Reducing of the Energy Consumption in the Federal Buildings in UAE Using Lighting and Control Technologies

دراسة حول التقليل من استهلاك الطاقة في المباني الاتحادية في دولة الامارات باستخدام تقنيات وأنظمة مختلفة للتحكم بالانارة

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Dissertation submitted in partial fulfilment of
MSc Intelligent Building Design and Automation

Faculty of Engineering

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April-2014

DISSERTATION RELEASE FORM

Student Name	Student ID	Programme	Date
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Abstract

UAE has one of the highest electricity consumption per capita in the world. This reflects negatively on the CO_2 emissions which is an increasing determination in the UAE. CO_2 emissions must be reduced as part of the global effort to reduce the greenhouse gases and mitigate global warming effects. This study aims to reduce the electricity consumptions in the federal buildings in the UAE. This research used to find the best lighting and control technologies that can be used in Federal Buildings in UAE to reduce the total energy consumption by reducing lighting energy consumption as a direct energy and also the HVAC (cooling) energy which is the indirect energy that can be saved depending on saving in lighting energy. Three lighting technology proposals were compared to the existing lighting in MOPW-RAK building. The three proposed lighting technologies were compared to the existing lighting technology in three different areas: Meeting Room, Electromechanical Office, and Corridor. Also, lighting control technologies were also applied to the selected areas in the building and compared to the base case also.

The building was simulated in two different simulation software's: Dialux lighting simulation software and IES-VE building energy efficiency modeling software. Some calculations and comparisons between the results were done. From the results, analysis and comparisons we found that LED lights is the best because it has the highest amount of saving the lighting energy. CFL is the worst solution for our case because it uses magnetic ballast. This is the main reason of the high energy consumption in CFL. It was found that with the use of Occupancy sensors, energy savings were 10%, while for Daylight Sensor and Dimming Systems were 25%. The most expensive option is when using the full power lighting without control Systems. Using energy savings Lighting technologies not only affects lighting energy consumption, but are also affect HVAC energy savings because of the outcome heat from the Lighting technologies. Lighting Control Technology also have an effects on HVAC energy savings because of the relation between the HVAC and Lighting which was proved using IES-VE software which show that the Fraction between Lighting and HVAC is 0.33. In another word, each 1KWH of lighting energy equal 3 KWH of HVAC energy consumptions.

نبذه عن الدراسة

تعد دولة الامارات العربية المتحدة واحدة من اكثر الدول استهلاكا للكهرباء مما أدى الى ان اصبحت خامس اعلى دولة في استهلاك الكربون، لذا فان الدولة تسعى الى تقليل استهلاك طاقة الكهرباء بشتى الطرق. ولذا فقد جاءت هذه الدراسة لكي تركز على التقليل من استهلاك الطاقة خاصة في المباني الاتحادية في الدولة وهذا من خلال دراسة حقيقية على احدى المباني الحكومية في احدى امارات الدولة وهو مبنى وزارة الاشغال العامة برأس الخيمة حيث تركز الدراسة على احد اهم العوامل في استهلاك الكهرباء في المباني وهو استهلاك الطاقة عن طريق الانارة. لذا فان الدراسة تقوم على دراسة مدى فاعلية التقليل من مقدار الطاقة المستهلكة عن طريق استخدام انظمة حديثة مختلفة ومتنوعة من انظمة الانارة كاللمبات الموفرة للطاقة بالاضافة الى الانواع المستحدثة مثل LED وCFL بالاضافة الى استخدام انظمة مختلفة من طرق التحكم بالانارة مثل الحساسات الضوئية و نظام التقليل من الانارة او ما يطلق عليهdimmer. اعتمدت هذه الدراسة بشكل رئيسي على استخدام برامج متخصصة في تحليل ودراسة الانارة في المباني وهو برنامج Dialux بالاضافة الى برنامج يعد من البرامج المختصة بدراسة كفاءة المباني (IES-VE) وذلك عن طريق عمل وادخال نموذج المبنى و كافة مكوناته كنوع الزجاج و العوازل و الجدران...الخ بالاضافة الى ادخال ما يتعلق بالمبنى من عوامل الجو وساعات العمل وعدد وكمية المستخدمين من اشخاص و أجهزة وغيرها من العوامل التي تؤثر في مقدار الطاقة المستهلكة وذلك يؤدي الى الحصول على دراسة دقيقة ومفصلة هي خلاصة موضوع هذه الاطروحة. لقد توصلت هذه الاطروحة للعديد من النتائج وهي كالتالي: تعد انارة LED أفضل تقنية للانارة الموفرة للطاقة حتى الأن وذلك يتضح من النتائج التي تم الحصول عليها من الدراسة، حيث بلغت نسبة توفير الاضاءه في بعض الحالات مايقارب 50% توفير في الطاقة. بينما انارة CFL هي الأقل توفيرا للطاقة حيث جاءت بعض النتائج بقيمة سالبة مقارنة بباقي الأنظمة المستخدمة في الدراسة. اما بالنسبة لأنظمة التحكم بالانارة فقد أثبتت الدراسة أن انظمة الحساسات المعتمدة على وجود أو حركة الأشخاص في الغرفة توفر طاقة بمقدار 10%. بينما نظام التحكم المعتمد على قياس مقدار الانارة الداخلة للمبنى والمزود بنظام التقليل من الانارة يوفر طاقة بمقدار 25% من طاقة الانارة. كما أثبتت الدراسة وجود علاقة بين مقدار التوفير في طاقة الانارة وطاقة أنظمة التكييف وذلك لوجود معامل مقداره0.33، حيث ان كل استهلاك من الانارة بمقدار 1كيلووات ساعة يقابله استهلاك في أنظمة التكييف بمقدار 3 كيلووات ساعة. هذا الأمر يجعل من استخدام انظمة الانارة الموفرة للطاقة وانظمة التحكم بالانارة ذات أثر واضح في التقليل من طاقة المبنى وذلك على اعتبار أن أنظمة التكييف تعد السبب الأساسي والأكثر استهلاكا للطاقة في المبنى بما يقارب 70% من طاقة المبنى يليه أنظمة الانارة والتي تمثل مايقارب 20% من الطاقة الكلية للمبنى..

Acknowledgements

First and foremost, I would like to thank Allah, the Lord of the Worlds, the Magnificent and the Merciful, for inspiring me with the knowledge and providing me with the strength and health to carry this research.

No achievement of significant impact can be executed solo, and this research is no exception. I would like to seize this opportunity to extend my heartfelt gratitude to the people who have knowingly and unknowingly contributed to this project.

I would like to thank my family who support me while doing my dissertation especially my mother, father and my sister Shaima for her time and effort that she gave me to make my dissertation better.

I would like to thank all my Professors: Dr.Alaa Ameer, Prof.Bassam Abu Hijleh and Prof.Walley for everything.

I would like to thank Ministry of Public Works especially the Ministers of Public Works (Shaikh.Hamdan Bin Mubarak when I started my study and then Dr.Abdulla Belhaif Alnuaimi who is the MoPW Minister now)for the scholarship that was given to me for doing this Master and because they support emirate employees to get higher degree of education and without their support I couldn’t be the first Emirate graduated from Master of Intelligent Building Design and Automation (IBDAA) and the second graduated student from this program that I feel proud of that.

I would like to thank the engineers and employees of MoPW who helped me in my dissertation such as: Eng.Abdulrahman Al Kholy, Eng.Mohammed Al Daly, Eng.Karim Moh. Mustafa and Ammar Majed Safi.

Also I would like to thank the following persons from different companies:

- Mr.Ramsey Joseph: from AMG Group Scientific Solutions Supplier Middle East Office.
- Mr.Thohchom SunilMeetei,Mr.Hozefa.Jawadwala, Mr.Karim Daoudi, Mr.Rocky Valez, Mathew Punnoose: from Bahri and Mazrooei (BMTC) Lighting Supplier Middle East branch Office for Trilux Lighting.
- A.Sheik Azaz: from Trilux Lighting Factory.

- Eng.Haider A.K, Eng.Haider Ghadhban and Mr.Jaber: from Projects and Supply Lighting Suppliers UAE branch Office for Regiolux Lighting.
- Mr.Osama Haroon: from Forza Lighting Supplier Middle East branch for Disano Lighting.
- Mr.Ali Hawili, Amir Imam: from Philips Lighting Factory.
- Mr.Rohan Rawte for IES software supporting.
- Eng.Nadia Al Badri from Ajman University.

Finally, thanks for everyone who support me during doing my Master and especially during doing my Dissertation and please forgive me if I forget to mention anyone name.

To my family.

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List of Abbreviations and Terminologies

BIM	Building Information Modeling, process involving digital generation and management of physical characteristics of places
CFL	Compact Florescent Light
CRI	Color Rendering Index, a measure of the ability of light source to reproduce colors
GUI	Graphical User Interface, a visual representation of a computer program that allows the user to interact with the software
HID	High Intensity Discharge, a type of lamp that uses electrical gas discharge to produce light
HPS	High-pressure Sodium lights, type of light that produces dark pink glow when first struck, and an intense orange light when warmed
HVAC	Heating, Ventilation and Air Conditioning
IEAHIJ	International Energy Agency
LED	Light Emitted Diode
LEP	Light Emitting Plasma is a type of gas discharge lamp which is energized by radio frequency
LUX	The unit of luminance and luminous emission, measures luminous flux per unit area
PIR	Passive Infrared Sensor, an electronic sensor that measures infrared light radiating from objects in its field of view
UPC	Urban Planning Council in Abu Dhabi, UAE

Chapter1

Introduction

1.1 Research Background

Since the local discovery of oil in the 1960s, the United Arab Emirates has witnessed a dramatic development in all sectors, including construction and building infrastructure. The environmental impact of the boom in building construction was reflected in the increase in energy consumption in the country (AlAwadhi et al., 2013). Since 1980, the UAE has continued to have the highest energy consumption per capita compared to the average rate in the Middle East, Europe, the United States, and the world. However, the peak rate in UAE was witnessed from 1985 to 1995 when it was identified as the country with the highest ecological footprint per person worldwide in 2007 (Ecological Footprint , 2007).

The hot climate in the region increases the challenges of adapting the buildings environmentally especially in terms of cooling and lighting under the extreme solar radiation and the high temperatures. The exterior temperature in this region can exceed 50 °C in the summer season which results in wasting large amounts of energy due to increased cooling and lighting demands. In the last decade, investigators conducted various researches that aim to achieve residents comfort whilst reducing energy consumption. Furthermore, as a consequence of the building energy demands, there has been an increase in sulphior oxides and carbon dioxide emissions. As mentioned above, the UAE was listed as the second country in terms of carbon dioxide emissions, with 40% of the yearly electric loads coming from the HVAC equipment, and up to 60% of emissions occurring during the summer. Moreover, according to the IEA energy report in 2009, the electricity consumption in UAE has increased 12 times from 5 to 75 billion (KWH) over the past 25 years (Rahman, 2013). A report by (Hammad & Abu-Hijleh, 2010) highlighted that buildings consume 40% of the total world energy use, whilst the buildings are responsible for roughly 70% of sulphior oxides and 50% of the carbon dioxide emissions. The dramatic increase in the carbon dioxide emissions of the gulf region are due to the high consumption of energy used to cool buildings.

According to (Piper, 1999) and (Chung et al., 2005), there are six main factors that influence the energy use performance in buildings. These factors can be classified in: occupants, indoor temperature set point, type and age of the buildings, occupancy factors, climate factors, and energy end use system factors such as office equipment or lighting control. Another study by (Kofoworola & Gheewala, 2009) investigated the life cycle energy assessment of a typical office building. The study has measured simple energy efficiency and low cost energy demand using a design strategy by applying set point temperature close to the standard indoor room of 26°C, applying shading devices, using appropriately sized windows, employing glazing with lower heat transfer coefficient and low solar heat gain coefficient. This design technique successfully reduced the energy consumption of office buildings during the operational periods.

The high temperature and humidity resulted in growth of using full HVAC systems mechanism for most residential and commercial buildings. A study by (Al-Sallal & Ahmed, 2007) noticed that there is a yearly 2200 kWh/m^2 solar radiation in the UAE, and direct falling illumination can exceed 90,000 lx in the summer with 50°C temperature. On the other hand, some other factors such as inadequate building form, shading devices, large area of glass windows and glass curtain walls can expose the building to strong solar radiation. However, high energy savings estimation could be achieved by refurbishing of the buildings.

Additionally, (Juan et al., 2010) estimated that the annual energy consumption in office buildings varies between 100-1000 KWH. This energy depends on the location, office equipment, users, operation schedules, building envelope properties and the lighting system. As mentioned in the same study, the United States alone consumes 70% of HVAC and Lighting systems of the total energy in office buildings, whilst the rate in the United Kingdom is almost 72%. Solar radiation and natural daylight are the main factors affecting the building's energy performance in order to control the thermal comfort, visual comfort and energy demand. An article by (Li & Wong, 2007) illustrates the effect of optimum daylight design solution where the total electricity consumption for lighting and cooling electric demand reached 70% in office buildings. In addition, cooling demand is naturally reduced when reducing the lighting.

Although the focus has been on developing and expanding the use of renewable energy resources, reducing energy consumption per capita is also an important aspect. The construction sector has been identified as one of the highest energy consumption sectors in the UAE, and thus CO_2 producers. So far, the country has concentrated its efforts to establish regulations for new buildings. As a relatively young country, the UAE compulsory building regulations relating to energy savings and conservation were introduced only within the past decade (in 2003 in Dubai and in 2007 in Abu Dhabi). This means that even if all the new buildings have to achieve high energy conservation standards, UAE will still have a large stock of buildings, some just completed, which have excessive cooling loads, rendering them not environmentally friendly. Some models achieved by researches also show that the UAE has one of the highest electricity consumption per capita in the world as computer modeling has proven to be a powerful tool among building professionals and researchers, whether they are used for drawing, rendering, evaluating or optimization.

Furthermore, the built environment is estimated to contribute to nearly two-fifths of the total energy consumption in the country in which only 0.5-2% is considered as new developments, whilst considering the newly set green building regulations (AlAwadhi et al., 2013). Many researches were conducted in different climates to assess the potential of the energy savings that could be achieved through building retrofitting strategies. Some of which focused on active systems such as upgrades of the HVAC system (Yu & Chow, 2007), others highlighted low-cost solutions based on passive strategies such as adding insulations (Ruiz & Romero, 2011). Researchers mentioned the importance of addressing cost efficient refurbishment solutions by providing a multi-objective approach. This was achieved by weighing the energy savings against the estimated costs of multiple scenarios prior to making decisions for implementations. A study by (Asadi et al., 2012) indicated that one level upgrade in refurbishment solutions, around 2.5% increased cost, would result in 32% additional annual energy savings. In the past few decades, energy modeling and building simulation has become a widely popular and reliable tool used by researchers and designers. Designers tend to use such tools prior to building construction to ensure a highly efficient building performance. On the other hand, researchers utilize these tools to conduct studies and investigations on the built environment in a timely manner using minimal human and financial resources. A computer simulation modeling program simulates an abstract model of a particular building and can be used to explore new design ideas, technological products and verdicts. Computer energy modeling is a subset of this category which can be used to enhance buildings designs and systems through assessing and estimating the performance of a building by integrated systems. Such programs and models are used when systems are too complex for an analytical assessment. Moreover, this type of modeling assists designers in processing building regulations, simulate solar analysis, thermal analysis, acoustic analysis, ventilation and air flow, and create shading designs and lighting designs within a 3D model.

The UAE only recently implemented energy conservation regulations for buildings. In 2003, Dubai Municipality started enforcing Decree 66 which included energy saving requirements, mainly insulation and glazing. In Abu Dhabi, the Urban Planning Council (UPC) was established in 2007 and became responsible for preparing and enforcing building regulations including energy saving requirements. This means that the majority of the buildings in the UAE were constructed with minimal consideration to the energy savings. This is especially true for buildings constructed by developers to be sold to end users. Thus initial cost savings were the dominant concern rather than long term energy operating costs savings. This also indicates that the vast majority of these inefficient buildings will still be operational by 2020, the target year for the Copenhagen accord. Without proper refurbishment of these buildings, the drain in energy used in the buildings will remain high and would require significant investment in renewable energy resources if the UAE is determined to achieve the required CO_2 emissions reduction goals for 2020.

The poor energy saving construction approach used along with the harsh weather conditions in the UAE have resulted in the UAE being ranked in the top 10 countries in terms of electricity and heat usage per capita and the 2nd highest in terms of CO_2 emissions per capita. The high growth in electricity demand reached 25, 50 and 76 (terawatt hr/year) in 1995, 2003 and 2007, respectively. This is also an indication that new buildings are not incorporating with the energy savings measures. The highest electrical load comes from HVAC equipment which accounts for an average of 40% of the total year electrical load and up to 60% of the peak electrical load during the summer time. Allied to the trends for energy use, the UAE is also a major producer of carbon dioxide emissions and, despite trends towards reducing total emissions, was the 4^{th} highest emitter per capita in 2002. To continue the trend of reducing emissions, The Environment Agency in Abu Dhabi has published documents reporting on the introduction of zero emission flaring technologies and a move towards the use of natural gas in power and desalination plants. The provision of public facilities and services should seek to enable a reduction in carbon emissions over time.

As mentioned earlier, lighting energy consumption is another reason for high energy consumption in the UAE that usually reaches 22%-30% of the monthly electricity consumptions (Sunikka & Boon, 2003). There is a significant determination in the UAE to reduce CO_2 emissions as a part of the global effort to reduce greenhouse gases and mitigate the effects of global warming. A literature search was done to determine the current state of knowledge in the field of energy saving studies and lighting control technologies. According to (The European Commission Directorate-General for Energy, 1994), recent developments in lighting technologies combined with planned lighting control strategies which can result in a significant cost reduction. It is well established nowadays that buildings consume almost 40% of the world’s energy, 16% of the world’s fresh water and 25% of the forest timber, whilst they are responsible for almost 70% of sulphior oxides and 50% of the CO_2 emissions (Santamouris, 2005). In Europe, about 30% of the total energy consumption is consumed by buildings, and a large amount of energy is used for heating (Ghiaus & C., 2004).

A study by (AlAwadhi et al., 2013) addressed the sectorial energy consumption in the UAE in 1998 based on statistics cited from the IEA. It mentioned that the residential and commercial sectors had almost an equal share of the total primary energy consumption of 16.2% and 15.1%, respectively. Conversely, the transportation sector demonstrated the lowest share of 10.3% of the country’s overall energy consumption. However, this percentage is anticipated to double in the next decade due to the predication of the growth in the population. Without a doubt, the environmental impact of these figures would be severe especially with respect to carbon emission. In this dissertation, computer energy modeling is used to estimate the potential energy savings of refurbishing existing public federal buildings in the United Arab Emirates

Furthermore, this study focuses on reducing lighting energy consumptions which can be achieved using energy saving lighting technologies like T5, Light Emitted Diode (LEDs) and Compact Florescent Lights (CFLs). Another way to reduce the energy consumption is using lighting control technologies like different type of lighting sensors and dimmers like the daylight and occupancy sensors. UAE uses high levels of energy and data suggests a trend towards increasing levels of usage. The residents in UAE consume around 11,000 KWH per person per annum and peak demand for electricity is rising at an annual growth rate of approximately 9% (Sunikka & Boon, 2003).

1.2 Aims and Objectives

1.2.1 Aims of the Research

UAE has still a long road towards achieving optimum building energy savings through proper use of energy saving technologies. Using lighting and control technologies to conserve energy is one field which can be explored and deployed within federal buildings and offices in the country to condense energy.

This dissertation intends to place a roadmap towards achieving reduced energy consumptions by deploying lighting and control technologies to improve lighting in federal buildings in UAE. This study used the building of Ministry of Public Works in Ras Al Khaimah (MOPW-RAK) as a case study building to be modeled and simulated using building and lighting simulation software's to do analysis on the results that can be applied to most other federal buildings in the country with varying degrees of modification.

1.2.2 Objectives of the Research

The objective of this study is to reduce the energy consumptions in federal building in UAE which can be realized by fulfilling the following:

- Identify and assess the current energy saving measures deployed within federal buildings in the country
- Identify and investigate areas of possible energy saving potential using lighting control technologies and evaluate the energy consumption rates in the building
- Utilize modeling and simulation tools to provide accurate results of the building

- Provide an economic viability analysis of the applied lighting technologies using investment/savings/payback calculations
- Analyze and discuss the simulation results

1.3 Organization of the Dissertation

This dissertation consists of six main chapters, in addition to the references and appendices.

- Chapter 1: is the introduction chapter which consists of two main topics, the background about energy consumption and energy savings, and the motivation and aims of this dissertation.
- Chapter 2: presents a historical overview with regards to energy savings in buildings, highlighting notable relevant projects. It is concluded with three case studies that directly contributed to the motivation behind this dissertation.
- Chapter 3: provides an in-depth description of lighting and lighting control technologies. This chapter further describes the different types of lighting and the benefits that each lighting technology adds to any building.
- Chapter 4: provides the methodology used to conduct this research, where the different approaches of data collection, simulation and experimental measurement are detailed.
- Chapter 5: compliments the previous chapter as it discusses the building of the simulation model where the building description and usage presented. This chapter also presents the most important services in the building, and describes the high energy consumption problems in the MOPW-RAK building. The office model was implemented and described. The research parameters were defined and the Matrix of the simulation cases and model validation were discussed.
- Chapter 6: addresses the results and discussion of the simulation model of the selected case study building. This section is the most important chapter because it includes the simulation results of the case study model. It consists mainly of two parts which are the technical analysis and the second part is the economic analysis of the study.
- Chapter 7: concludes this dissertation by providing a summary of results, recommendations and major contributions.

Chapter2

Literature Review

2.1 Introduction

The engineering literature witnessed many references to mechanisms using varied methodologies to reduce energy consumption in buildings. From using HVAC optimization technologies, replacements of steam traps, retro commissioning of current systems and using advanced technologies and lighting fixtures; Electrical engineers have considered with the idea of energy consumption reduction for years. New technologies are constantly changing the way we tackle existing problems. Older buildings were not developed with energy savings in mind. Therefore, a recent trend towards using new technologies, in essence, lighting technologies, has focused the attention of new contractors and investors alike.

This chapter provides a literature review considering energy saving studies with relevance to lighting control technologies, using studies and researches obtained from relevant books, journals, articles, websites, conferences as well as past and peer reviewed papers. The lighting factories and suppliers have been used as major references for this study where the author has used some of the most reliable lighting results, reports and analysis documents. These sources allow one to identify how the lighting and lighting controls are used worldwide, permitting the buildings to save energy. Choosing the right type of light and lighting controller buildings, and investigating intelligent envelope characteristics are essential for this purpose. Daylight controls (photocells) or occupancy sensors (PIRs) are two of the most common types of lighting controls that are used nowadays. This review focuses on studies related to the applications of lighting technologies and lighting control strategies in some previous projects done by researchers.

A literature search has been conducted to determine the current state of knowledge in the field of energy saving studies related to the lighting and lighting control technologies studies and researches. The use of these information sources helps to set the research questions for this study. It shows how the lighting and lighting controls are being used worldwide, allowing buildings to save energy.

2.2 A Historical Perspective

The history of electrical engineering and construction combined had witnessed deviations in the way commercial and residential buildings are built to address climate change mitigation. Buildings around the world account for about 40% of primary energy use. The industry today enters a new era of change with a trend towards minimizing energy due to the growth in housing market which resulted in increased energy consumption. This change is driven by the need to conserve resources. Global governments have made attempts to control this massive consumption of energy by legislating laws to regulate the way new buildings are constructed. Furthermore, the use of newer technologies has been utilized to govern energy consumption in older buildings. For example, smart meters were utilized in buildings, commercial and residential, to allow in-house displays and measures of essential components; allowing residents and users to monitor energy consumption. The self-awareness of the importance of energy consumption is vital towards achieving reduced energy consumption in these buildings. There is a high demand to produce commercial buildings to near-zero energy use levels. Using the advanced technologies with electric lights allow buildings to save considerable energy at reasonable costs. In fact, energy-efficient lighting is one of the most cost-effective ways to reduce CO2 emissions. In 2005, electricity consumption for lighting systems was about 19% of the total global electricity consumption; this included approximately 31% for the residential sector, 43% for the service sector and 18% for the industrial sector (Earth Policy Institute, 2011). Office buildings are classified among the buildings presenting the highest energy consumption. The total annual energy usage varies in the range of 100 - 1000 (kWh/m2.yr), subject to the geographic locations, office equipment, operational schedules, use of HVAC systems and type of lightings. Most of the light sources available in office buildings is provided by fluorescent lamps, representing around 76.5% of the light output, the rest of the light output was provided by a mixture of incandescent, compact fluorescent and HID lamps (Moreno et al., 2010). Recently, the use of energy in buildings has been increased due to the growth in demands of energy used for warming and cooling in the buildings. According to (D. L., 2009) energy efficiency is a prime consideration for all lighting professionals as the climate changes unpredictably. Moreover, sustainability lighting is a major contributor to the energy costs in the commercial buildings (CIBSE, 2008). This requires providing the correct amount of light to be used. The appropriate amount of light, depends on the type of task, the locations and timing that lighting controls are required to apply.

A report by (The European Commission Directorate-General for Energy, 1994) emphasized the importance of daylight in buildings. Certain buildings require more light than others due to the nature of activity held; for example, offices require more daylight than movie theaters. Daylight is the light to which we are naturally adapted to, but day lighting will not save energy without the control of the electric lighting system. This is due to over and under dimming, and frequent cycling; in fact, a report by (DiLouie, 2006) offers arguments as to why the use of daylight to reduce artificial lighting energy sometimes fails. Day lighting controls also fail in some buildings because of improper location of controls and inadequate specification of the control systems. Energy saving attempts using daylight is affected by location, climate, building use and form (The European Commission Directorate-General for Energy, 1994).

Latest developments in lighting technologies combined with intended lighting control strategies can result in remarkable cost savings. The commercial sector and office buildings along with retail have the highest energy consumption rates and CO_2 emissions. In the USA itself, offices account for 17% of the total non-domestic area and about 18% of the energy use. This corresponds to the 3.2% of the total energy consumption. In Spain, third of the commercial sector energy consumption and almost 2.7% of the total energy are consumed, and in the UK, 17% of the energy consumption and 2% of the total energy are consumed. Various researches such as (DiLouie, 2005), state that lighting controls, can reduce lighting energy consumption by 50% in the existing buildings (retrofit) and by at least 35% in the new constructions. These percentages are not limited to the office buildings; they could be a school or a warehouse building (Hammad & Abu-Hijleh, 2010).

