, which leads to a suitable design structure. Three design scenarios in the hospital simulated test room were applied, the designs were assessed in terms of energy and economical aspects, the simulation considered three types of lights used in hospitals, incandescent lamp, CFL, and LED lights.

Significant savings in energy consumption was found using design with LED light compared to CFL and incandescent lighting designs. This simulation lighting design test shows that despite CFL being a very common lighting selection in the hospitals, their efficiency in terms of power saving is not optimal, and that LED can be considered as the best suited solution in terms of the most energy efficient lighting system design in the hospital.

From the financial aspect, when comparing the cost of operation of these lighting scenarios, the results of the design with CFLs show an almost forty percent less cost than incandescent, while LED achieved eighty percent savings in cost. Whole Life Cycle Cost (WLCC) is another criteria used to evaluate the effectiveness of this selection and the results confirm the economic value of the LED design selection. Payback Period (PBP)

Analysis was performed to study the required time to cover the high capital cost of LED lighting, the results revealed that the cost can be recovered after seven years to replace incandescent lighting with LED and nine years when replacing CFLs with LED. Hence, as far as the monetary decision is concerned the design using LED is the better choice, despite its high initial cost as compared to the design using incandescent lamps and CFLs.

The above findings suggest that hospital lighting design using LED light is an energy efficient lighting design from an energy saving perspective and monetary concern and could be the new lighting design generation if it were adopted by regulatory bodies, such as, CIBSE and ASHRAE.

7.7 Overview of Accomplished Work

This research's main objective has been developed from the literature review. This was done as a first stage of this study to gather the needed knowledge about lighting and daylighting in hospitals, which gives clear reason as to the research's approach and direction.

In reviewing the literature on hospital lighting design in Chapter One, it became evident that daylight is an important factor in hospitals to the medical staff to help them perform the required clinical functions within a healthcare environment. This has been reflected in the hospital lighting design historical development over the decade. The emphasis here is that the process of hospital design should give an opportunity for staff, as the targeted professionals in hospitals, to identify a preference for their hospitals. Within this context, the literature suggests staff requirements for light as the main concept, especially to perform their duties. The importance of lighting to hospital staff has been referenced in many guidelines and regulations that are related to hospital design (see Chapter Two). Hospital as a healing environment is working 24/7 and requires a special design for lighting system to help professionals working inside to do their jobs in the best way possible, as hospital professional staff spend most of their time in the hospital and interact with the surrounding physical environment within the hospital. This was confirmed by the findings in Chapter Three, which presented the lighting preferences theory and its associated impact on individual's work performance, a strong relationship between light and critical human functions was found, and that lighting setting can influence task performance through three routes: the visual system, the circadian rhythms and mood. Lighting conditions can impact the visual system and therefore individual's visual performance. In healing environments, such as, hospital, this can benefit patients as well as staff in healthcare, it was also reported that good quality lighting settings are crucial for visual performance of tasks by hospital staff, and poor lighting environments show potential medical errors. A significant association was found also between types of light and job satisfaction and that it had been related to improved work performance and mood. The other important findings in Chapter Three were that most of the studies on the effect of lighting on workers are limited due to the lack of generality and reliance in the experiment on specific tasks and that subjective judgment studies based on controlled survey and questionnaire can gave better understanding of what individuals preferred and what can help them do their work properly, which represents an important methodology in determining the adequate quality of light, however this methodology should also consider the results from field tests and theoretical analysis.

In Chapter Four, the outcomes of the paper-based survey questionnaire were presented, the results of the questionnaire survey regarding staff comfort and staff performance under different lighting regime scenarios were linked to understand the hospital staff preferences. The importance of this chapter is to provide data from the hospital staff's subjective judgment on lighting in hospitals, the results show that in spite of the common comfort light level preference in work places, it found a significant proportion of hospital staff prefer to work under higher light levels, this outcome is consistent with the results suggested from Chapter Two and Chapter Three, which illustrate higher lighting level is associated with the task been performed. Another important finding was that daylight was found to be the most preferred source for lighting in hospitals and appeared to be the main reason for light comfort preferences among the hospital staff. These findings highlight the hospital staff's awareness of the importance of lighting design in the hospital and the need to find a solution to the lack of daylight in hospitals. As a consequence, the concept of delivering daylighting inside hospital was reviewed in the worker-environment relationships literature and the importance to maintain an adequate level of daylight for staff in the hospital which was surveyed and presented.

After exploring the hospital staff opinion on hospital lighting and analysis of the survey results revealed their experience of the positive impact of daylight on their own comfort and performance in the workplace. However due to many reasons explained in this research, such as, the availability of daylight in buildings, limiting weather conditions (overcast, cloudy), atmospheric conditions (dust, pollution) and varying light levels with the diurnal passage of the sun from dawn to dusk, as well as, by restrictions following from the building design itself. Hence it is not feasible to rely on daylight as a universal lighting solution, and inevitably alternative sources of daylight are needed in hospitals. To overcome this fact a new lighting system has been proposed by Philips Lighting (HealWell), which uses artificial lighting to emulate daylighting and at the same time provide the required lighting levels for the full range of tasks required, this new lighting design and its effectiveness were studied in Chapter Five, Smart Lighting System; this proposed lighting system solution (Healwell by Philips) and the daylight problematic in the hot climate countries' hospitals were studied to assess the effectiveness of this new lighting system through visual and performance comfort. An experiment was conducted in a mockup room in Hamad Hospital in Qatar. The complete description of the experiment methodologies were explained in Chapter Five. Hospital staff, who participated in the experiment, preferred the new tested light, SLS, over the reference scenario, RLS, and the analysis of the results confirmed, despite the limitations of its experimental design, that when working under an artificial lighting regime that mimics daylight conditions, even during the limited test period of the evening hours, the positive impact on staff performance is significant. The assessment results for visual comfort and performance were also discussed in detail to validate the selection of the system, and it is also concluded that new lighting design systems, such as, SLS that can imitate the daylight without jeopardizing performance and visual comfort could provide a good future solution to the lack of daylight in hospitals, particularly important in very hot regions where sunlight is usually avoided in hospital design.

In Chapter Six, the performance of different types of lighting installations used for hospital lighting system designs was assessed from two perspectives: the energy consumption and cost impact associated with each selection. Proposed design methodology is presented to achieve an optimal energy efficient lighting design. In addition simulation software is used to assess the efficient lighting scheme visually and functionally, and the assessment of the energy performance and lighting power consumption were studied also and compared with other case study in hospital efficient lighting design. Cost impact of using each system was assessed as well, and the results from this experiment revealed that even though CFL is a very common lighting selection in hospitals, their efficiency in terms of power saving is not optimal. LED lighting design can be considered as the best suited solution in terms of the energy efficient lighting system design in the hospital. As far as the monetary decision is concerned hospital lighting design using LED appears to be the better choice despite its high initial cost as compared to the design using incandescent lamps and CFLs. The conclusion from the above is that hospital lighting design using LED light is an energy efficient lighting design from the energy savings perspective and monetary concern, which is consistent with the findings reported in Chapter Six.

Chapter Eight: Conclusion

8.1 Conclusion

This doctoral thesis had four main aims:

1. To explore the relationship between lighting type and hospital staff preferences.

To review the preferences for smart lighting in Ward

2. To assess the effects of lighting type, in particular, HealWell Lighting System, on hospital staff's performance.

3. To identify the required measures toward achieving an energy efficient lighting system design in hot climate region hospitals.

In relation to the first aim of the thesis a questionnaire survey was undertaken to get a better understanding of hospital staff on the preferred lighting regime in the hospital and to explore hospital staff's preferences to the lighting regime, in particular, to its effect on their performance, and it was concluded that a higher light level was preferred by hospital staff in their work places. This outcome is consistent with the results suggested from previous studies, which illustrate higher lighting level is associated with the task being performed (see Chapters Two and Three). It was also concluded that daylight obtains higher comfort preferences among the hospital staff and that highlights two things, firstly, it highlights the importance of daylight for hospital staff as a tool to help them do their work more efficiently in their workplace. Secondly, it demonstrates that staff is appreciating the daylight and its impacts on the healing environment, as explained in earlier research (Edwards and Torcellini, 2002). Despite these findings, it seems that the current daylight provision in hospitals do not meet staff expectations for daylight. More than 90%, which is a majority, of the survey participants see daylight in the patient’s room as an important factor in assisting them to do their work more easily; interestingly a mixed type of light source of daylight with electrical light is the preferred source of light in hospitals, which highlights that daylight and electric light complement each other and help staff do necessary work routines.

The second aim of the thesis was to explore the criteria to achieve a Smart Lighting Solution (SLS), such that, a series of analyses on the conducted survey in addition to experiments in the designated test facility were undertaken to investigate the lighting elements' factors affecting the hospital staff's performance, it is concluded that when emulate the daylighting in hospital areas through a Smart Lighting System that emulates daylighting and is able to provide satisfactory daylight levels during the working hours, while minimizing the effect of discomfort and glare, , then the electric lighting installation in such facilities can be considered as a solution for health care facilities that suffer from the lack of daylight, especially in countries where daylight is associated with high glare and heat gain, and would result in improved staff mood and performance. Also, it is concluded that the Smart Lighting System that combines both daylight elements and artificial light with focus on maximizing the benefit of daylight features provides a satisfactory lighting design solution, which can be considered the Smart Lighting Solution.

With regards to the third objective of this research a HealWell Lighting System, which is newly developed by Philips, with the aim to improve the visual environment in hospital wards by emulating daylighting features through the use of electrical light fixtures, was assessed through experiment in a test facility in a patient room at the Skilled Nursing Facility in the Hamad Medical Corporation Hospital in Doha Qatar. The experiment was designed such that a comparison of the performance of hospital staff with the common lighting(Reference Lighting System) versus the HealWell Lighting System could be made, and it was concluded that an overwhelming majority of the study’s participants from the hospital staff (more than 90%) prefer the HealWell Lighting System over the Reference Lighting System. It was also shown that staff’s performance for the paper-based tasks is significantly better under the Smart Lighting System, HealWell, than under the Reference Lighting Scenario. Also, it is concluded that new Lighting Design Systems, such as, the SLS, which can imitate the daylight without jeopardizing performance and visual comfort, could provide a genuine viable solution in the future to the lack of daylight in hospitals, which is particularly important in very hot regions like Qatar.

In relation to the fourth aim of the thesis a case study in a hospital test room was conducted to explore the measures that need to be taken to achieve an energy efficient lighting system. Different types of common lighting designs were studied, and the simulation considered three common types of lights used in hospitals, incandescent lamp, CFL, and LED lights. It was concluded that an energy efficient lighting system design can be achieved by assessing the lighting design's energy consumption and its economic viability. It was found that the design with LED light had achieved significant savings in energy (up to 80%) compared to CFL and incandescent lighting designs. It can be concluded that from this experiment that despite CFL being a very common lighting selection in hospitals, their efficiency in terms of power savings is not optimal, LED can be considered as the best suited solution in terms of the energy efficient lighting system design for the hospital. From the financial aspect, when comparing the cost of operations for these lighting scenarios, the results of the design with CFLs show an almost forty percent (40%) less cost than incandescent, while LED achieved eighty percent (80%) savings in cost. Whole Life Cycle Cost (WLCC) is another criterion used to evaluate the effectiveness of this selection and the results confirming the economic value of the LED design selection. Payback Period (PBP) Analysis was performed to study the required time to cover the high capital cost of LED lighting; the results revealed that the cost can be recovered after seven years to replace incandescent lighting with LED and nine years when replacing CFLs with LED. Hence, as far as the monetary decision is concerned the design using LED is the better overall choice, despite its high initial cost as compared to the design using incandescent lamps and CFLs. The above suggests that hospital lighting design using LED light is an energy efficient lighting design from an energy savings perspective and monetary concern, and could become the new lighting design standard for the next generation if it were adopted by regulatory bodies, such as, CIBSE and ASHRAE.

8.2 **Research Limitations**

The limitations of the study are those characteristics of methodology or design that influenced the analysis of the findings from the research and its added limitations on the generalization of the findings. This research has covered a variety of research areas related to hospital lighting design and mixed types of methodology have been used to reach the final conclusion. Knowing that every study is subjected to potential weaknesses, this study is not excluded, and therefore maximum care was taken to minimize the risk.

A mixed method, which combines qualitative and quantitative methodologies, is suitable for this research because it combines both detailed views of the meaning, the generalization of the concept under study to enable a variety of techniques to be used in the research, including collection and analysis of data through the use of survey, test the hypothesis through experiments, utilize literature reviews and the case study techniques to accomplish the research objectives. However, these techniques still have limitations when applied.

8.2.1.*Possible Methodological Limitations*

Survey Limitations: One of the methods used in this research was launching a questionnaire survey as a technique to analyse the subjective judgments of the hospital staff lighting requirements and satisfaction, survey has its limitation in similar studies including: Sample size – Although the number of survey's participants was relatively small and it can be argued that a small sample size can yield ambiguous results, for instance, the outcomes may demonstrate that there is no difference between groups or between variables, when actually there is an association or a difference. In contrast, too large a sample size might lead to needless effort, wasted time and finance, and this is why the reported preferences of participant's were selected from one hospital and only professional workers were considered, they are indicative of a trend, but cannot be deemed to provide comprehensive conclusions because of the sample location and also size limitations of the study, despite this limitation this study can be considered as a pilot study.

Field Experiment: another limitation of the study was associated with the field experiment presented in Chapter Five of the study. These limitations refer to the test conditions, such as, short test times used to conduct the test of lighting influence on the participants (less than two hours), which might affect the reliability of results as it might not imitate the actual work routines of the hospital staff and make findings debatable. The test conditions in this study were not designed to completely replicate the work routine of the hospital staff, a factor that could lead to biased judgment that impact the reliability of the reported findings as non-standard work conditions in the hospital under which the tests were taken. The designed tests were intense work procedures and were applied to overcome this limitation. The Hawthorne effect is another factor that might affect the test findings, in which the observer of the effect can influence participants in the experiment, as participants tend to modify or improve an aspect of their performance in reaction to their knowledge of it being part of an experimental procedure. To mitigate this challenge a complete description of the test was provided to each participant before the test start.

8.3 **Scope for Further Work**

Throughout the development of this study the need for more work raised to fill in the gaps and satisfy the additional questions, include:

- Engage larger groups of participants (hospital staff) in the survey to get a better understanding of their perception of the delivered illuminance by SLS in different areas of the hospital.

- Conduct field measurements of the light system design in different locations in the hospital to validate energy savings studies.

- Regular updates are recommended for the benefits and costs analyses with the SLS in different locations. That leads to a call for more investigations to measure the productivity gain due to the utilization of daylighting systems, such as, Smart Lighting Systems, and to what extent they can replace the outside sunlight.

- More laboratory studies are required to investigate light quality in terms of changes in the daylight spectrum delivered by the Smart Lighting System technologies.

- Additional photometric measurements are required to enhance Smart Lighting System design methods.

This is an important topic, much has been revealed by this study but it can be seen from the above that much remains to be done by future researchers.

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Appendices

Appendix A

Ethical approval from Hamad hospital in qatar to conduct the study

مؤسسة حمد الطبية
Hamad Medical Corporation
HEALTH · EDUCATION · RESEARCH صحة · تعليم · بحوث

مركز البحوث الطبية
Medical Research Center

Ref. No: RC/14513/2013
Date: 7th February 2013

Dr. Abdulla Al Ansari
A/ Chairman
Surgery Department

Dear Dr. Al Ansari,

Subject – Ethical Approval for the Research proposal# 12236/12: "Study on the Smart Lighting System Performance and Evaluation at Health facility"

The above Research Proposal submitted to the Medical Research Center has been reviewed and classified as 'Exempt', according to the rules and regulations for research at HMC.

On behalf of the Research Committee we inform you that the above Research Proposal meets with the ethical requirements of the Hamad Medical Corporation and approval is granted for one year from 7th February 2013.

This research study should be conducted in full accordance with all the applicable sections of the rules and regulations for research at HMC and you should notify the Research Committee immediately of any proposed changes that may affect the 'exempt' status of your research proposal .It is the Principal Investigator's responsibility to obtain review and continued approval of the proposal before the date of expiry of the ethical approval.

A study progress report should be submitted bi-annually and a final report at the study's completion.

We wish you all success and await the results in due course.