2.3 Energy Saving Using Lighting and Lighting Control Technologies

In office buildings, lighting makes about 20 to 45% of electricity demand. One study (Edwards & Torcellini, 2002) presents the energy efficiency of different lighting and lighting control technologies applied to the office buildings which are based on software calculations to perform day lighting and lighting systems. Different types of the lighting systems and lighting controls were compared using fluorescent lamps and other types of lamps to determinate how the potential energy was saving, maintaining or increasing the quality of the lighting level distribution on the work plane. The same study shows a general localized lighting system that provides higher energy savings and uniformity of lighting levels in the work place than the other studied systems. According to (Edwards & Torcellini, 2002), the incorporation of lighting controls can reduce the lighting energy consumption down to 15%. A manual on/off switch is the most widely used and simplest lighting control system. This system cannot improve energy efficiency by itself as it depends on the user's behavior. Lighting control can provide energy savings by adjustments to real-time occupancy. Some researchers like (Veitch et al., 2010), and (Newsham & Birt, 2010), attest the positive impact of lighting control systems, but there are different opinions about quantifying their energy saving, for example, manual regulation has a range between 7% and 25%. Occupancy sensors can provide a range of energy savings between 20% and 35% (Edwards & Torcellini, 2002).

Several researches attempted to find the relation between daylight availability, control lighting systems, blinds, electricity use for lighting and other parameters based on simulations using validated programs. Lighting simulations may be useful to evaluate daylight availability in the studied space and to calculate the artificial lighting that is needed annually, depending on the number of occupants, performances and their interactions with blinds and lighting controls. There are many advantages for installing lighting controls such as: reducing the buildings energy consumption, providing a healthy environment for employees and reducing greenhouse gas emissions (GHG). Some advantages of this system are as the following:

1) Remote lighting dim for each zone

2) Automatic control in sequencing of beam lights
3) Remote status monitoring within the building

Lighting controls can simply lead users to use switches, time switches and photocells to turn luminaries on and off. More advanced solutions include using high frequency dimmable control gear linked to photocells to provide constant illumination and daylight linking. According to (Victorian Legislation and Parlimentary Documents, 2006), intelligent luminaries, such as Intellect, provide a straight forward solution for lighting control with a user selectable functionality which requires at least:

1) Maximum daylight usage
2) Maintaining an efficiency target of greater than 40 lumens/circuit watts
3) Electric lighting control

2.4 Effects of Lighting on Productivity and Cost-Effectiveness

In a paper by (Boyce et al., 2003), it was mentioned that certain life events, such as uncomfortable environmental conditions may lead to an increase in the residents' stress levels. A simple real or simulated window with a view has shown evidences to relief stress levels. Moreover, environment-based stress can be caused by various reasons such as glare, noise or overcrowding. Prolonged experience of stress can lead people to have high blood pressure, poor job performance or absenteeism. One research (Clarke, 2009) published results indicating that "properly designed day lighting decreases the incidence of headaches, seasonal affective disorder and eyestrain". Another study (Boyce et al., 2003) stated that "lighting installations do not have the simple effect on performance or well-being that many researchers have sought. His argument is correct to some point, as not all lighting installations would help to increase productivity where they were simply not designed for this purpose. The research looked at different designs and combinations of previous lighting systems that worked effectively and were useful for the environment. This leads to the creation of a healthier environment which subsequently helps to an increase in productivity. Perfect lighting systems contribute to an improved visual environment and this can assist visual stimulation and in general, human well-being. In an effort to study the effect of daylight on building occupants, a case study on Tomo Therapy Incorporated was conducted that showed 70% of staff wanting to be seated near the window, however the employees realized that there could be problems with glare on their computer screens (Morante, 2003). This argument of working beside windows is backed up by previous research (Heerwagen & & Heerwagen, 1986) where it was identified that people prefer to work beside windows rather than further back into a room, especially when those windows have direct access to sunlight. Allowing an appropriate amount of personal control over lighting, may increase occupant's comfort leading to higher productivity (DiLouie, 2006). The same research also states that "people costs outweigh building costs on a ratio of 3:1". Therefore, it is rational that the management takes into consideration regarding lighting to enhance productivity and the workplace design". His statement regarding people costs outweighing buildings costs may be true, but the real concern is will lighting really have such positive effect on workers performance that increase in profit. A good lighting control may be the key to positive attitudes in work and an increase in productivity, but the ideal lighting scenario is different for every user. Offices with good personnel control may require T5 or T8 lamps, dimmable electronic ballasts, task lighting if required in some areas and some sort of occupancy sensor. It could well be the occupant's preference over the energy efficiency side of lighting control that will create the ideal system, and energy managers must be aware of this.

On the other hand, research also shows that it is possible for lighting controls to fail when deployed. Many reasons are linked to such failure, which include under-dimming of lights that affect the comfort of occupants, over-dimming of lights resulting in occupant irritation and possible glare and repeated cycling of light switching resulting also in irritation.

If proper training and commissioning of a well designed and installed system are achieved, then there is no reason for not obtaining energy savings. Researchers got invested to find out if day lighting controls in buildings could improve productivity and enhance the well-being; and most results show increases in productivity. A research by (DiLouie, 2006) mentioned that "access to daylight versus no daylight in classrooms has been correlated into large increases in students test scores". He states that "occupancy sensors are ideal for areas that require greater control than can be achieved using scheduling such as office buildings with perimeter offices that must be controlled individually". Using occupancy sensors that is appropriately positioned makes a practical effort to automatically switch the light off when no users are occupying the area. The same study indicated that energy savings can reach up to 50% in private offices, up to 90% in toilet areas, up to 80% in corridors and would range from 45% to 80% in storage areas. Some benefits of continuous dimming with day lighting controls include the highest level of flexibility and user satisfaction, and also often the greatest energy savings.

Adequate indoor luminance is accepted as a determinant condition for comfort and productivity in offices. Additionally, daylight plays an important role as a component of lighting, which helps to illuminate interior of the building and provides information about exterior environment. A European survey showed that about 35.6% of the offices working time is invested in avoid daylight, and their electric lighting use is about 85.7%. This lighting use is distributed in 30.3% for blinds closed, and 55.4% for blinds opened. Therefore, generally energy savings are related to lighting, not only depend on daylight availability, but also depend on when and how workers use blinds and lighting control systems (Moreno et al., 2010).

Different lighting and control systems have been studied to analyze the lighting conditions effect on the health, well-being, and task performance of employees in an office. Lighting environment using direct-indirect luminaries seems to be more comfortable than that from direct luminaries, but individually controllable workstation specific lighting was the most comfortable option. Individual control over lighting seems to be positive for motivation and well-being. In office buildings, different case studies show that it is possible to obtain both good visual quality and low installed power for lighting with the current technology. The studies also indicate that the best performance is reached in an office environment when the luminaries are shared between two people (Halonen et al., 2010).

For example, working beside day-lit spaces can be associated with thermal and visual liabilities such as solar heat gains during summer months and heat loss during winter months. The best solution would be a combination of daylight without undesirable heat gain. There are shortcomings associated with day lighting systems such as glare, which can cause problems such as visual disability and discomfort. Glare can also have adverse effects on people and productivity alike. Artificial lighting can also cause direct glare. One way to combat direct glare from artificial lighting is to install an array of ceiling mounted luminaries having a luminous intensity distribution that avoids glare reflected from display screens. Glare from daylight can be controlled with properly selected blinds and careful location of visual display terminals. This has consequences for wall and ceiling luminance values but these problems can be overcome with good design. Daylight is the preferred method for people to work in. Studies by (Heerwagen & & Heerwagen, 1986) have shown that working in daylight results in less stress and discomfort than working in artificial light. General and visual health becomes more apparent when working under daylight. Increased productivity and well-being are linked directly to users having a direct visual connection to the outdoors.

As mentioned above, electricity makes for the vast majority of building energy consumption. In fact, according to the English Department of Energy, buildings in general make for 50% of energy consumption and carbon emissions. The cost of energy is on the rise, a report by (Office of Gas and Electricity Markets, 2009) shows that the energy cost is set to reach 60% by 2016. Based on the same report, Fading Footprints Ltd conducted a series of case studies to estimate the savings that will be achieved by using simple building upgrades in terms of cost and energy saving. For instance, the Sea Front Hotel is one building that was constructed in 1928, has been extended seven times and spans over 3159 m^2 area. The building owners have to pay £141,787 annually in order to cover the 2,281,508 kWh energy usages, inclusive of £63,479 for electricity alone. Furthermore, the building emits about 602,026 kg of carbon yearly. The company made alterations to the building in order to reduce this amount including wall and roof insulation, draught proofing, boiler replacements and lighting upgrades. The results were phenomenal. The lighting upgrades actually costs £36,102 but allowed the owners to save £24,475 annually, with payback period of 1.48 years. In total, the entire set of alterations costs £140,948, with a payback period estimated at 2 years when savings would reach £71,766 annually, including an astonishing 1,046,386 kWh in energy savings which makes for 50% of original energy spent (Fading Footprints Ltd., n.d.).

A number of research papers have provided overviews of lighting controls studies and the opportunities they open up in terms of cost savings. Using lighting controls can vary from have intelligent lighting systems linked to daylight (using on/off photocells or using constant lux dimming), or using controls based on time by switching lighting on and off based on programmed time controls, or using presence controls based on acoustic or movement detectors. One research (Von Neida et al., 2001) focused on the gains obtained using lighting controls and occupancy sensors with the objective of better quantifying the performance estimates of occupancy sensors across typical space types.

2.5 Reported Solutions from Relevant Case Studies

This section demonstrates the findings from relevant case studies and reports that have been conducted by researchers, providing some of the solutions for lighting controls and energy consumptions savings using collected data and numerical results. The purpose of this section is to provide an insight regarding the opportunities which are introduced by enforcing energy consumption reduction measures.

In an attempt to identify the impact of different lighting control systems on office energy consumption, (Jennings et al., 2000) have conducted a test by measuring the consumption of retrofit installations. The study concluded that occupancy sensors can save up to 20% of energy, whilst daylight diming controls can save up to 26% when compared to manual switching. It was also found that open loop dimming control system as well as different shading systems vary in energy savings from 5% going up to 45%. A Norwegian study measured the saving potential using daylight dimming systems based on geographical location; it found that south-facing rooms energy savings ranged from 30%-40%, and north-facing rooms saved from 20%-30% (Leslie et al., 2005).

One case study focused on a company called March Foods, which is one of the UK's leading food contract manufacturers and packing businesses. The company has dedicated a team to provide continuously improvement focusing on examining all lines of production, new or established, and recommending how it can improve every aspect of its operation. Specifically, the processed foods warehouse was lit by HPS lights on the left and then by LED lights on right. For the last three years, the Managing Director of March Foods had been scouting for a way to lessen energy consumption in his warehouses. After discarding voltage controllers as old technology, the manager began to examine LED lighting as a potential smart solution. The warehouse measured 3,250 m^2 with a total of 84x450W HPS lights, operating 24-hour a day, six days a week. Even when the warehouse was vacant, the lamps were not switched off because older lamps took longer to turn back on. Furthermore, the lamps were plunged in 15-meter-high ceiling which caused a hassle when a replacement or maintenance is needed. This caused the operators to wait until up to 8 lamps fail before getting them replaced, which was costing about £2,000 annually. Interior control replaced the HPS lamps with the LED. The new lighting system allowed better light distribution with less light wasted, and delivered an immediate saving in power of 66%. LED lighting is instantly-on, making it work very well with occupancy sensors which have further increased energy saving to 72% as well as reducing carbon emissions by over 100 tons per year (Dialight, 2010).

Siemens is one of the leading companies in the world and it prides itself with its vision to continuously improve in all aspects. In an attempt towards sustainable urban infrastructure, Siemens conducted a case study on its very own six-story headquarters in Dublin City Center. By using lighting controls, Siemens targeted reducing energy consumption. A test on the 1900 sq. feet fourth floor was conducted to examine the energy savings and cost effectiveness of the three different lighting control systems in private offices, open day lit areas and interior open plan office spaces, by installing lighting controls on that particular floor and monitoring the electricity consumption from the lighting controls. They used presence detection, central off and constant daylight lighting controls for this test. The presence detection sensor works by detecting the presence of occupants using PIR technology, even if they are sitting at a desk and working quietly, rather than requiring them to actually get up and move around the detection field. This makes them ideal for open plan offices, corridors and reception areas and so forth. The other control is the constant daylight which causes the photocell to sense daylight and to maintain a constant light level in that given space. It can be combined with presence detection to provide a constant lighting load which is switched off when the area is no longer occupied. In some cases, on bright sunny days, constant light control can eliminate the need for artificial lighting completely. One major disadvantage with this is that it will not work at night. The last type of control in this case is the central off which is a timing function that switches off forgotten lights (Siemens Limited, n.d.). The lighting design company installed power monitoring system in order to measure and monitor energy consumption. Prior to the year 2009, no lighting controls were installed in the office pan. Following the installment of lighting controls in 2009, it was noted that energy savings peaked to 53.13% for the year. Autumn and winter months had shorter days, thus, the lights were getting turned on for longer periods of times, and this had allowed for increased energy usage. Nevertheless, the energy savings were still prominent.

Another case study is that of Chef Express Motorway which operates in 35 locations along Italian motorways, building its restaurant chain around a concept to provide high quality products in a relaxing environment for its customers. Lighting was found to be a major energy consumer for the enterprise and sought professional consultation. The lighting company developed a design concept using high flux density LED arrays. In addition to %45 energy savings, the lighting design created a more relaxed environment for both customers and staff since LEDs do not produce heat in the light beam. Overall, the company was able to reduce energy with an estimated annual savings of €30,000, reduce maintenance costs by providing long-service life of lights, reduced CO2 emissions to 50 tons a year, and reduced climate control costs by eliminating IR radiation (Bridge Lux, 2012).

Another case study has been conducted on BC Hydro which is an electric utility based in British Columbia, Canada. The company’s power smart division occupied four floors of its office building which allowed it to use different lighting solutions and assess them accordingly. Prior to deploying controls it was using Phillips Ergo light fixtures which distribute lights directly downwards and upwards. This combination of lighting and contrasts created dim ceiling and very tough shadows. The used system included integrated network controls, occupancy sensors, personal dimming and daylight dimming. The energy-savings technologies then worked according to criteria set by building manager and occupant. For example, a few minutes after the fixture integrated occupancy sensor detects no movement within the workspace, the downright is automatically and gradually dimmed to off. One lamp in each fixture that projects light up to the ceiling is left on the maintained ambient illumination in the space. Outside regular office hours, the occupancy sensors in the open office are scheduled by the manager to control both the up lighting and the down lighting, thereby ensuring that uprights are not left on in vacant workspaces. Each light is connected to the employee's computer through the corporate LAN system. Staff members use an icon on their computer screen to control the light level overhead and adjust it usually downward to deliver the optimum illumination level. During the summer, most Hydro staff set their lighting at 50 %, yielding additional savings (Philips Lighting, 2009).

Next, Advocate BroMenn Medical Center intended to extend the life of lighting in its parking garage. For safety reasons, the garage is lit full time daily which makes for hefty energy depletion. The garage was initially using metal halide lighting which is expensive to operate and maintain. The hospital made an investment to replace MH mixtures with 304 Series luminaries in early 2011, which boosted savings to 325,000 kWh annually, an estimated 65% reduction in energy (Ruud Lighting, Inc., 2012).

The final case is that of a Swedish housing company called Svenska Bostäder. While looking at annual costs, the company identified an astounding $2,500,000 fee, as a result of avoidable lighting in public areas. After a series of investigations on the company's 11-storey building, the company decided to deploy intelligent luminaries that direct the level of light in relation to the physical presence of humans in the current area by means of thermal effect (IR) and motion, in combination. This lead to the saving of between 80%-90% of the electricity required for a conventional lighting system. The payback time after using this technology is less than a year compared with installation of a conventional lighting system. The total potential of savings is approximately $500,000 USD per year and this is accomplished by only changing all luminaries located in the stairways (United Nations Environment Programme , n.d.).

In summary, this section provided solutions for energy savings using lighting control as follows:

- Reducing CO_2 emissions in the short to medium range by refurbishing the existing building stock.
- Identifying the impact of different control systems on office lighting consumption by measuring the consumption of retrofitted installations.
- Using day lighting controls (photocells) and PIR to reduce energy consumption saving costs in buildings.

- Discarding voltage controllers as old technology and using LED lighting as a potential smart solution.
- Installing lighting controls on a particular floor of a building and monitoring the electricity consumption from the lighting controls and then applying this control, if satisfied, to other floors.
- Adjusting the interior and exterior lighting as mentioned earlier.
- Guiding the light only where needed using system included integrated network controls, occupancy sensors, personal dimming and daylight dimming.
- Upgrading lighting to reduce energy consumption.
- Using of “intelligent” luminaries that directs the level of light in relation to the physical presence of humans in the current area by means of thermal effect (IR) and motion combined with (The PIR-system) passive infrared detection.

Chapter3

Lighting and Lighting Control Technologies

This research focuses on upgrading lighting fixtures and deploying lighting control mechanisms to conserve energy in federal buildings. Therefore, it is beneficial to first describe the variety of lighting technologies available in today's market. Furthermore, this chapter takes a deeper look at the commercially available lighting controls in order to deliver the desired outcomes.

3.1 Lighting Technologies

Lighting, whether artificial or daylight, is an important factor that engineers take into account when designing buildings. Artificial lighting obtained by fixing lamps allows occupants to work within a building independently of the time of the day. Utilizing appropriate lighting technologies would allow buildings to consume minimum energy while maintaining occupants' comfort, productivity and safety. Ambient lights are used to illuminate indoor and outdoor areas. Recent advances in the field allow buildings to reduce the consumed energy without the loss of amenity as inefficient lighting produces a lot of heat which would increase the energy consumed for air conditioning. Furthermore, inappropriate lighting can affect the workers because it can create glare problems and cause user irritation which would eventually result in less productivity. Some types of light fixture may fail in satisfying building occupants due to their inability to provide the correct luminance, the appropriate color temperature or a good level of CRI. The CRI denotes how accurately the light source renders colors in comparison to the ideal light source. The next subsections will provide an overview of the different types of lamps used in lighting fixtures today.

3.1.1 Halogen Lamps

The traditional halogen lamp as shown in Figure3.1 is composed of ductile tungsten placed in a high-pressure gas filled bulb. It is known for having a higher luminous concentration than that of the incandescent lamp. Halogen lamps set the reference value for the color rending index for having wide color spectrum making them closer to sunlight than the standard tungsten, which allows them to be very popular in spot lighting. It is often used in open spaces, such as exhibitions, stores, offices, hotels and homes. These lamps are lightweight and are cheap to produce, and they do not use mercury or mercury vapor like other popular lamps. The lifetime of halogens is about five times of the lifetime of incandescent lamp. Despite its benefits, these lamps produce a high amount of heat and are able to cause severe burns if touched.

Figure 3.1: Halogen Lamp (www.freetentsonline.com)

3.1.2 High Intensity Discharge Lamps

HID lamps as presented in Figure 3.2 are a group of gas-infused bulbs where light emanates from an arc discharge between two closely spaced electrodes. In order to operate, these lamps require a special ballast to carefully regulate the voltage supplied to the gas. These lamps require a warm-up and cool-down periods, for instance, HID bulbs produce about 5% of their output when first ignited and require sometime to reach full lighting capacity. They can therefore be active for long periods, making them ideal to be used for outdoor lighting. Sodium vapor lamps are highly efficient in terms energy conservation when compared to florescent lamps. On the other hand, they also provide little color rending and shorter overall lifetime. HID lamps gained popularity when Europeans automobile manufacturers started using them as vehicle headlights. These lamps provide whiter light output and consume less power, but also narrow spectral line.

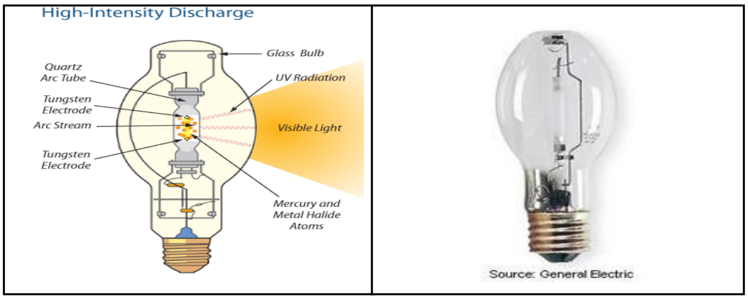


Figure 3.2: HID Lamps (www.freetentsonline.com)

3.1.3 Incandescent Lamps

Incandescent Light bulb that shown in Figure3.3 has been first introduced by Thomas Edison in 1879, and hasn't changed much since then. This lamp is composed of a very thin wire which is sealed with a glass bulb, when the tungsten heats up, it emits light. The major disadvantage of incandescent lamps is that it devours energy as most of the energy is converted to heat and only 10% of it is converted to light. Due to this disadvantage, many countries have set up regulations to eliminate the use of this type of lamps in order to enforce the transition to energy efficient alternatives. On the other hand, incandescent lamps produce suitable dimmable light and are very cheap to produce.

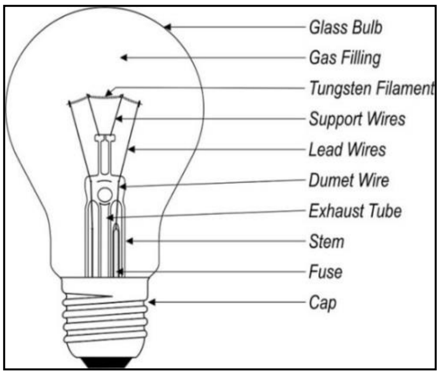


Figure 3.3: Incandescent Lamp

(www.lamptech.co.uk)

3.1.4 Fluorescent Lamps

Fluorescent lamps which shown in Figure3.4, are used to replace incandescent lamps because of their energy-efficient characteristics. In order to understand how fluorescent lamps work, one must be familiar with the basic chemistry of atoms. Fluorescent lamps produce light from collisions in a hot gas of electrons and atoms, where electrons used to higher energy levels and then drop back to emit UV emission lines. The fluorescent coating of the glass bulb converts these UV lines into visible light. The components of fluorescent lamps are illustrated in Fluorescent lamps are very energy efficient and only need around 15% energy of an incandescent lamp and have a very long lifetime. These lamps emit very little heat, and because of their popularity, their quality continues to improve. The early versions of fluorescent lamps took some time to light up when switched on and made a buzzing sound, whereas today's CFLs as shown in Figure3.5

are the opposite; they are silent and come on almost instantly. They are also available in many variations regarding color temperature and color rending index.

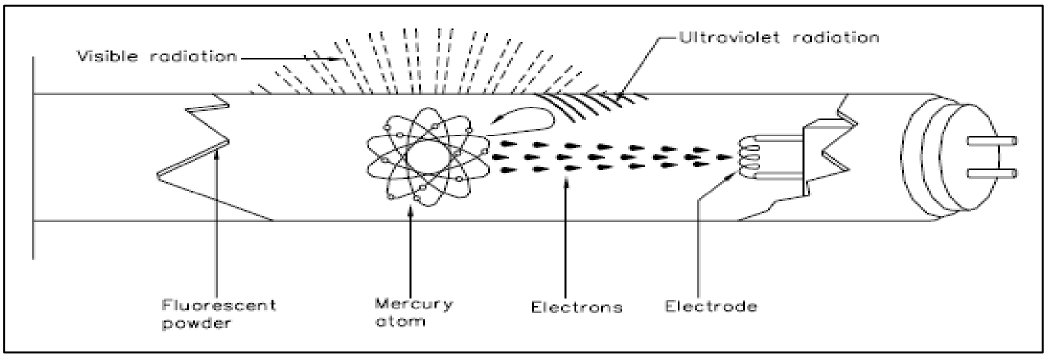


Figure 3.4: Florescent Light Components

(http://home.howstuffworks.com/flourescent-lamp4.htm)

Fluorescent light bulbs contain ballast which controls the current flow that the lamp draws regardless of how hot the gas is. Ballasts can also help in igniting the lamp. Some ballast contain transformers that allow them to increase or decrease the voltage supplied to the lamps in order to allow same-size lamps to be used irrespective of electrical line voltage. Ballasts can be magnetic or electronic. Magnetic ballast, often referred to as inductive ballast, contains an electrical coil of wire. This type of ballast utilizes the physics of electricity and magnetism; since the current flowing through the wires generate a magnetic field around it and changing the magnetic field around the wire changes the flow of the current, this ballast uses this mechanism to balance the current that passes through the coil.

Figure3.5: Compact Florscent Lamp

(www.howardcountymd.gov)

The small transformer inside the ballast operates at 50 to 60 Hz which would make it generate a low frequency hum when operating which is why ballasts have sound rating. The sound generated by the ballast, even in the best sound-rating ballasts, can prevent the lighting to be used in certain facilities like recording studios. Figure3.6 demonstrates the magnetic ballast.

Figure 3.6: Magnetic Ballast

(www.made-in-china.com)

On the other hand, electronic ballast is similar to switching supplies found in computers; it creates small electrical currents up to 50,000 pulses of electricity supplied to the lamp per second. Electronic ballasts are more power-efficient than magnetic ballasts and are smaller in weight, and can be typically placed in very small spaces. Most importantly, these ballasts are silent contrary to their magnetic counterpart. Most fluorescent lamps use electronic ballast. Figure3.7 shows the electronic ballast.

Figure 3.7: Electronic Ballast

(www.iquaticsonline.co.uk)

The other component of florescent lights is the starter, which consists of a small bulb containing argon gas as well as a bi-metal contact. When bulbs are not able to light up when first turned on, a small amount of electricity runs through the argon gas in the starter, which in turn heats and begins to bend the metal contacts until they move out of position create a direct electrical circuit. Figure 3.8 demonstrates the starter.

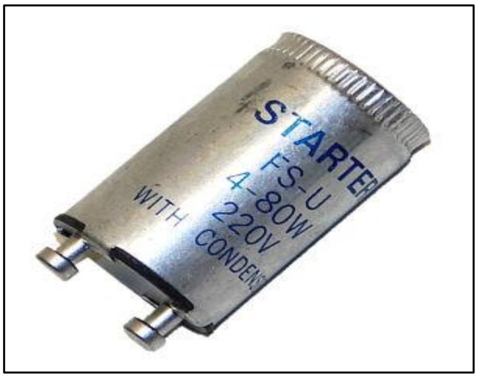


Figure 3.8: The Starter

(http://secrets-of-self-sufficiency.com)

3.1.5 Light Emitting Diode Lamps

LED lamps are the most promising replacement of incandescent lamp. LED lights are superior to conventional lamps in many ways that include energy efficiency, wide color palette and excellent color saturation. Not only that, but they also come in very small and light forms that they can be fitted in almost any structure. The light quality emitted by LED lights is close to daylight which makes it comfortable to building occupants. Figure3.9 illustrates the components of LED lights.

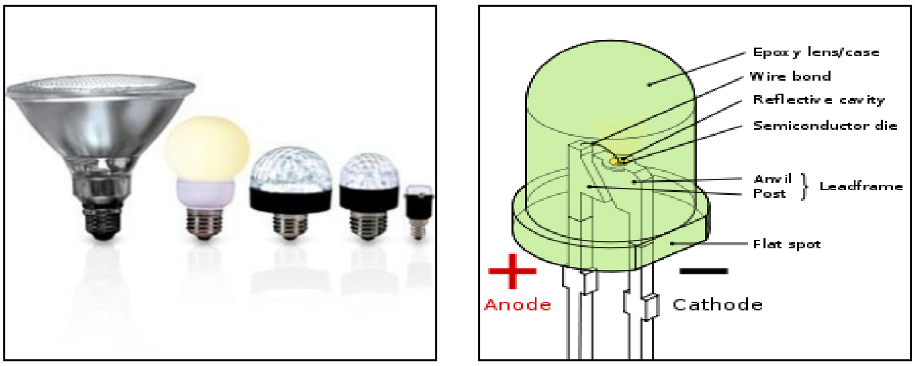


Figure 3.9: (a) LED compared to the other types of lights

(b) LED Light Components

(http://en.wikipedia.org/wiki/light-emitting_diode)

Unlike the incandescent lamps, the light emitted from the diode is generated as part of an electrical reaction within where recombination of positive and negatives charges occur inside the semiconductor. During that process, electromagnetic radiation energy is released in the form of visible light.

LED lights serve more than any other commercially-available light source of up to 50,000 operating hours, which sums up to 5.7 years of continuous operation. The operational time of LED is influenced by the electrical current, voltage, humidity, chemicals, radiation, mechanical forces and temperature.

3.1.6 Light Emitting Plasma Lamps

Although LEP lamps share certain characteristics with LED lamps, they are different. LEP lamps generate radio frequency energy to power up the plasma light source. In essence, LEP offers the reliability of solid-state technology and the brightness of HID sources. As Figure3.10 shows, LEP technology shares many of the same characteristics with LED but also performs differently. Like LED, LEP provides solid directionality of the light output as well as and the ability to dim instantaneously. On the other hand, LEP has an order of magnitude higher lumen density, which means that a single source, only a few millimeters in size, can produce 23,000 lumens of brilliant white light. It also provides a full color spectrum with a CRI up to 94, and better source efficacy. LED luminaires work best in low and mid luminance applications, whereas LEP has superior performance in higher luminance applications such as streetlights, parking lots, big box retail, distribution centers and factories.

Figure 3.10: (a) LEP Lamp (www.worldwideenergy.com)

(b) LED & LEP (http://www.flashlightnews.com)

3.2 Lighting Control Technologies

Lighting automation is now becoming the rule rather than the exception. Looking around commercial buildings nowadays, one would notice that lighting automation is being used in a majority of these buildings, and is also considered in renovation projects. The reason that lighting control gained viral popularity can be summed in three reasons; energy management, aesthetics and code compliance. With energy and cost savings being the most important factor in order to reduce power and time of use, lighting controls also allow to create an emotional appeal when equipped correctly. By using simple means of light, the functions that this space can be used for can be changed drastically. Furthermore, energy requirements are normally regulated and must therefore be adhered to. Not only that, but occupants have different needs depending on the tasks they are requested to perform.

There are many ways to enforce lighting controls, but it is essential to take into account that lighting controls must not disrupt the normal working activities. This section will highlight lighting control technologies gained from building automation systems, occupancy sensors and day lighting systems.

3.2.1 Building Automation Systems

A building automation system is a smart network of electronic devices designed to automatically manage resources used in an entire building. While it sounds straight-forward by definition, it is in fact very difficult to achieve because all mechanical, electrical and lighting systems in the building must communicate together and speak the same language in order to produce the desired outcome. An effective way of utilizing building automation is by deploying occupancy schedules to control program when lights must go on and off. Although there are no solid numbers, it is estimated that about 10-30% of energy savings can be achieved by scheduling the control. Essentially, building automation is comprised of a number of controllers. Controllers are purpose-build computer devices that take commands as inputs and result in a preprogrammed output. The inputs of a controller can be the temperature, the humidity, the current flow or the air flow, or other essential factors. Once a controller is triggered by any or a combination of these inputs, it sends a command to one of its slave devices with desired outcome.

Furthermore, building automation system can help control energy emissions. Demand control ventilation allows the proper amount of outside air to be introduced into an office space by closely monitoring return. Not only that, but a critical but sometimes forgotten practice that improve the building energy efficiency is resetting various air steam temperatures and supply water temperatures to optimum set-points as dynamic loads change. Deploying lighting controls would reduce the unnecessary artificial lighting via schedules or motion sensors, and the automation of controls within a building optimizes HVAC efficiency.

One of the benefits of utilizing this method is allowing for lower operating and maintenance cost. The nature of intelligent automated interrelated systems working collaboratively together allow designers to deploy fault tolerance mechanisms to detect and correct errors, or at worst-case scenarios, safely halt the system all together. This would mean that maintenance would only be necessary as part of the periodic maintenance schedule, or if a fault is detected that the smart system was not able to resolve. Sensors would be deployed to monitor consumption which would allow service personnel to troubleshoot errors and view logs, as well as extract accurate statistics of building energy consumption rates. Building automation allow engineers to receive notifications when certain aspects of the building require attention. For example, alarms can be set for the following:

- Status alarms for mechanical devices
- High level of carbon alarm utilizing carbon sensors
- Low current alarms to indicate clogging strainers

Furthermore, operational costs are naturally reduced because the smart system is programmed to turn off or dim lights at none-working hours while still allowing manual control. Building automation systems can cover different aspects of indoor controls, such as air quality. Many sensors can be deployed to monitor temperature changes and humidity fluctuations, and carbon detectors can be utilized to monitor pollutants in order to ensure fresh air quality in the building. Building automation systems are likely to be deployed in larger, commercial-size buildings. In smaller buildings, lighting control panels are found instead. Lighting control panels are built using a modular framework in order to handle any type or size of lighting. It connects ballasts, field relays, relay panels and general purpose dimming modules for dimming or on/off control for all lamps in the building. These can have network capability which results in connecting devices on the panel network. It can also use clock functions for automatic astronomical calculations of sunrise and sunset, adjustable daylight savings time and timer scheduling.

3.2.2 Occupancy Sensors

Lighting accounts for up to 50% of building energy use. By simply turning off unneeded lights, building tenants and operators are able to reduce costs inexpensively which would lessen the environmental impacts associated with electricity consumption. Occupancy sensors are small devices often installed on office walls or ceilings in order to determine the presence or absence of people in a defined area. When the sensor detects an absence, lights are automatically switched on. Recent advances in these technologies allowed them to have more control by turning on or off depending on the amount of daylight available in their coverage area. Occupancy sensors are best used in areas with irregular use patterns or areas which are not frequently used; such as stairwells, corridors, small work rooms, locker rooms or storage units. Occupancy sensors utilize different technologies like passive infrared (PIR), ultrasonic and dual technology, or even acoustic detection as shown if Figures 3.11(a, b).

Figure 3.11: (a) Ultrasonic Sensor (b) Infrared Sensor with Daylight Filter

(www.3gegadegets.com/sensors)

The difference between PIR and ultrasonic sensor is that PIR sensors measures the difference between the heat emitted by moving people and the background heat, while ultrasonic sensors sends ultrasonic sound waves and measures the speed at which they return. Dual-technology sensors use a combination of PIR and ultrasonic technologies. Generally, occupancy sensors are comprised of motion sensor, electronic control unit and a controllable switch/relay. The motion sensor unit detects motion within a defined area and hence determines the occupancy status; it gives off a timer that signals the control unit after a set period of inactivity. The signal is processed by the control unit in order to issue on/off commands to the switch/relays.

When looking at occupancy sensors to install at a workplace, it is important to consider the sensitivity of the device as well as its detection accuracy and the capability to adjust multiple times. Sensors are prone to false triggers where the sensor thinks an object is present where in fact it is not, such as those movements associated with air from HVAC vents or motion on desktop due to HVAC flows. On the other hand, the constant switching of lights has an adverse effect on lamp life. A research by the Lighting Research Center at Rensselaer Polytechnic Institute concluded that occupancy sensors that are set to a short switching cycle will reduce the lifespan on fluorescent life (Maniccia et al., 2000). Therefore, most occupancy sensors have at least a 30-second delay time that engages when occupancy is no longer detected. Although the faster the lights are turned off, the more energy saved; but this also means that fixture cycling is increased as well which shortens the lamp life. Research also concluded that appropriate balance of lamp life and energy conservation using occupancy sensors by calibrating them to high delay setting. Furthermore, it is suggested to install programmed-start ballasts in areas where high number of switching cycles are expected per day. Figure 3.12 show the impact of lamp life based on switching cycle.

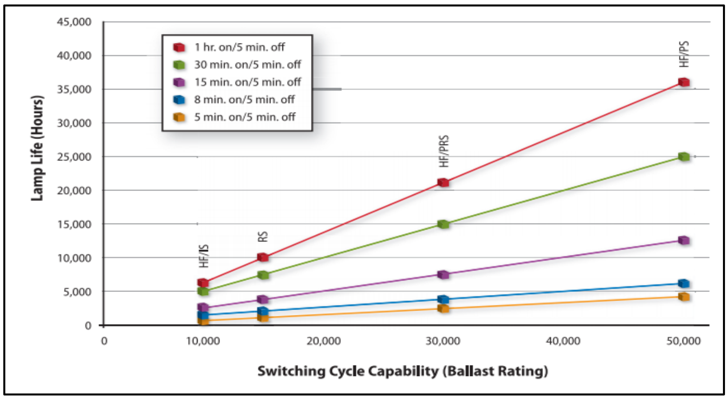


Figure 3.12: Impact of Lamp Life based on Switching Cycle

(http://hewilliams.com/brochure/OccSensWP.pdf)

3.2.3 Daylight Systems

Daylight can be optimally implemented with an innovative daylight system in buildings. Daylight systems employ the physical laws of absorption, reflection and refraction to illuminate rooms perfectly and still avoid excessive warmth. These systems create a pleasant room illumination with low glare and outstanding color rendering and highlight the rooms' space. Not only that, but because of the nature of daylight systems and its utilization of natural sunlight, they allow rooms to view outdoor scenery which nourishes the health and well-being of building occupants. Daylight systems do not allow direct sunlight exposure which tans the skin, warms the room and causes glare. On the contrary, daylight is the ideal light for viewing and it covers the complete color spectrum. Daylight systems come in two forms, with or without shading. Daylight systems with shading direct the sunlight onto varied locations in order to reduce glare problems. Daylight systems that do not have shading are mainly used to redirect daylight to other areas away from the window and provide homogeneous illumination. An example of day lighting system is the light shelf which is a flat baffle inside or outside a window to reflect light on its top surface and shield direct glare from the sky. Light shelves, as illustrated in Figure3.13, must be considered at the design phase of the building because they require high ceiling in order to function effectively; however, they movable versions of the light shelves may be introduced to existing buildings at an increased cost.

Figure 3.13: Stittsville Public School Vertical Light Shelves

(http://www.designshare.com/index.php/projects/stittsville-elementary/images@3973)

The geometry of the light shelf and the way it is positioned determines how effective it can be. When the light shelf is tilted upward, the penetration of reflected daylight is improved by the shading effect of the window is reduced. In contrast, when the light shelf is tilted downward, the light shelf reduces the amount light is reflected to the ceiling. Using light shelves increases the uniformity of light distribution and allows the room to appear well lit, which would reduce the probability of occupants turning on the artificial lighting. One of the disadvantages of using light shelves is that they can collect dust and snow and therefore they require regular cleaning. No other maintenance is required. Another example of day lighting systems are prismatic panels which are shown in Figure 3.14. Prismatic panels are thin devices made of clear acrylic that are used in hot climates to redirect or refract daylight. These units are positioned in the window pane on the exterior or interior sides. They are able to diffuse daylight from the outdoors to the ceiling of the room. The panels also reduce the brightness of the window so they serve as an anti-glare system. They can also reflect light coming from a range of angles while still transmitting light coming from other angles in order to change the direction of transmitted rays. Normally, prismatic panels are places in double glazed glass in order to eliminate the need for maintenance. However, if the designer of the building chooses not to have the panels in double glazed glass, the panels must be regularly cleaned in order not to damage the optical surfaces. Daylight systems come in different shapes and forms, and each system comes with its range of advantages and disadvantages. However, they all share one important benefit which is that they cut the requirements for artificial lighting and therefore sustainably reduce energy costs.

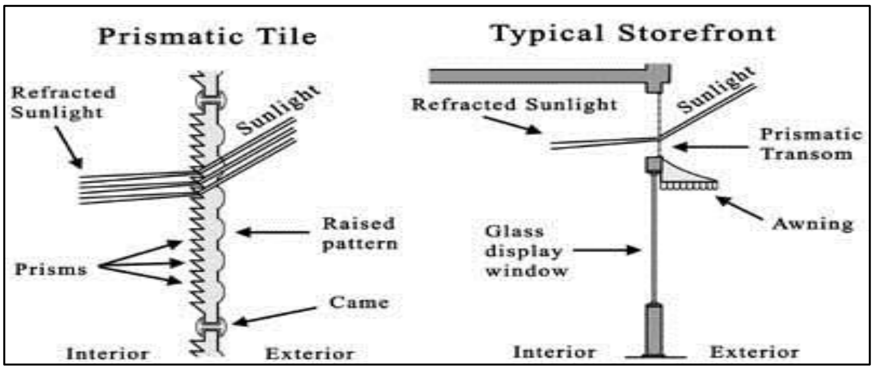


Figure 3.14: Prismatic Tile vs. Typical Storefront

(http://www.heathconstruction.com/page/82/title/10-5-11%20Prismatic%20Glass/)

3.2.4 Light Dimming Systems

Dimming systems are light control systems that adapt to the change in light levels steadily and hence reduce power and light output. Unlike switching devices (the on/off switches that provide the building occupants a sense of control over light within a room), dimming devices are expensive. Dimming can be either continuous or step. Step dimming is associated with dropping power to all lamps within the luminaire. On the other hand, continuous dimming is a uniform adaptation of the luminous flux of the light source with relevance to external information. There are many commercially available lighting systems today, such as the following:

- Conventional leading-edge and trailing-edge dimming systems: these are actually replacements of on/off switches in order to control circuits up to 1500W using electronic dimmable ballasts and transformers within the light fittings. These are the cheapest dimming systems available and come with a hefty list of disadvantages including noise, heat and minimum lighting levels at almost 15%-20%.

- Direct System Interface dimming: is a digital dimming system which can control independent channel or group of channels up to 64 fixtures, each channel connected to one number of lighting circuits.

- DALI (Digital Addressable Lighting Interface) dimming systems: are digital dimming systems with the highest specifications in the dimming technology as it can control one or more channels up to 128 and also can control every individual light fitting alone.

Chapter4

Research Methodology

The term "Research Methodology" refers to the way to systematically solve a research problem. In essence, research methodology allows the researcher to break down the steps required to derive the problem statement and produce a solution based on the logics involved. This section provides a brief about two of the most used research methodologies in the field of lighting and energy consumption, followed by a description and reasoning behind the selected.

4.1 Types of Research Methodologies

There are many types of methodologies that help to formulate theories and provide accurate results. Specifically, when deciding on a research methodology in order to derive conclusions regarding the most appropriate and energy-efficient lighting controls we consider the following three methods: experimental measurement method, computer simulation method and computer mathematical calculations method.

4.1.1 Experimental Measurement Method

As the name suggests, the experimental measurement method is used by researchers to collect data about lighting energy consumption when lighting controls are deployed by experimenting using predefined and controlled conditions. It uses cause-and-effect mechanism in order to derive conclusions by testing the controlled variables and allowing the researcher to manipulate the variables directly and develop experimental observations based on experiments which provide the strongest argument for cause-effect relationships. This method requires random sampling of subjects from a population and random assignment of subjects for treatment and control. Although this method is excellent in terms of the results it provides, it comes with a set of disadvantages that cannot be overseen. For example, it can be very costly to gather the equipment required to conduct the research and control the variables. Furthermore, the measurement time that is used to make the comparisons varies from seconds up to yearly, making it somewhat difficult to attain. This method is often used by researchers that have a research lab facility or a sponsor that is able to cover the associated costs and provide the tools and technologies used. Nevertheless, this method was used to present the results of an experiment at the Energy Center of Wisconsin (Energy Center of Wisconsin, 2005). The report intended to demonstrate reductions in lighting and HVAC energy consumption caused by lighting and window specifications. The researchers set up two sets of four identical rooms with independent lighting and HVAC systems. The first set, referred to as the test set, was configured with high-performance glazing and reduced transmittance as well as electric lighting and photo sensor dimming. The second set, referred to as the control set, was given standard configuration of clear-glass glazing and ceiling-mounted fluorescent fixtures with no dimming. All other aspects of the room were identical. The researchers conducted this experiment over three rounds of summer, fall and winter of 2003 in about 70 days of operation. An evaluation of the following was conducted at each round:

- Base configurations
- Reduced sources of light by covering windows in high-performance rooms with external panels
- Adding interior light shelf to enhance the distribution of natural light

During the experiment, the researchers continuously monitored the following attributes:

- The lighting energy calculated by the average lighting power draw per room.
- The interior light levels, represented by the vertical and horizontal luminance levels captured for each room.
- The air flow.
- The HVAC energy.
- Humidity and temperature indoor.
- Humidity and temperature outdoor.
- Space heating and cooling load based on energy balance across the water coils.

Using the minute-averages of the above attributes, the researchers were able to compute saving estimates and apply commercial utility rates in order to calculate the operating cost savings between the test and control sets. The results of this research were substantial. It was noticed that lighting and HVAC operational costs for the rooms with high-performance produced clear cut savings of more than 20%, about $1.13 per square foot (Energy Center of Wisconsin, 2005).

4.1.2 Simulation Method

Due to the disadvantages highlighted in the previous section about the experimental method, researchers and engineers had to tap into new areas in order to generate faster results. The computer technology paradigm as we know it has expanded against all expected bounds and is now able to generate accurate results based on entered parameters. Lighting simulation is being increasingly used by researchers substituting other methods. A survey conducted by (Reinhart & Fitz, 2006) showed that about 77% of participants used both computers and physical models for their professional practice. Simulation software became part of engineering education and provides evident mechanisms to verify code and compliance measures.

Computer simulation can be broke down into two main categories. There is the physical simulation where the real objects are exchanged with physical objects and the simulation software is applied on these models. The other category is concerned with the interaction of human being with the physical objects, called an interactive simulation. Lighting simulation models vary by the algorithms they use. However, all scientific computerized simulations utilize technology to provide predictive rendering, which means that the intention is to create accurate representation and prediction of objects under certain conditions and following the general laws of physics. In (Bekaert et al., 2006)'s book, the different lighting simulation algorithms were highlighted along with the way they have evolved through history. The book stated that modern physical models are too complex for computer calculation and image rendering, and therefore a substitution is necessary. The simulation model uses a model which combines simple geometrical optics and energy conservation which would allow it to solve most illumination problems using different light sources. The following is a list of lighting simulation algorithms with a brief description about each (Jensen, 1996):

- Direct calculations for artificial lighting: This method allows the researcher to simulate lighting based on national standards; it uses very simple calculation formulas.
- Ray-tracing algorithms: this algorithm is used to determine lighting calculations and portray appropriate rendering. It traces the light rays in different ways; from their light source, from the observer's eyes or from both.

- Scene-dependent algorithms: in computer modeling and simulation, a mesh is a collection of interlaced structures combined to formulate an object. Scene-dependent algorithms determine radiometric values for each mesh regardless of the view.
- Combinational approaches: these are a combination of two or more algorithms. They provide very efficient and accurate results because they run different calculations. This method also utilizes energy particles (photons, referred to as photon map in this context) to calculate ray trace.

The most widely used geometrical optics algorithms are those associated with ray tracing and radiosity. Despite having algorithms that are automated to generate very accurate results, when introducing new elements using principles beyond the capacities of these algorithms it is necessary to perform physical experiments.

Figure shows the most commonly used lighting simulation algorithms.

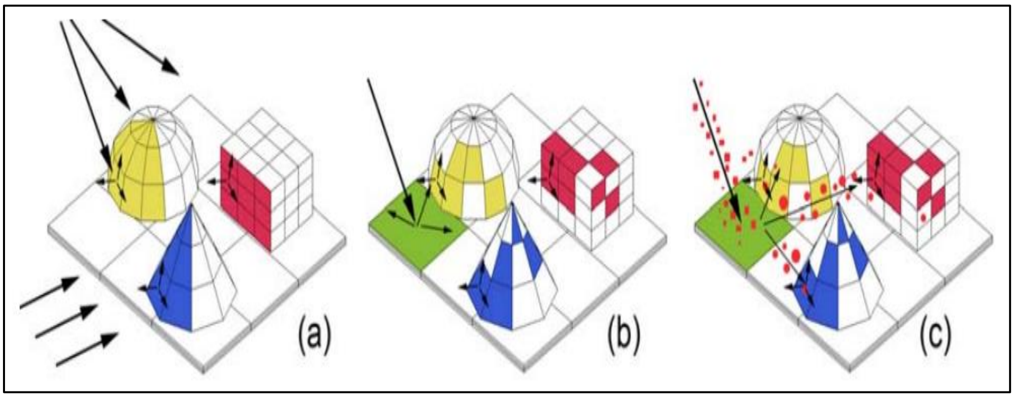


Figure4.1: Three commonly used lighting simulation algorithms

(a) raytracing (b) radiosity (c) photon map

(http://www.bwk.tue.nl/bps/hensen/publications/10_ibpsa-nvl_ochoa.pdf)

A study by (Bülow-Hübe, 2008) about daylight availability and electricity use for lighting in offices uses simulations and demonstrates that it can be possible to reduce energy use about 50% with different proposals of occupancy and lighting control. A similar study was developed by (Roisin et al., 2008) focused on the effect of building positioning using diverse control lighting systems. The results demonstrated that daylight-linked control systems provided high energy saving reaching up to 61%. There are over twenty computer applications available in the market, which are used to measure energy efficiency in a building. Other than the general modeling and rendering features, these applications often have the following added capabilities: zone loads, building envelope and day lighting, infiltration, ventilation and multi zone airflow, renewable energy systems, electrical systems and equipment, HVAC systems, HVAC equipment, environmental emissions, economic evaluation, climate data availability, results reporting and validation. Some of the major building energy simulation applications available include BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-lO, Energy Plus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS (Crawley et al., 2008). The journal article published by (Crawley et al., 2008) compared the twenty most commonly used energy simulation software listed above, and found that the IES-VE software provided various interlinked parameters and assessment options including building envelope, daylight and solar variables which are important for this study. IES has proven to provide high reliability and accuracy of its results with its collection of advanced features. In fact, (Hammad & Abu-Hijleh, 2010) used the computer simulation method and utilized IES-VE in order to explore the influence of the external dynamic shading system on the energy consumption for an office building. The researchers investigated the energy saving effect by using IES-VE software due the wide-range of features that the software provides such as availability, flexibility of environmental control and the time saving.

4.2 Selected Method and Software

Due to the flexibility offered by the simulation method, demonstrated in Table4.1, it was chosen to perform and analyze results presented in this research. Evaluations of lighting simulation software can be either comparisons of a replicating built reality or comparisons in a controlled lab setting. Comparisons that replicate existing built environments show increase usage and accuracy of models in architectural contexts, whereas validations under controlled labs show the correctness of a model in foreseeing illumination data (Roy, 2000).

Table4.1: Advantages and Disadvantages of Simulation and Field Study Methodologies (Hammad & Abu-Hijleh, 2010)

Characteristics	Simulation Study	Field Experimental Study
Reliability	+	-
Replicability	+	-
Cost	+	-
Subject to Disturbance and errors	+	-
Use of Resources	+	-
Control of Variables	+	-
Easy to conduct	+	-
Time	+	-
Reality	-	+
Validity	-	+
Understanding future behavior	+	-
Ability to scale objects	+	-
(+) Advantage (-) Disadvantage		

4.2.1 Basic Principles of Energy Simulation Techniques

As discussed in previous section, energy simulation applications emulate results based on predictions by taking into account various factors. The key of providing the most accurate results lies in the accuracy of the inputs to the simulation engine. For example, the building's geometry and components like walls and windows must be precisely entered in the simulation software because variations in these aspects can affect the energy consumption rate. Furthermore, the surrounding environmental data, such as that associated with external temperature, humidity or even wind speeds, must be taken into account as well. Other than that, the data supporting the electricity of the building must also be considered because they measure against the building's overall energy consumption. Figure simplifies the process of simulation using simulation software.