Yours sincerely,

Dr. Anjum Susan John
Coordinator, Research Committee

Cc:

1. Dr. Riad Ali Thalib, Consultant, Urology Department
2. Ms. Safaa Alzubaidi, PhD Candidate-Built Environment, Heriot-Watt University,UK
3. Dr. Yousef Al Maslamani, Medical Director, Hamad General Hospital

Sa/Su

Tel: (+974)4439 2440
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research@hmc.org.qa

P.O.Box 3050
Doha, Qatar
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Appendix B

sample paper-based questionnaire

مؤسسة حمد الطبية
Hamad Medical Corporation
HEALTH · EDUCATION · RESEARCH

Participant number: QSS___

Date: __/__/20 13

Questionnaire

Hospital lighting

(Staff satisfaction and preferences to lighting regime)

The objective of this is survey is to explore hospital's users preferences, complains, needs and expectations regarding hospitals lighting regime.

i. Personal Information:

1. *Ethnicity:* ☐ *Western* ☐ *Indian* ☐ *Arab* ☐ *Asian* ☐ *African*
2. *Age:* ☐ *21-30* ☐ *31-40* ☐ *41-50* ☐ *+ 51*
3. *Gender:*

   ☐ *Male* ☐ *Female*

4. *Do you have any visual/eye conditions e.g. Myopia, cataract that require the use of glasses, contact lens or other aids?*

   ☐ *Yes* ☐ *NO*

HMC Research Committee
Approved
Approval Date : 7/Feb/2013
Expiry Date : 6/Feb/2014

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مؤسسة حمد الطبية
Hamad Medical Corporation
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ii. **Work Information**

5. What is your work shift

☐ Day shift ☐ Night Shift

6. *Profession:*

☐ *Doctor* ☐ *Nurse* ☐ *Auxilliary staff* ☐ *admin/cleaning/repair*

☐*Other, Please specify___*

7. Where do you usually **spend most** of your working hours?

☐*Doctor's office* ☐*Ward* ☐*Patient room* ☐*nurse desk* ☐*Others___*

---

iii. Lighting comfort:

10. *How do you rate the Lighting level in the following areas of the hospital*

a) Doctor's office	☐*Not at all satisfied*	☐*Slightly satisfied*	☐*Somewhat satisfied*	☐*Very satisfied*	☐*Extremely satisfied*	☐*N*
b) Private patient room	☐*Not at all satisfied*	☐*Slightly satisfied*	☐*Somewhat satisfied*	☐*Very satisfied*	☐*Extremely satisfied*	☐*N*
c) Shared patient room	☐*Not at all satisfied*	☐*Slightly satisfied*	☐*Somewhat satisfied*	☐*Very satisfied*	☐*Extremely satisfied*	☐*N*
d) Nurse desk	☐*Not at all satisfied*	☐*Slightly satisfied*	☐*Somewhat satisfied*	☐*Very satisfied*	☐*Extremely satisfied*	☐*N*

11. *Are there any areas of the hospital you consider brighter, ?please specify*

☐*No* ☐*If Yes, please specify__*

12. *Are there any areas of the hospital you consider as having insufficient light?*

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please specify

☐No ☐If Yes, please specify __

13. Are there any areas of the hospital you consider as having glare from lights

☐No ☐If Yes ,please specify ____

14. Are there any areas of the hospital in which you consider that light **reflections** prevent you from working properly or accurately?

☐No ☐If Yes , please specify ____

---

iv. Lighting preferences in your main workstation

15. Which type of light **setting up** (mounting)you prefer

☐Direct(wall) ☐Direct(ceiling) ☐Indirect(Hidden/cove) ☐Indirect (Wall)

16. Which illumination **color** you prefer at your main workstation

☐White ☐Yellow ☐Blue ☐Natural (daylight) ☐Mix of white and yellow

10. Do you switch off the lights of your workstation during the day?

☐Always ☐Sometimes ☐Never ,please give reason_____

11. Do you currently have control over your levels of lighting at your main workstation?

☐Yes ☐ If No, would you prefer to have it ☐

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Expiry Date : 6/2/2014

v. ***Daylight comfort and preferences :***

12. *Are you satisfied with the* ***Daylight level*** *in the*

a) Doctor's office	☐Not at all satisfied	☐Slightly satisfied	☐Somewhat satisfied	☐Very satisfied	☐Extremely satisfied	☐N/A
b) Private patient room	☐Not at all satisfied	☐Slightly satisfied	☐Somewhat satisfied	☐Very satisfied	☐Extremely satisfied	☐N/A
c) Shared patient room	☐Not at all satisfied	☐Slightly satisfied	☐Somewhat satisfied	☐Very satisfied	☐Extremely satisfied	☐N/
d) Waiting area	☐Not at all satisfied	☐Slightly satisfied	☐Somewhat satisfied	☐Very satisfied	☐Extremely satisfied	☐N/
e) Nurse desk	☐Not at all satisfied	☐Slightly satisfied	☐Somewhat satisfied	☐Very satisfied	☐Extremely satisfied	☐N/

10. Is there enough amount of sunlight at your *workstation*

☐*Yes* ☐ *If No, would you prefer to have it* ☐

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Approval Date : 7/2/2013
Expiry Date : 6/2/2014

11. *Do you prefer to workplace illuminated mainly with*

☐*Daylight* ☐*Artificial (electrical) light* ☐*mixture of daylight and artificial light*

12. *Do you think it is easier to treat patients in a room with daylight?*

☐*Strongly agree* ☐*Agree* ☐*Neither* ☐*Disagree* ☐*Strongly disagree*

13. *If identifying changes in a patient skin colour is important to you: Do you find it easier to do it in a room with daylight?*

☐*Strongly agree* ☐*Agree* ☐*Neither* ☐*Disagree* ☐*Strongly disagree* ☐*N/A*

14. Do you need control the amount of sunlight in your workplace,

☐No ☐if yes please specify when ☐*Morning* ☐*midday* ☐*Afternoon*

vi. *Perception* and attitude towards lighting

15. *Are there any area in the hospital where the color of the light makes you unconformable , if yes where*

☐*No* ☐*Yes , please specify* _ _ _ _

16. *Are there any areas in the hospital where you think your skin color looks unnatural?*

☐*No* ☐*If Yes , please specify* _ _ _ _

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Approval Date : 7/2/2013
Expiry Date : 6/2/2014

17. *In your opinion ,do wards with daylight help patients to* ***recover*** *faster*

☐*Strongly agree* ☐*Agree* ☐*Neither* ☐*Disagree* ☐*Strongly disagree*

18. *Which lighting scenario do you think a patient would feel as more* ***relaxing***

☐*White light and sunlight with the room painted blue or green*

☐ *White light and sunlight with the room painted white*

☐ *yellow light+ sunlight with the room painted blue or green*

☐ *yellow light+ sunlight with the room painted white*

☐*Others ,please specify____*

19. *In your view, do room with daylight help* ***patients feel more comfortable and at ease?***

☐*Strongly agree* ☐*Agree* ☐*Neither* ☐*Disagree* ☐*Strongly disagree*

20. Uniformity of illuminance is a quality issue that addresses how evenly light spreads over a task area. Please state your level of agreement with the following:

a. *I am satisfied with the current uniformity of illuminance in doctors' offices*

☐*Strongly agree* ☐ *Agree* ☐*Neither* ☐*Disagree* ☐*Strongly disagree* ☐ *N/A*

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Approval Date : 7/2/2013
Expiry Date : 6/2/2014

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b. *I am satisfied with the current uniformity of illuminance in the patients' ward*

☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree* ☐ *N/A*

HMC Research Committee
Approved
Approval Date : 7/2/2013
Expiry Date : 6/2/2014

Appendix C

Heriot Watt Ethical Approval

STUDENT SURNAME or PROJECT NO:……………AL ZU BA I DI……………..

HERIOT-WATT UNIVERSITY

APPLICATION TO SCHOOL ETHICS COMMITTEE FOR ETHICAL APPROVAL FOR A RESEARCH PROJECT

Click on the grey boxes to insert text

Section A: Project Overview

1. Project Title:...................... Study on the Integrated Lighting System performance and evaluation
2. Approval sought: Full approval ☒ Re-Submission ☐ In principle ☐

If 'In principle', when will full approval be sought?

Contact Information

3. Responsible Staff Member / Supervisor of student research:

a) Name.. Prof. Sue Roaf

b) Telephone ....

c) Email ....S.Roaf@hw.ac.uk

4. Investigator (if different from Responsible Staff Member) / Student:

a) Name... Safaa Alzubaidi b) Telephone

.... 0097466017988 c)

b) Email ....saa79@hw.ac.uk

5. Duration of Proposed Project ....three years

6. Anticipated Start Date:..1/8/2012

7. Does the proposed research involve human participants or living animals in Yes ☒ No ☐

any way?

Note: Involvement of human participants includes obtaining information from people through methods such as experiments, observation, surveys or interview, or any use of previously obtained personal data, or any use of human tissue samples.

If your answer to Question 7 is ‘yes’ complete the rest of the form; if it is ‘no’, simply sign the declaration in section F at the end of the form.

8. Please provide a brief summary of the proposed study (if possible, in less than 300 words. Include an overview of the design, variables, and other ethically-pertinent considerations). Feel free to attach a document if convenient.

The aim of this research is to investigate hospital's novel interior lighting's design that utilize Integrated lighting system (ILS) , this system combines both Daylight and electric lighting. The main objective for this system is to maximize the benefit of daylight and minimize the energy consumption of the electric lighting. The system will address the qualitative needs of the visual environment and health issues with the least impact on the natural environment through applying innovative and sustainable design model for lighting systems in hospitals.
Hospital staff/patients satisfaction will be surveyed and the new lighting design will be studied and modelled throughout the natural lighting (Daylighting) and efficient lighting fixtures to come up with novel prototype model that can be used by lighting designer and be included in the local regulation as guidelines to reduce the energy consumption. Complete Proposed research is attached.

Section B: Administration

1. Will participants be appropriately informed of: the aims of the study; their ethical rights; their expected contribution; and their subsequent debrief? For example, their right to withdraw, any deception employed or potential consequences of the study.

Yes No

2. Will consent be obtained from all appropriate parties? ☒☒ ☐

3. Will the Heriot-Watt University Code of Practice governing recruitment of research participants be followed? (Code of Practice available at **Code of Practice governing recruitment of research participants**) ☒ ☐

Section C: Ethical Considerations

1. Will the study require participants to potentially experience stressful or unpleasant situations?
2. Will the data collection and management (storage and disposal) potentially compromise the interests of the participants? For example, body fluids, tissue samples or other personally identifiable materials, such as, visual, auditory or other data? ☐ ☒
3. Will payment or non-payment of participants have potentially negative implications in the study? ☐
4. Are there potential negative outcomes from the study for the participant? For example, compromise to or damage of, their physical, psychological, financial or social wellbeing. ☐ ☒
5. Are there any other potential negative outcomes from the study? For example, damage to property or risk of criminal or civil liability. ☐ ☒

		Yes	No
6.	Would you identify any other issues that may have potential ethical implications for your study?	☐	☒

If you responded ‘No’ to any questions in section B, or ‘Yes’ to any questions in section C, please now complete section D and E. Otherwise, proceed to section F. ☒

Section D: Further Information Regarding Ethical Considerations

If you responded 'No' to any questions in section B, or 'Yes' to any questions in Section C, please provide further information, indicating how you would address this issue. Please be as comprehensive as possible, as this will speed the process for the referees and may avoid the need to contact you for further information or clarification.

Section E: Potential Referees (Optional)

If you have completed Section D, this form and any appended information will be reviewed by the full SBE Ethics Sub-committee. In addition, if you think it may be helpful for the review, you can suggest up to two staff members with appropriate expertise to review the submission.

1. Name .... Contact...

2. Name .... Contact...

Section F: DECLARATION

The information in this form is accurate to the best of my knowledge

Signature of Responsible Staff Member (PI or research supervisor)

....

Date ....

Signature of Student (if applicable)..

.

Date ....

Once completed this form should be forwarded to the Research Administrator: Claire Cook, Cathy Lord or Shauna Thompson (sberesearchadmin@hw.ac.uk). If it relates to PG student research it should be forwarded to the PG Research Assistant: Gillian Rae (g.rae@hw.ac.uk)

APPROVAL OF SECTIONS A.8, B, C and D (if completed)

I am satisfied that the researcher has properly considered the ethical implications of the intended study and has taken the appropriate action.

(Chair of SBE Ethics Sub-committee or delegated representative)

....

Date ....

FINAL APPROVAL

I am satisfied that the researcher has properly considered the ethical implications of the intended study and has taken the appropriate action.

(Head of School / Director of

Research)...

Date ....

Appendix D

Sample experiment test results document

Participant age : 28

Gender : F

Time : 8:10 [illegible] 2014

The Karolinska Sleepiness Scale KSS (1)

Please indicate your level of sleepiness during the last 10 minutes

	Status	Level
1	Extremely alert	✓
2	Very alert	
3	Alert	
4	Rather alert	
5	Neither alert nor sleepy	
6	Some signs of sleepiness	
7	Sleepy, but no effort to stay awake	
8	sleepy, some effort to stay awake	
9	Very sleepy, great effort to keep awake, fighting sleep	

Computer based test results

Acuity test A results:

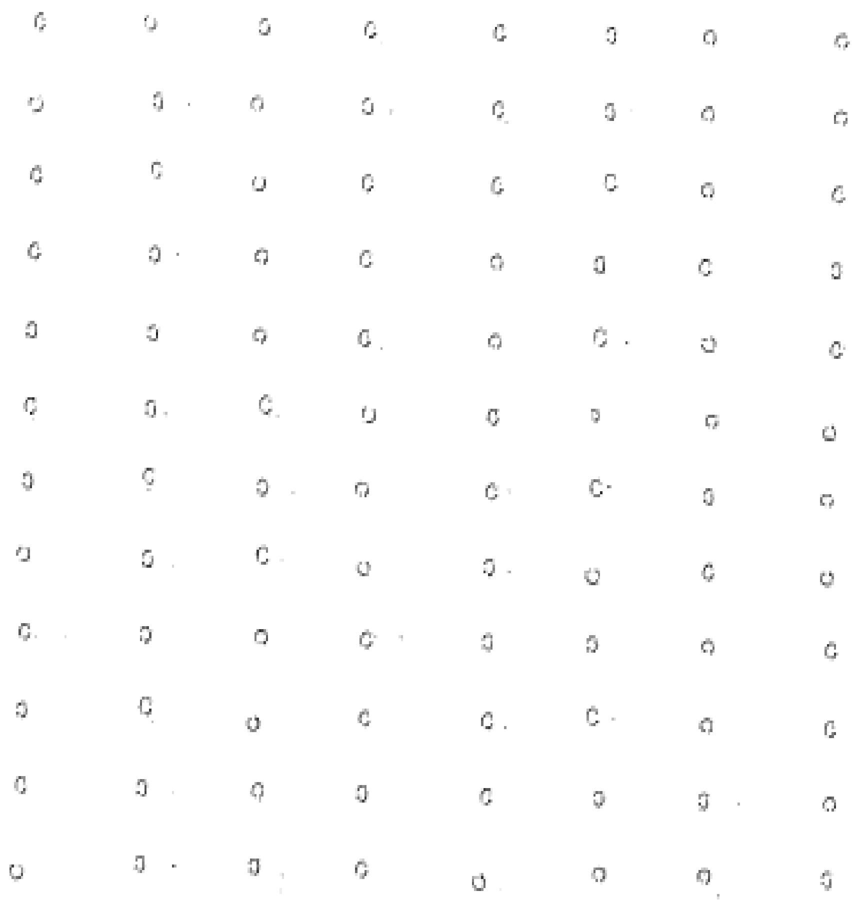
Dec VA: 1.04 LogMAR: -0.02

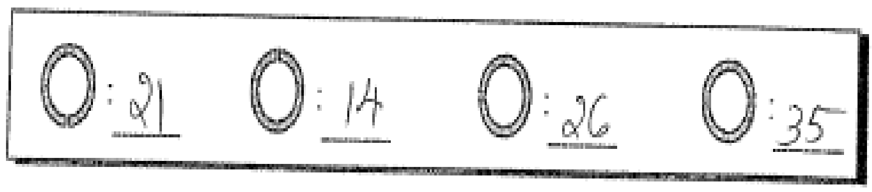
Contrast Test results A:

Weber= 0.44% Michelson= 0.22%

Count the rings A

Please Count the rings with each their orientation and write down the number found for each opening (Note, don't make any a mark on the rings and as quickly as possible)





Computer based test results

Acuity test results B:

Dec VA: 1·04 LogMAR: -0·02

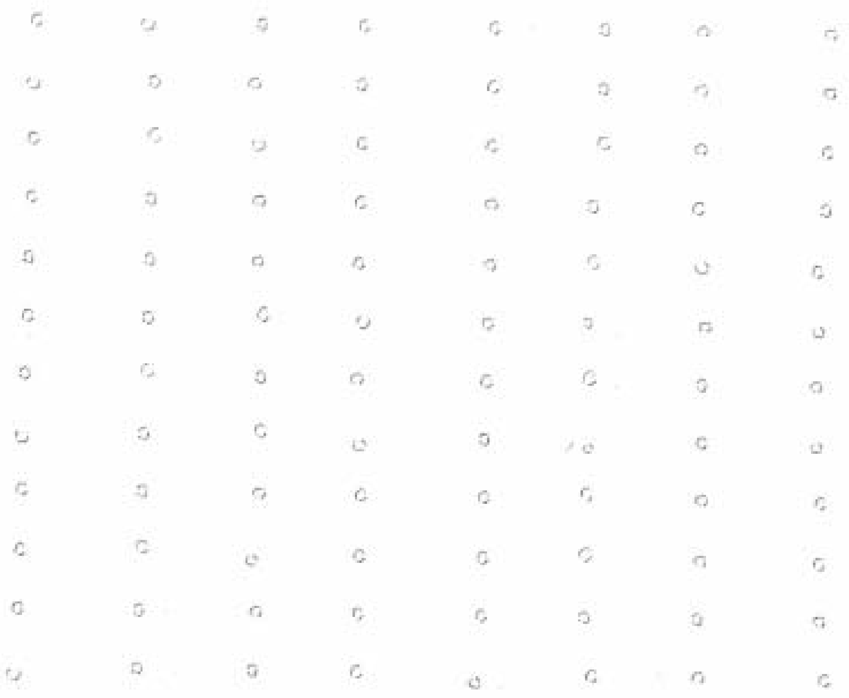
Contrast Test results B:

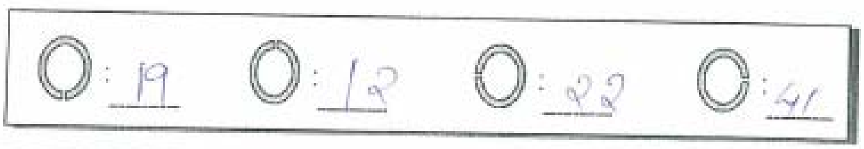
Weber= 1·21% Michelson= 0·61%

Count the rings B

2

Please Count the rings with each their orientation and write down the number found for each opening (Note, don't make any a mark on the rings and as quickly as possible)





The Karolinska Sleepiness Scale KSS (2)

Please indicate your level of sleepiness during the last 10 minutes

	Status	Level
1	Extremely alert	✓
2	Very alert	
3	Alert	
4	Rather alert	
5	Neither alert nor sleepy	
6	Some signs of sleepiness	
7	Sleepy, but no effort to stay awake	
8	sleepy, some effort to stay awake	
9	Very sleepy, great effort to keep awake, fighting sleep	

Computer based test results

Acuity test results C:

Dec VA: _1·04_ _ LogMAR:_-0·02

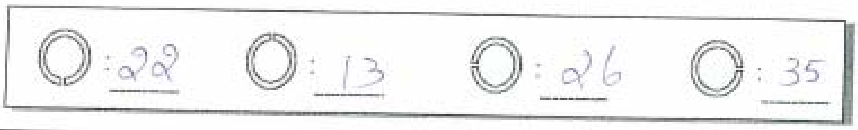
Contrast Test results C:

Weber= _0·59%_ Michelson=_0·3%_

Count the rings C

3

Please Count the rings with each their orientation and write down the number found for each opening (Note, don't make any a mark on the rings and as quickly as possible)



The Karolinska Sleepiness Scale KSS (2)

Please indicate your level of sleepiness during the last 10 minutes

	Status	Level
1	Extremely alert	✓
2	Very alert	
3	Alert	
4	Rather alert	
5	Neither alert nor sleepy	
6	Some signs of sleepiness	
7	Sleepy, but no effort to stay awake	
8	sleepy, some effort to stay awake	
9	Very sleepy, great effort to keep awake, fighting sleep	

Ward Lighting Survey (WLS)

Please state your agreement with the following statements:

1. I like the Lighting color in this ward
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
2. The lighting in this ward is pleasant
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
3. I feel comfortable working under this light
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
4. This ward seems too bright
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
5. This ward seems too dark.
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
6. There is no enough light to examine patient or give medicine in this ward
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
7. Do you think it is easier to treat patients in a ward with this light
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
8. My skin color looks unnatural under this light
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
9. The lighting in this ward create shadow
   ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
10. I feel eye strain working under this light
    ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
11. I have difficulties in seeing object s on the screen
    ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*
12. The lighting in this ward makes me feel sleepy
    ☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *Strongly disagree*

Appendix E

Published papers

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Survey of Hospitals Lighting: Daylight and Staff Preferences

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Abstract Hospital staff's preferences for daylighting to notions of the effects of daylight on patient's recovery times and processes, their experiences of daylight when treating and diagnosing patients and patient comfort levels is studied. A questionnaire survey was developed as a tool to review subjective judgments of the staff lighting needs and satisfaction. Responses obtained from one hundred and thirty four staff showed that seventy nine percent of the participants identify daylight in patient's room as a factor helping them do their work more easily, and Seventy seven percent of the surveyed nurses and doctors claimed that daylight is an important element in patient rooms to aid in reviewing patient recovery through recognizing and interpreting changes in patient skin color. Seventy eight percent of hospital nurses and all the surveyed doctors believe that daylight has many health benefits including fast recovery and reduced length of stay for patients. Moreover, ninety two percent of the surveyed staff stated that patients preferred to stay in rooms with access to daylight as it makes them feel comfortable. These results should be taken on board by hospital designers and regulation makers as an indication of the importance of using good daylight in hospital wards to achieve two important goals of improving both hospital staff working conditions and the patient's healing environment.

Keywords Daylight, Survey, Hospital Lighting, Staff Preferences, Patient Comfort, Recovery Process

1. Introduction

Good daylighting design in hospitals does not just depend solely on the aesthetics or engineering of a space, but it is strongly influenced by the psychology of the viewer, the behavioural opportunities available to them and the interactions between these factors and the Architecture of the space itself. Our knowledge with these interactions is still limited and has been hampered over the last half century by the growing dependence on engineered solutions over less prescriptive and product oriented building designs. Daylighting is commonly underderstood to enhance comfort and well-being for building occupants[1]. Architects were traditionally masters of daylighting design although in recent decades the increasingly heavy hand of both regulation and standardization of design has led to a significant reduction in the quality of daylighting design in most types of buildings [2]. People in different places and climates respond to the light in very different ways and experience it in terms of what is recognized and felt, not only as visible spectrum. The desert dweller may shun large windows because of excess light and thermal gain while the northern Tundra dweller will have almost the opposite response as they seek out the visual, thermal and health benefits of sunlight.

Sunlight and human health has shown strong relation in terms of improving wellbeing or causing serious disease. The role of sunlight to boost the body's crucial vitamin D supply was presented by many researchers such as Mead; Altomonte and Osmancevic et al[1, 4, 5]. A recent study by Lusk and Lash has described the light as an important element in hospital to improve mood and reduce stress[3], and it's well-known that sunlight was used as treatment of tuberculosis in the 19th century sanitaria where a TB bug is killed after five hours in sunlight[4].

Beauchemin and Hays found that treating patients in sunny hospital rooms can reduce their stays in hospital compared to other patients in dull rooms[12]. Moreover, Walch et al found that sunlight can work as analgesic therapy for patients and therefore can reduce the use of painkilling medication in hospitals[16]. The power of light in healing psoriasis, herpes and skin disorders were described in a recent study by Osmancevic et al as a reliable curing source [5]. In addition, many studies found that a lack of exposure to sunlight causes many illnesses and syndromes such as vitamin D deficiency, cancer, bone diseases, stress, depression, seasonal affective disorder (SAD) and disturbs the circadian rhythms[1, 3, 4, 6].

A hospital's physical environment is seen as a place imbued with high levels of stress for both staff and their

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vulnerable patients and their families due to its nature[7]. For hospital staff stress can be exacerbated by long hours, the human situations they deal with and the need to avoid making mistakes because of their potential high impact consequences. For patients, research has shown that hospitals are stressful places for three types of reason:

1) Psychological: Patients perceive a hospital as a potential last place they visit in their life (danger of death) and it is also a place where they become socially isolated[8].

2) Fear of the pain inflicted by and the consequences of procedures associated with their treatment exacerbated by the visual reminders of being surrounded by the types of machines that are with both.

3) The hospital environment itself is perceived as abnormal, alien and possibly hostile environments, due to its special activities, odors and noises, especially noises resulting from the pain of other patients[9].

Researchers have investigated a range of factors that reduce the stressfulness of the hospital environment and increase the comfort experienced by both staff and patients, with the aim to increasing their well-being, reducing medical errors and improving patient's recovery times. These studies concluded that lighting regimes in hospitals play an important role in improving hospital environment for staff and patients[6, 12, 14].

This paper investigates the impact of daylight in the hospital in making staff work easier, increasing patient comfort and reducing the duration of patient stays in hospital. The study presents the findings of a survey distributed to hospital staff designed to explore their subjective judgments on daylight and their experience with its impact on their work and on the patients. The needs of the human body in relation to lighting can be categorized into two groups: biological and visual lighting needs. These two needs require balance in any lighting design, as health and performance problems can occur when there are inadequate light levels for biological stimulation or higher light level for visual tasks[18].

1.1. Patient Recovery and Comfort

Recent research has led to an understanding of some factors that influence the recovery of patient in a healing environment such as hospitals[12, 35]. Daylight is seen as one of these factors due to its visual and non-visual impacts on the human body[13]. Studies that have surveyed the impact of daylight on mood or specific task performance in hospitals are very few which trigger the need for more research in this field[21]. A survey conducted at a healthcare facility in Turkey found that hospital staffs have access to sunlight during the working day feel less stress and more comfort[20]. Another study carried out at health care center to explore the impact of natural light on hospital staff comfort found that more than forty percent of the surveyed staff perceive the natural light in their workplace as having positive impact on their work[23]. However, in most hospitals, nurses' stations lack the necessary exposure to natural light. Therefore there is a need for further studies to understand the significance of sunlight to staff, and its impact on their mood and performance. In addition, some studies on the relation between sunlight and patient healing time suggest that daylight is one of the factors that would help in reducing the length of patient's stay in hospitals[6, 12]. Not only the visual spectrum of sunlight affects the mood and comfort but the non-visual effects of light can have important impact as well and can contribute to reducing depression among people as suggested by recent studies[28]. Three impacts of the light effect on the human body are often cited:

1) Physiologically: daylight has the effect of stimulating the human circadian system and human visual system[14]. When light enters the eye it stimulates a complex process of endocrine and autonomic responses that occur inside the human body. Psychologically it can make a patient feel more comfortable and at ease and this improves mood and the immune system in the body[3].

2) Psychological: a study demonstrated that daylight can help reduce the use of pain killer drugs for patients in a retrospective study on two types of patients. The first of which stayed in the bright rooms and others in dimmed rooms. It was noted that those who stayed in brighter rooms perceived less pain and took fewer analgesics, indicating that they were less stressed[16].

3) Sociability: Lighting affects the emotional and behavioral responses of patients. This had been referenced in some studies which demonstrate the significant impact of daylight on the patient's perceived sociability, emotion and behavior[18,19].

1.2. Staff Comfort

4) Health care facility is a people-centric industry. A variety of professionals are involved in providing different services that include healthcare, medicines, therapy, food, hospitality and extensive use of materials and equipment. Hospitals are often challenging workplaces and can place staff under extremes of stress. Therefore, it is important to give staff easily managed working environments in terms of spatial planning and appropriate visual comfort[13]. The need to minimize the risk of failure in executing necessary tasks requires good visibility by providing sufficient light quantity, with consideration of the nonvisual issues of lighting quality to enable staff to operate optimally. Studies have identified some of the negative factors that significantly impact staff such as inappropriate lighting lux level, color, direction and setting[14, 19, 21]. Other studies suggest a range of positive impacts of lighting on patient and staff well-being arises from many factors which include daylight effects[15, 26, 27].

A key issue for medical staff is the need to identify the changes in the patient's skin color which occurs with physiological changes inside the body. For instance, when a patient's skin becomes yellow it may be due to some liver problems, blue skin color might result from breathing problems or red because of skin problems.

On the other hand, color changes may result from an improvement in a person's health over time. Therefore it's important to recognize the patient skin color and to do that we need a light type that helps staff easily see these changes and distinguish between them[16]. Researchers have studied the influence of light types on the object's color appearance and found that Color Rendering Index CRI is the reference for lighting ability to give the objects its true color. The high CRI means actual object color. Daylight is considered as owning the highest Color Rendering Index CRI reaching one hundred percent[33, 36]; therefore it's very desirable to have it in any applications that need true colors, such as in hospitals where observing any changes in patient's skin color may be crucial[17].

1.3. Previous Questionnaires

Many survey questionnaires have been conducted to explore the relationship between employee performance and few of these surveys look at the relation between light and patient comfort with daylighting[22, 23, 25]. In a survey conducted at a newly constructed healthcare center in Malaysia, the author of the study showed that staff age has a strong impact on the selection of daylight preference when treating patients[24].

Over sixty percent of participants (nurses) of forty years old or under believed that serving medication orally for patients in open wards with natural lighting is hassle-free, while older nurses expressed their dissatisfaction in performing the same task with natural lighting.

The number of years of experience was another subject studied during one survey, where it was shown that over fifty percent of the hospital professionals who have different years (more than three years) of work experience performed one task using artificial lighting without having difficulty. Less than eighteen percent with less than three years' experience stated that they found some difficulty in performing the same task with natural light[24].

In a study conducted at an office building in South Korea by Geun Young Yun[25], a field survey on illumination levels and light type showed that employees felt more comfortable with good daylight entering into the office, especially when the brightness level was adequate. It demonstrated that a linear relationship exists between the comfort illuminance and the level of illuminance perceived by occupants as being neither bright nor dim. Applebaum et al conducted a survey to explore the relationships between environmental factors like light and perceived stress for nurses.

The study showed a relationship between staff working in acute-care settings and observed stress which was reduced when working in an area lit with daylight. This could be the result of the nature of the acute-care area and the type of light it used to have (dimmed)[27].

2. Methodology

In the current study a structured interviews technique were selected to collected data from a focus group, face to face interviews were conducted to explore the staff satisfaction with hospital lighting in which the questions were read as it's written on the questionnaire without explanation or clarification. The survey was administered from January 2nd till April 2nd 2013. The questionnaire was aimed at hospital professionals who visit the patient on a daily basis. The survey initially tested with fifteen volunteered participants (pilot survey) to ensure clear and understandable content of the questionnaire, in the next stage, one hundred and thirty four participants volunteered to participate were asked twenty eight questions, but for the purpose of this study we will present their response on four questions that show their preference and experience with daylighting at patient rooms.

The study was conducted at Hamad General Hospital (HGH) the central healthcare facility in Doha, Qatar. The hospital contains 603 beds that offer different health support departments, such as emergency medicine, pediatrics, specialized surgery, critical care, laboratory medicine, specialized medicine, and radiology services[28]. It provides health care services to more than 600,000 people.

The primary focus group consisted of doctors, nurses, administrators and auxiliary staff, the subjective judgment was assessed by the means of a questionnaire. The qualitative professional judgments of staff used as the reference indicator, surveyed in the study for a range of types of work, as daily observations in different patients' rooms.

2.1. Questionnaire

In order to explore the relationship between staff preferences for hospital lighting and current lighting design standard, twenty eight questions have been asked. In this paper we consider the analysis of only four questions and focus on the two groups, nurses and doctors. Following a verbal introduction to the nature and purpose of the survey and acquiring the background information about the participant, the subjects were then asked to rate their satisfaction with the following four questions:

1. Do you think it is easier to treat patients in a room with daylight?

☐ *Strongly agree* ☐ *Agree* ☐ *Neither*
☐ *Disagree* ☐ *strongly disagree*

2. If identifying changes in a patient skin colour is important to you, do you find it easier to do it in a room with daylight?

☐ *Strongly agree* ☐ *Agree* ☐ *Neither*
☐ *Disagree* ☐ *strongly disagree*

3. In your view, do rooms with daylight help patients feel more comfortable and at ease?

☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *strongly disagree*

4. In your opinion, do wards with daylight help patients recover faster?

☐ *Strongly agree* ☐ *Agree* ☐ *Neither* ☐ *Disagree* ☐ *strongly disagree*

2.2. Sample Size

An important question in any survey is how many participants are needed to make the survey statistically significant, an issue that needs to be determined before the beginning of the survey to ensure useful results[29]. There are many factors that influence this selection, such as the main aims of the survey, the required precision level for results and anticipated response rate. For the current survey a large number of randomly surveyed staff were targeted who were selected from a range of different professional groups working in the hospital. Thus we were able to harvest opinions from most of the working staff in the hospital. In answer to the question of the optimal size for the group surveyed, we referred to the work of Niles[30] who defined a suitable confidence interval for the result with the following the equation:

$$K = 1/\sqrt{N} \quad (1)$$

Where:

K is the confidence interval

N is the number of participants or sample size.

In this study 134 subjects were selected to ensure an acceptable margin of error[31, 32].

2.3. SPSS

For the purpose of this study IBM SPSS Statistics software was used to analyze the staff responses to the survey questionnaire. This software was developed by IBM and is used mainly for handling data, running statistical analyses, and producing tables or graphs to summarize the data. Its features, including the ability to work on different variables at the same time and the range of the tools included in it. , it's been considered satisfactory for use in this analysis of the survey database and table production[32]. Especially useful here were the functions it contains for recoding data, tables, graphs and adding many new variables.

3. Results and Discussion

The participants were randomly selected from the professional groups in the hospital including doctors, nurses, auxiliary staff, administrators and technicians, who were asked to participate voluntarily in this survey. Nurses represented the highest percentage of those interviewed as they represent the majority of staff in the hospital. The proportion of staff from different groups in the survey is shown in Table 1.

Figure 1 shows that seventy nine percent of the staff believes that daylight in patient's room helped them do their work more easily, including treating and diagnosing patient health and monitoring their recovery. This is an important finding, especially because it springs from people who spend most of their working day inside the hospital and are thus well versed in the relative merits of daylight versus artificial lighting. Nineteen percent of respondents expressed their uncertainty in responding to this statement. Two percent of the participants disagreed with this statement as they don't consider daylight an important factor that can make their work easier.

Table 1. Participant Staff by groups

Group	Percent
Administrators &technicians	8%
Auxiliary staff	13%
Doctor	7%
Nurse	58%
Technician	14%

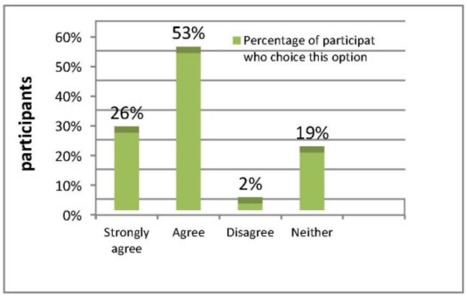

Figure 1. Treat Patient in room with Daylight

Responses from the professional groups on the first question are presented in Table 2. It showed that eighty one percent of the nurses who give treatment to patients support the opinion of having daylight in the patient's room and see daylight as a factor which helps them do their work more easily at the hospital. Most of them said "we feel more comfortable when treating patients in rooms with daylight". All participants from the doctors group showed strong agreement with this statement. Nineteen percent of the nurses groups were unsure whether daylight can make their work in the patient rooms easier. This could be due to other factors which are not linked to the type of the profession, such as age, work shift or years of experience as stipulated in earlier study[24]. However, these factors were not investigated in this study. On the other hand, participants who chose neither as answer or disagreed with the statement came from non-medical staff such as administrators and technicians, who don't spend much of their time in patient rooms or their work is not linked to the patient treatment.

For the second question, the responses were analyzed and the results on the hospital's professional groups who believe that daylight can help identifying changes in a patient skin colour are shown in Figure 2. Staff were asked if they find it easier to identify changes in a patient's skin colour in a room with daylight. The results confirmed that the perception of seventy one percent of the staff think daylight plays an important role in recognizing changes in patient skin color. The daylight features of providing brighter light source during the day and having a more balanced colored spectrum than other light sources contribute to it being a suitable source to be used in patient rooms. Two percent of the staff disagreed with this statement as they don't consider that daylight has this capability, while twenty seven percent were unsure of the ability of daylight helping them see changes in patient's skin color.

Table 2. Daylight Preferences when Treat Patient

Status	professionals	Percentage
Strongly agree	Administrator	6%
	Doctor	7%
	Nurse	13%
Agree	Auxiliary staff	13%
	Nurse	34%
	Technician	6%
Disagree	Administrator	2%
Neither	Nurse	11%
	Technician	8%

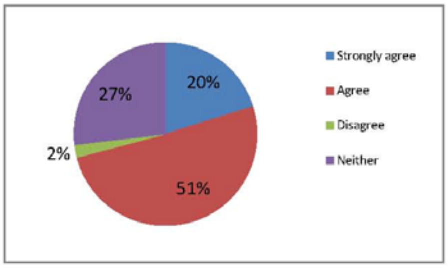

Figure 2. Daylight helps identify patient skin colour

Table 3. Daylight helps identify patient skin colour (by profession)

Status	Profession	Percentage
Strongly agree	Auxiliary staff	13%
	Doctor	7%
Agree	Nurse	45%
	Technician	6%
Disagree	Administrator	2%
Neither	Administrator	6%
	Nurse	13%
	Technician	8%

Question two's groups were represented in Table 3. The interesting finding is that all doctors participating see daylight as an important factor that can help facilitate their work with the patient, including diagnosis of patient true skin color. Seventy seven percent of the nurse group agrees with this concept and twenty three percent of them are not certain of this idea of daylight's role in facilitating the diagnosis of the patient's changes in skin color. This response from hospital's staff highlights the need for a hospital architect to take into consideration the effect of daylight on hospitals rooms.

The results of the question asking whether daylight makes patient feel comfortable are shown in Figure 3. A very high percentage (ninety two percent) of the staff agreed with this statement highlighting the need for hospital designers to take this fact on board. This finding also confirms the results of earlier studies on the positive psychological effect of daylight[12, 13, 22].

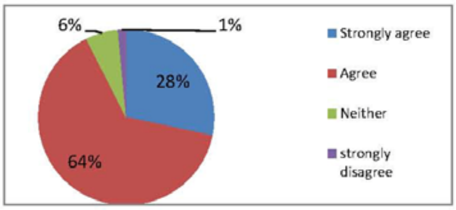

Figure 3. Daylight makes Patient Feel Comfortable

Staff groups who supported the idea of the positive psychological effect of daylight in making patients feel more comfortable were seven percent doctors, fifty six percent nurses. This means almost all doctors and nurses observe the effects of daylight on patients and how it makes them feel comfortable. One percent of the surveyed nurses disagreed with this option. This disagreement with nurses might be due to other factors such as the type of patient illness they work with (i.e. those in intensive care units who don't have access to daylight or who may have sensitivities to sunlight). The results of the groups' reply are shown in Table 4.

Table 4. Daylight makes Patient Feel Comfortable

Status	Profession	Percentage
Strongly agree	Administrator	8%
	Auxiliary staff	13%
	Doctor	7%
Agree	Nurse	56%
	Technician	8%
Neither	Technician	6%
strongly disagree	Nurse	1%

As discussed earlier, reducing the length of stay for patients in hospital has large cost benefits for most involved parties, including reduced health care costs for patients and for hospitals[34]. It means a faster turnover rate for beds and enhanced reputation for healing. Moreover, when the healthcare facility is funded by the government (e.g. non-profit facility), it means reduction in the running cost.

The subjective judgment of the surveyed staff shows that eighty two percent of the hospital staff see daylight as an element that can help speed up the recovery process for patients and hence reduce the length of stay in the hospital. However, eighteen percent of the staff were uncertain of the health, comfort or diagnostic benefits of daylight. The reasons for this were not identified in this study but point to the need for further work in this field.

The agreement among the doctors group reveals that all the surveyed doctors are in consent with this feature of daylight (healing feature), seventy eight percent of the nurses have concluded from their experience with patient and healing process that daylighted rooms result in fast recovery of the patients, twenty two percent of the nurses were unsure of this statement applicability when linked to patient recovery time; the same is illustrated in Table 5.

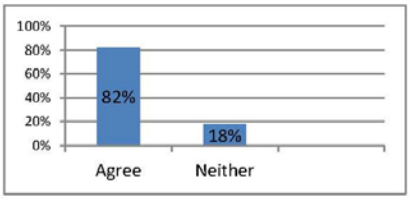

Figure 4. Daylight makes Patient Recover Faster

Table 5. Daylight makes patient recover faster

Status	Profession	Percentage
Strongly agree	Administrator	7%
	Doctor	4%
	Nurse	1%
Agree	Administrator	1%
	Auxiliary staff	13%
	Doctor	3%
	Nurse	44%
	Technician	8%
Neither	Nurse	13%
	Technician	6%

4. Conclusions

This study has confirmed that hospital staff perceive daylight to have a strong health, comfort and diagnostic benefit for staff and patients in hospital wards. The study provided clear evidence of the subjective judgment of hospital staff showing:

- Seventy nine percent of the participants identify daylight in patient's room as a factor helping them do their work more easily.
- Seventy seven percent of the surveyed nurses and doctors claimed that daylight is important element in patient rooms to aid in reviewing patient recovery through recognizing and interpreting changes in patient skin color.
- When it comes to patient comfort ninety two percent of the surveyed staff stated that patients preferred to stay in rooms with access to daylight as it makes them feel comfortable.
- Seventy eight percent of hospital nurses and all the surveyed doctors believe that daylight has many health benefits including fast recovery and reduced length of stay for patients.

This study has presented the view of people who deal with patients on a daily basis and do their work with different lighting regimes (with and without daylight). The clear evidence presented above of the perceptions of hospital staffs of the health, comfort and diagnostic benefits of daylight spaces should be taken on board by hospital designers as an indication of the importance of using good daylight in hospital wards to achieve two important goals of improving both hospital staff working conditions and the patient's healing environment.

ACKNOWLEDGEMENTS

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Research note

Energy Efficient Lighting System Design for Hospitals Diagnostic and Treatment Room—A Case Study

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ABSTRACT

Lighting plays an important role in the Hospital Diagnostic and Treatment Room. It shall be environmentally and functionally suitable for three groups of people: patients, hospital professionals and visitors. On the other hand lighting is considered a major consumer of electrical energy and therefore, hospital lighting design should consider the visual performance, visual comfort and energy efficiency. This article discusses the performance of different types of lighting installations used for hospital lighting system design applications: first the visual comfort and second to save energy consumptions in such applications. DIALux 4.8 simulation software is used to study and evaluate the efficient lighting scheme for the hospitals through the use of different types of lamps. Also, visual environment lighting system design procedure is explained. Economics of different lighting scenarios are highlighted.

KEYWORDS: Compact Fluorescent Lamp (CFL), Light Emitting Diode (LED), Light Fitting Cost (LFC), visual performance, visual environment

1. Introduction

In multi function and diverse habitant environment such as hospital treatment rooms, lighting system design plays a major role. Lighting must be suitable for three different categories of people: it should consider the comfort of the patients, the critical visual requirements for hospital staff, the comfort and visual need of the visitors. In addition to these goals, lighting systems can achieve considerable energy cost savings through the careful design of lighting schemes used in such applications. In this article, how the visual comfort and energy efficient lighting system can be designed for hospital lighting applications are highlighted.

The distributions of light within a space substantially influence the perception of the space as well as people within it. Hospital lighting system has two main functions: one is to meet the task requirements in each area of the hospital and the second is to create an environment that is visually satisfying the patients as a good lighting system design can influence human emotions and feelings of well-being.

The works of Patricia Rizzo, Mark Rea and Robert White[1], Hilary Dalke, Jenny Little, Elga Niemann, Nilgun Camgoz, Guillaume Steadman, Sarah Hill, Laura Stott[2][3], Flynn J. E, Spencer T. J, Martyniuk O, Hendrick C[4] are the important studies concerning hospital lighting design. Their findings focus only on the visual aspect and human perception of lighting in the hospital lighting design applications.

This article explains the hospital lighting system design procedure using DIALUX 4.8 simulation software as per the international standards. Also, the most appropriate selection of lighting type which is visually and financially viable is highlighted.

2. Requirements of hospital lighting system

i) For the Patients: The physical environment in which a patient receives care affects patient outcomes, patient satisfaction and safety of patients. Patients require a quality lighting environment.

ii) For Staff: From the staff perspective, the visual environment should be conducive to hard work. Studies show that a well-designed working environment can aid recruitment and the retention of staff as well as improving their morale. Another role that lighting can play is to make the environment of the hospital easy for orientation of new staff working in the ward unit. It needs to be visually prominent and provide lighting with maximum efficiency for all users. The immediate environment should be harmonious with variety of luminaires to give the eyes a chance to rest.

iii) For the caretakers of patients: Their needs differ from those of hospital staff and professionals as they may try to sleep during the night rather than try to stay awake.

iv) Visual Discomfort: Studies shows that, there are four situations in which lighting installations may cause visual discomfort. They are:

- visual task difficulty, in which the lighting makes the required information difficult to extract,
- under or over stimulation, in which the visual environment is such that it presents too little or too much information,
- distraction, in which the observer's attention is drawn to objects that do not contain the information being sought,
- perceptual confusion, in which the pattern of illuminance can be confused with the pattern of reflectance in the visual environment.

The most common aspects of lighting that cause visual discomfort are insufficient light, too much variation in illuminance between and across working surfaces, glare, veiling reflections, shadows and flicker. All these aspects are considered in the proposed design.

v) The energy used by lighting system depends on both the power rating of lamps used and the time. Energy efficiency can be achieved by using the most effective and efficient lighting equipment and control that can keep the energy requirement minimum whilst achieving the lighting design objectives.

3. Lighting system design

Luminous intensity, luminance, luminous flux and illuminance are the four basic parameters used in lighting system design. Different types of lamps used in lighting system design with their luminous efficiency and lamp service life is given in Table 1.

The various factors to be considered in the design of lighting system for hospitals are:

i) Natural Illumination: The provision of natural illumination and access to windows is always appreciated by patients and should be considered in the design. Also it is required to limit sun penetration so that thermal and visual discomforts do not occur.

ii) As the common lines of sight for the patient in the hospital is toward the ceiling and the top portion of the opposite walls, design should avoid glare to patients, while still providing good visibility to hospital professionals. A limiting glare index is recommended for each application[6]. Discomfort glare is quantified by the Unified Glare Rating (UGR) derived using equation (1) below.

$$UGR = 8\log_{10}\frac{0.25}{L_b}\sum\frac{L_S^2\,з}{p^2} \qquad (1)$$

L_b=background luminance (cd/m^2), excluding the contribution of the glare sources.

L_S=luminance of the luminaire (cd/m^2).

з =solid angle subtended at the observer's eye by the luminaire (steradians).

p=Guth position index.

Typically UGR values ranges from 13 to 30[6]. The lower the value, the less is the discomfort.

iii) Colour rendering requirements: The ability of a light source to render colours of surfaces accurately can be conveniently quantified by The Commission Internationale de l'Eclairage (CIE) general colour rendering index. The colour rendering index is used to compare the colour rendering characteristics of various types of lamp. Eight test colours are illuminated by a reference source, which is a black body radiator of 5000 K correlated colour temperature or 'reconstituted' daylight if more than 5000 K is needed[9]. These eight colours are then illuminated by the test lamp. The average of the colour differences produced between the source and the test lamps provides a measure of the colour rendering properties of the test lamp. The recommended values are given in Table 2[6].

iv) Recommended reflectance values are given Table 3[6].

4. Computer simulation using DIALux 4.8

Computer programs are preferred in architectural

Table 1 Lamp efficiency and service life

Type of Lamp	Lumens per watt	Average lamp life in hours	Color rendering
Incandescent	8–25	1000–2000	100
Fluorescent	60–600	10000–24000	82–95
High Pressure Sodium (HPS)	45–110	12000–24000	83
Low Pressure Sodium (LPS)	80–180	10000–18000	5
Metal halide	60–100	10000–15000	87–93
LED	28–79	25000–100000	40–85

Table 2 Recommended lighting requirements for different areas in a hospital

Area	Illuminance in Lux	Limiting glare index	Minimum colour rendering
General lighting	100	19	80
Waiting rooms	200	22	80
Corridors: during the day	200	22	80
Corridors: at night	50	22	80
Day rooms	200	22	80
Staff office	500	19	80
Staff rooms	300	19	80
Reading lighting	300	19	80
Simple examinations	300	19	80
Examination and Treatment wards	1000	19	80

Table 3 Recommended Reflectance Ranges

Surface	Reflectance
Ceiling	0.7 or higher
Walls	0.5–0.7
Partitions	0.4–0.7
Floor	0.1–0.3
Furniture	0.2–0.5
Window blinds	0.4–0.6

projects to design the lighting systems. Using simulation, concepts can be visually compared during the design phase in order for decisions to be made prior to construction particularly in the lighting calculations due to its ability to provide visual impact of the lighting design for the projects without requiring any real life applications either for all or part of the project such as adding furniture or placing certain interior elements. It also provides an easy way to calculate the required lighting installations and optimize the energy usage.

In this article, DIALux4.8 simulation software is used for the analysis. The accuracy of the result from Dialux software depends on the data provided. Professional lighting designers have been utilizing Dialux software due to its many features such as the Render feature, user-friendliness, the ability to optimize the lighting distribution and quantity which will lead to energy efficient lighting system design. It determines the physically correct numerical values for the proposed system based on CIBSE and IES standards. It has been found in many projects that the results obtained from the simulation with the field measurements are close to real data[10]. For these reasons DIALux4.8 based simulation is proposed in this article. The simulation also helps to check compliance with requirements specified in standards, such as uniformity of illuminance and the recommended lux level as per EN 15193.

A further effective visualization method is false colour rendering diagrams which allow levels to be represented through a colour scale.

Following are the steps to be followed in the lighting system design using DIALux software:

i) Enter project information input.

ii) Enter room geometry: In this step we provide room geometry such as length, width and height, the type of material used for ceiling, walls and ground (which will have impact on the lighting calculation due to different reflection factor associated with each material), lighting loss factor, and the work plane height.

iii) Luminaire selection: Luminaire selection and mounting height will have direct effect on lighting simulation results (Software has electronic library/catalogues).

iv) Placement of luminaire, calculation and visualization of the results: In this step the placement of luminaire will be either manual or automatic, where the designer will have the options to input the desired illuminance. Software will provide the simulation results. One of the major disadvantages of using this software is the standard values provided for many parameters in which case the accuracy is questioned. The design proposed here allows one to input the values as per the standards mentioned in Tables 1–3.

5. Case study

A Hospital Diagnostic and Treatment room in Qatar is selected for the case study. The Diagnostic and Treatment room is a rectangle parallelepiped of 10 m wide, 10m long and the height of the room is 4 m. This room is divided into small diagnostic rooms separated from each other by sliding curtain wall. The reflection coefficients (supposed diffuse) of the walls are ρ_{wall}=0.5, floor ρ_{wall} =0.2, and the ceiling $\rho_{ceiling}$=0.7[9]. The required Lux level as per Table 2 is 1000 lx. The measurement of required illumination was taken on a work plane that has a height 0.850 m and a grid of 32×32 points were selected. The maintenance factor is assumed as 0.8. The visual comfort shall match the glare index and the colour rendering index is set as per the recommended standards. The price of energy consumption for healthcare applications in Qatar is 0.10 United States Dollars ($) per unit of energy (kWh) consumed. Three lighting scenarios were applied to know the visual comfort through glare effect, color rendering and the power consumption of the diagnostic and treatment room of the hospital through the use of different types of lamps like incandescent, CFL and LED lamps. In the design, the working hours of the hospital is assumed to be 24 h a day, seven days a week. DIALux 4.8 simulation software is used for the case study and the simulation results are shown for each scenario.

6. Scenario 1

The diagnostic and treatment room is illuminated through the use of ERCO product ERCO 46608000 Quintessence Down light 2×TC-TELI26W equipped with ERCO Compact Fluorescent of 2×26 W. Figure 1 shows the lighting distribution values in Lux. Photometric data are shown in Figure 2.

The luminaire layout plan is shown in Figure 3. 3-D colour rendering is shown in Figure 4 which is an accurate representation of the lighting effect. It shows effect of lighting on different area in the room.

False colour rendering is shown in Figure 5 which shows the different area in the room and the possible false colour rendering. A value chart is shown in Figure 6.

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1. Introduction

Qatar has seen fast growth in its construction sector and confirmed that it is willing to go to green and focus on more sustainable buildings design. The reasons behind this decision is country willingness to improve the environment by reducing the CO2 emission and reducing energy consumption, as such the Sustainable Development represents one of the important principles stated in Qatar National Vision 2030, published in July 2008. It calls for collaborated efforts from two important sectors, the Private Sector and the Public sector, to participate in achieving the country's future vision through engagement in Sustainable Development initiatives alongside with the Government[2][3] .