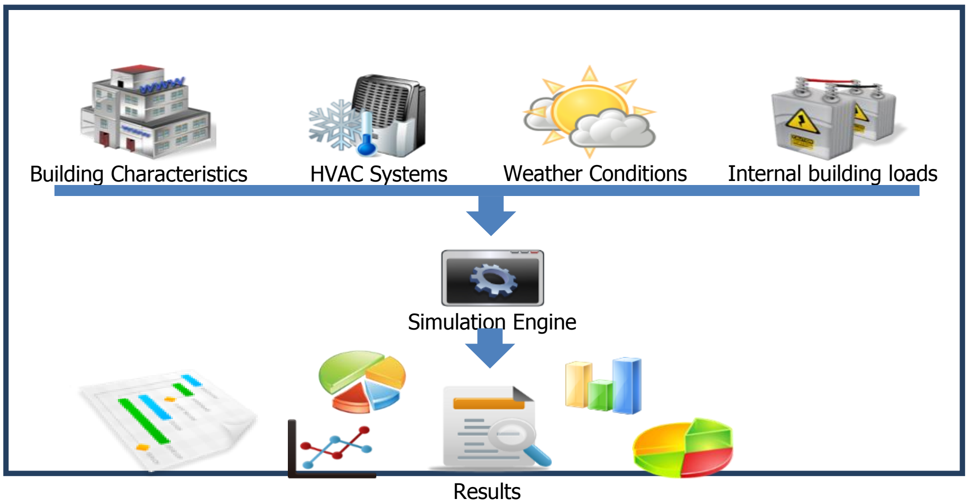


Figure4.2: Process of Simulation

(http://www.bwk.tue.nl/bps/hensen/publications/10_ibpsa-nvl_ochoa.pdf)

When simulating models to measure energy consumption, it is essential to consider weather conditions. Data formats of weather should include the basic location information such as the name, state, province, region, country, latitude, longitude, time zone, elevation level, peak hot and cold temperatures. In addition, daylight savings, average and extreme temperature periods are also included as input data. After supplementing the software with the required inputs, the simulation engine in the desired software runs for some time, and then produces a rendered emulation of the building. Most software come with analytical tools that can also be run after the rendering has finished. The analytical capabilities of the software provide tables and graphs about every aspect of the building in terms of energy use.

To evaluate the benefits of controls, a cost benefit analysis was be performed. This cost benefit analysis was used to find the payback period for the system installed in the MOPW-RAK building. It took into account the capital cost of the system, annual maintenance, electricity bills and tariffs etc. The payback period does have certain limitations and qualifications for its use. It will not take into account the time value of money, the risk involved or opportunity cost. The cost benefit analysis was completed to find out the time value of money for long terms projects like this. Although the payback period for projects like this are usually considered in around 3-4 years. This research focused on the possibility of using all different lighting controls to save energy. Motion occupancy sensors are already installed in the MOPW-RAK building. The occupants had problems with the sensors and often disabled them. The reason for this was that the occupants were working at their desk for long periods of time and when the PIR did not sense any movement (after the pre-set period 5-10 minutes), the lights went off. This led to the occupants overriding the system and manually dimming lights or switching lights on in offices.

4.2.2 Dialux Lighting Simulation Software

For the purpose of this research, the Dialux software was used to simulate the building's lighting design. Dialux is a lighting simulation application that can be used to analyze energy consumption results based on predefined conditions which can me automatically altered using the features of the program. The Dialux software features a set of advanced capabilities that serve the purpose of this research, including:

- Simple, effective and professional light planning
- Latest luminaire data of the world's leading manufacturers
- Energy evaluation
- Colored light scenes with LED or other color changing luminaires
- Planning whole buildings including outdoors spaces

The Dialux software allows for entering the required lux level and the room dimensions in order to find the most appropriate recommendations of different types of lighting fixtures. It also gives a full technical and economic analysis report of each area of the study. This researched used building simulation to study the effects of each type of lights on HVAC systems.

4.2.3 IES-VE Building Simulation Software

Virtual Environment by Integrated Environmental Solutions (IES-VE) is commercially-available software that represents a modern example of dynamic building energy simulation software. It is commonly used within the building services industry because it is capable of modeling complicated building environments. It does not require the user to have any knowledge of computer programming or of the mathematics and equations that govern the building physics, as all the interaction between the user and the software is done through a graphical user interface (GUI). The user, therefore, is only required to give the software specific inputs, whilst the output results are given graphically; however, knowledge of building physics is fairly essential to be able to sensibly interpret the results. IES-VE is able to take the following factors into account when performing the simulation:

- Employee productivity
- Flexibility to accommodate multiple types of work and spaces
- Personal comfort and safety
- Organizational culture
- Total cost ownership.
- Model Validation (Validity and Reliability)

VE has different modules that serve different purposes. Building models can be constructed the "Model IT" module, which can then be analyzed in a variety of ways. For instance, a module called "MacroFlo" investigates the effectiveness of natural ventilation. One of the most commonly used modules is the "Apache" thermal analysis module, which provides steady-state or dynamic analysis of energy consumption and indoor thermal conditions. The day lighting calculation is conducted by using the "Radiance" module. Additionally, for the overheating analysis the software is be able to model bulk air flow within the building in order to establish the effectiveness of the proposed ventilation strategy. IES-VE performance analysis tool allows architects and engineers to simplify a sustainable design progression by offering measurable feedback on the environmental performance of diverse design options. On average, green buildings use 30% less energy than conventional buildings, although through the use of IES software the potential is much higher. It is a robust energy analysis tool that offers a high degree of accuracy and interoperability. The downsides are its current complexity for the user and the relatively expensive cost of the software. Energy simulation tools caused a tectonic shift in the building construction age and are increasingly used for the analysis of energy efficiency of buildings and comfort of their occupants by engineers and architects alike. Figure4.3 illustrates the ranking of IES-VE software amongst a sample of other tools according the preferences of engineers and architects. Numerous researches indicated that tiresome manual data input for building energy performance and consumption simulation distracts time and resources from productive simulation runs, and also because of the fact that data defining a building, its heating, ventilation, air conditioning (HVAC), Lighting systems and its expected pattern of use and operating schedules, is managed by different and non-interoperable software. Data obtained in previous studies (Maile et al., 2007) show that the ideal workflow for energy performance simulation tools is divisible into six phases which are the following:

- Define the location of the building.
- Provide 3D details, construction and materials definitions, and space types.
- Assign space or lighting loads to the specific appropriate space types.
- Define HVAC and lighting systems and components.
- Perform simulation.

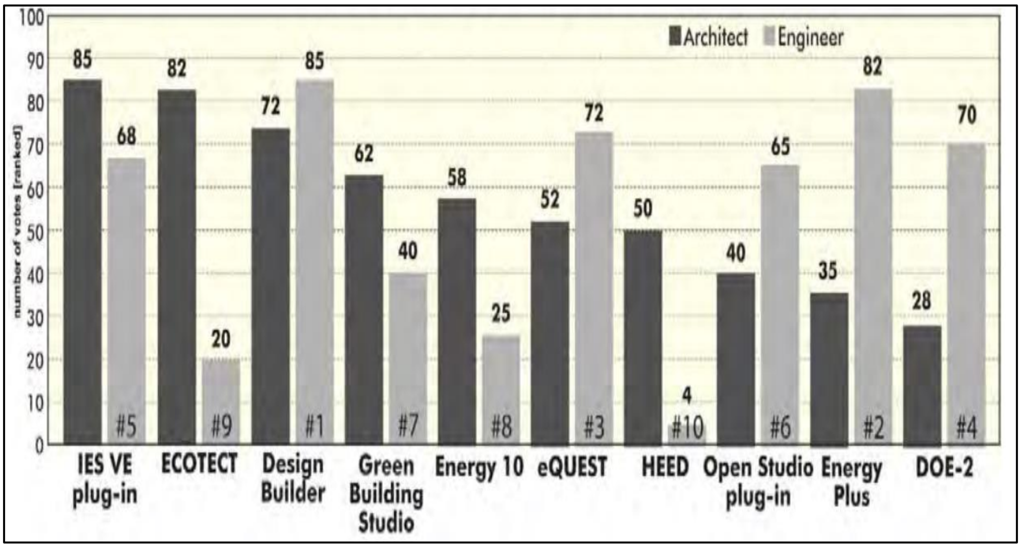


Figure 4.3: IES-VE amongst Other Tools

(Attiaa et al., 2012)

4.3 Study Validity and Reliability

IES-VE software provides some valid and reliable results. The software has received attestations for validity and reliability from different environmental authorities such as the American Institute of Architecture (AIA), Communities and Local Government (CLG) and Energy Balance Evaluation (EBE). The output model was constantly being reviewed by an IES technical advisor. Several sessions were organized to verify the modeling process as well as to confirm that all steps and parameters undertaken by the researcher were the accurate. Dialux lighting simulation software was used to compare results with IES-VE. The analysis discussion and results were debated with more than three established professionals and lighting specialist engineers from different lighting manufacturers, factories and lighting suppliers. The results of the HVAC and cooling systems were validated with the mechanical engineer who specializes in HAP HVAC simulation software. In addition to software simulation and validation, this research used the experimental method by using lux measurement instrument to measure the lux level during the working day at different times.

Chapter5

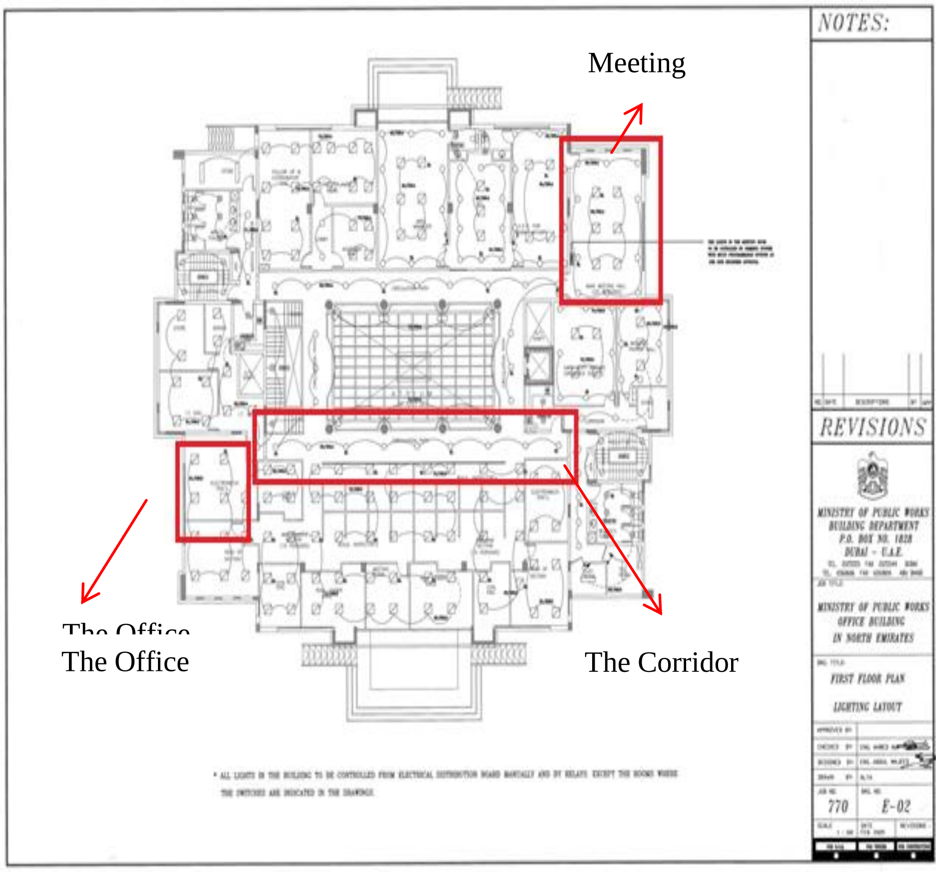
Building the Simulation Model

5.1 Building Description

This research uses the building of Ministry of Public Works in Ras Al Khaimah (MOPW-RAK) as a case study. A number of factors contributed in the selection process of evaluation options to favor the selected building. Perhaps, the most obvious factor is the fact that the researcher is already an employee of MOPW and thus has easy access to all required documents of the facility; the researcher of this study was one of the consultants for this building while it was still under construction. Furthermore, the building has only been recently established in 2010 which means it used relatively new technologies. Figure5.1 shows the building of the MOPW-RAK. As for Figure5.2, it shows the chosen areas for the study.

Figure5.1: (a) MOPW-RAK Building (Back Side)

(b): MOPW-RAK Building (Front Side)



Number of Rooms	
Offices	13
Nursery	1
Prayer Room	2
Cafeteria	1
Nurse Room	1
Multipurpose Room	1
Meeting Room	2
Storage Room	4
Reception	2
Library	1

Figure5.2: First Floor Layout of MOPW-RAK Building Indicating the Three Selected Areas for the Study

The electricity consumption bills of MOPW-RAK indicate high usage of wnwrgy consumption. In an attempt to reduce energy consumption rate, this research pursues the best way to achieve this target with the lowest possible cost. To begin with, this research presents a comparison of the amount of power consumption for all the electrical and mechanical systems of the building, then chooses the system that consumes the most energy and finally investigate a way to reduce the amount of consumed. The load schedules for all the mechanical and electrical systems in the building will be analyzed to define each system electricity consumption amount in KWatt. The following results were found based on the load schedule of the MOPW-RAK building project documents. The data in for the power consumption of all the mechanical and electrical systems in the building were summarized inTable5.1. For the purpose of this research, the lighting systems were selected to be upgraded because it is easier and less expensive than the HVAC system.

Table5.1: Power Consumption for MEP Systems in MOPW-RAK Building

System Description	Power Consumption (KW)	Percentage
Lights	50.6	17%
13A Power Outputs	41.5	14%
Water Heaters	6	2%
Isolators	22.3	7.50%
Air Conditioners	174	59%
Total	294.4	100%

To achieve the required target of the research, the following steps are included:

- Structural and MEP specifications of the building to use them as an input to the simulation software.
- Matrix for the study will be created to include the different types of lighting energy saving technologies and lighting control technologies to simplify the results and analysis of the study.
- Dialux simulation software will be used to study and simulate the existing lighting technologies and lighting control technologies in the selected areas of the building.
- IES-VE simulation software will be used to find the effects of changing lighting systems on HVAC and cooling systems.
- A comparison between the simulation results of the existing and the proposed lighting and control technologies will be done.

In order to appropriately simulate MOPW-RAK using Dialux and IES-VE, the researcher had to find the correct building construction materials which were used to build MOPW-RAK. The simulation process used by the software is described in Figure5.3.

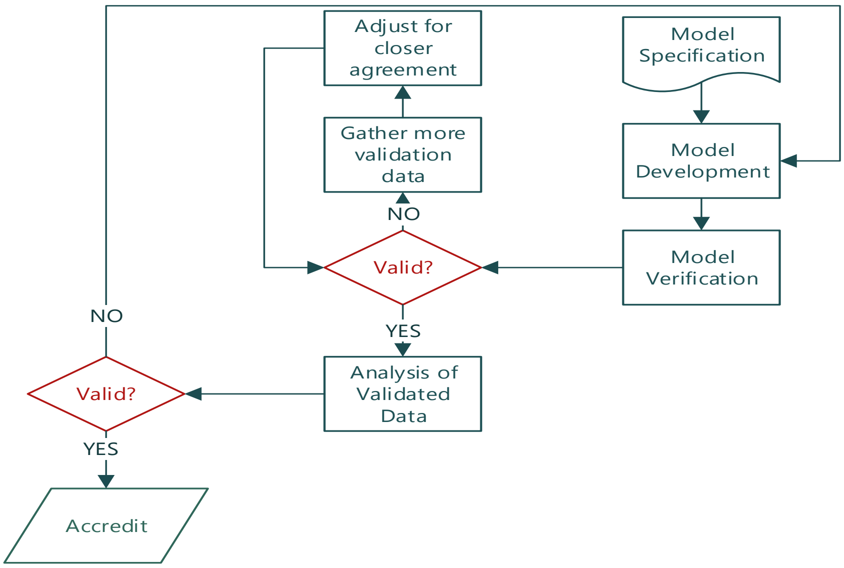


Figure5.3: Simulation Model Development Process

There are three simulation areas which were created and simulated in Dialux which are the followings: The Meeting room, The Electromechanical Office and a part of the Corridor. The construction materials layers define the thermal properties for building elements which has an important role in the building thermal performance. The construction materials that have been used in IES-VE are demonstrated in Figure5.4

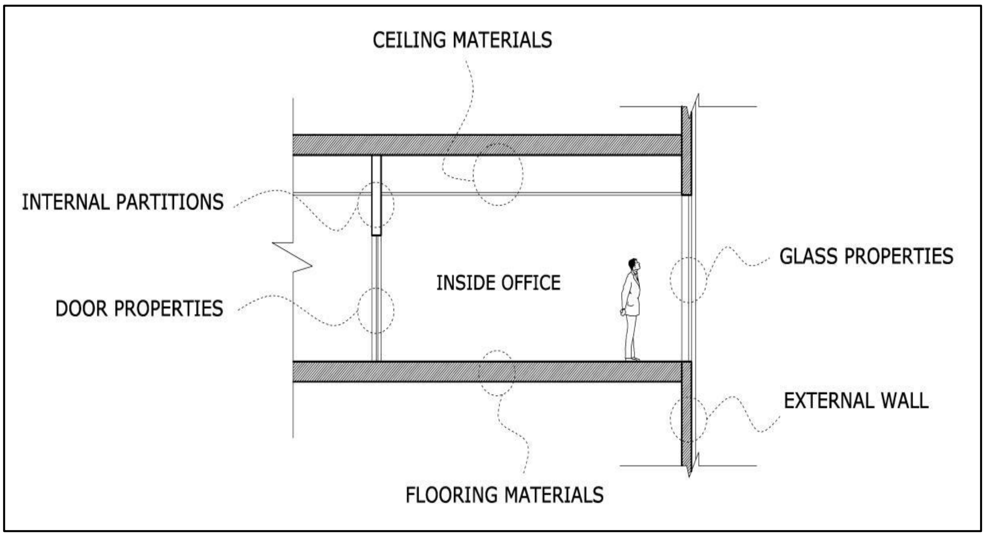


Figure5.4: Six Building Consideration Materials for Simulating Building Models

(Al-Geresi, 2011)

5.2 Description of Building Utilities

As previously mentioned, the building is relatively new so it is equipped with some new control systems. Namely, the HVAC and Lighting systems use fairly recent equipment. This section provides a brief about the technologies deployed in the MOPW-RAK building.

5.1.1 Mechanical HVAC System

The building is equipped with a ducted split HVAC system that guarantees an air-conditioned atmosphere in summer and winter. The ducted split HVAC technology offers a central temperature that can be zone controlled and is able to cover a very large range. The ducted split HVAC illustrated in Figure5.6 is used on the ground floor of MOPW-RAK. Table5.2 shows the air flow statistics for the unit and Table5.3 provides some technical specification about the unit. Furthermore, some rooms are equipped with packaged air conditioning system which comes in the specs described in Table5.4

Figure 5.5: Ducted Split Units

(http://www.klrtrades.com.au/Photos/Refrigeration/ducted-air-conditioning.jpg&imgrefurl)

Table 5.2: Air Flow versus Statistics Pressure Performance

	Air Flow (cfm)						
Fan Speed	External Static Pressure (in.W)						
	0 cfm	0.05 cfm	0.10 cfm	0.15 cfm	0.20 cfm	0.25 cfm	0.30 cfm
High	650	595	540	465	385	305	225
Medium	560	505	450	370	295	225	
Low	360	310	250	170			

Table 5.3: Technical Specifications of Ducted Split Unit

(http://www.klrtrades.com.au/Photos/Refrigeration/ducted-air-conditioning.jpg&imgrefurl)

System size		20	28	32	39	48	60
System model	Cool only	53CCD20-C	53CCD28-C	53CCD32-C	53CCD39-C	53CCD48-C	53CCD60-C
Indoor unit model	Cool only	42CCD20-C	42CCD28-C	42CCD32-C	42CCD39-C	42CCD48-C	42CCD60-C
Outdoor unit model	Cool only	38CCD20-C	38CCD28-C	38CCD32-C	38CCD39-C	38CCD48-C	38CCD60-C
Cooling capacity	Btu/hr	20000	25800	30000	39500	49500	57500
	kW	5.86	7.56	8.79	11.58	14.51	16.85
Power input (Outdoor + Indoor)	W	1915	2540	3060	4020	3970	5045
Current input (Outdoor + Indoor)	A	9.2	12.3	15.7	19.5	9.2	10.9
E.E.R.	Btu/wh	10.44	10.16	9.80	9.82	12.47	11.40
	W/W	3.06	2.98	2.87	2.88	3.65	3.34

Table 5.4: Package Unit AC Specification and Capacity

(http://www.klrtrades.com.au/Photos/Refrigeration/ducted-air-conditioning.jpg&imgrefurl)

Model	Nominal Tons	Height (in.)	Width (in.)	Length (in.)	Capacity Cooling-BTUH	Seer
TCC018F	1 ½	25	36	55	18,000	10
TCC042F	2	25	36	55	23,400	10
TCC030F	2 ½	29	36	55	29,800	10
TCC036F	3	29	36	55	35,200	10
TCC042F	3 ½	29	36	55	40,500	10
TCC048F	4	33	45	64	48,000	10
TCC060F	5	33	45	64	60,000	10

5.1.2 Electrical Lighting Systems

There are fifteen types of lighting in MOPW-RAK Building which are specified in Table5.5. It appears that the type of lamp that is mostly used within the building is the T8, a 4*18W recessed mounted florescent lighting fixture with opal diffuser with protection of (IP-40) which is used mainly in all offices. The location of each type of light is shown in Figure5.7and Figure5.8. Circulation areas and halls use a 2*13W down light recessed mounted compact florescent lighting fixture with protection of (IP-20) and Aluminum louver. The lux level for each area found in the building specification document is described in Table5.6.

Table5.5: Lighting Fixture Types in the MOPW-RAK Building

TYPE	SYMBOLS	DESCRIPTIONS
A		2X58W SURFACE MOUNTED FLUORESCENT LIGHTING FIXTURE WITH OPAL DIFFUSER TO (IP-54)
B		2x36W BATTEN TYPE WITH REFLECTOR FLUORESCENT LIGHTING FIXTURE TO IP (IP-40)
C		4x18W RECESSED MOUNTED FLUORESCENT LIGHTING FIXTURE WITH OPAL DIFFUSER TO IP (IP-40)
D		4x18W RECESSED MOUNTED FLUORESCENT LIGHTING FIXTURE WITH ALUMUNUIM LOUVERS TO (IP-20)
E		2X13W DOWN LIGHT RECESSED MOUNTED COMPACT FLUORESCENT LIGHTING FIXTURE TO (IP-20) WITH ALUMINUM LOVER
F		2X18W DOWN LIGHT RECESSED MOUNTED COMPACT FLUORESCENT LIGHT FIXTURE COMPLETE WITH REFLECTOR TO (IP - 43)
G		POLE LIGHTING SYSTEM WITH ALUMINUM BODY AND GLASS DIFFUSER (80-135cm) HIEGHT TO (IP-44)
H		18W COMPACT FLUORESCENT BULK HEAD FIXTURE WITH DIE-CAST ALUMINIUM BODY, (IP-44)
I		100W, METAL HALIDE LAMP UNBREAKABLE CLEAR COVER TO (IP-44) + 300cm HIGH POST COMPLETE WITH BASE
J	EM	8W SURFACE EMERGENCY LIGHTING FIXTURE FOR NON-MAINTAINED 3 HOURS OPERATION
K	EXIT	8W EXIT LIGHTING FIXTURE FOR MAINTAINED 3 HOURS OPERATION
L		70W UP & DOWN CYLINDRICAL FIXTURE WITH DIE-CAST ALUMINIUM BODY TO (IP-44) .
M		70W NIGHTLINE FIXTURE WITH WALL ARM TO ILLUMINATE THE LOGO WITH DIE-CAST ALUMINIUM TO (IP-65) .
N		70W NIGHTVISION WALL WASHER FASAD LIGHT WITH DIE-CAST ALUMINIUM TO (IP-65) .

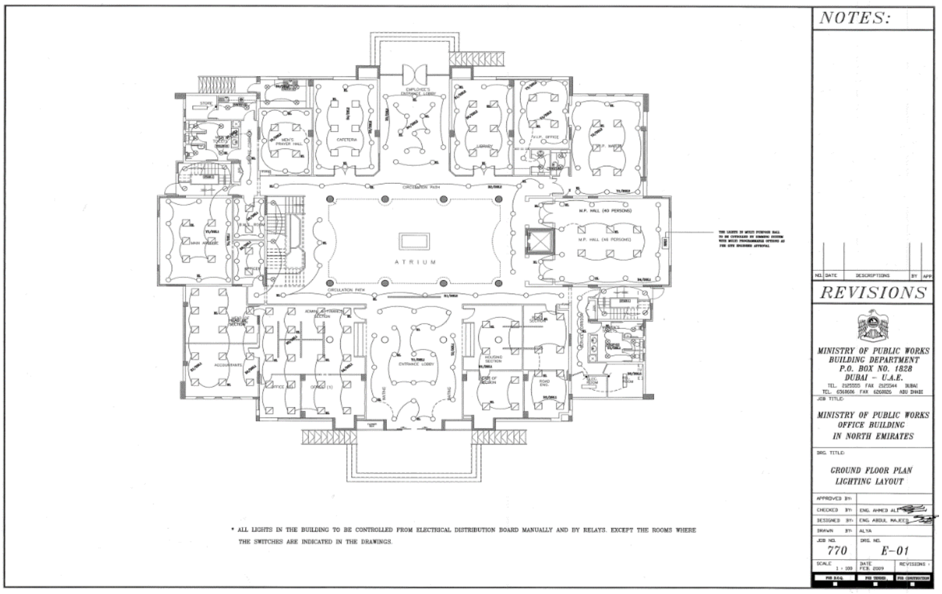


Figure5.6: Ground Floor Lighting Layout

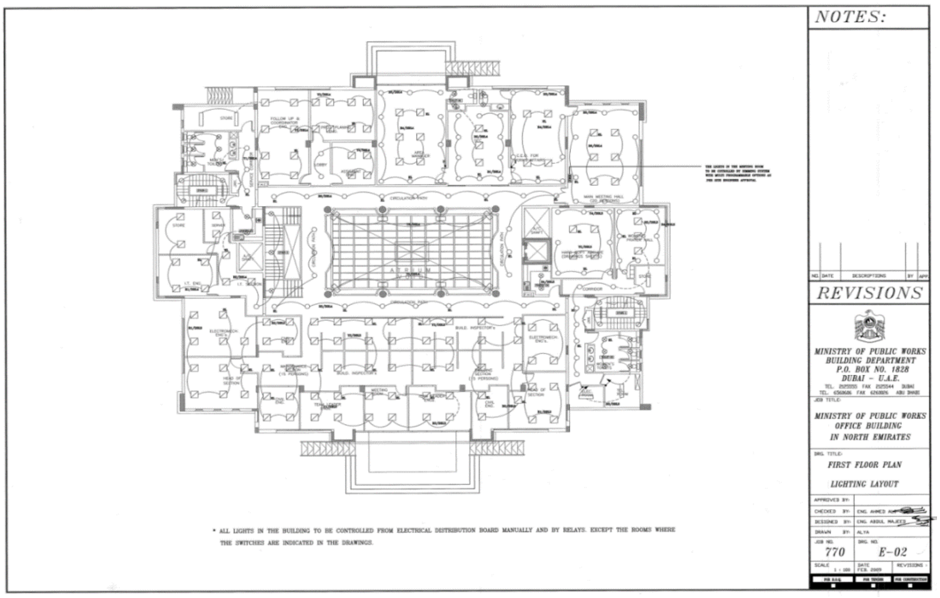


Figure 5.7: First Floor Lighting Layout

Table5.6: Lux Levels for Each Area in the NOPW-RAK Building

Location (area)	Lux level
Offices	400-600 lux, fluorescent
Meeting rooms	400-600 lux, fluorescent
Corridors	150x, fluorescent

5.3 MOPW-RAK Building Simulation Model

The requirements to model the MOPW building, such as the dimensions and measurements described in **Error! Reference source not found.**, were gathered to ltimately model the MOPW-RAK using IES-VE software, the result is presented in Figure5.8

Figure 5.8: MOPW-RAK Simulated Building Model

The meeting room assumed to host a maximum of 20 persons with two computer workstations using power of 400W, two workers with maximum sensible gain 90.0 W/person and Internal lighting luminance of 500 Lux was fixed.