In the United States LEED® is the dominant green system in the market and currently is being adapted to multiple markets worldwide [13]12]. Due to its simplicity as a third-party certification and rating system, LEED has become a globally accepted benchmark for the design, construction and operation of green buildings [14].However, relying on this system to assess the sustainability of the building could cost more in Middle East compared to US.

Cost represents one of the important challenges in the way to achieve this transition into sustainable buildings, especially when it comes to private sector investments. The primary concern of many developers and building owners is the potential increase in upfront costs [4][5], where they believe that the cost of switching from traditional buildings they use to construct to new sustainable design buildings will have a huge cost impact and could add more burden to their investment in Qatar. This study was conducted to investigate these doubts and provide realistic cost impact due to applying LEED rating system in achieving sustainable buildings design.

Numerous studies have been conducted to compare the cost incurred due to applying USGBC LEED rating system for certifying building to traditional designs [6][7][8][10]. These studies have concluded that the greater parts of these costs are resulting from to the following [16][17]:

- Improved Architectural design
- Utilize conservative and sustainable Electrical and Mechanical systems
- Employ specialized green Design Consultant
- Commissioning consultant and commissioning agent fees. Commissioning is the procedure used by the green building to verify the system quality of work and to ensure that it has been designed, installed and functionally tested to the design intent.

In Qatar the cost impact may vary and the items to be considered can be different from USA for many reasons, such as implementing energy policies, local legislation,and availability of local manufactures, material and resources. These can all lead to a different cost impact to applying green buildings in the region compared to US green buildings. These factors will be investigated and presented. The study will not look at the cost impact result from running green building.

Figure 1 below shows the result of the recent studies which compares LEED project vs. premium cost in USA [15].

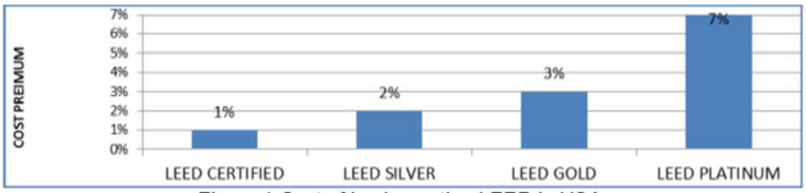

Figure 1 Cost of implementing LEED in USA.

2. Case study

Energy City Qatar (ECQ) is a green economic development project, located in the heart of Lusail City, 15km north of Doha, capital of State of Qatar and occupying 720,000m2. Total built-up area will reach 728,000m2. Energy City Qatar is planning to host 22,000 industry professionals. The city consists of 96 plots, more than 72 projects with 58 sub-developers, 6.2km of internal roads, 6 main entrances, 1 Train station, and all the buildings are designed as low rise buildings, Ground plus Mezzanine plus three floors, (except the ECQ Headquarter with 7 floors), with different public utility lines running north [18]. Home to the world's third largest natural gas reserve and thus logistics and communication among the residents on the city (hydrocarbon companies) will be easier and effective. The city headquarter plot ECQ-HQ land area is a 25,108m2 and the total built-up area is 85,000m2. The HQ represents the brain of the city and it is targeting high-end oil & gas tenants.

The ECQ-HQ project comprises of three buildings of 5 to 7 floors above ground including Ground and mezzanine floors, the building usage varies as follows:

- Building 1 – Corporate offices with restaurants and amenities
- Building 2 – Multi use for banks, retail, trading and offices.
- Building 3 – Multi use for Data Centre, Command and Control Centre, Network Operation Centre, training and ECQ offices

2.1 Assumption

The study is based on the following parameters and assumptions:
-Selection of a real building (ECQ-HQ) where the design has been completed, the contractors bids have been received, and the building construction will commence shortly.
- Identification of building performance and constituent elements for both LEED buildings and conventional buildings.
- Creation of a score point and cost model of the ECQ-HQ building creating two iterations, the base building and improved building model. Both buildings iterations have been assumed to be occupied between 08:00 – 19:00 during week days. During the hours of operation, the building's internal temperature is maintained at 24°C. The same assumption was applied to the twenty four LEED projects in ECQ.

2.1.1 Methodology

Energy City Qatar Headquarter ECQ-HQ project has reached the final tender stage and ready to go for construction stage. Priced Bill of Quantity (BOQ) is considered as the reference for the actual cost difference between the Gold rated building ECQ-HQ and the conventional building.

The basis for the comparison is the LEED report prepared by the design consultant; LEED credits score sheet, consultancy agreements/contracts and LEED commissioning authority/agent agreement. The cost plan was reviewed against the drawings to ensure accuracy. A separate cost plan was then developed using ECQ design guidelines and LEED score sheet. All other elements' prices were deemed as being the base-building (conventional building) mandatory requirement for construction of such a building in the region. Therefore the scope for construction of the external envelop, roof, substructure, external walls, windows, external doors, selection of material, optimum energy performance, mechanical systems, environmental measures and electrical system were taken into consideration. Capital estimates were prepared and then the overall comparison was developed.

An analysis was performed to identify green building measures — above and beyond those included in ECQ standards and Lusail development guidelines — that would likely be implemented to meet the specific LEED prerequisites and credits requirements [19]. From these measures, cost impact estimates were developed for each prerequisite and credit, with predefined variations for both the conventional building and headquarter building models. The individual credit costs were also categorized, using the following category cost reference in Table 1:

Description	Classification
Measures are applied for classic buildings as well as green buildings.	No Cost
Measures are applied to promote the building to sustainability requirement cost less than traditional.	Potential Cost Decrease
Credits = < QR200K	Low Cost
Credits QR200K - QR500K	Moderate Cost
Credits > QR500K	High Cost

Table1 Cost Categories

Per the following equation:

$$\mathbf{C} = \frac{\mathbf{X}}{\mathbf{Y}}\,\% \qquad (1)$$

Where, **C** is the credit cost impact, **X** is the actual cost of the credit, and **Y** is the overall project cost.

The LEED credits which are anticipated for Energy City Headquarter are following LEED for Core and Shell V2.0 registered project credits checklist. LEED credits checklist has been established for the six areas, the assessment was based on evaluating the impact of each credit, and as follows:

Prereq. 1	Construction Activity Pollution Prevention
Credit 1	Site Selection
Credit 2	Development Density & Community Connectivity
Credit 3	Brownfield Redevelopment
Credit 4.1	Alternative Transportation: Public Transportation Access
Credit 4.2	Alternative Transportation: Bicycle Storage & Changing Rooms
Credit 4.3	Alternative Transportation: Low-Emitting and Fuel-Efficient Vehicles
Credit 4.4	Alternative Transportation: Parking Capacity
Credit 5.1	Site Development: Protect of Restore Habitat
Credit 5.2	Site Development: Maximize Open Space

Credit 6.1	Storm water Design: Quantity Control
Credit 6.2	Storm water Design: Quality Control
Credit 7.1	Heat Island Effect, Non-Roof
Credit 7.2	Heat Island Effect, Roof
Credit 8	Light Pollution Reduction
Credit 9	Tenant Design & Construction Guidelines

Table 2 Sustainable Site Credits

The cost of these credits (Table 2) are considered moderate in average due to including cr such ash as adding Bicycle Storage & Changing Rooms, Parking Capacity and the use of l Emitting and Fuel-Efficient Vehicles. Other credits were gained based on the site selection.

Credit 1.1	Water Efficient Landscaping: Reduce by 50%
Credit 1.2	Water Efficient Landscaping: No Potable Use or No Irrigation
Credit 2	Innovative Wastewater Technologies
Credit 3.1	Water Use Reduction: 20% Reduction
Credit 3.2	Water Use Reduction: 30% Reduction

Table 3 Water Efficiency Credits

The cost of these credits (Table 3) are considered as low cost in average as most of the credits are in line with local authority requirements and implemented in classic buildings, such as Water Efficient Landscaping credits and Innovative Wastewater Technologies credits that utilize measures which cost less. For instance, no urinals are specified, dual flush WCs are specified (1.6/0.8 GPF), no janitors sink proposed and Pantry/Kitchen sink specified (2.2 GPM).

Prereq 1	Fundamental Commissioning of the Building Energy Systems
Prereq 2	Minimum Energy Performance
Prereq 3	Fundamental Refrigerant Management
Credit 1	Optimize Energy Performance:
	10.5% New Buildings or 3.5% Existing Building Renovations
	14% New Buildings or 7% Existing Building Renovations
	17.5% New Buildings or 10.5% Existing Building Renovations
	21% New Buildings or 14% Existing Building Renovations
	24.5% New Buildings or 17.5% Existing Building Renovations
	28% New Buildings or 21% Existing Building Renovations
	31.5% New Buildings or 24.5% Existing Building Renovations
	35% New Buildings or 28% Existing Building Renovations
Credit 2	On-Site Renewable Energy

Credit 3	Enhanced Commissioning
Credit 4	Enhanced Refrigerant Management
Credit 5.1	Measurement & Verification - Base Building
Credit 5.2	Measurement & Verification - Tenant Sub-metering
Credit 6	Green Power

Table 4 Energy & Atmosphere Credits

These are high cost credits (Table 4) due to the contracting commission authority company, utilizing Minimum Energy Performance and associated energy reduction scenario measures. Fundamental Refrigerant Management credit is a high cost as any refrigerants specified should have zero use of CFC. Optimize Energy Performance credit is a high cost as local energy cost is low and then the net cost to reduce energy is high. Installing high cost photovoltaic panels to satisfy the Onsite Renewable Energy credit and the use of sub metering as well as Measurement & Verification: Base Building credit cost is also high. The Green Power credit is not achievable in Qatar as there is only one utility provider relying on a thermal power station fuelled from gas.

Prereq 1	Storage & Collection of Recyclables
Credit 1.1	Building Reuse: Maintain 25% of Existing Walls, Floors & Roof
Credit 1.2	Building Reuse: Maintain 50% of Existing Walls, Floors & Roof
Credit 1.3	Building Reuse: Maintain 75% of Interior Non-Structural Elements
Credit 2.1	Construction Waste Management: Divert 50% from Disposal
Credit 2.2	Construction Waste Management: Divert 75% from Disposal
Credit 3	Materials Reuse: 1%
Credit 4.1	Recycled Content:10% (post-consumer + ½ pre-consumer)
Credit 4.2	Recycled Content: 20% (post-consumer + ½ pre-consumer)
Credit 5.1	Regional Materials: 10% Extracted, Processed &Manufactured Regionally
Credit 5.2	Regional Materials: 20% Extracted, Processed & Manufactured Regionally
Credit 6	Certified Wood

Table 5 Materials & Resources Credits

These are high cost credits (Table 5) due to the type of material being imported and some credits are not attainable as the availability of recycling opportunities is unpredictable in the region. The achievability of Recycled Content: 10% / 20% Post Consumer & ½ Pre Consumer credits depend on market availability and it shows high costing by the contractor during tender stage. The credits like Regional Materials: 10% are not achievable for the projects in Qatar. Given the project location, it is very difficult for 10% of the base cost of materials to be extracted/harvested/recovered and manufactured within 500 miles of the project site. Moreover, for credits like Resource Reuse; the city developers will not allow the use of salvaged, recycled, refurbished or re-used drawings in the project. The credit such as Certified Wood is not applicable due to the limited amount of timber specified on the project and hence this point will not be achievable.

Prereq 1	Minimum IAQ Performance
Prereq 2	Environmental Tobacco Smoke (ETS) Control

Credit 1	Outdoor Air Delivery Monitoring
Credit 2	Increased Ventilation
Credit 3	Construction IAQ Management Plan: During Construction
Credit 4.1	Low-Emitting Materials: Adhesives & Sealants
Credit 4.2	Low-Emitting Materials: Paints & Coatings
Credit 4.3	Low-Emitting Materials: Carpet Systems
Credit 4.4	Low-Emitting Materials: Composite Wood & Agrifiber Products
Credit 5	Indoor Chemical & Pollutant Source Control
Credit 6	Controllability of Systems: Thermal Comfort
Credit 7	Thermal Comfort: Design
Credit 8.1	Daylight &Views: Daylight 75% of Spaces
Credit 8.2	Daylight &Views: Views for 90% of Spaces

Table 6 Indoor Environmental Quality Credits

These are also found to be high cost credits (Table 6) due to the certain design requirement, such as that found with Increased Ventilation credits where the design shall achieve 30% improvement over ASHRAE-62.1. Moreover, credits like Low Emitting Materials: Paints & Coatings and Low Emitting Materials: Carpet Systems: Adhesives & Sealants are highly priced by the contractors.

Credit 1.1	Innovation in Design: Use underground parking
Credit 1.2	Innovation in Design: Innovative wastewater
Credit 1.3	Innovation in Design: Innovative cooling system
Credit 1.4	Innovation in Design: use innovative efficient water design
Credit 2	LEED® Accredited Professional

Table7 Innovation & Design Process Credits

The cost of these credits (Table7)are considered as low cost on average, where at least one principle participant of the project is a LEED Accredited Professional and the cost is related only to the salary of this professionall.

2.1.2 Soft Cost Impacts

Soft cost impacts were defined for LEED related tasks that the cost which represent variation beyond and above those of classic construction project requirements. Tasks were defined in two categories:
• LEED Design's Costs: Those tasks that increase the design teams scope of work during the design and construction stages of a project. Basically this includes appointed LEED consultant fees and commissioning authority review for the design fees [21].
• Documentation of LEED prerequisite and credits costs: Those tasks linked with submitting a LEED application and documentation of the project to the U.S. Green Building Council including registration fees and process fees.

The construction cost has been added to the overall cost through using the following equation:

$$\mathbf{S} = \left(\frac{\mathbf{D}}{\mathbf{Y}} + \frac{\mathbf{P}}{\mathbf{Y}} + \frac{\mathbf{A}}{\mathbf{Y}}\right)\% \qquad (2)$$

Where **S** is the soft cost impact, **D** is the LEED Design Costs ,**P** is the Documentation of LEED requirement cost, **A** is the credits applications fees, **Y** is the overall project cost.

2.1.3 Construction Cost Impacts (Hard cost)

The construction cost estimates reflect a number of ECQ-HQ specific design features and project assumptions; as such, the numbers must be used with caution [20]. The cost impacts may not be directly transferable to other project types or building owners as each building has its own characteristics and features [22].
For ECQ Headquarter it includes items such as development and implementation of the Construction Indoor Air Quality Management, implementation of the Environmental Tobacco Smoke (ETS) control management and allowances for the provisions of LEED statement of the total cost for building materials used for the project. The construction hard cost has been added to the overall cost impact through using the following:

$$\mathbf{H} = \frac{\mathbf{M}}{\mathbf{Y}}\% \qquad (3)$$

Where H is the hard cost impact, M is LEED Construction cost, Y is the overall project cost

3. Results and Discussion

Based on the study results, it can be concluded that the overall cost impact on the building due to the application of sustainable building design (LEED design gold rating), is the combination of the three cost groups: the first group is the "Credit Cost" which is derived from equation 1, the second group is the "Soft Cost" which is derived from equation 2, and finally the "Hard Cost" which is taken from equation 3.

Figure 2 shows the cost impact for each of the soft cost requirement of LEED related tasks that were applied to complete the LEED projects which includes: hiring LEED consultant ,LEED design specific expertise ,Commissioning authority and agent in addition, the cost of documentation for the LEED credits submittals and US Green building fees for anticipating of each credits .

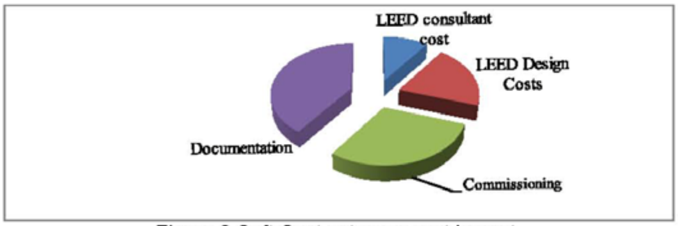

Figure 2 Soft Cost category cost impact.

Figure 3 illustrate the credit cost contribution of each of LEED credit category

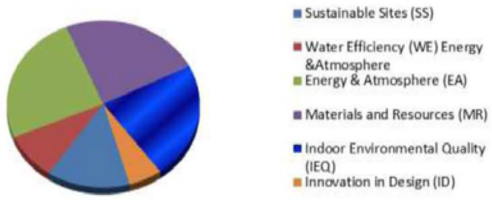

Figure3 LEED credits group cost impact

Figure 4 shows the construction Hard Cost impact for some of the construction requirement of LEED related assignments that were functional to complete the LEED projects which includes develop ,implement and monitor the LEED design specific jobs including , Construction Indoor Air Quality Management plan, implementation of the Environmental Tobacco Smoke (ETS) control management, Erosion and sedimentation control plan (ESC),commissioning plan, waste management plan and allowances for the provisions of LEED statement of the total cost for building materials used for the project

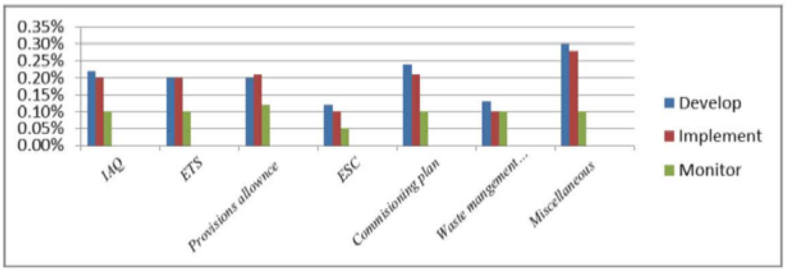

Figure 4 Hard Cost group cost impact

The result of summation of the three additional costs of project shown in equation 4 had resulted in increasing of the cost of applying LEED Gold certificate to ECQ Headquarter to about five precents from overall project cost when compared with the cost difference of LEED requirement to the original project budget. Cost saving achieved annually due to LEED requirement for energy saving is 0.2% annually which can be translated as QAR12.5/m2, this low saving in cost is primarily due to the subsidized utility charges in Qatar and hence no significant Return of Investment (ROI) will come from energy saving for this project [19][20][21]. The overall project increase cost can be obtained from the following equation:

$$K = C + H + S \qquad (4)$$

Where K percentage of costs increased, C the credit cost impact, H hard cost impact and S soft cost impact.