Table5.7: MOPW-RAK Measurements

Area	Length (L) Meter	Width (W) meter	Height (H) meter
Meeting Room	9.15	6	3
Office	5.05	3.55	3
Corridor	15.30	2	3

The model was constructed using the Model IT module inside IES-VE. The model utilized the predefined model parameters which used the Building Template Manager, Constructions Database and APLocate to identify the room parameters, construction materials, location and weather data, respectively. Then, the radiance lighting simulation component is used to position the lighting sensor in its place at a certain distance from the window at the centerline of the area. The "Apache" button will produce a model file for use in the ApacheSim Radiance link. Next, the profiles database (APpro) is used to set up the profiles of lighting system. Light luminaries are linked to the variation (operation) and dimming profiles. Sun cast component was also used to perform shading analysis and solar insolation for the obstructions, windows and openings. This analysis is carried out every time the lighting technology or lighting control technology file is changed or if there is any change in the orientation. The results of this simulation are linked to the Apachesim before running the simulations. Finally, ApacheSim is used to carry out the simulations. In this component, a link can optionally be created to Sun cast and Radiance to incorporate the effect of shading devices as well as the lighting sensor profiles.

The meeting room has a perimeter location in the building; it has three windows on the external façade with 961x760 centimeters in dimensions, hovering across a heavy duty powder-coated aluminum-box window which has been divided into thirty-eight fixed parts. The window uses a double-glazed clear glass that is about 6 millimeters thick in the inner section and another 6-millimeter-thick reflective tinted glass from the outer section. Another 120x110 centimeter window resides in the room that is equipped with medium duty powder coated aluminum box and is divided into two parts, fixed and sliding, with 6 millimeter thick reflective glass. The room also has two doors; one is made of beech wood that is 50 millimeters in thickness that measures 90x220 centimeters. It has a hollow core, about 60% solid, with hard wood lipping all around with powder coated heavy duty aluminum frame.

The door leaf is finished and sprayed by a good quality and approves stain paint coating. The other door is also made of beech wood that is 50 millimeters in thickness, but is slightly larger, about 140x220 centimeters. It also has a hollow core, about 80% solid, with beech wood veneer fixed on 6 millimeter thick plywood on both sides. It has a 25 millimeters hard wood lipping all around the finishing and a beech wood door frame with sprayed good quality and approved stain paint coating. On the other hand, the electromechanical engineer office is a rectangular shaped office that has no windows and only has one door similar to the small meeting room door above. It has four 4x18 Watt aluminum louver lighting fixtures and one motion sensor in the middle of the office.

Finally, the corridor is a rectangular open area that has offices on the right side, and W14 medium duty powder coated aluminum box section with decorative sand blasted glass on the left side. There are two motion sensors on the corridor with seven 2x13 Watt down light fixtures. The meeting room has a dimming occupancy sensor which was fixed on the ceiling, about 2 meters away from the external window in order to maintain the artificial lighting level during all operational time to provide 500 lux on the working desk level. Furthermore, the ceiling was fixed with fluorescent luminaries lighting unit at 2.8 meters high, with installed power density of 2.2 $W/m^2/100lux$. Table5.8 includes the List of glazing construction materials used while Table 5.9 includes a list of the opaque construction materials used.

Table5.8: Glazing Construction Materials of MOPW-RAK

	Material (Outside to Inside)	Thick (M)	Transmittance	outside Reflect	Inside Reflect	CIBSE U Value (W/m2.K)
External Windows	low-e double glazing(6mm+6mm)(2002regs)					**1.977**
	Pilkington 6mm	0.006	0.69	0.09	0.09	
	Cavity	0.012				
	Clear float 6mm	0.006	0.78	0.07	0.07	
Internal Windows	4mm Pilkington single glazing					**3.688**
	Clear float 4mm	0.004	0.82	0.07	0.07	
Roof Lights	low-e double glazing(6mm+6mm)(2002)reg	0.006	0.69	0.09	0.09	**2.103**
	Pilkington 6mm	0.012				
	Cavity	0.006	0.78	0.07	0.07	
	Clear float 6mm					

Table5.9: Opaque Construction Materials of MOPW-RAK

	Material(outside to inside)	Thickness (M)	Density (Kg/m2)	Conductivity (W/m.K)	Category	CIBSE U-Value (W/m2.K)
External Walls	standard wall construction (2002 regs)(lightweight)					**0.3495**
	Brickwork (Outer Leaf)	0.1	0.84	1700	Brick & Block work	
	Dense EPS Slab Installation - like Styrofoam	0.0585	0.025	30	Insulating	
	Concrete Block (Medium)	0.1	0.51	1400	Concrete	
	Gypsum Plastering	0.015	0.42	1200	Plaster	
Interna Partition	Steel (very light weight)	0.001	50	7800	Metal	**5.8817**
	ALUMP sheet Aluminum (very light weight)	0.001	160	2800	Metal	**5.8821**
	13mm pll 105mm bri 13mm pll very light(weight)					**1.6896**
	Plaster (Light weight)	0.013	0.16	600	Plaster	
	Brickwork (Inner Leaf)	0.105	0.62	1700	Brick & Block work	
	Plaster (Light weight)	0.013	0.16	600	Plaster	
Internal Ceiling/Floors	Carpeted 100mm reinforced -concrete ceiling					**2.2826**
	Synthetic Carpet (Light Weight)	0.01	0.06	160	Carpets	
	Cast Concrete (Dense)	0.1	1.4	2100	Concrete	
Ground-Contact /Exposed Floors	Standard floor construction(2002 regs)(very light weight)					**0.2499**
	London Clay	0.75	1.41	1900	Sands Stones	
	Brick Work(Outer Leaf)	0.25	0.84	1700	Brick & Block work	
	Cast Concrete	0.1	1.13	2000	Concrete	
	Dense EPS Slab Installation - like styrofoam	0.063	0.025	30	Insulating	
	Chipboard	0.025	0.15	800	Timber	
	Synthetic Carpet	0.01	0.06	160	Carpets	
Roofs	Flat Roof (2002 regs)(very light weight)					**0.2497**
	Stone Chippings	0.01	0.96	1800	Sands & Stones	
	Felt/bitumen layers	0.005	0.5	1700	Asphalts &other	
	Cast Concrete	0.15	1.13	2000	Concrete	
	Glass Fiber QuilT	0.134	0.04	12	Insulating	
	Gavity	0.1				
	Ceiling Tiles	0.01	0.056	380	Tiles	
Doors	wooden door pine (20%moist)(very light weight)	0.04	0.14	419	Timber	**2.1944**

In order to achieve accurate simulation models, (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2009) recommends some key parameters to be considered. These parameters include the glass shading coefficient, U-value, thermal coefficient, transparency, conductivity and emissivity:

- The glass shading coefficient indicates the ability of glazing to prevent solar radiation; when the value of shading coefficient is low, it means that lower solar heat gain penetrated through the glass.
- The U-value indicates the air-to-air thermal diffusion of building materials due to the thermal conduction of its components and the radiation effects of its surface.
- The thermal coefficient in IES is expressed as a number between (0) to (1). The higher the thermal coefficient value is, the more preferred it becomes in solar heating applications in order to attain maximum sun radiation.
- Transparency is, as the name suggests, a condition where the component is see-through.
- Conductivity in IES shows the transmission of heat across materials and the ability to transmit from higher to lower temperature.
- Emissivity indicates the ability of this element to radiate long-wave radiation.

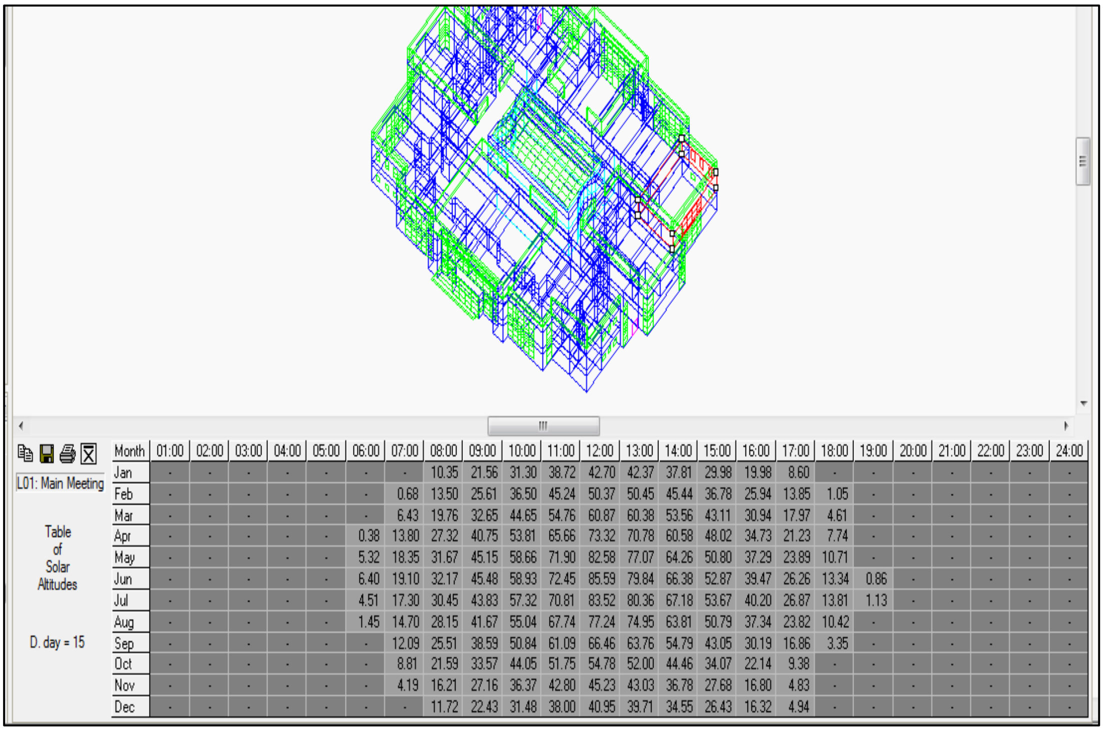
5.3.1 Operational Times

The operational timing of the office is entered in the software based on the normal working days which span across 7-working-hours per day, Sunday to Thursday. Working hours must also be scheduled for HVAC system using the simulation process; therefore, the APpro tool in IES-VE comes in handy to allow users to create different operation profiles for each operating system individually with different operational periods, such as daily, weekly and annual profiles.

This research used two profiles for differently operating systems. Namely, the office lighting fixtures are modeled to achieve between 300 and 500 lux in two different cases which are presented in the matrix for the combined natural daylight and artificial light. The second profile is for the computers equipment.

5.3.2 City Weather Data

The city of Ras Al Khaimah (RAK) lies between latitudes 25°-47°N, and longitudes 55°-57°E. The region is generally very hot during the summer because of the subtropical site. Areas overlooking the Arabian Gulf often have very high humidity as well, reaching up to 90% between the months of April and September. Winter, on the other hand, is sunny and dry with occasional short rains. The average temperature lies between 18°C to 25 °C in January and 29°C to 43°C in July, with the highest recorded temperature is 48.8°C. Rains and thunderstorms occur rarely, and when they do they only happen in winter. Snow has only been reported twice and it occurred on the high mountains of RAK. Table5.10 shows provides the climate data for the city of RAK, It also shows how it was plugged into the software. A module of IES-VE software called APlocate allows the simulator to manipulate the weather and site location to account for the heat loss and heat gain. APlocate location can be used to select four different days representing the 4 different seasons to test the building office energy consumption performance in different seasons.



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan	-	-	-	-	-	-	-	10.35	21.56	31.30	38.72	42.70	42.37	37.81	29.98	19.98	8.60	-	-	-	-	-	-	-
Feb	-	-	-	-	-	-	0.68	13.50	25.61	36.50	45.24	50.37	50.45	45.44	36.78	25.94	13.85	1.05	-	-	-	-	-	-
Mar	-	-	-	-	-	-	6.43	19.76	32.65	44.65	54.76	60.87	60.38	53.56	43.11	30.94	17.97	4.61	-	-	-	-	-	-
Apr	-	-	-	-	-	0.38	13.80	27.32	40.75	53.81	65.66	73.32	70.78	60.58	48.02	34.73	21.23	7.74	-	-	-	-	-	-
May	-	-	-	-	-	5.32	18.35	31.67	45.15	58.66	71.90	82.58	77.07	64.26	50.80	37.29	23.89	10.71	-	-	-	-	-	-
Jun	-	-	-	-	-	6.40	19.10	32.17	45.48	58.93	72.45	85.59	79.84	66.38	52.87	39.47	26.26	13.34	0.86	-	-	-	-	-
Jul	-	-	-	-	-	4.51	17.30	30.45	43.83	57.32	70.81	83.52	80.36	67.18	53.67	40.20	26.87	13.81	1.13	-	-	-	-	-
Aug	-	-	-	-	-	1.45	14.70	28.15	41.67	55.04	67.74	77.24	74.95	63.81	50.79	37.34	23.82	10.42	-	-	-	-	-	-
Sep	-	-	-	-	-	-	12.09	25.51	38.59	50.84	61.09	66.46	63.76	54.79	43.05	30.19	16.86	3.35	-	-	-	-	-	-
Oct	-	-	-	-	-	-	8.81	21.59	33.57	44.05	51.75	54.78	52.00	44.46	34.07	22.14	9.38	-	-	-	-	-	-	-
Nov	-	-	-	-	-	-	4.19	16.21	27.16	36.37	42.80	45.23	43.03	36.78	27.68	16.80	4.83	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-	11.72	22.43	31.48	38.00	40.95	39.71	34.55	26.43	16.32	4.94	-	-	-	-	-	-	-

Figure 5.9: IES-VE Weather for the Main Meeting Room

Table 5.10: Climate Data for RAK (Wikipedia)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	32.0 (89.6)	33.4 (92.1)	42.2 (108)	42.8 (109)	46.6 (115.9)	48.1 (118.6)	47.8 (118)	47.2 (117)	46.1 (115)	41.6 (106.9)	37.9 (100.2)	32.3 (90.1)	48.1 (118.6)
Average high °C (°F)	24.8 (76.6)	25.9 (78.6)	29.5 (85.1)	35.2 (95.4)	39.3 (102.7)	42.1 (107.8)	42.7 (108.9)	41.9 (107.4)	40.1 (104.2)	36.7 (98.1)	31.4 (88.5)	26.8 (80.2)	34.7 (94.46)
Daily mean °C (°F)	18.3 (64.9)	19.4 (66.9)	22.3 (72.1)	26.8 (80.2)	31.2 (88.2)	33.6 (92.5)	35.5 (95.9)	35.0 (95)	32.2 (90)	28.4 (83.1)	23.5 (74.3)	20.3 (68.5)	27.21 (80.97)
Average low °C (°F)	11.8 (53.2)	12.9 (55.2)	15.5 (59.9)	18.9 (66)	22.6 (72.7)	25.6 (78.1)	28.5 (83.3)	28.6 (83.5)	24.7 (76.5)	20.7 (69.3)	16.6 (61.9)	13.5 (56.3)	19.99 (67.99)
Record low °C (°F)	4.4 (39.9)	4.6 (40.3)	7.6 (45.7)	11.0 (51.8)	15.0 (59)	18.7 (65.7)	22.5 (72.5)	22.4 (72.3)	18.3 (64.9)	11.8 (53.2)	7.3 (45.1)	5.2 (41.4)	4.4 (39.9)
Precipitation mm (inches)	12.8 (0.504)	35.7 (1.406)	35.0 (1.378)	12.5 (0.492)	2.8 (0.11)	0.0 (0)	0.6 (0.024)	0.3 (0.012)	1.3 (0.051)	6.4 (0.252)	8.0 (0.315)	17.4 (0.685)	132.8 (5.229)
Avg. precipitation days (≥ 0.2 mm)	1.7	3.3	4.7	0.9	0.2	0.0	0.1	0.2	0.1	0.1	0.7	2.3	14.3
% humidity	69	66	62	53	46	50	50	53	57	59	62	69	58
Mean monthly sunshine hours	238.7	218.4	238.7	285.0	344.1	327.0	303.8	310.0	300.0	303.8	279.0	235.6	3,384.1

5.3.3 Sun Path and Simulation Days

In order to simulate the four different seasons, the research used four different days to represent each season. The days were chosen by fulfilling two criteria: being a working day and having a clear sky. The four selected days are the 21st of March, June, September and December and the climate details of these days are presented in Table5.11. Figure5.10 shows the sun path on these days.

Table 5.11: IES Weather Data for Selected Days

IES Weather Database				
	21-Mar	21-Jun	21-Sep	21-Dec
Dry Bulb Temp Min	17 C	25 C	26 C	13 C
Dry Bulb Temp Max	32 C	43 C	39 C	25 C
wet bulb Temp Min	13 C	21 C	22 C	11 C
wet bulb Temp Max	18 C	27 C	26 C	18 C
wind speed Max	6.7 m/s	6.2 m/s	7.5 m/s	4.3m/s
External relative humidity range	22%-80%	15%-85%	26%-80%	46%-87%
Solar radiation falling	950 Lux (W/m2)	1050 Lux (W/m2)	990 Lux(W/m2)	700 Lux(W/m2)
Cloud Cover	purely clear sky	purely clear sky	purely clear sky	purely clear sky

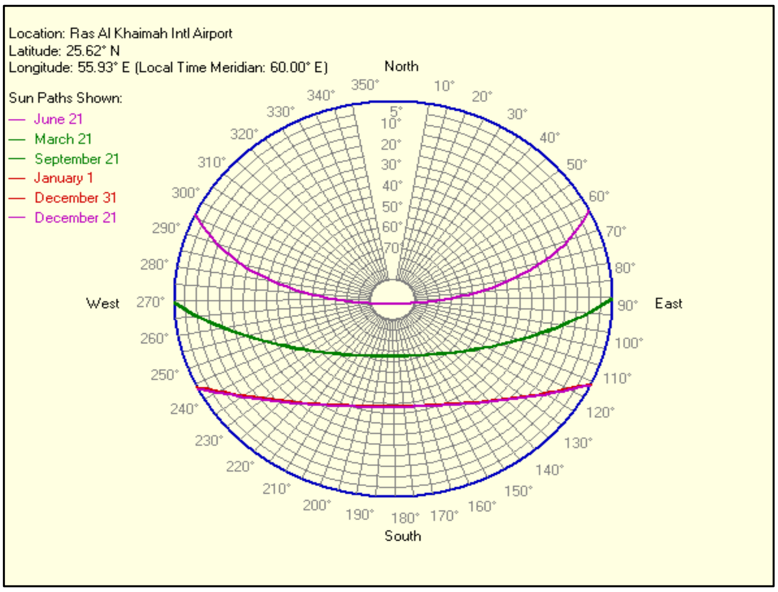


Figure 5.10: Sun Cast Weather from IES Weather Database

5.3.4 Defining the Simulation Case Matrix

This research experimented with different variations of the configurations in order to reach the best energy-efficiency and cost-efficiency output. Specifically, this research modified the following:

1) Lighting Technologies

- The base case of existing lights: T8. The lighting is assumed to be continuously operated during the proposed office operation timing.
- The first proposed lights: T5
- The second proposed lights: CFL
- The third proposed lights: LED

2) Lighting control technologies

- The existing occupancy sensors
- Deploying daylight sensors with dimmers.

Each lighting fixture above is tested against the lighting control technologies mentioned, and results are illustrated in next chapter.

Chapter 6

Results and Discussions

6.1 General Matrix for the Study

The energy consumption in any system can be calculated as following:

Energy Consumption (KWh) =

Input Watts (KW) x **Time of Operation/Year** (h/Y) (6.1)

According to the formula above, to reduce energy consumption, either reduce the input wattage or reduce the hours of operation. Input wattage can be reduced by changing the lighting technology with more-energy-efficient technologies. The hours of operation can be reduced using different types of lighting control technologies. A lighting retrofit is the practice of replacing components in the system with counterparts that leads to consume energy more efficiently. A lighting upgrade is a strategy that reduces the system's energy use. Energy savings are considerable over time for any systems. Based on the above, a matrix for better understanding of the simulation cases is shown in Table 6.1.

Table 6.1: Matrix of the Study

		Lighting Technologies				Lighting Controllers			
		T8 (Base Case)	T5	CFL	LED	Occupancy (motion) Sensor	On/Off	Daylight Sensor	Dimming System
Meeting	March	X	x	x	x	X	x	x	x
	June	X	x	x	x	X	x	x	x
	Sept	X	x	x	x	X	x	x	x
	Dec	X	x	x	x	X	x	x	x
Office	March	X	x	x	x	X	x	x	x
	June	X	x	x	x	X	x	x	x
	Sept	X	x	x	x	X	x	x	x
	Dec	X	x	x	x	X	x	x	x
Corridor	March	X	x	x	x	X	x	x	x
	June	X	x	x	x	X	x	x	x
	Sep	X	x	x	x	X	x	x	x
	Dec	X	x	x	x	X	x	x	x

X reference value when changing the other parameter

The simulation configurations have been divided into three groups based on the areas for the study as following: Main Meeting Room, Electromechanical Office and the Corridor which is part of the circulation area in the first floor of the building. This study is divided into 2 main parts based on changing either lighting technologies or lighting control technologies. The lighting technologies are four types including T8 (base case which is already exists in the building) and three other proposals (T5, CFL, and LED). The existing lighting control technology in the MOPW-RAK Building is the occupancy (motion sensor). The proposed control technologies are Daylight Sensor and Dimming Systems which are coming in one control system.

According to the above matrix, the total numbers of cases are 20 cases for the 3 selected areas as shown in Table 6.1. These cases will be simulated using two different simulations software's. Dialux software will be used for lighting simulation. This software can give a clear analysis and results of lighting technologies according to the input data of lights. Dialux simulation results are simpler and shorter comparing to the IES-VE software results. The results coming from the Dialux software are mainly about lighting technologies and it can't do similar simulation for HVAC system or cooling system as can be done in IES-VE software. So, IES-VE software will be used to find the effects of changing lighting technologies and lighting control technologies on the HVAC and especially on AC Systems in MOPW-RAK Building.

In this section, a clear analysis and discussions about the output results will be presented. This section for will be divided into 3 main parts according to the selected areas for the study. Some parameters such as: the lux levels were estimated from Dialux Software according to the lighting input specifications and area measurements. All light fittings that were simulated in Dialux software were from Trilux lighting manufacturer. Trilux brand were chosen because of many reasons such as: Trilux light fittings have been used in many of Ministry of Public Works projects not only is RAK, but also all over the emirates since long time. Trilux has replaced all the luminaires for many schools & offices with high output luminaires all over the world. A team of electrical engineers from MOPW and from many other big contracting and consulting companies in UAE visited the main factory of Trilux in Germany. This dissertation researcher was one of the team who had the chance to see the high quality lighting materials that used to produce Trilux Light fittings, lamps and the latest lighting technologies. Trilux has Middle East distributer in Dubai which is called Bahri and Mazroee Trading Company (BMTC). BMTC is the agent in Middle East Region and also a distributer of lighting control technologies that is a main part of this research. Trilux has one of the best training centers. They also used to cooperate with engineers from MOPW to do hard studies to get best projects like the sustainable schools and hospitals. Trilux has more than 75% output & developed new technology which give 98% reflectance value of the luminaire. Trilux has the right luminaire to use for this project. Trilux updated catalogues are provided to MOPW engineers yearly to know the latest products.

Now, a brief of the different types of lighting fixtures used in the simulation will be presented. Four types of lighting technologies were used: T8, T5, CFL, and LED. These types were selected because of many reasons such as: comparing to other old types of lighting technologies, these technologies are the latest and they generate less heat comparing to the Halogen, Metal Halide and other old lighting technologies. This is very important because HVAC systems will be less affected and this is more suitable specially to the working areas where employees and customers spend long time to finish their works and of course they can't finish their works if the working environment are unsuitable and uncomfortable as lights affects cooling and heating of the HVAC systems because lamps generates heats. Another reason for the importance of using lighting technologies with less heating dissipation is the high AC monthly payments which depend on the environmental working areas of the building which is usually big and wide areas with many floors for federal and governmental buildings. If we take care about this point, we can make large saving amount of the electricity monthly payments for the federal buildings by saving energy. This can be measured by comparing the monthly and yearly electricity payments from the Federal Electricity and Water Authority (FEWA).

The First type of lighting technologies is T8 (4 * 18) Watt which is the existing lighting technology in the MOPW-RAK building. It is used for the three selected areas in the building. The Axis dimensions for the light fitting are 600 mm x 600 mm which is the standard false ceiling dimensions. The light fitting includes Aluminum Louver

Luminaire body in sheet steel with electronic control gear. The Aluminum louver is used for diffuser uniformity and it decrease the glare effects of the lamp, increase energy savings, and it has better visual comfort. The electronic ballast is used because it is smaller, lighter and faster than a magnetic one. It is usually supply power to the lamp at a frequency of 20,000 Hz or higher, rather than the mains frequency of 50 - 60 Hz. This substantially eliminates the stroboscopic effect of flicker, a product of the line frequency associated with fluorescent lighting. The high output frequency of electronic ballast refreshes the phosphors in a fluorescent lamp so rapidly that there is no perceptible flicker.

Flicker index used for measuring perceptible light modulation. It has a range from 0.00 to 1.00, where 0 indicating the lowest possibility of flickering and 1 indicating the highest. Lamps operated on magnetic ballasts have a flicker index between 0.04-0.07 while digital ballasts have a flicker index of below 0.01 because more gas remains ionized in the arc stream. The lamp operates at about 9% higher efficacy above approximately 10 kHz. Lamp efficacy increases sharply at about 10 kHz and continues to improve until approximately 20 kHz. Electronic ballasts offer higher system efficacy for low pressure lamps like the lamp because of the higher efficiency of the ballast itself and the higher lamp efficacy at higher frequency.

For HID lamps there is no improvement of the lamp efficacy in using higher frequency, but for these lamps the ballast losses are lower at higher frequencies and also the light depreciation is lower which means the lamp produces more light over its entire lifespan. Some HID lamp types like the ceramic discharge metal halide lamp have reduced reliability when operated at high frequencies in the range of 20 - 200 kHz. For these lamps, a square wave low frequency current drive is mostly used with frequency in the range of 100 - 400 Hz, with the same advantage of lower light depreciation. Application of electronic ballasts is growing in popularity.

Most new generation electronic ballasts can operate both high pressure sodium (HPS) lamps as well as metal-halide lamps, reducing costs for building managers who use both types of lamps. Electronic ballasts (digital ballasts) also run much cooler and are lighter than their magnetic counterparts. T8 has a service life of 10,000 hours. Three proposed lighting technologies were used for this study. They are the followings:

- T5 (4*14) W: It is the equivalent of T8 (4*18) Watt lighting technology. This will be used for all the three selected areas in MOPW-RAK Building. T5 has the same as the previous characteristics of T8 technology. It has a service life of 15,000 hrs.
- CFL: It is Compact Fluorescent Lamp. It is circular recessed down light with different wattage according to the selected area characteristics and required lux measurements as follows:
    - (1*13)Watt, (2*13) Watt, and (2*26) Watt for meeting room.
    - (2*32) Watt for office.
    - (1* 32) Watt for the corridor

The lux measurements are different according to the worldwide international standards which depend on the room or area characteristics and uses. CFL used in this study are for ceiling cut-out 210 mm. Recess depth 100 mm with electronic control gear. It has A service life of 10,000 hours.

- LED: It is down light with round construction. It has recessing dimensions of (140 x 120) mm. Service life for LED is 50,000 hours. It has different wattage according to the selected area characteristics and required lux measurements as follows:
    - (40) Watt for meeting room.
    - (40) Watt for office.
    - (27) Watt for the corridor.

Table6.2 indicates the equivalent wattage for the above different lighting technologies.

Table 6.2: Equivalent Wattage for the Different Lighting Technologies

T8	T5	CFL		LED
		1* W	2*W	
18 W	14 W	13 W		7 W
36 W	28 W	26 W		25 W
58 W	49 W	32 W		40 W

In this section, only one of the Dialux lighting simulations will be presented. The rest of simulations were shifted to the appendix as the supervisor instructions. As mentioned in Table6.1which is the matrix of this study, there are more than 20 cases for this study according to changing of the existing lighting and control technologies with different proposals. Appendix (A) represents the Dialux lighting simulation software results for the 3 selected areas (Meeting Room, Electromechanical Office, and Corridor). Each simulated case represent the selected areas dimensions, type of lighting technologies, wattage per room, lux measurements (Max. and Min. lux), and lighting uniformity. As can be shown in appendix A, each simulated case is followed by a table with different physics symbols as shown in Table 6.3 that indicates one of the simulated cases. Each of these symbols has a meaning and it affects the lighting dissipation and lux measurements. To start analyzing the results of the Dialux lighting simulation software, it is better to give a brief description of these physical symbols that are included in the Table6.3.

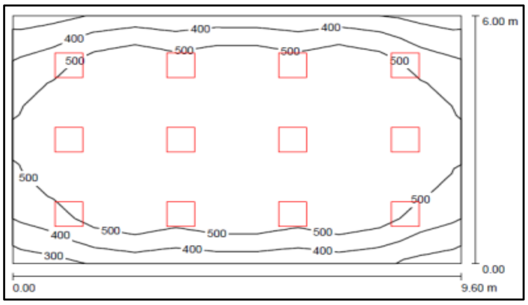


Figure 6.1: Meeting Room Dialux Simulation Results

Table6.3: Meeting Room Dialux Simulation Results

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	554	296	786	0.535
Floor	20	499	262	699	0.524
Ceiling	80	92	66	105	0.713
Walls (4)	50	180	69	327	/

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	12	TRILUX Enterio M73 RPV 418 E Enterio (1.000)	3381	5200	76.0
			Total: 40574	Total: 62400	912.0

Specific connected load: 15.83 W/m² = 2.86 W/m²/100 lx (Ground area: 57.60 m²)

The first symbol is "ρ" which is the reflection coefficient of the surface. Each room has four surfaces which are: work plane, floor, ceiling, and walls. The amount of light reflection is different according to the different surfaces. Materials, physical characteristics and performance of each of these different surfaces are very important because it has direct relation to lighting dissipation amount and lux measurement on each point or spot of each of these different surfaces. For example: dark color surfaces absorb more light and this resulted in needed more lamp energy wattage to get the desired lux calculation measurement which means more energy consumption that resulted in more electricity payment.

Table6.3 mentioned that "ρ%" is "/" for the Work plane surface which is unreal surface that indicates the working area surface. So, if we have a computer on a desk inside office, the work plane means the height between the light in the ceiling until the desk surface where the light is needed for the desired work. The other three surfaces "ρ%" is "20" for floor, "80" for ceiling, and "50" for the 4 walls. This indicates the amount of the reflection coefficient as mentioned above. For example "20% "for floor means that floor will absorb "20%" of the light and will reflect the rest which is "80%". This is depending mainly on the paint color, type, and construction material of the surface. It is also depends on the light fitting characteristics and wattage. So, the smaller "ρ%" means better reflection surface.

Figure 6.2: Lighting Measurements and Different Surface Characteristics

(http://www.lightlouver.com)

To reach proper light levels and uniform light distribution in the visual environment, many light fixtures are designed to reflect light off walls, ceilings and objects. The amount of light reflected off a surface can be measured. Suggestions for the percent of light reflected off surfaces in a typical office include:

- Window blinds (40-50%).
- Walls (50% maximum).
- Business machines (50% maximum).
- Ceiling (70-80%).
- Floor (20-40%).
- Furniture (25-45%).

The percent value refers to the amount of light that a surface reflects relative to the amount that falls on the surface.

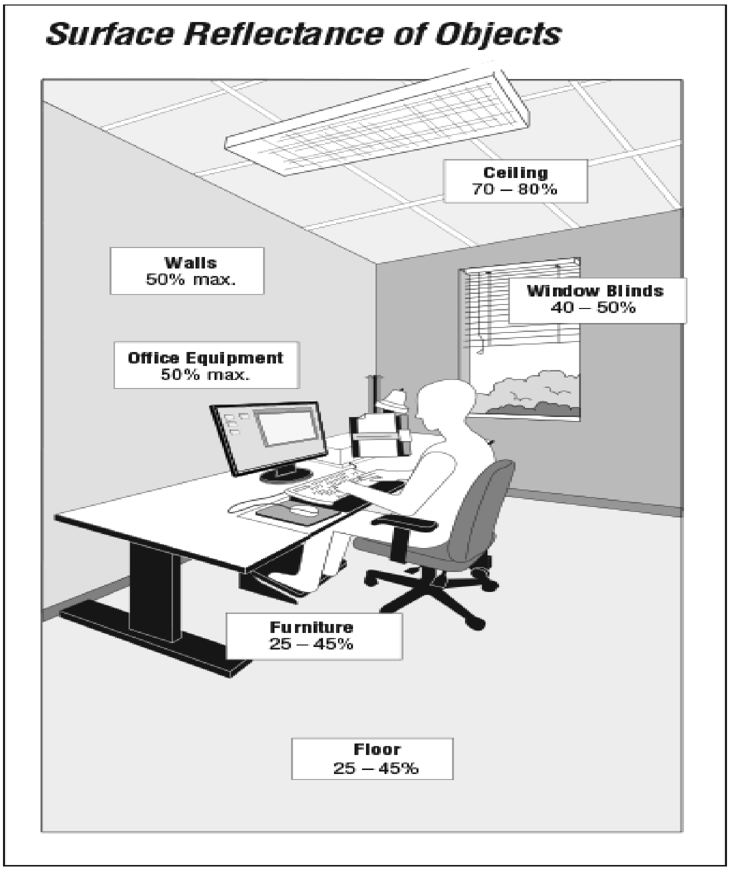


Figure6.3: Suggestions for the Percent of Light Reflected Off Surfaces in Office

(http://www.ccohs.ca/oshanswers/ergonomics/lighting_survey.html)

The next symbol in Table 6.3 is E [lx] which means the lux measurement amount that is different in each surface. Lux = Lumens (quantity of light) per square meter. $E_{av}[lx]$ is the average lux measurement, $E_{min}[lx]$ and $E_{max}[lx]$ are the minimum and maximum lux measurements. Each of these measurements is different in each spot. As can be noticed in Dialux drawing in Figure 6.2 or any other figure in Appendix A, $E_{min}[lx]$ is always on the part side of the room, while $E_{max}[lx]$ is always in the points in the centers of the cross sections of more than one solid angle. Figure6.4 represents the light lux measurements on a surface.

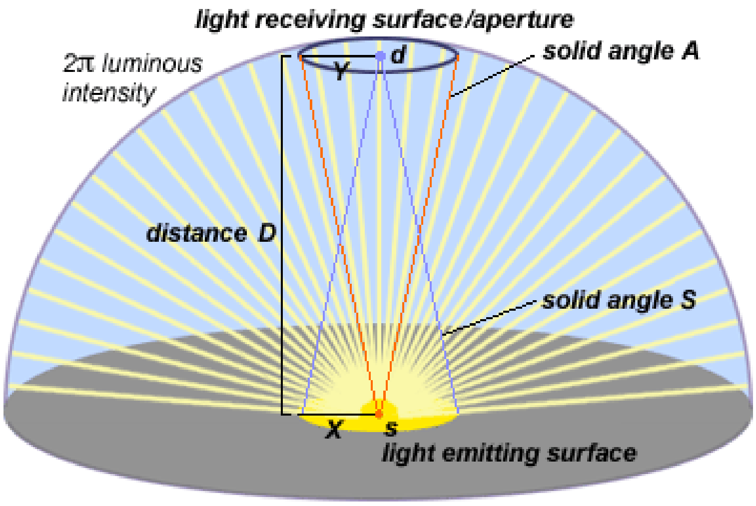


Figure6.4: Light Lux Measurements on a Surface

(http://www.handprint.com/HP/WCL/color3.html)

The last main symbol in Table6.3 is "u0" which means the uniformity where it is u0=$\frac{E_{min}}{E_{av}}$. According to the Lighting International Standard, "u0" must be ≥0.4 as can be seen in Table 6.2 and in all Dialux simulation tables in Appendix A. This means that it is better when "u0" is greater and this is happen when E_{min} is nearly to E_{av} that means better uniformity. In other words, better uniformity means having less of dark areas in the room. When "u0< 0.4", this means that there is something wrong in the room with the uniformity of the light. In this case, the light designer must repeat the simulation by using different lighting model with different wattage, or adding more number of light fittings, or changing the light positions and distances between the light fittings. One of the solutions is to increase E_{min} by adding some spot lights or down lights around the room borders where the minimum lux measurements are concentrated. This section is based on Dialux and IES-VE Software's which used to find the followings:

- Savings in Direct Energy Consumption (Lighting Energy): Dialux Software.
- Savings in Indirect Energy Consumption (HVAC Energy): IES-VE Software.
- Total energy savings for each case: Both Software's.

These savings will be analyzed for the three different selected areas in the MOPW-RAK Building. The best lighting technology for each area will be defined and the reasons for that will be discussed. The same will be done for the best lighting control technology in each area. The results will be shown as figures and diagrams related to the base case with discussions.

6.2 First Simulated Area (Meeting Room)

6.2.1 Lighting Technologies

(A) Lighting Energy (Direct Energy)

From Appendix (A-1) that includes Dialux simulation software results, Table6.4 is created. The table is summarizing the lighting energy (Direct Energy) for all cases of lighting technologies in Meeting Room compared to Base Case (T8). Table6.4 show that according to the Dialux simulation software results, Case1 (Base Case) consists of 6 units of T8 (4*18) Watt lighting technology with76 Wattage per Luminaire (W/L) and supported with 10 units of CFL with 28 (W/L). This is the existing lighting technologies in the meeting room. The reason of using the CFL in this situation is to increase the Minimum Lux Level in the borders of Meeting Room area. This is used to increase the uniformity u0 level of the room which depends on the E-min as mentioned previously in equation of uniformity u0=$\frac{E_{min}}{E_{av}}$. This can't be done if we use more units of T8 (4*18)Watt because this will increase the lux level that can exceeds the standard lux level for the Meeting Room area which is 500 lux as the International Standard that attached in the MOPW-RAK Building project contracting document. Since T8 wattage is more than twice time than CFL wattage, so roughly we mentions that T8 (4*18) W is the Base Case for the Meeting Room. According to the following equation:

Yearly Energy Consumption (KWH) =

(Wattage * Quantity) KW* **Operation Hours per Year** (Hrs/Yr) (6.2)

Where the Yearly Operation Hours = Number of Working Hours per Year.

According to Equation (6.3), the working hours for MOPW-RAK is 1680Hrs/Yr

Yearly Operation Hours (Hrs/Y) =

7 (hours) * **5** (days) * **48** (weeks) = **1680** Hrs/Yr (6.3)

The uniformity for Base Case is around 0.544, and the yearly energy consumption is 1162.56 KWH. There is no saving energy since we didn't change anything in the existing system. Case2 consists of the same quantity of light fittings as for T8 but with our first proposal T5 lighting technology. According to the International Standards, T8 (4*18) Watt is equal to T5 (4*14) Watt which means that we can save 16 Watt (72-26=16W) with using same quantity of light fittings which improves the lighting energy savings. Some CFL fittings were used for the same reason mentioned in the Base Case but with different quantities. The reason for that is the distribution of the light fittings in the Meeting Room that designed by Dialux which is shown in appendix (A-1) Case2. It is shown that using 14 units of CFL (1*13) Watt, we can get better lux level in the borders of the Meeting Room compared to the Base Case situation which is used to increase the uniformity as mentioned above. Comparing the first proposal (T5) with the Base Case (T8), it is shown that the lux level when using T5 is less than that for the Base Case by 8 Lux which is negligible since they are almost reached the standard lux level of 500 lux. The Lux uniformity u0 is also less by 0.065 which is not affecting the room lighting performance. The energy savings for Case2 is calculated from the following equation:

Saving Energy (KWH) =

Energy Consumption for **Base Case** - Energy Consumption for **Case2** (6.4)

The following equation used to find Energy Savings (%):

The Saved Energy Percentage of Case2

$$= \frac{\textbf{Saved Wattage for Case2}\ (\text{KWH})}{\textbf{Yearly Consumed Wattage per room for Base Case}(\text{KWH})} \qquad (6.5)$$

So, Case2 can save 292.32 KWH which is 25.14% of the lighting energy comparing to Base Case, which means T5 is better than T8 technology as have been proven from the calculation. The second proposal is CFL lighting technology where we exchange all the existing lighting for the Base Case with CFL. In this case we remain the 10 numbers of

(2*26) Watt of CFL and replace the 6 numbers of T8 by 14 number of (1*13) Watt CFL. The reason of that is to study the effects of the pure CFL lighting technology in saving energy and study its performance while remaining the lux level as standard of 500 lux.

Dialux simulation results are presented in Appendix (A-1) Case3. From Table6.4, it is shown that the lux level is almost the same as the Base Case with 1 level lux reduction which is negligible. The uniformity is increased by -.012 where it became 0.566 instead of 0.544 that means it is better than the Base Case. The yearly energy consumption is 1179.36 KWH. The saving energy is -16.8 KWH which is -1.45% comparing to Base Case. This means that there is no saving but instead of that, it is noticed that the Base Case was better than Case3 of CFL which means that Case3 is the worst case than the Base Case and Case2. Case4 is the LED lighting technology which mentioned in chapter4as the best lighting technology up to date. By comparing Case4 to the other different technologies, it is clearly noticed that Case4 is the best of all the above cases. In Case4, 16 light fittings were replaced by only 12 light fittings of LED which is a good quantity reduction comparing to the increasing in the average lux measurement which increases by 45 lux to reach more than the desired lux level as the International Standards that it became 532 instead of 500 lux. The uniformity is much more than all the above cases and more than the Base Case by 0.1 which means a very big difference in lighting uniformity. The yearly energy consumption is 806.4KWH. The yearly energy savings is 356.16KWh which is 30.64% that is the best of all the above cases.

Table6.4: Total Annual Lighting Energy Consumptions for All Cases in Meeting

<table>
<tr><th>Case Number</th><th>Type of Lighting Fixture</th><th>Lighting Wattage for Each Type of Light (W)</th><th>Luminaires Quantities</th><th>Wattage per Luminaire (results from software) (W)</th><th>Average Lux E-av</th><th>Uniformity u0</th><th>Annual Lighting Energy Consumption (KWh)</th><th>Annual Lighting Energy Savings (KWh)</th><th>Annual Lighting Energy Savings % (KWh)</th></tr>
<tr><td rowspan="2">Case1
Base Case</td><td>T8</td><td>(4*18) T8=72</td><td>6</td><td>76</td><td rowspan="2">487</td><td rowspan="2">0.544</td><td rowspan="2">1162.56</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>CFL</td><td>(2*13) CFL=26</td><td>10</td><td>28</td></tr>
<tr><td rowspan="2">Case2</td><td>T5</td><td>(4*14) T5=56</td><td>6</td><td>61</td><td rowspan="2">479</td><td rowspan="2">0.479</td><td rowspan="2">870.24</td><td rowspan="2">292.32</td><td rowspan="2">25.14%</td></tr>
<tr><td>CFL</td><td>(1*13) CFL=13</td><td>14</td><td>15</td></tr>
<tr><td rowspan="2">Case3</td><td rowspan="2">CFL</td><td>(2*26) CFL=52</td><td>10</td><td>15</td><td rowspan="2">488</td><td rowspan="2">0.556</td><td rowspan="2">1179.36</td><td rowspan="2">-16.8</td><td rowspan="2">-1.45%</td></tr>
<tr><td>(1*13) CFL=13</td><td>14</td><td>56</td></tr>
<tr><td>Case4</td><td>LED</td><td>(40) LED=40</td><td>12</td><td>40</td><td>532</td><td>0.644</td><td>806.4</td><td>356.16</td><td>30.64%</td></tr>
</table>

From all the above, it is noticed that, the quantity of the light fittings were changed according to many reasons such as: the lighting technologies features, the brand of the used model of the lighting fixture and the performance for each type of lighting technologies which depends mainly on the materials used and on the electronic components that makes a huge difference in the used lighting technology like the difference when using the electronic ballast or magnetic ballasts. This difference not only affects the physical performance and technical analysis, but also it covers the economical and prices of the light fitting. This is different when using expensive and high quality materials or using materials with opposite criteria.

In the Meeting Room, LED light fittings were the least quantity than all other cases. The quantities were less than the Base Case by 4 units. It was less by 8 lighting units than the Case2 and it was half the quantity of Case3 which is CFL lighting technology. There were no difference between the total wattage per luminaire (W/L) that designed and simulated by the Dialux Lighting Simulation Software and the real amount of the luminaire Wattage that already introduced in the Table6.4 which is 40 Watt in both situations. For the other 3 cases, it was noticed that there were little difference between the two measurements which were between 6 -7 Watt. This is means that the simulated design that was used in the case of LED light was accurate, but it wasn’t accurate 100% in the other 3 cases. This means that some modifications must be done. In another words the software must be used again to do better lighting design. For example, the lighting designer has to use another lighting model with different features. Another solution is to re-distribute the light fittings in the room with different positions of the units or different distances between them. The room surfaces construction materials and the color of the paint of these surfaces can also be taken into consideration for having similar design situation. There are many other reasons for having these measurements differences and there are more and more solutions that can be used to make better lighting design. . Figures 6.5 to Figure6.8 show the Lux levels, uniformity, annual energy consumptions and energy saving percentages for all cases in the Meeting Room.

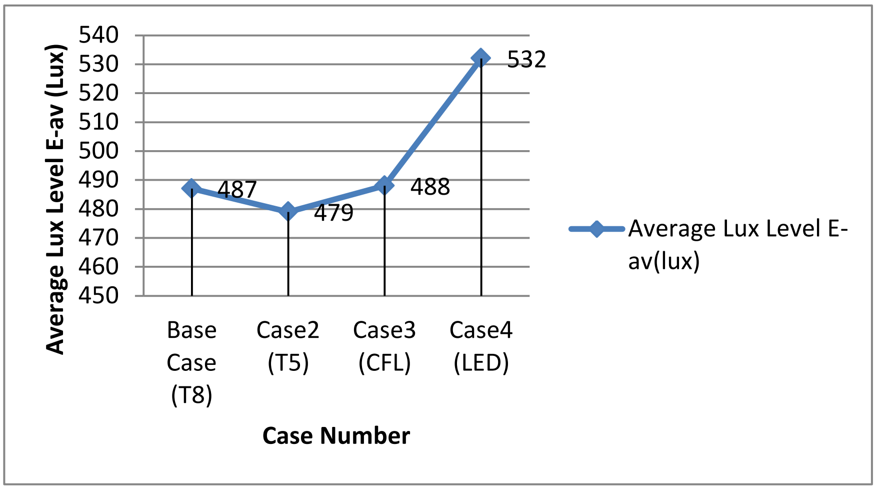


Figure6.5: Average Lux Level for All Cases in the Meeting Room

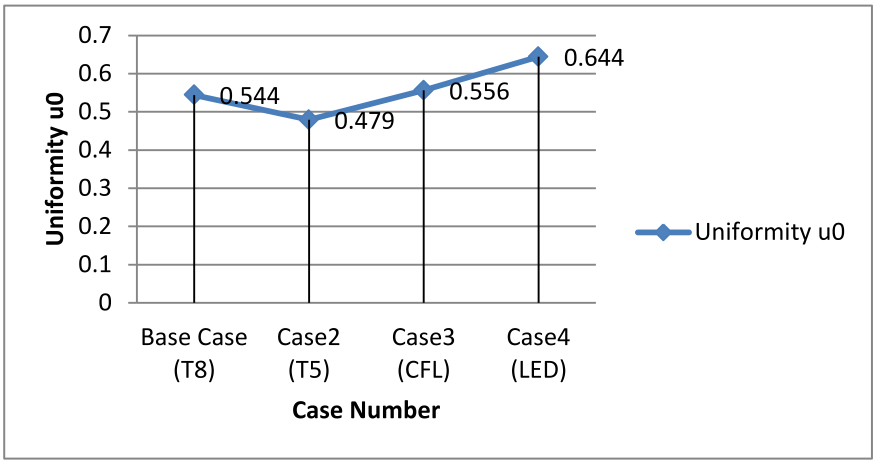


Figure6.6: Uniformity u_0 for All Cases in the Meeting Room

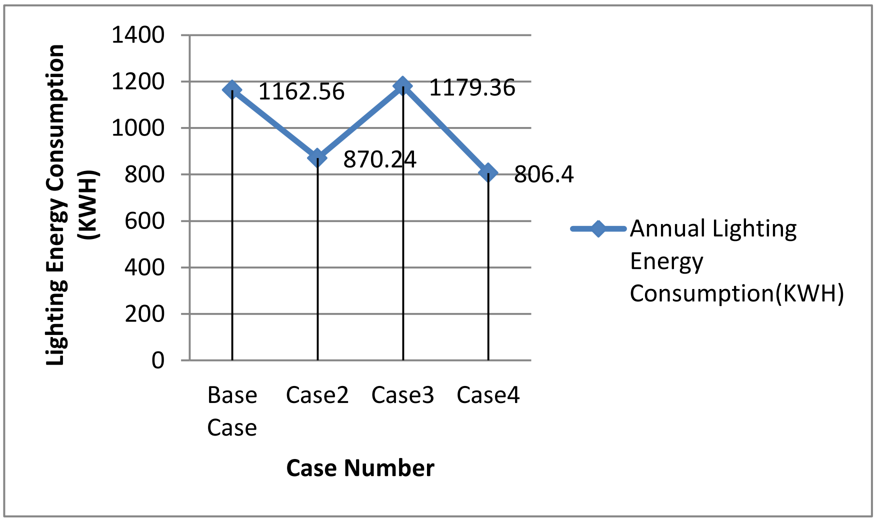


Figure6.7: Energy Consumption for All Cases in Meeting Room

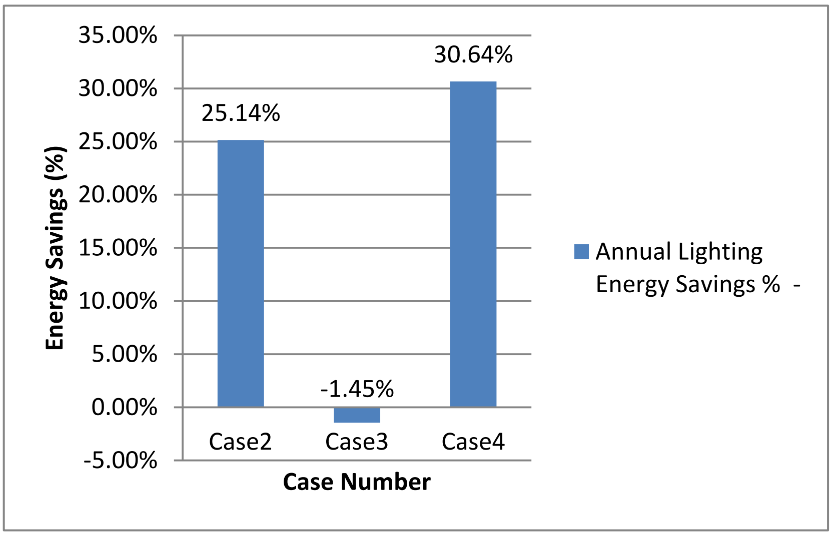


Figure6.8: Energy Saving for All Cases in the Meeting Room

(B) HVAC Energy (Indirect Energy)

HVAC consists of Cooling and Heating Systems which are AC or chillers and Heaters or Boilers. In this study we will consider HVAC energy as a cooling energy since there are no heaters or boilers in the selected areas. Tables 6.5 to 6.8were resulted from IES-VE simulation software. The tables clearly indicate the monthly energy consumptions for chillers, lighting and equipment to get the total energy in MWH.