There is an inherent degree of variability to LEED construction cost impacts and our finding of this study is contradicted with facts announced by USGBC and its LEED rating system cost impact as shown in Figure 1 [12]. The primary factors creating this variability are due to the following reasons and causes:

Firstly, the absence of correlation between LEED credit point value and its cost is undeniable. For instance, many LEED credits are either "no cost" or "low cost" (such as development density, no irrigation systems, proximity to public transportation and use of locally manufactured materials, low-VOC adhesives and low emission carpets) which earn 1 point each. On the other hand, the study shows that some credits (renewable energy for example) can cost millions of Qatari Riyals each — and still earn only one point. The selection of credits used to achieve a LEED rating can therefore result in a wide range of costs impact. LEED credit depends on the project team and available resources diversity of strategies can often be used to earn the same individual credit.

Secondly, sustainable buildings require certain material to be used in order to achieve credits and earn points. These nonstandard materials and systems contribute towards more burdens to the initial "capital" cost. Also, some credits such as the use of locally manufactured materials can't outfit projects in non-developed countries where most of the materials are imported from overseas. These materials are sometimes considered high technology or require row material available overseas. Therefore these credits become ineffective. Many of the LEED credit criteria are performance based rather than prescriptive which means the design consultant and engineers will have the flexibility to come with novel and innovative designs and solutions. On the other hand it can be seen as a drawback as it makes the selection of the credits difficult to define the qualitative aspect of it, additional training might be required for engineers conducting this project and the most important issue is that it will be difficult to analyze and evaluate the project credits and green design with equivalent project.

From the above we can summarize that the design teams have many options in defining an approach to comply with credit requirements as a result of using diverse strategies in attaining credits. Overall project budget will result in significantly different cost impacts.
This study has also examined the LEED cost impact for twenty five LEED buildings at Energy City Qatar including ECQ-HQ with different LEED rating levels as follows: three projects targeting Platinum, four projects attempting to achieve Gold and seventeen projects which achieved silver rating [22], the resultant cost impact is shown in Figure 5.

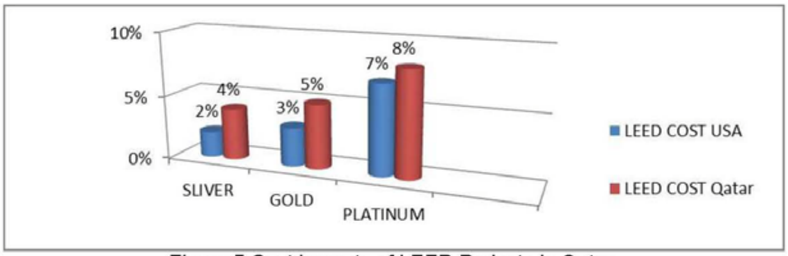

Figure 5 Cost Impacts of LEED Projects in Qatar.

The result shows the cost of LEED Sliver rating is about 4% on average, for Gold rating it is around 5% and for Platinum rating it is almost 8.2%. The finding of this study shows that applying LEED system in Qatar can cost more than in USA. This is basically due to the fact that items to be considered can be different from USA for many reasons such as implementing energy policies, local legislation and availability of local manufacture, which can all lead to different cost impacts to applying green buildings in the region compared to USA green buildings. These factors have resulted in a higher cost difference over the project budget.

We believe there is a need for further studies on sustainable building cost in Qatar which can be extended to studying in detail the reasons for the cost difference in implementing sustainable projects in Qatar and United States. Modification to the LEED project could be proposed to suit local requirements.

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6. Biography

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Safaa is an internationally recognized researcher and technical expert in developing sustainable cities. He has worked on key benchmark projects that aimed to promote sustainability awareness and environmental needs. Safaa has conducted important researches in the field of Building Design, Energy Savings and Sustainable Building Design.

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Study on Energy Efficient Street Lighting System Design

Safaa Alzubaidi, and Prashant Kumar Soori

Abstract--**Today, energy shortage and carbon emission are the major challenges faced by many countries. There are many ways to save energy in every sector thereby reducing the carbon emission and global warming. Qatar, in the Middle East has shown growing demand for electricity consumption. In Qatar, the energy consumption by 2020 is expected to reach 80,648GWh and the energy consumption for lighting alone is expected to be 15,323GWh. Lighting is used in many applications and it is one of the areas that offer many opportunities for improving the energy efficiency thereby reducing the energy consumption. This paper presents a case study on energy efficient street lighting system design for the roadways in Energy City Qatar. Simulation software DIALux4.9 is used to investigate the efficient street lighting scheme through the use of different types of lamps and highlights how the concepts can be visually compared, its cost effectiveness can be studied during the design phase in order for the decisions to be made prior to its implementation. The study has concluded that forty percent reduction in the energy consumption can be achieved with the proposed street lighting system design.**

Index Terms--**Energy Efficiency; Light Emitting Diode; Low Pressure Sodium; High Pressure Sodium**

I. Introduction

THE design of street lighting has many objectives and considerations: night-time safety of the community members and the road users, the reduction of crime and fear of crime, minimizing its effect on the environment whilst enhancing the night-time ambience, provide public lighting that is cost effective, taking into account energy conservation and sustainability.

Studies show that a well-designed street lighting shall reduce crime rates by twenty percent in the public places [1] due to the fact that improved street lighting will lead to increase social surveillance and decrease criminal opportunities. Work has been reported by many authors concerning the effect of improved street lighting on crime levels [1-3]. However, their findings focus only on the role of street lighting in the reduction of crime rates through improving visibility and by increasing the number of people on the street in the public area while the energy saving and illumination level is not reviewed. This paper highlights the energy efficient street lighting system design.

There are many ways to save energy. Lighting is one such area that offers many opportunities for improving the energy efficiency. The electricity consumption for lighting alone is estimated to be 19% of the total global electricity consumption. According to United State Energy Information Administration (EIA), the global electricity consumption for lighting in the year 2005 was estimated to be 3418TWh (terawatthours) out of the global total electricity consumption of 17,982TWh. In Qatar, the forecasted energy consumption by 2020 is 80,648GWh of which lighting energy consumption accounts to 15,323GWh [4].

Reducing electricity consumption for lighting by 40% can lead to major reduction in the total electricity consumption for lighting from 19% to 11%. This has many advantages. The energy saving will lead to drop off the need for the establishment of new power plants thereby minimizing carbon emission and hence global warming. Qatar, in the Middle East is mainly depending on natural gas and petroleum products for energy consumption. Due to its rapidly growing economy Qatar has shown a growing demand for electricity consumption and the energy consumption has doubled over the past ten years and forecasted to double over the next ten years also [4]. This study focuses on providing the design methodology and presents a case study for one of the new developmental projects (Energy City) in Qatar to reduce power consumption by designing an efficient street lighting system that can be adopted and considered by local authorities for the development of roadways in other parts of Qatar [5]. The performance of different types of lighting technologies used for street lighting applications and saving in energy consumptions in such applications are discussed.

II. Street Lighting System Design Considerations

Road lighting can be categorized according to the installation area, performance and their use as: Lighting for traffic routes, lighting for subsidiary roads and lighting for urban centers and public amenity areas [6]. Street lighting can be classified according to the type of lamp used such as: Low Pressure Sodium (LPS) which produce monochromatic orange-yellow light, High Intensity Discharge (HID) lamps,

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High Pressure Sodium (SON) lamps that can give golden white light, Metal Halide, Mercury Vapour and Light Emitting Diode (LED) Street lights. Adjustable lamp reflectors and/or holders are usually provided along with the road lighting luminaires in order to optimize the distribution of the light according to road layout. Different types of lamps used in lighting design with their luminous efficiency and lamp service life is given in Table I [6].

TABLE I
LAMP EFFICIENCY AND SERVICE LIFE

Type of Lamp	Lumens per watt	Average lamp life in Hours
Incandescent	8-25	1000-2000
Fluorescent	60-600	10000-24000
High Pressure Sodium (HPS)	45-110	12000-24000
Low Pressure Sodium (SON)	80-180	10000-18000
Metal halide	60-100	10000-15000
LED	28-79	25000-100000

Average road surface luminance (cd/m^2), Overall luminance uniformity (U_O), Longitudinal luminous uniformity (U_l), Threshold Increment (TI) and Surround Ratio are the basic parameters used in street lighting system design [6]. The percentage TI is given by expression (1) [6].

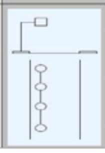
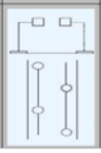
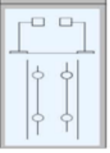
$$TI=65(L_v/L^{0.8}) \qquad (1)$$

L_v is the equivalent veiling luminance (cd/m^2).
L is the road surface luminance (cd/m^2)

As per The Commission Internationale de l'Eclairage (CIE) standard 115:1995, TI should be lower than 10% and never higher than 15%.

There are many arrangements for street lighting. Table II illustrates standard Luminaire arrangement based on lighting class and road type.

TABLE II
LUMINAIRE TYPICAL ARRANGEMENT AND LUMINOUS EFFICIENCY [6]

Lighting Class	Single row	Double row, with offset	Double row, opposing
Road information	W ≤ 6m N ≤2	W ≥ 8m N ≥2	W ≥ 16m N ≥4
Uniformity	0.4~0.5	0.5~0.8	0.5~0.8
Figure			

Road lighting luminaires used for lighting traffic routes are designed to deliver light to the road so that the surface is seen to be of uniform luminance and objects on the road can be seen in silhouette. The light distribution is therefore dependent on the position of the luminaire relative to the road. Most road lighting luminaires are mounted on columns placed at regular intervals at the side of the road or between crash barriers in the median. A recommended lighting criterion for dry road is given in Table III [6].

TABLE III
LIGHTING CLASSES FOR STRATEGIC TRAFFIC ROUTES

Road characteristic	Detailed description	Average Daily Traffic Flow (ADT)	Lighting class	Minimum maintained average road surface luminance (cd/m^2)
Trunk roads and some main roads between primary destinations	Single carriageway	< 15000	ME3a	1.0
		>15000	ME2	1.5
	Dual carriageway	< 15000	ME3a	1.0
		>15000	ME2	1.5

ME2 refers to urban areas lighting class. These roads have 30 miles per hour (m.p.h.) as speed limits and have very high levels of pedestrian activity with some crossing facilities including zebra crossings. On-street parking is generally unrestricted except for safety reasons. ME3a refers to the speed limits which are usually 40 m.p.h. or less, parking is restricted at peak times and there are positive measures for pedestrian safety reasons.

The design requires following information:

- The determination of the street lighting class according to the relevant CIE document [6], lamp power and pole spacing which depend on the street lighting class.
- Data collection such as pole height, type of luminaire, type of lamp, IP rating (Ingress Protection Rating) which indicates the degree to which the device is protected against intrusion of solid objects, dust, accidental contact and water.
- Luminaire maintenance factor [7].
- Carriageway width
- Driving lane width
- Luminaire arrangement and the road surface type (paving material).
- Glare effect is another important factor in the design as the glare produced by the luminaire should be controlled in order to limit the disability glare [8].

III. CASE STUDY

The street lighting system design for Energy City project in Qatar which is located in Lusail city, north of Doha is presented. Energy City Qatar project is one of many cities that Qatar is aiming to develop in the coming years. The total length of the road in this city is 6km. DIALux 4.9 simulation software is used for the case-study. Strategic route is considered for the study and the lighting class ME3a is selected for the lighting level calculation. The other parameters are: The width of the carriageway is 7.3m, number of lanes is two. Three lighting scenarios were applied to know the power consumption of the street lighting. This has been done by designing the road with three types of light fixtures and lamps like Metal halide, High Pressure Sodium (SON) and LED lamps. In the design, the working hours of the lighting is assumed to be 12 hours a day from 6 P.M till 6 A.M, seven days a week. The price of the light pole is considered the same for all three scenarios and it is not included in the calculation. The tariff of energy consumption for public area applications in Qatar is 0.11 United States Dollars ($) per unit of energy (kWh) consumed. The required luminance value for the lighting class ME3a is 1 cd/m^2 and a maintenance factor of 0.8 is assumed [1]. The measurement of required illumination was taken at different locations in the street under consideration and a grid of 14 × 6 points was selected.

A. *Scenario-I*

The strategic route in Scenario I is illuminated through the use of Philips BGP323 160×GRN-1S/740 DC with LED Lamps. Street lights are arranged in single row placed on one side of the road. Fig. 1 shows the luminaire arrangement. 3-D colour rendering is shown in Fig. 2. Fig. 3 and Fig. 4 show the lighting distribution values.

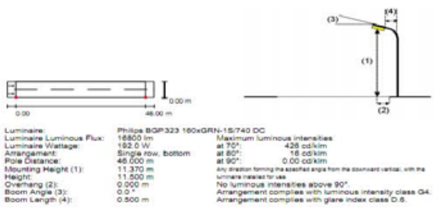


Fig. 1. Luminaire arrangements

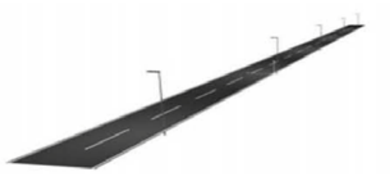


Fig. 2. 3-D renderings

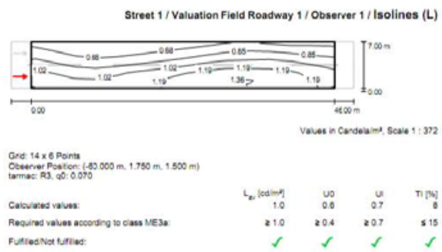


Fig. 3. Lighting distribution values in cd/m^2

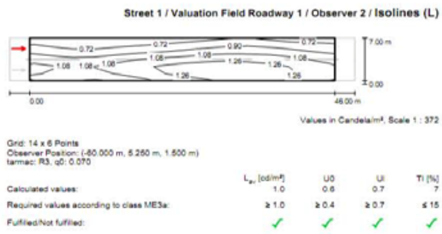


Fig. 4. Lighting distribution values in cd/m^2

B. *Scenario-II*

The strategic route is illuminated through the use of Philips CGP431 PC 1×CDO-TT250W equipped with Ceramic Metal Halide Outdoor lamp with clear tubular outer bulb. Street lights are arranged in single row placed on one side of the road. Fig. 5 shows the luminaire arrangement. Fig. 6 is the isolines and Fig. 7 shows the lighting distribution values.

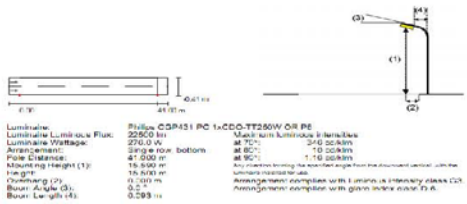


Fig. 5. Luminaire arrangements

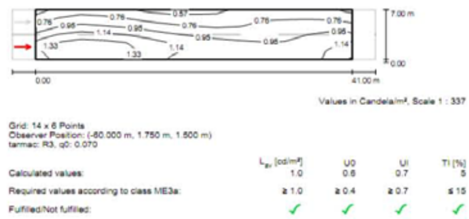


Fig. 6. Lighting distribution values and Isolines in cd/m^2

Fig. 7. Lighting distribution values in cd/m^2

C. Scenario-III

The strategic route is illuminated through the use of Philips SGS254 GB 1×SON-TPP250W CP P2 equipped with High Pressure Sodium SON lamp. Fig. 8 shows the luminaire arrangement. Fig. 9 shows the isolines and lighting distribution values are shown in Fig. 10.

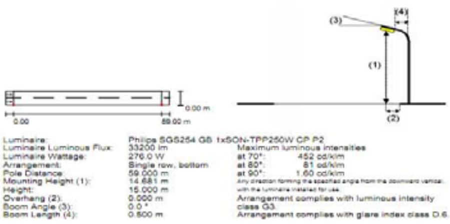


Fig. 8. Luminaire arrangements

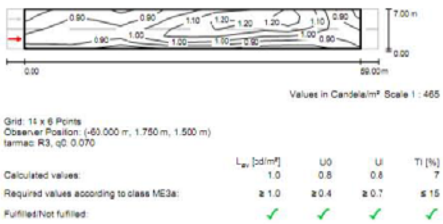


Fig. 9. Lighting distribution values and Isolines in cd/m^2

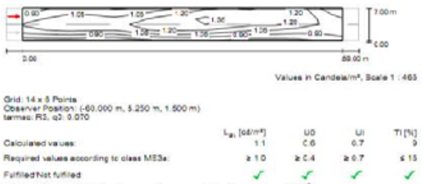


Fig. 10. Lighting distribution values and Isolines in cd/m^2

IV. Results and Conclusions

It is concluded from many studies that lighting play an important role in crime reduction; improved street lighting shows increase in perceived public safety. On the other hand, the energy shortage and carbon emission should be addressed in any developmental projects for the fast growing country like Qatar. Thus, the energy consumption of different type of lighting scenarios in the design of street lighting has been investigated in this paper.

Professional lighting simulation programs presented in this article provide accurate results with option to optimize and visualize the impact of different lighting design scenarios. Manual verification of the results shows that the accuracy of the proposed design is high. The summary of the Simulation results is given in Table IV.

TABLE IV
Results Summary

Type of Lamp	No. of Lamps	Power Consumed (W)	Unit Price in $	Light Fitting Cost (LFC) in $
LED	130	24960	2830	367900
Metal Halide	146	40296	729	106434
High Pressure Sodium (SON)	102	28067	580	59160

In *Scenario-I*, LED lamps are utilized and the design is requiring 130 light fittings to provide illumination of 1 cd/m^2. There is approximately 40% power saving compared to the design with Metal Halide lamps and 9% compared to High Pressure Sodium (SON) lamps. Lighting distribution values illustrate very good illumination level of lighting on different areas in the street; however TI is 8% which is near to the maximum value and glare might be observed.

In *Scenario-II*, Metal Halide lamps are used. Although the power consumption is 40296W, TI is only 4%. Hence minimum glare effect can occur with this design.

In *Scenario-III*, High Pressure Sodium (SON) lamps are introduced and it is observed that there is approximately 31% power saving compared to the design using Metal Halide lamps. TI is 7%. Hence it is well within the maximum limit.

Life-cycle cost analysis is carried out assuming that the only part of the light fittings which requires replacement is the lamps. It is observed that over twenty years of operation, the design using LED lamps will have lesser lamp replacement cost despite its high initial cost. Simple pay-back period (SPBP) calculations have been performed using (2).

$$SPBP = Y/X \qquad (2)$$

Y is the difference in capital cost
X is the expected annual saving in energy cost

It is observed that pay-back period is around thirty five years with the design using LED lamps over Metal Halide lamps and few hundreds of years over High Pressure Sodium (SON) lamps. However, pay-back period is around eight years with the design using SON lamps over Metal Halide lamps. This shows that the design using LED is a bad choice as far as the financial judgment is concerned despite its high energy saving. A High Pressure Sodium (SON) lamp is the best choice due to short return of investment and cost effectiveness.

The design procedure explained in this paper allows the designer to compare different lighting options and select the best possible option with the ultimate goal of achieving energy efficiency without compromising the recommended standards before its implementation in the actual site. This is expected to help the local authorities for proper planning and development of roadways in other parts of the city.

The simulation helped in determining the physically correct numerical values for the proposed system based on CIBSE standards which shall yield better lighting for the road users thereby reducing crime rates. It has been found in many projects that the results obtained from the simulation with the field measurements are close to real data [7]. For these reasons DIALux4.9 based simulation is proposed and used in the proposed design.

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VI. Biographies

Safaa Alzubaidi obtained Master of Science degree in Energy from Heriot Watt University,Edinburgh, United Kingdom. Currently doing his PhD study with the same university. He is LEED BD&C and LEED AP from United States Green Building Council. PMP from United States Project Management Institute and MCIBSE.

He is a Senior Engineering manager and Sustainability Specialist, Energy City Qatar. He held a number of key positions in the energy and sustainability fields, making his role in different companies an imperative asset. Having been a Senior Researcher, Technical Expert in addition to many years of experience in the field of Energy, Safaa has valuable know-how of the industry.

He has worked on key benchmark projects that aimed to promote sustainability awareness and environmental needs. Specifically, through working at Masdar City Abu Dhabi and Energy City Qatar. Safaa has conducted important researches and studies in the fields of Building Design, Energy Savings and Sustainable Building Design; these researches have been published in international conferences and journals.

Prashant Kumar Soori is a Teaching Fellow in the School of Engineering & Physical Sciences at Heriot Watt University, Edinburgh,UK in their Dubai Campus in Dubai. He was Associate Professor in the Department of Electrical Engineering and the Dean of Mekelle Institute of Technology, a non-profit, accredited higher education institution in Ethiopia. He has served as the Member of the Steering Committee of the Mekelle ICT Business Incubation Center sponsored by the World bank and received Certificate of Appreciation for the Services rendered.

He has an experience of more than 19 years in teaching undergraduate and postgraduate courses in the areas of Energy systems, Power Electronics, Electrical Machines, Electrical Drives and Control. He was the recepient of Oscar's night 2011 Award for Best style of teaching and Best overall academic organized by Heriot Watt University, Dubai. He has guided many Undergraduate and Postgraduate projects in the area of Energy Conservation. He has to his credit many conference and journal papers. He is a life member of Indian Society for Technical Education (ISTE).

STUDY ON IMPROVING THE ENERGY EFFICIENCY OF OFFICE BUILDING'S LIGHTING SYSTEM DESIGN

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ABSTRACT

Lighting for both functional and decorative purposes is a major consumer of electrical energy. Setting up new power plants to meet growing consumption requirements is not financially viable. In a country with a growing demand for energy, increased efficiency in utilizing the energy is the only way to meet the shortfall. The scope of increasing efficiency exists in the performance improvements of lighting systems, pumps and different processes in industries where engineering techniques can be used to enhance their efficiencies. This paper discusses the performance of different types of lighting installations used in the commercial buildings in UAE and saving in energy consumption in the office lighting applications. The study of different types of lamps used in practice, its suitability and cost effectiveness is highlighted. DIALux simulation software is used to study and evaluate the efficient lighting scheme for the office buildings through the use of different types of lamps.

Index Terms— *Compact Fluorescent Lamp (CFL), Light Emitting Diode (LED), Light Fitting Cost (LFC), Low Pressure Sodium lamp (LPS), Luminous efficiency (lm/W)*

1. INTRODUCTION

Natural illumination in the office buildings requires correctly designed passive architecture to provide sufficient day lighting at some distance into the building but can also cause glare, overheating, high heating and cooling energy costs. Thus, artificial illumination is required to supplement daylight on a temporary or permanent basis. The basic parameters used in lighting design are luminous intensity, luminance, luminous flux and illuminance. Table 1 shows different types of lamps used in lighting applications with their luminous efficiency and lamp service life.

Table 1. Lamp efficiency and service life

Type of Lamp	Lumens per watt	Average lamp life in Hours
Incandescent	8-25	1000-2000
Fluorescent	60-600	10000-24000
High Pressure Sodium (HPS)	45-110	12000-24000
Low Pressure Sodium (LPS)	80-180	10000-18000
Metal halide	60-100	10000-15000
LED	28-79	25000-100000

Illuminance levels are specified for specific visual tasks area. Illuminance is the luminous flux density at a surface measured in lumens per square meter (lm/m^2) or Lux (lx). Table-2 gives the recommended illuminance in Lux [1].

Table 2. Recommended Lux (lx) values

Area/location	Lux (lx)
Open plan office mainly screen based work	300
Open plan office mainly paper based work	500
Deep plan core area (more than 6m from window)	500
Cellular office-mainly screen based work	300
Cellular office-mainly paper based work	500
Graphics workstations	300
Dealing rooms	300- 500
Executive offices	300- 500

Light quality is an important factor in the design as it affects how well people can see to do visual tasks and how visually comfortable they feel. Also, it is important to energy efficiency because spaces with higher quality lighting need less illumination and less light fittings. High quality lighting is fairly uniform in brightness and has no glare. Lighting system can be categorized as Direct Lighting, Indirect Lighting and Indirect/Direct Lighting. Alternatively, based on their use, it can also be classified as Ambient Lighting, Task Lighting, Accent or Display Lighting and Security & Street Lighting. Lighting system has many characteristics; power (it refers to power consumption of the lighting system), service life and the light colour. Colour temperature is the term used in the description of the colour-rendering property of the lamp, where the colour of the surface under artificial illumination are compared with the colour produced by a black body heated to a certain temperature and radiating in the visible part of the spectrum between the ultraviolet and infrared bands [2]. Measured in Kelvin (K), the higher the temperature, the cooler is the colour and the same is shown in the Table 3. The selection of the light type depends on the applications.

Table 3. Colour temperature appearance

Type	Temperature	Colour	Appearance
Ww	Up to 3300K	Reddish	Warm
nw	3300-5300K	White	Intermediate
tw	Above 5300K	Bluish	Cool

Colour rendition, the colour-rendering index Ra8 is used

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to compare the colour rendering characteristics of the various types of lamp [2]. One of the important parameter in the design is the glare effect and the reflections effect of the light. A limiting glare index is recommended for each application. Under the new European Standard for interior workplace lighting EN 12464, glare is assessed by the Unified Glare Rating (UGR) Method [1].

The common types of lamps for indoor and outdoor use are Incandescent, Halogen, Fluorescent, CFL, Metal halide, Mercury vapor, HPS, LPS and LED. Lighting system designer has to take in mind the following:

1. Designer should not select the high wattage incandescent lamp without considering the amount of light needed for certain area due to the fact of low energy efficiency of the lamp.

2. The high to very high luminous efficiency Fluorescent lamps (in particular T16 HE) have well to excellent colour rendition.

3. CFL has high luminous efficiency, good colour rendition.

4. The main features and characteristics of LED lightings are low energy consumption, smaller size, dimmable, low maintenance cost, no heat worries and effect on the building energy consumption due to minimal heat generated by the fixture, faster switching and very good colour rendering.

2. LIGHTING SYSTEM DESIGN

Following are the steps to be followed in the lighting system design.

1. Determine the lighting requirement. For each area, there is a recommended lux level as in Table 2.

2. Select adequate lamp fit for the purpose based on the application for the lighting indoor or outdoor, commercial or industrial or residential.

3. Estimate the required number of the light fixtures either by using equation 1 or using DIALux software.

$$NF = \frac{Lux \times A}{(LDL \times UF \times MF)} \qquad (1)$$

NF is the number of fittings required

A is the working plane area in m^2

LDL is the lighting design lumens produced by each lamp

UF is the utilization factor

MF is the maintenance factor

4. Next step in the design is to position the luminaries, which will help in achieving the optimum design for the lighting system, provides a uniform illuminance across the notional working plane, avoid problems such as poor distribution for the lighting fixture and other lighting problems like glare or shadow.

5. Verify the selection through analysis, the results against the technical requirements, lighting features, energy saving and the cost.

3. CASE STUDY

An office space in UAE is selected for the case study. The office room is a rectangle parallelepiped of 12m wide, 30m long and the height of the room is 3m. Two northward oriented windows, each 3m and 1 m high is transversally placed across a small wall. The reflection coefficients (supposed diffuse) of the walls are ρ_{wall}=0.57, floor ρ_{floor}=0.2 and ceiling $\rho_{ceiling}$=0.7. The required Lux level as per Table 2 is 500. The measurement of required illumination was taken on a work plane that has a height 0.850cm and a grid of 128×128 points were selected. The price of office energy consumption in UAE is 0.11$/kWh. Three lighting scenarios were applied to know the power consumption of the office through the use of different types of lamps like incandescent, CFL and LED lamps. In the design, the office working hours is assumed to be 10 hours a day, seven days a week. DIALux 4.6 simulation software is used for the case study.

3.1. Scenario-1

The office room is illuminated through the use of ERCO product ERCO 46608000 Quintessence Down light $2\times$ TC-TELI26W equipped with ERCO Compact Fluorescent of 2×26W. Figure 1 shows the lighting distribution values in Lux.

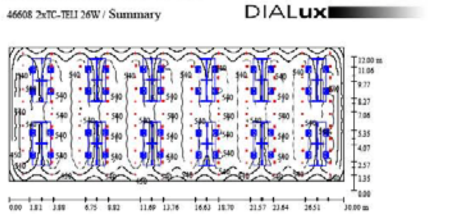


Fig-I-Values in Lux, Scale 1:215
Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	510	214	644	0.420
Floor	20	358	13	578	0.037
Ceiling	70	59	45	77	0.762
Walls (4)	50	152	41	569	/

Workplane:
Height: 0.850 m
Grid: 128 x 128 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.280, Ceiling / Working Plane: 0.116.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	132	ERCO 46608000 Quintessence Downlight 2xTC-TELI 26W (1.000)	3600	52.0
		Total:	475200	6864.0

Specific connected load: 19.07 W/m² = 3.74 W/m²/100 lx (Ground area: 360.00 m²)

Figure 1.Lighting distribution values in lx

Figure 2 gives 3D rendering for the office room which shows the effect of lighting on a different area in the room. False Colour Rendering scheme is provided by the software (Figure 3) which shows the different area in the room and the possible false colour rendering.

Figure 2.3D Rendering

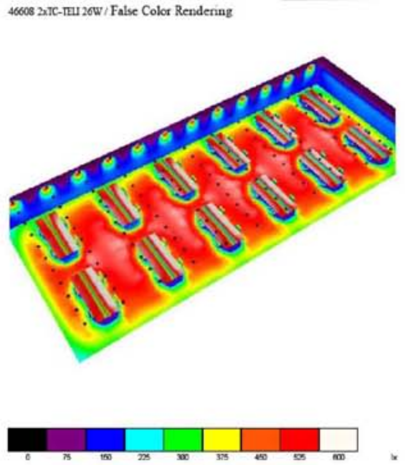
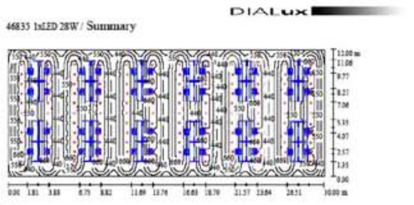


Figure 3.False Colour Rendering

3.2. Scenario-2

The office room is illuminated through the use of ERCO product reference ERCO 46815000 Quintessence Down light 1 × LED 28W daylight white, equipped with ERCO LED lamp of 28W. Simulation results are shown below.



Values in Lux, Scale 1:215
Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	531	185	727	0.349
Floor	20	390	11	603	0.029
Ceiling	70	58	42	72	0.720
Walls (4)	50	115	36	406	/

Workplane:
Height: 0.850 m
Grid: 128 x 128 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.197, Ceiling / Working Plane: 0.109.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	156	ERCO 46815000 Quintessence Downlight 1xLED 28W daylight white (1.000)	2160	28.0
		Total:	336960	4368.0

Specific connected load: 12.13 W/m² = 2.28 W/m²/100 lx (Ground area: 360.00 m²)

Figure 4.Lighting distribution values in lx

Figure 5.3D Rendering

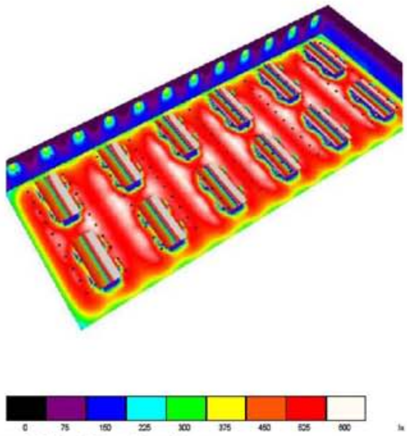


Figure 6.False Colour Rendering

3.3. Scenario-3

The office room is illuminated through the use of ERCO product reference ERCO 46012000 Quintessence Down light 1 × QT12-ax100W equipped with ERCO Incandescent lamp of 100W. Simulation results are shown below.

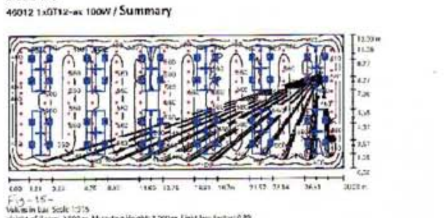


Fig - 15 -
Values in Lux, Scale 1:275
Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	513	288	530	0.424
Floor	70	380	14	588	[illegible]
Ceiling	73	67	43	67	[illegible]
Walls (4)	[illegible]	131	39	460	/

Workplane:
Height: 0.850 m
Grid: 128 x 128 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.246, Ceiling / Working Plane: 0.132.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	162	ERCO 46012000 Quintessence Downlight 1xQT12-ax 100W (1.000)	2700	100.0
		Total:	400400	18530.0

Specific connected load: 50.56 W/m² = 9.85 W/m²/100 lx (Ground area: 300.00 m²)

Figure 7.Lighting distribution values in lx

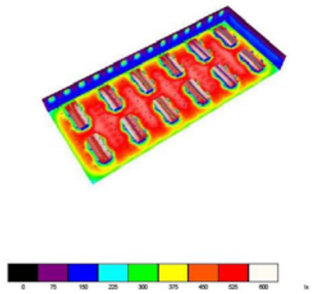


Figure 8.False Colour Rendering

4. RESULTS

The simulation results of the lighting system design are summarized in the Table 4.

Table 4. Results of simulation

Type	No. of Lamps	Power Consumed P in (W)	Power Density (W/m^2)	Unit price in $	Light fitting cost (LFC) in $
CFL	132	6864	19.07	400	52800
LED	156	4368	12.13	1000	156000
Incand escent	182	18200	50.56	225	40950

In scenario-1, CFLs are utilised and the design is requiring 132 light fittings to give 500 lx levels. There is 62% power saving compared to the design with incandescent lamps. The power density is $19.07W/m^2$ which is higher than the recommended. In an efficient lighting design, the recommended lighting power density for offices shall be in the range of $12W/m^2$. Therefore this is not the best lighting system design from the energy density perspective.

In scenario-2, LED lamps are introduced and there is 76% power saving compared to the design using incandescent lamps. Also the power density is $12.13W/m^2$ which meets the recommended standards.