Table6.5: Total Annual Energy Consumption for Base Case (T8) in Meeting Room

Date	Total Chillers energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	0.31	0.15	0.09	0.59
Feb 01-28	0.31	0.12	0.11	0.42
Mar 01-31	0.32	0.09	0.10	0.52
Apr 01-30	0.33	0.05	0.14	0.52
May 01-31	0.31	0.10	0.10	0.58
Jun 01-30	0.29	0.17	0.11	0.52
Jul 01-31	0.30	0.10	0.08	0.58
Aug 01-31	0.30	0.02	0.07	0.52
Sep 01-30	0.31	0.10	0.18	0.42
Oct 01-31	0.31	0.10	0.12	0.57
Nov 01-30	0.31	0.12	0.10	0.52
Dec 01-31	0.33	0.11	0.05	0.42
Summed Total	3.52	1.20	1.25	6.18

Table6.6: Total Annual Energy Consumption for Case2 (T5) in Meeting Room

Date	Total Chillers energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	0.24	0.08	0.18	0.49
Feb 01-28	0.24	0.08	0.19	0.49
Mar 01-31	0.23	0.06	0.18	0.50
Apr 01-30	0.24	0.08	0.18	0.51
May 01-31	0.24	0.08	0.19	0.50
Jun 01-30	0.23	0.07	0.18	0.50
Jul 01-31	0.24	0.08	0.18	0.50
Aug 01-31	0.25	0.09	0.19	0.50
Sep 01-30	0.24	0.08	0.18	0.50
Oct 01-31	0.25	0.09	0.19	0.51
Nov 01-30	0.24	0.09	0.19	0.51
Dec 01-31	0.24	0.08	0.19	0.50
Summed Total	2.63	0.89	2.22	6.01

Table6.7: Total Annual Energy Consumption for Case3 (CFL) in Meeting Room

Date	Total Chillers energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	0.39	0.13	0.09	0.52
Feb 01-28	0.39	0.13	0.11	0.52
Mar 01-31	0.39	0.13	0.10	0.52
Apr 01-30	0.38	0.12	0.14	0.51
May 01-31	0.39	0.13	0.10	0.52
Jun 01-30	0.39	0.13	0.11	0.52
Jul 01-31	0.39	0.13	0.08	0.52
Aug 01-31	0.40	0.14	0.07	0.53
Sep 01-30	0.39	0.13	0.18	0.52
Oct 01-31	0.39	0.13	0.12	0.52
Nov 01-30	0.39	0.13	0.10	0.52
Dec 01-31	0.39	0.13	0.05	0.52
Summed Total	3.62	1.21	1.25	6.24

Table6.8: Total Annual Energy Consumption for Case4 (LED) in Meeting Room.

Date	Total Chillers energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	0.20	0.07	0.25	0.53
Feb 01-28	0.20	0.07	0.25	0.53
Mar 01-31	0.20	0.07	0.25	0.52
Apr 01-30	0.20	0.07	0.25	0.51
May 01-31	0.20	0.07	0.25	0.52
Jun 01-30	0.21	0.07	0.26	0.53
Jul 01-31	0.21	0.08	0.26	0.52
Aug 01-31	0.20	0.07	0.25	0.51
Sep 01-30	0.20	0.05	0.25	0.53
Oct 01-31	0.21	0.05	0.24	0.52
Nov 01-30	0.20	0.07	0.24	0.49
Dec 01-31	0.20	0.07	0.24	0.52
Summed Total	2.43	0.81	2.99	6.23

From the above tables from IES-VE software, HVAC yearly energy consumption for all cases summarized in Table6.9.

Table6.9: Annual HVAC Energy Consumptions for All Cases in Meeting Room

Case Number	Annual AC Consumption (KWH)	Annual AC Savings (KWH)	Annual AC Savings (%)
Base Case (T8)	3523.12	_	_
Case2 (T5)	2637.20	806.4	25.15%
Case3 (CFL)	3573.82	-997.92	-1.44%
Case4 (LED)	2443.60	1290.2	30.6%

From Table6.9 we can know the relation between the AC and Lighting energy consumptions by dividing AC energy by lighting energy. Easily we can say that each 1 KWH of lighting energy = 3 KWH of HVAC energy. So, the fraction between Lighting and HVAC energies can be described in Equation (6.6).

Fraction between Lighting Energy and HVAC Energy

$$= \frac{\textbf{Lighting Energy}\ (\text{KWH})}{\textbf{HVAC Energy}(\text{KWH})} = \frac{1}{3} = 0.33 \quad (6.6)$$

6.2.2 Lighting Control Technologies

(A) Lighting Energy (Direct Energy)

In this section, the existing and proposed lighting control technologies results will be discussed to find the best control technology for the Meeting Room. The existing control technology is the Occupancy Sensors, while the proposed are the Daylight Sensors and Dimming System. We can consider the Daylight Sensor and Dimming System as one Control System since they have to work together and it is difficult to separate between them in real working areas and it is also difficult to measure the effect of each of them separately. First of all, we have to know how much each type of the above control technologies can save energy. IES-VE software results will be used to find the amount of energy saving for each of the above lighting control technologies. Let's say that we will do the analysis based on the Base Case (T8). We have to compare the results for the selected case (Base Case) in the one of the selected areas with and without the Occupancy Sensors and then compare the results when adding Daylight Sensors and Dimming System.

- **Base Case (T8 with and without Occupancy Sensor)**

From Table6.5, The IES-VE simulation software results show that lighting energy consumption is 1.20 MWH which is about 20% of the total energy consumption, while it is 3.52 MWH for chillers which is about 60%. Table6.10 represents IES-VE results when adding the Occupancy Sensor to the same case (Base Case) in the Meeting Room. From the results we can notice that lighting energy consumption decreases from 1.20 MWH to 1.10 MWH which means that there is a saving amount of about 10%. According to these results we can say that the Occupancy Sensor can save up to 10%

- **Base Case (with Daylight Sensor + Dimming System)**

Similarly, same procedure will be done to find the amount of the lighting energy saving using Daylight Sensor and Dimming System. comaprison will be done between Table6.5 and Table6.12 that represents IES-VE results when adding the above proposed ligthing control technologies. From Table6.12 we can see that the lighting energy consumption reduced from 1.20 MWH to 0.95 MWH which means 25% lighting energy savings. Table6.12 presents the findings of the energy saving for the Occupancy Sensors, Daylight Sensors and Dimming Systems based on the IES-VE results.

Table6.10: Energy Consumption for the Base Case with the Occupancy Sensor

Date	Total Chillers energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	0.27	0.09	0.16	0.51
Feb 01-28	0.28	0.08	0.13	0.51
Mar 01-31	0.27	0.09	0.14	0.52
Apr 01-30	0.29	0.09	0.11	0.51
May 01-31	0.28	0.09	0.14	0.51
Jun 01-30	0.27	0.09	0.15	0.51
Jul 01-31	0.28	0.09	0.14	0.53
Aug 01-31	0.28	0.10	0.15	0.51
Sep 01-30	0.27	0.09	0.14	0.51
Oct 01-31	0.28	0.09	0.14	0.52
Nov 01-30	0.29	0.10	0.14	0.51
Dec 01-31	0.27	0.09	0.18	0.52
Summed Total	3.33	1.11	1.72	6.17

Table6.11: Energy Consumption for Base Case Using Daylight S and Dim. Sys.

Date	Total Chillers energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	0.23	0.08	0.20	0.52
Feb 01-28	0.23	0.07	0.22	0.51
Mar 01-31	0.23	0.08	0.21	0.52
Apr 01-30	0.24	0.08	0.21	0.52
May 01-31	0.23	0.09	0.20	0.51
Jun 01-30	0.23	0.08	0.21	0.52
Jul 01-31	0.23	0.08	0.21	0.52
Aug 01-31	0.23	0.07	0.20	0.52
Sep 01-30	0.24	0.06	0.20	0.52
Oct 01-31	0.23	0.07	0.21	0.52
Nov 01-30	0.23	0.08	0.20	0.50
Dec 01-31	0.24	0.09	0.21	0.52
Summed Total	2.79	0.95	2.48	6.20

Table6.12: Energy Savings Using Occupancy Sensor, Daylight Sensor, and Dimming System

Type of Lighting Control System	Total lights energy (MWh)
Base Case (T8 without any lighting control technology)	1.20
Base Case (T8 with Occupancy Sensor)	1.11
(Base Case with Daylight Sensor + dimming)	0.95
Percentage of Energy Saving for Occupancy Sensor (%)	**10%**
Percentage of Energy Saving for Daylight Sensor + dimming (%)	**25%**
Total energy saving percentage for (Occupancy + Daylight sensors + Dimming)	**35%**

Table6.13 presents the summary of lighting energy savings when adding each control systems for all cases in the Meeting Room compared to the original case. It shows that energy savings in Case1 is 116.2KWH (10%) when adding the Occupancy Sensor, 290.6KWH (25%) when adding Daylight Sensor and Dimming Systems, and is 406.9 KWH (35%) when adding all of the control technologies. The energy savings in Case2 is 379KWH (33%) when adding the Occupancy Sensor, 509KWH (43.8%) when adding Daylight Sensor and Dimming Systems, and is 597 KWH (51.3%) when adding all of the control technologies. The energy savings in Case3 is 101KWH (8.7%) when adding the Occupancy Sensor, 278 KWH (24%) when adding Daylight Sensor and Dimming Systems, and is -396 KWH (34%) when adding all control technologies. The energy savings in Case4 is 436.9KWH (37%) when adding the Occupancy Sensor, 557.6 KWH (48%) when adding Daylight Sensor and Dimming Systems, and is 638KWH (55%) when adding all of the control technologies. Figure6.9 represents the annual lighting energy consumptions for all cases of changing lighting technologies and Lighting control technologies in the Meeting Room. While Figure6.10 represents the lighting energy savings for the same situation.

Table6.13: Lighting Energy Consumptions for All Lighting Control Technologies

		Occupancy Sensor (10%)			Daylight. S and Dim. Sys.(25%)			3 Control Systems (35%)		
Case Number	Type of Lighting Fixture	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)
Case1	T8	1046.3	116.2	10%	871.92	290.64	25%	755.66	406.90	35%
Case2	T5	783.22	379.3	33%	652.68	509.88	43.8%	565.66	596.90	51.3%
Case3	CFL	1061.4	101.1	8.7%	884.52	278.04	23.9%	766.58	395.98	34.1%
Case4	LED	725.76	436.8	37%	604.8	557.76	47.9%	524.16	638.4	54.9%

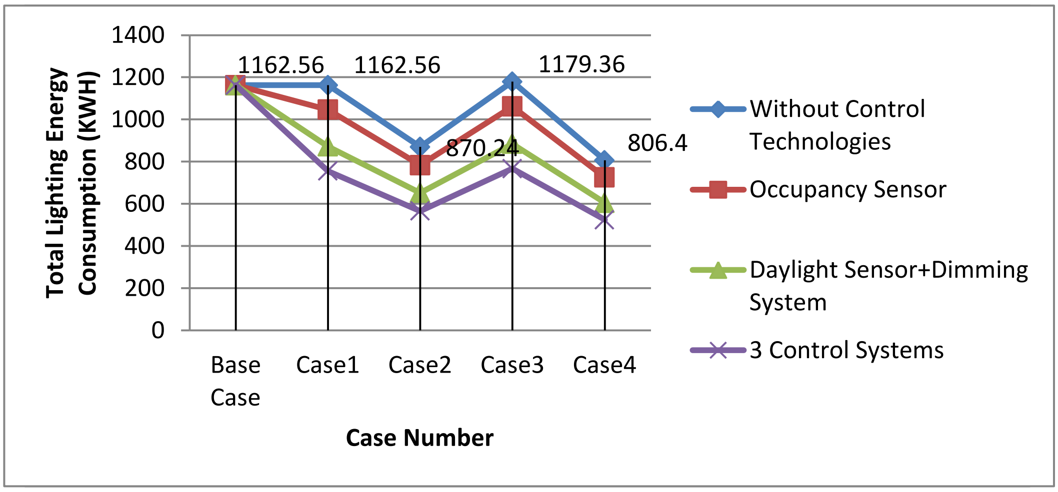


Figure6.9: Lighting Energy Consumptions for All Cases in Meeting Room

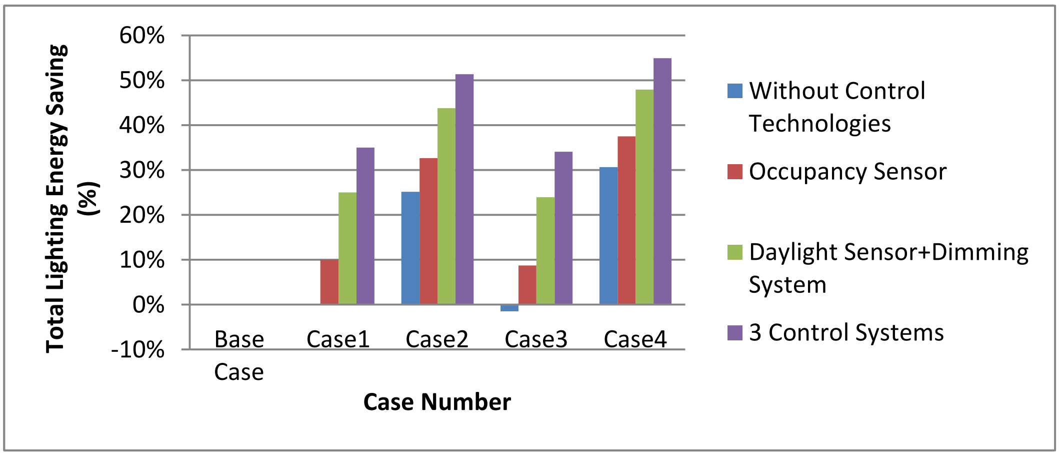


Figure6.10: Lighting Energy Savings for All Cases in Meeting Room

(B) HVAC Energy (Indirect Energy)

Table6.14 is created to summarize the HVAC energy consumptions for all lighting control technologies and also to indicate the annual energy savings for each case. It presents that energy savings in Case1 is 352KWH when adding the Occupancy Sensor, 88.7KWH when adding Daylight Sensor and Dimming Systems, and is 1233KWH when adding all of the control technologies. Energy savings in Case2 is 1149KWH when adding the Occupancy Sensor, 1545KWH when adding Daylight Sensor and Dimming Systems, and is 1808KWH when adding all of the control technologies. Energy savings in Case3 is 306.6KWH when adding the Occupancy Sensor, 842.7KWH when adding Daylight Sensor and Dimming Systems, and is 2323KWH when adding all of the control technologies. Energy savings in Case3 is 1323KWH when adding the Occupancy Sensor, 1690.7KWH when adding Daylight Sensor and Dimming Systems, and is 1934KWH when adding all of the control technologies. The table shows that all the HVAC energy savings have the same percentage amount as for lighting technologies. Figure6.11 represents the annual HVAC energy consumptions for all cases of changing lighting technologies and Lighting control technologies in the Meeting Room. While Figure6.12 represents the HVAC energy savings.

Table6.14: HVAC Energy Consumptions and Energy Savings for All Lighting Control Technologies in the Meeting Room

		Occupancy Sensor -10%			Daylight. S and Dim. Sys.- 25%			3 Control Systems -35%		
Case Number	Type of Lighting Fixture	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)
Case1	T8	3170	352.3	10%	2642.34	880.78	25%	2290	1233	35%
Case2	T5	2373	1149	32.6%	1977.9	1545.2	43.86%	1714	1808	51.34%
Case3	CFL	3216	306.6	8.7%	2680.36	842.75	23.92%	2323	1200	34.06%
Case4	LED	2199	1323	37.5%	1832.7	1690.4	47.98%	1588	1934	54.92%

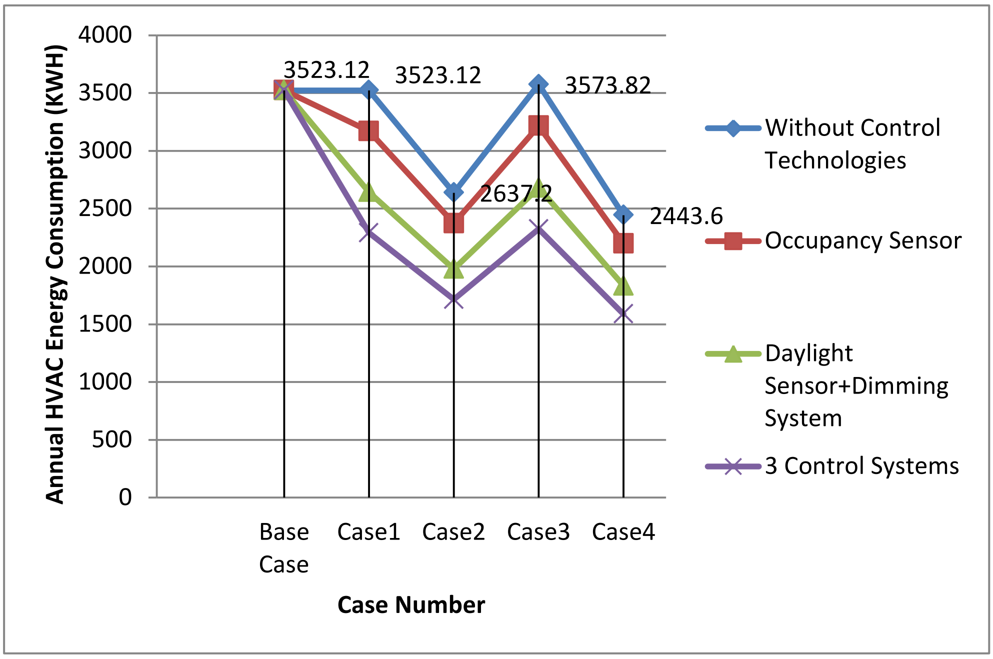


Figure6.11: Annual HVAC Energy Consumptions for All Cases of Lighting and Control Technologies in the Meeting Room

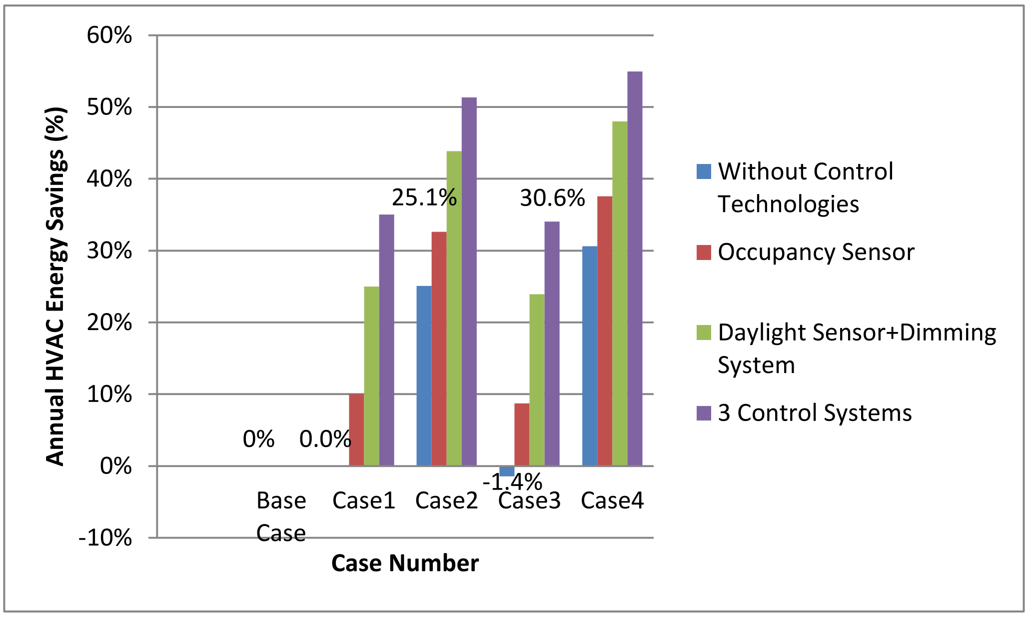


Figure6.12: HVAC Energy Savings for All Cases of Lighting and Control Technologies in the Meeting Room

6.3 Second Simulated Area (Electromechanical Office)

6.3.1 Lighting Technologies

(A) Lighting Energy (Direct Energy)

From Dialux Appendix (A-2), Table6.15 is created which summarizing the Lighting Energy (Direct Energy). From the table it is shown that the lux level when using T5 is less than that for the Base Case by huge Lux level which is 174 lux comparing to the meeting room that have negligible difference in the lux levels between these two cases since they are almost reaches the standard lux level of 500 lux. As can be noticed here, there is un correct design of the existing lighting since its average lux level exceeds the International Standard by 159 Lux which means that the amount of consuming lighting energy is more than the desired and it is better if we reduce it by minimizing the number of the light fittings as a suitable and easy solution to save energy and money that are wasted in small office dimensions as in the Electromechanical Office in MOPW-RAK Building. The next reason that prove that the base case is a bad case is the uniformity u0 which show that although the lux level was more than the required international standard by 159 lux, but the uniformity is the least not only comparing to the base case but also comparing to the uniformities for the rest of cases that all are better than the base case uniformity with less average lux level than the others. The uniformity of Case2 is better than the Base Case by 0.188 which can result in a very big difference in improving the working environment for the employees which will improve their work productivity because they will feel comfortable. The annual lighting energy consumption for Case2 is 376.32KWh which is less than the base by 22.22%.

The second proposed lighting technology is CFL lighting technology where we exchange all the existing lighting for Base Case with CFL units. In this case we increased the light fittings into double of the base case to reach the required International Standard for Lux Level in offices which is 500Lux. Although the lux level reached 561 lux which is more than the standard by 61 lux, but it is still less than the lux level of the Base Case. The uniformity is 0.77 which is better than the Base Case by 0.091 and worse than Case2 by 0.097. We can say that the uniformity is good generally speaking, but when comparing to Case2, it is noticed that Case2 is better because although the difference in the lux level between Case2 and Case3 is 76 lux more in

Case3 than Case2, but still Case2 can give us almost the same desired lux level with little less amount than the standard level but, at the same time the uniformity in Case2 is better than that of Case3. The annual lighting energy consumption for Case3 is 698.88KWH. There is more energy consumption in Case3 than the Base Case by 44.44%. From Table6.15, it is noticed that Case2 is better than Base Case and Case3 because of many reasons such as: T5 gave us the required lux level, best uniformity and least wattage per luminaire without increasing the quantity of the existing base case. Case2 which is using T5 technology is better than the Base Case that using T8 because it saves around 22.22% of the energy of the existing Base Case. It is also better than Case3 which using CFL technology. From Table6.15, it is clearly noticed that LED which is Case4 is the best lighting technology because of many reasons such as: case4 has the least lighting wattage comparing to the other three cases. Although these 3 cases have the same quantity of light fitting units Case4 of the LED lights has only 40 Watt which is less than the base case that using T8 by 36Watt and less than Case2 which using T5 by 21 Watt. Case4 has 30Watt less than Case3 which using CFL, but it still worst because the quantity is reduced to the half of Case3. The average lux is in the middle between the Base Case and Case2. It is less than Case3 by 35 lux only although the quantity is half of Case3 as mentioned above. In general, the average lux is 526 lux which is almost reaches the required international standard. The uniformity of case4 is the best of all the other cases which is equal 0.869. The yearly consumed wattage per room is the best of all the others which is 268.8 KWh with 44.44% energy saving. As can be seen, it is a very huge energy saving amount comparing to the existing Case.

Table6.15: Lighting Energy Consumptions for All Cases in Electromech.Office

Case Number	Type of Lighting Fixture	Lighting Wattage for Each Type of Light (W)	Luminaires Quantities	Watt per Luminaire (results from software) (W)	Average Lux Level E-av (lux)	Uniformity u0	Annual Energy Consumption (W/r) (KWh)	Amount of Annual Savings watt per room (KWh)	Annual Energy Savings %
Case1 **(Base Case)**	T8	(4*18) T8=72	4	76	659	0.679	483.84	-	-
Case2	T5	(4*14) T5=56	4	61	485	0.867	376.32	107.52	22.2%
Case3	CFL	(2*26) CFL=52	8	70	561	0.77	698.88	-215.04	-44.4%
Case4	LED	(40) LED=40	4	40	526	0.869	268.8	215.04	44.44 %

Figures 6.13 to Figure6.16 show the Lux levels, uniformity, annual energy consumptions and energy saving percentages for all cases in the Electromecanical Office.