In scenario-3, incandescent lamps are used and the power consumption is 18.2kW to produce 500 lx levels. Also, the power density is $50.56W/m^2$ which is very high and exceeds the recommended standards.

Thus, LED lamps are best suited for the energy efficient lighting system design in the office buildings.

Results based on Simple-Pay-Back-Period (SPBP) Calculation are as under:

Capital cost of CFL-based lighting design=$52,800

Capital cost with incandescent lamps= $40,950

Difference in cost=Y=$11,850

Annual energy cost with CFL-based lighting design=$(0.11 $\times$ 52 $\times$ 132 $\times$ 3.650) =$2756

Annual energy cost with incandescent lighting design=$(0.11 $\times$ 100 $\times$ 182 $\times$ 3.650)=$7307

Expected annual saving in energy cost=X= $4551

SPBP can be calculated using equation 2.

$$SPBP=\frac{Y}{X} \qquad (2)$$

Its value is found to be 2.6 years.

SPBP with LED lamps instead of incandescent lamp is done in the similar way and it is found to be 20.7years.

Life cycle cost analysis is carried out assuming that the only part of the lamp fittings which requires replacement is the lamps:

100W if incandescent lamps with the cost of $1 per lamp, 1000 hours of operating life and 182 lamp fittings

2 $\times$ 26W if CFL with the cost of $10 each, 10000 hours of operating life and 132 light fittings.

28W if LED with the cost of $50 each, 50000 hours of operating life and 156 light fittings. The result shows that over twenty years of operation, the design using LED lamps will have lesser lamps replacement cost (LRC) despite its high initial cost as compared to the design using incandescent lamps and CFLs.

Also the whole life-cycle (WLC) cost which is given by equation 3 shows that WLC of the design using incandescent lamp is approximately two times more than CFLs despite their lower cost price and approximately similar WLC compared to the design with LED lamps. This shows that the design using CFL is better choice as far as the financial judgment is concerned.

$$WLC= LFC + LRC + consumption\cos t \qquad (3)$$

5. REFERENCES

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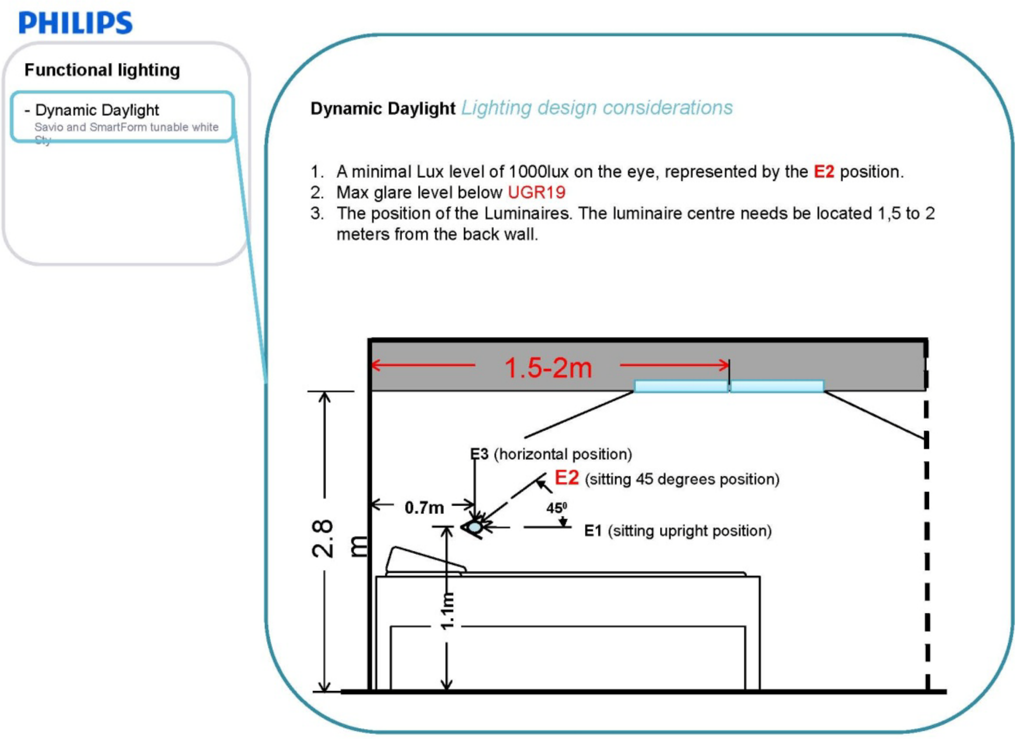
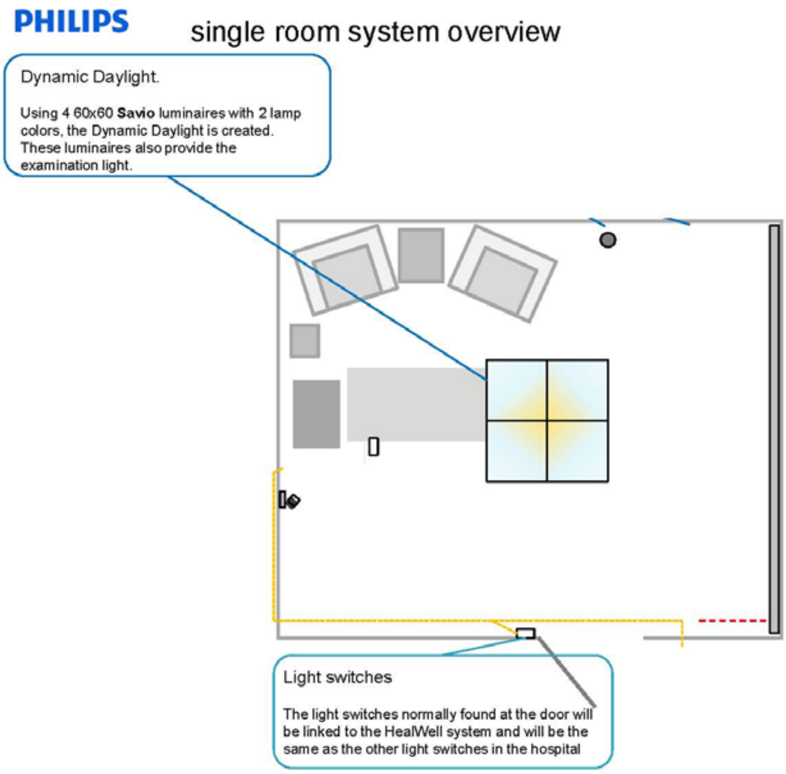
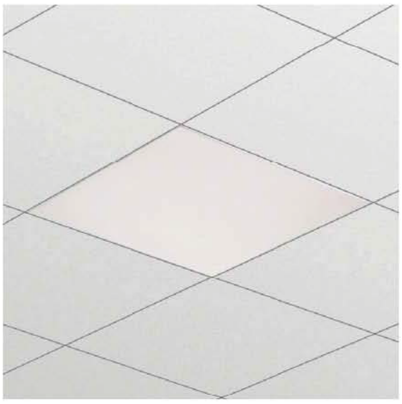
Appendix F

Healwell lighting system in the test patient room


PHILIPS
Functional lighting
- Dynamic Daylight
Savio and SmartForm tunable white
Dynamic Daylight Lighting design considerations
1. A minimal Lux level of 1000lux on the eye, represented by the E2 position.
2. Max glare level below UGR19
3. The position of the Luminaires. The luminaire centre needs be located 1,5 to 2 meters from the back wall.
1.5-2m
E3 (horizontal position)
E2 (sitting 45 degrees position)
0.7m
45⁰
E1 (sitting upright position)
2.8 m
1.1m


PHILIPS
single room system overview
Dynamic Daylight.
Using 4 60x60 Savio luminaires with 2 lamp colors, the Dynamic Daylight is created. These luminaires also provide the examination light.
Light switches
The light switches normally found at the door will be linked to the HealWell system and will be the same as the other light switches in the hospital



Savio TBS760/770

TBS770 6x14W/827/865 HFD AC-MLO

TBS770 - 6 pcs - 14 W - HF DALI - Acrylate micro-lens optic

Featuring Philips' patented micro-lens optic technology, Savio is a complete luminaire range that offers the ideal combination of stylish design and optimum performance for both task and general lighting.Savio has an edge-to-edge lighting appearance with a uniform and comfortable brightness impression – a real 'surface of light'. The micro-lens optic consists of a single plate and is embedded in a housing made of high-quality natural anodized aluminum. Savio ensures optimum light distribution and full glare control in compliance with the latest office-lighting norm (EN 12464-1). Savio luminaires with Dynamic Lighting keep us feeling active by creating dynamic artificial light that varies over the course of the day or is set according to personal preference. Savio is available as a full range: suspended, surface-mounted, recessed, free-standing and wall-mounted.

Product data

• General information

Product family code	TBS770 [TBS770]
Number of lamps	6 [6 pcs]
Lamp family code	TL5 [TL5]
Lamp power	14 W [14 W]
Lamp color code	827/865 [827 warm white and 865 cool daylight]
Kombipack	K [Lamp(s) included]
Gear	HFD [HF DALI]
Optical element	No [-]
Optical cover	AC-MLO [Acrylate micro-lens optic]
Emergency lighting	No [-]
Lighting control unit	No [-]
Fuse	No [-]
Cable	No [-]
Safety class	CLI [Safety class I]
IP code	IP40 [Wire-protected]
Protection foil	FL [Protection foil included]
Ready-to-install	No [-]
Glow-wire test	650/5 [Temperature 650 °C, duration 5 s]
Flammability mark	F [For mounting on normally flammable surfaces]
Safety device	No [-]
European Community mark	CE [CE mark]
ENEC mark	ENEC [ENEC mark]

• Electrical

Supply voltage	220-240 V [220 to 240 V]

• Mechanical

Housing configuration 2	No [-]

• Product Data

Order code	910501728203
Full product code	910501728203
Full product name	TBS770 6x14W/827/865 HFD AC-MLO
Order product name	TBS770 6x14W/827/865 HFD AC-MLO
Pieces per pack	0
Packs per outerbox	1
Bar code on outerbox - EAN3	8711559751719
Logistic code(s) - 12NC	910501728203
Net weight per piece	8.900 kg

product design award 2011

PHILIPS
sense and simplicity

Savio TBS760/770

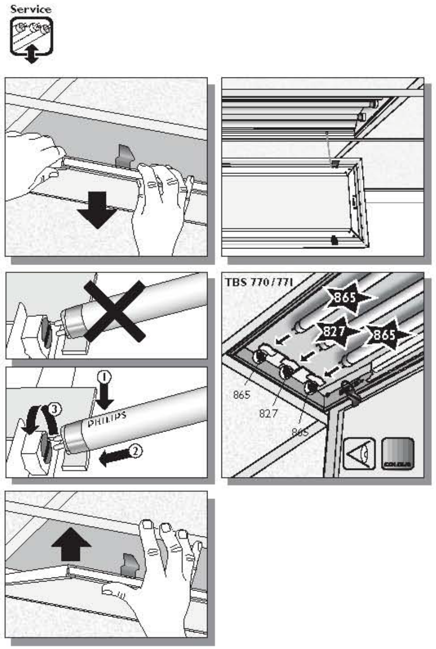
Dimensional drawing

TBS770 6x14W/827/865 HFD AC-MLO

TBS770 6x14W/827/865 HFD AC-MLO

www.philips.com/lighting

2013, January 23
data subject to change



4422 001 92543
09/06
Printed in the Netherlands
Data subject to change

SAVIO Lighting Technology

Pure light

Sav o's r m ess ght pane has a homogeneous edge-to-edge ghting appearance w th un form and comfortab e br ghtness mpress on – a rea surface of ght'.
Co our m x ng s done w th extreme y prec se opt cs ns de to assure a homogeneous ght-co our (tona ty) a over the surface of ght'. In comb nat on w th the m cro- ens opt c the appearance of the ght s very natura .

Maintenance instructions

G ven the cho ces made n th s un que ghting concept, there are a few nstruct ons regard ng the ma ntenance of th s um na re to assure the ghting qua t es:

Savio without colour variation:

- ☐ Dur ng nsta at on or ma nta n ng the um na re p ease use g oves to avo d spots on the cover.
- ☐ D rty spots can be removed:
  - o On y dust: w th m cro f ber c oth
  - o F ngerpr nts, etc.: w th a c eaner for synthet c matera w th ant stat c effect.
- ☐ A ways ensure that n square um na re conf gurat on the amp-pos t ons are n the p anned d rect on.
- ☐ In case of re- amp ng, p ease carefu y fo ow nstruct ons n the um na re, and p ace a amps n one d rect on n case of the co d spot (the branded s de).
- ☐ Remove the protect on fo on the cover on y short before usage of the ght ng nsta at on.

Savio with colour variation:

- ☐ After nsta at on, the um na re needs to burn- n 100 hours to reach ts stab e co our- and f ux-performance.
- ☐ It's not recommended to use other amps than the or g na Ph ps amps.
- ☐ At the moment of rep acement of amps or group-rep acement t's h gh y recommended to renew a amps n the um na re.

More information about Savio Lighting
www.savio.philips.com
www.dynamiclighting.philips.com

PHILIPS

SAVIO TBS 760/761/770/771

Installation instructions

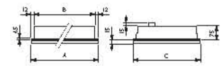
Instructions de montage	Instrucciones de montaje	Kokoonpano- ja kiinnitysohjeet	Szerelési utasítások
Montageanleitung	Instruções de montagem	Montaj yönergesi	Návod k montázi
Montage instruktie	Monteringsinstruktioner	Οδηγίες συναρμολόγησης	ИНСТРУКЦИЯ ПО МОНТАЖУ
Istruzioni di montaggio	Monteringsvejledning	Instrukcja montazu	Návod k montázi

IP 40 **Class I**

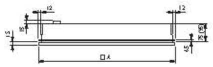
This luminaire must be earthed.
Ce luminaire doit être mis à la terre.
Diese Leuchte muß geerdet werden.
Dit armatuur moet worden geaard.
Questa armatura deve essere collegata a terra.

14/28/35 W	
24/49/54/80 W	

NO INSULATION

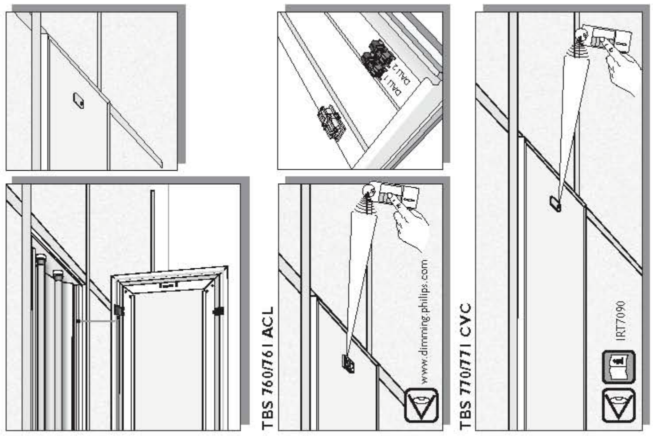


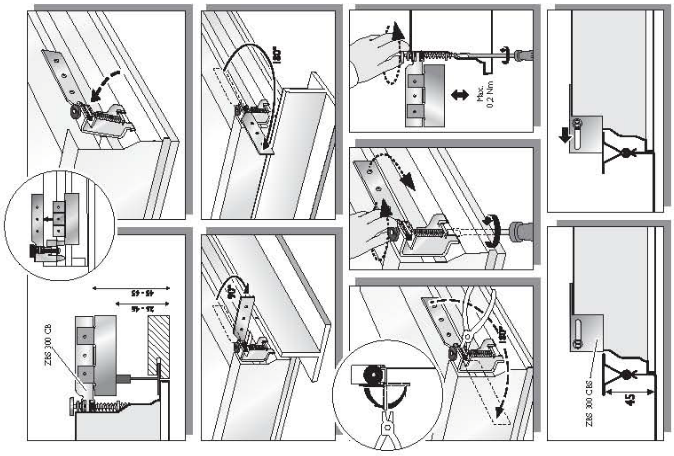
		A	B	C
		mm	mm	mm
TBS760/770	28/54W	1197	1173	297
TBS761/771		1247	1223	309.5
TBS760/770	35/49/80W	1497	1473	297
TBS761/771		1559.5	1535.5	309.5

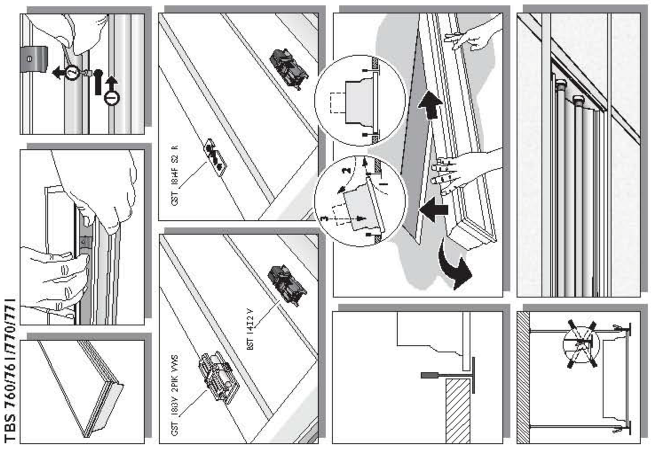


		A
		mm
TBS760/770	14/24W	597
TBS761/771		622

PHILIPS


TBS 760/761 ACL
www.dimming.philips.com
TBS 770/771 CVC
IRT7090


ZBS 300 CB
180°
45


TBS 760/761/770/771