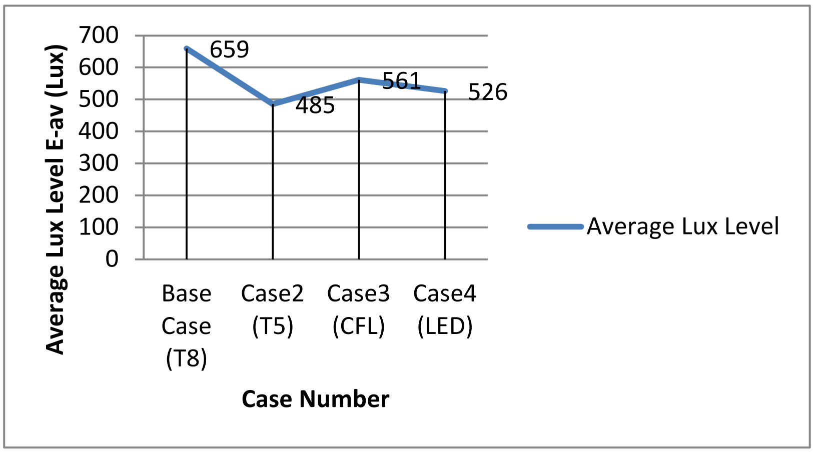


Figure6.13: Average Lux Level for All Cases in the Electromechanical Office

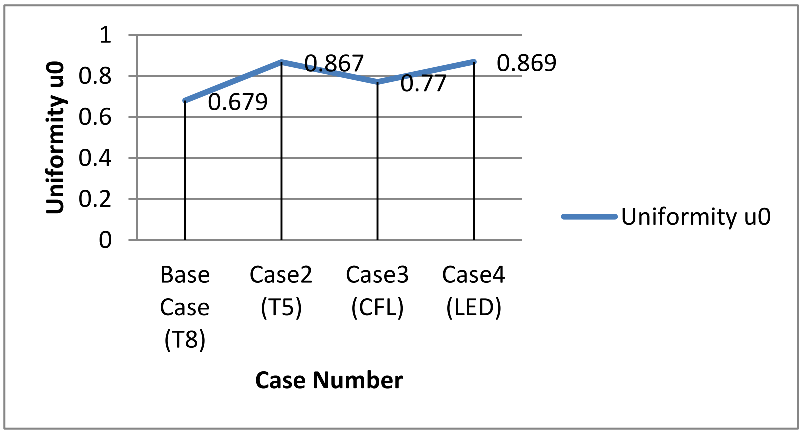


Figure6.14: Uniformity u0 for All Cases in the Electromechanical Office

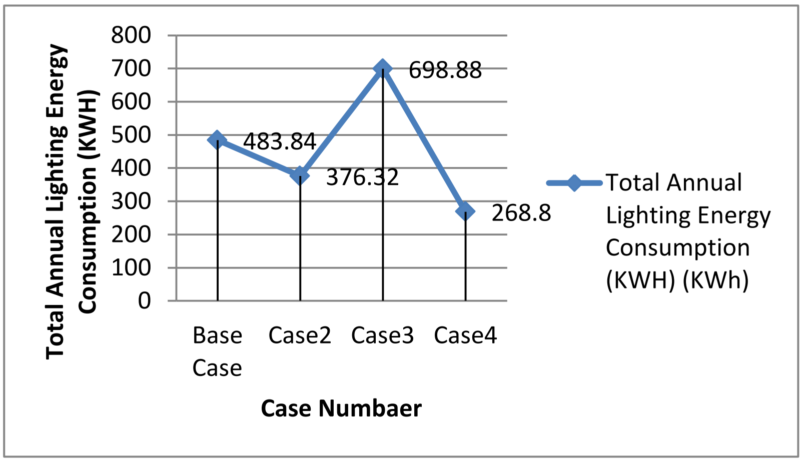


Figure6.15: Energy Consumption for All Cases in Electromechanical Office

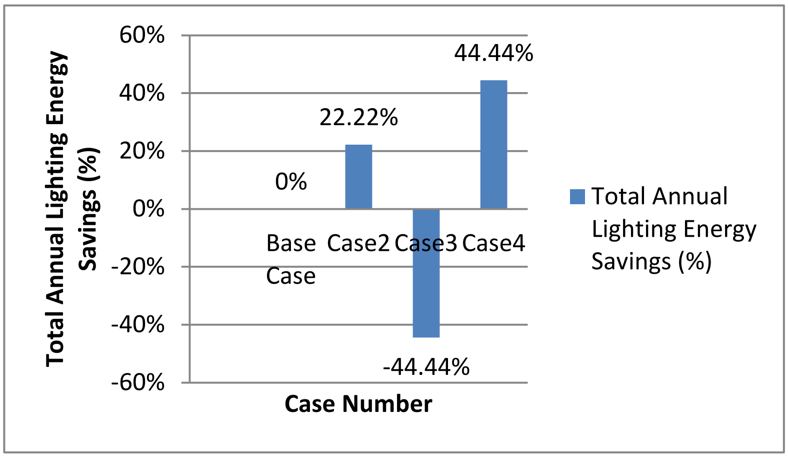


Figure6.16: Energy Saving for All Cases in the Electromechanical Office

(B) HVAC Energy (Indirect Energy)

Table6.16 presents the summary of HVAC energy savings. Case2 is saving 322.56KWH, Case3is saving -645.12KWH and 645.12KWH for Case4.

Table6.16: HVAC Energy Consumptions for All Cases in the Electromech.Office

Case Number	Annual AC Consumption (KWH)	Annual AC Savings (KWH)	Annual AC Savings (%)
Base Case (T8)	1451.52	0	0%
Case2 (T5)	1128.96	322.56	22%
Case3 (CFL)	2096.64	-645.12	-44%
Case4 (LED)	806.4	645.12	44%

6.3.2 Lighting Control Technologies

(A) Lighting Energy (Direct Energy)

Table6.17 presents the summary of lighting energy savings when adding each control systems for all cases in the electromechanical office. It shows that energy savings in Case1 is 48.4KWH (10%) when adding the Occupancy Sensor, 121KWH (25%) when adding Daylight Sensor and Dimming Systems, and is 169.3 (35%)KWH when adding all of the control technologies. The energy savings in Case2 is 144.9KWH (30%) when adding the Occupancy Sensor, 244.73KWH (42%) when adding Daylight Sensor and Dimming Systems, and is 282.4 (49%)KWH when adding all of the control technologies. The energy savings in Case3 is 1157KWH (-50%) when adding the Occupancy Sensor, 984 KWH (-58%) when adding Daylight Sensor and Dimming

Systems, and is -882 KWH (-64%) when adding all control technologies. The energy savings in Case4 is 120.96KWH (50%) when adding the Occupancy Sensor, 140.3 KWH (58%) when adding Daylight Sensor and Dimming Systems, and is 154.8 KWH (64%) when adding all of the control technologies. Figure6.17 represents the annual lighting energy consumptions for all cases of changing lighting technologies and Lighting control technologies in the Electromechanical Office. While Figure6.18 represents the lighting energy savings for the same situation.

Table6.17: Lighting Energy Savings for All Control Technologies in Electro. Office

		Occupancy Sensor -10%			Daylight. S and Dim. Sys. -25%			3 Control Systems -35%		
Case Number	Type of Lighting Fixture	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)
Case1	T8	435.45	48.384	10%	362.88	120.96	25%	314.49	169.344	35%
Case2	T5	338.86	144.972	30%	244.73	201.45	42%	282.83	239.102	49%
Case3	CFL	628.99	1157.9	-50%	524.16	984.46	-58%	454.27	882.79	-64%
Case4	LED	241.92	120.96	50%	201.6	140.3	58%	174.72	154.8	64%

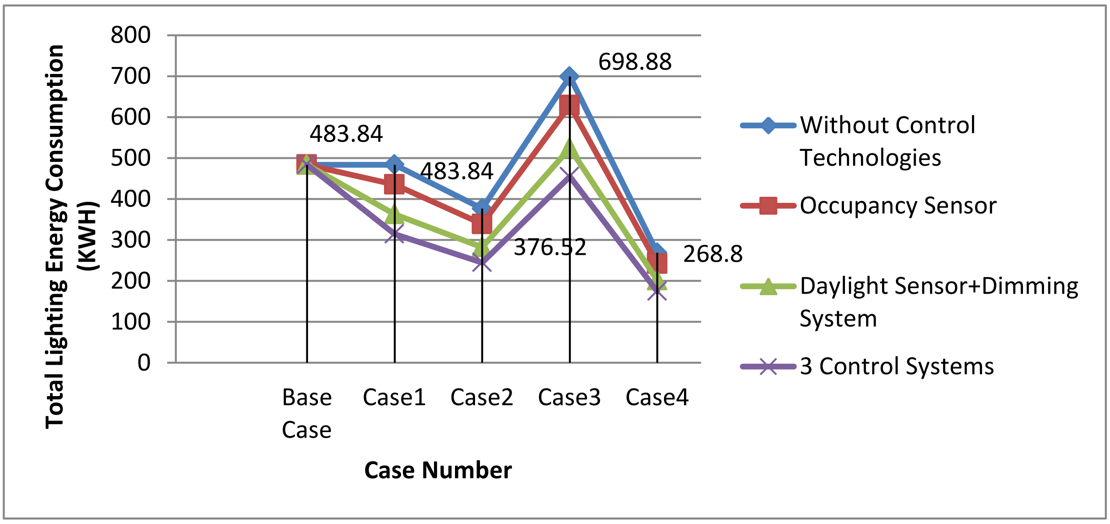


Figure6.19: Lighting Energy Consumptions for All Cases of Lighting and Control Technologies in the Electromechanical Office

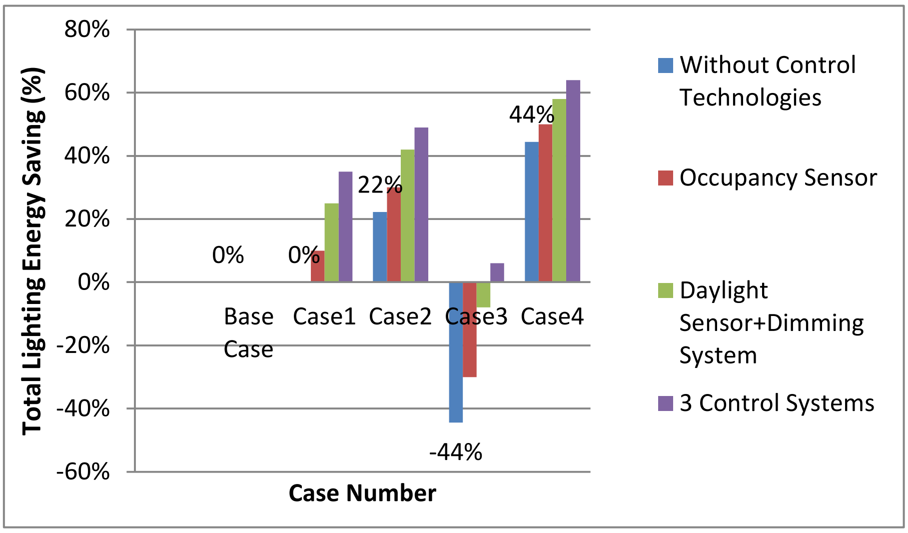


Figure6.18: Lighting Energy Savings for All Cases of Lighting and Lighting Control Technologies in the Electromechanical Office

(B) HVAC Energy (Indirect Energy)

Table6.18 is created to summarize the HVAC energy consumptions for all lighting control technologies and also to indicate the annual energy savings for each case. It presents that energy savings in Case1 is 145.152KWH when adding the Occupancy Sensor, 362.88KWH when adding Daylight Sensor and Dimming Systems, and is 508.3KWH when adding all of the control technologies. Energy savings in Case2 is 435.4KWH when adding the Occupancy Sensor, 604.8KWH when adding Daylight Sensor and Dimming Systems, and is 717.6KWH when adding all of the control technologies. Energy savings in Case3 is 367.38KWH when adding the Occupancy Sensor, 3153.3KWH when adding Daylight Sensor and Dimming Systems, and is 2848.2KWH when adding all of the control technologies. Energy savings in Case4 is 725KWH when adding the Occupancy Sensor, 846KWH when adding Daylight Sensor and Dimming Systems, and is 927KWH when adding all of the control technologies. The table shows that all the HVAC energy savings have the same percentage amount as for lighting technologies. Figure6.19 represents the annual HVAC energy consumptions for all cases of changing lighting technologies and Lighting control technologies in the Meeting Room. While Figure6.20 represents the amount of HVAC energy savings for the same situation.

Table6.18: HVAC Energy Consumptions and Energy Savings for All Lighting Control Technologies in the Electromechanical Office

		Occupancy Sensor -10%			Daylight. S and Dim. Sys. -25%			3 Control Systems -35%		
Case Number	Type of Lighting Fixture	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)
Case1	T8	1306.3	145.152	10%	1088.6	362.88	25%	943.48	508.032	35%
Case2	T5	1016.0	435.456	30%	846.72	604.8	42%	733.82	717.696	49%
Case3	CFL	1886.9	367.38	-50%	1572.4	3153.3	-58%	1362.8	2848.2	-64%
Case4	LED	725.76	362.88	50%	420.9	846.72	58%	524.16	464.48	64%

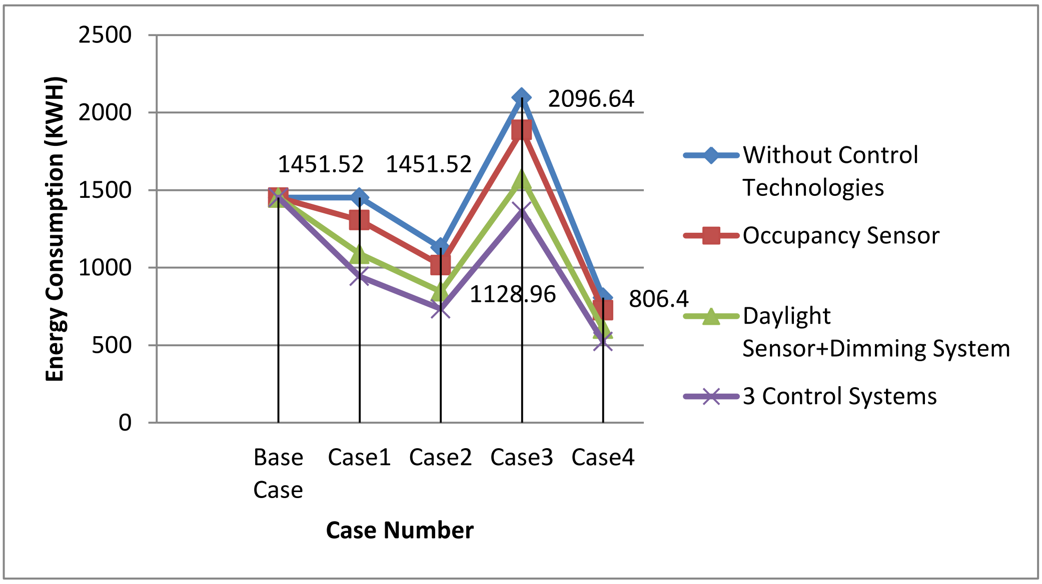


Figure6.19: Annual HVAC Energy Consumptions for All Cases for Lighting and Control Technologies in the Electromechanical Office

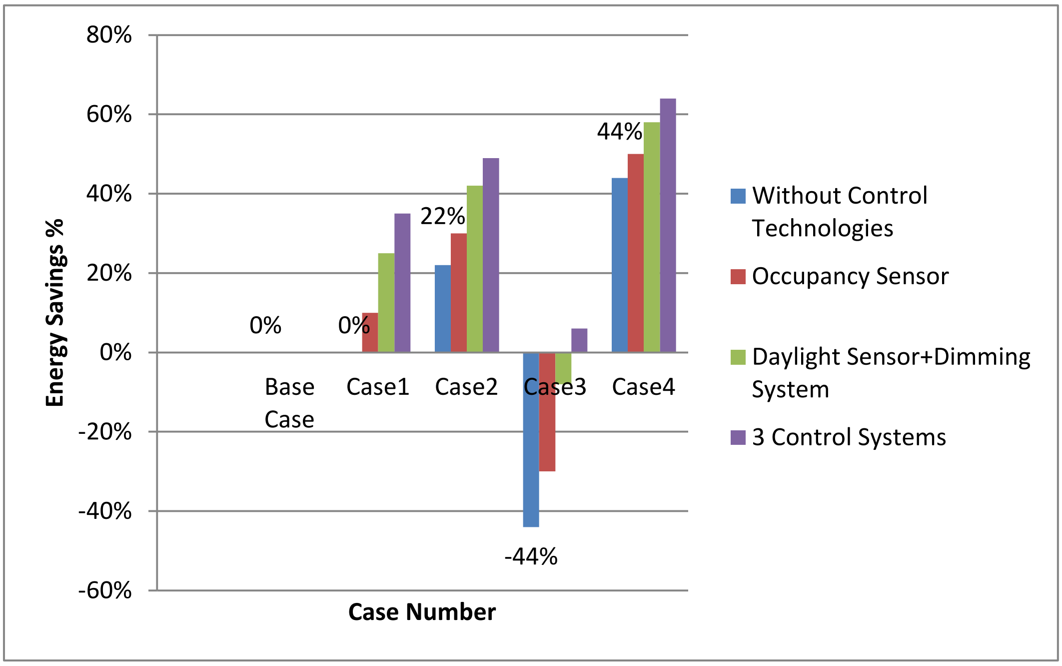


Figure6.20: HVAC Energy Savings for All Cases of Lighting and Control Technologies in the Electromechanical Office

6.4 Third Simulated Area (The Corridor)

6.4.1 Lighting Technologies

(A) Lighting Energy (Direct Energy)

From Dialux Appendix (A-3), Table6.19 is created which summarizing the Lighting Energy (Direct Energy). As it can be noticed from the table, Base Case consists of 7 units of CFL (1*26) Watt with 35 (W/L). The Annual energy consumption for Base Case is 305.76 KWh. Case2 is using T5 and it consists of less than half of the quantity that used in the Base Case. According to the International Standards, CFL (1*26) Watt is equal to T5 (4*14) Watt. It is shown that by using 3 units only of T5 (4*14) Watts, we can get better lux level in Corridor compared to the Base Case situation which uses to increase the uniformity as mentioned above. Comparing the first proposal (T5) with the Base Case (CFL), it is shown that the lux level when using T5 is more than the Base Case by 41 Lux which is much greater than the required of 150 lux level as the International Standard for corridors. The uniformity u0 is less than the base case by 0.059 which is negligible. The annual energy consumption for Case2 is equal 282.24 KWh which means saving energy of 7.7%. In Case3, we exchange all the existing lights of the Base Case with 3 units of T8 (4*18) Watts. it is also shown that the lux level is almost the same as the base case with 1 level lux reduction which is negligible. The uniformity is almost the same as the Base Cases. The energy consumption is 262.88 KWh with saving -18.7%. As for the other 2 selected areas, LED is the best lighting technology because in Case4 we reduce the quantity of the light fittings by one unit and at the same time we save 8 watt per light since the wattage reduced from 35 Watt in the base case to 27 Watt in Case4. The average lux increased by 24 lux level. The uniformity reduced by 0.011 than the base case. The energy consumption is around 272.16 KWh with saving energy of 11% which is the best of all the other cases.

Table6.19: Annual Lighting Energy Consumptions for All Cases in the Corridor

Case Number	Type of Lighting Fixture	Lighting Wattage for Each Type of Light (W)	Luminaires Quantities	Watt per Luminaire (results from software) (W)	Average Lux Level E-av (lux)	Uniformity u0	Annual Energy Consumption (W/r) (KWh)	Amount of Annual Savings watt per room (KWh)	Annual Energy Savings %
Case1 **(Base Case)**	CFL	(1*26) CFL=26	7	35	153	0.75	305.76	0	0
Case2	T5	(4*14) T5=56	3	61	194	0.69	282.24	23.52	7.7%
Case3	T8	(4*18) T8=72	3	76	152	0.749	262.88	-57.12	-18.7%
Case4	LED	(27) LED=27	6	27	177	0.738	272.16	33.6	11%

As can be seen from Figure6.21 to Figure6.23 the quantity of the light fittings were almost the same in the Base Case and Case4, but they reduced to half for Cases2 and 3 Although the lux level are same for base case and Case3 greater in case4 and the highest in Case2, but still Base Case is the best according to the uniformity which equal 0.75. CFL lighting technology is highly recommended for the corridor according to the reasons mentioned in the summary of the previous section which was talking about the second simulated area of the electromechanical office.

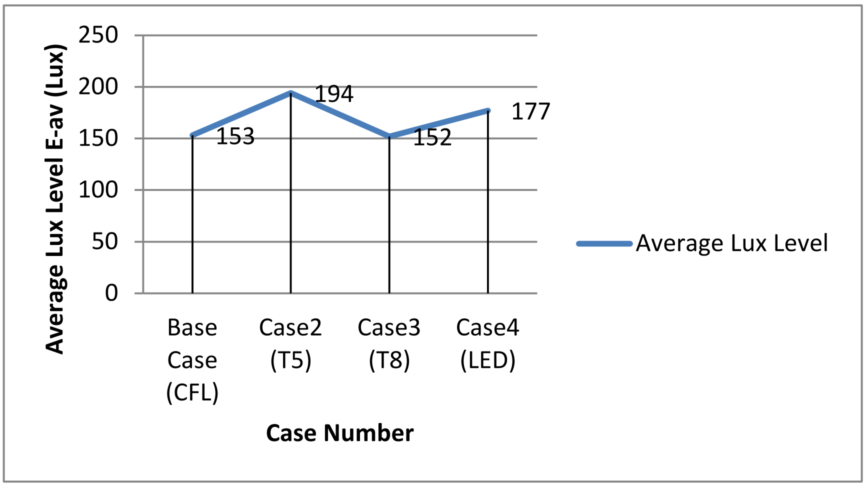


Figure6.21: Average Lux Level for All Cases in the Corridor

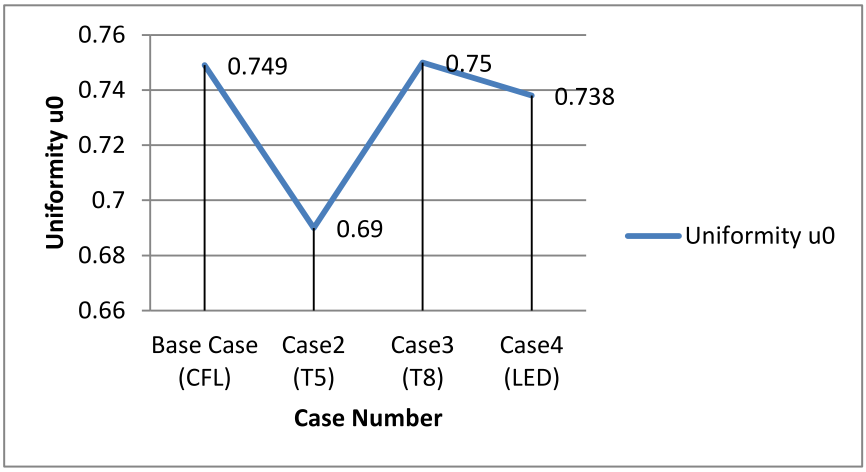


Figure6.22: Uniformity u_0 for All Cases in Corridor

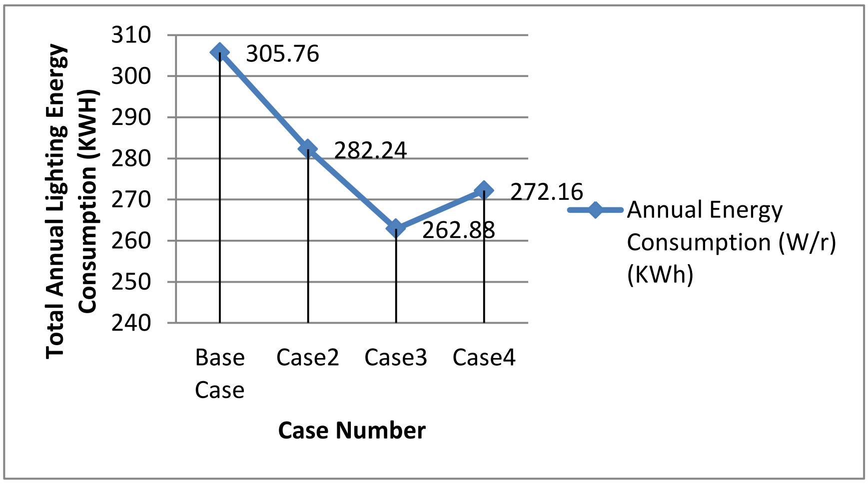


Figure6.23: Lighting Energy Consumption for All Cases in Corridor

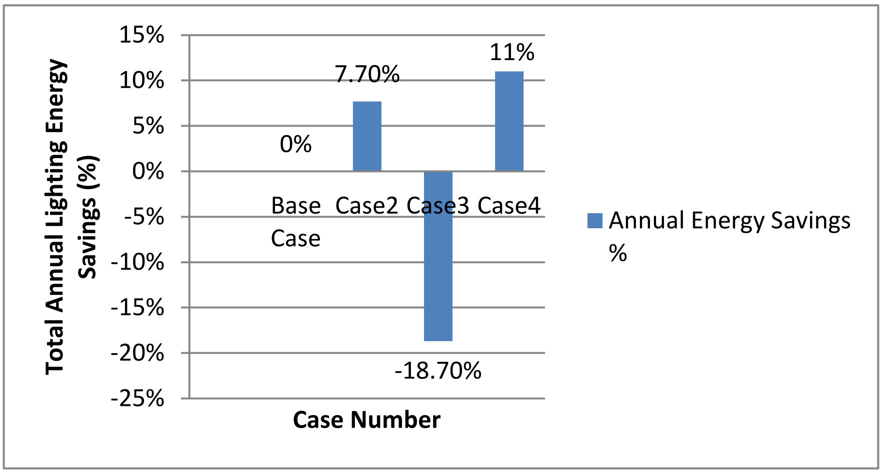


Figure6.24: Energy Saving for All Cases in Corridor

(B) HVAC Energy (Indirect Energy)

Table6.20 presents the summary of HVAC energy savings. Case2 is saving 70.56KWH, Case3is saving 128.64KWH and 100.8KWH for Case4.

Table6.20: Total Annual HVAC Energy Consumptions for All Cases in Corridor

Case Number	Annual AC Consumption (KWH)	Annual AC Savings (KWH)	
Base Case (CFL)	917.28	0	0%
Case2 (T5)	846.72	70.56	7.70%
Case3 (T8)	788.64	128.64	-18.70%
Case4 (LED)	816.48	100.8	11%

6.4.2 Lighting Control Technologies

(A) Lighting Energy (Direct Energy)

Table6.21 presents the summary of lighting energy savings for each control systems in the Corridor. It shows that energy savings in Case1 is 30.5KWH (10%) when adding the Occupancy Sensor, 76.4KWH (25%) when adding Daylight Sensor and Dimming Systems, and is 107 KWH (35%) when adding all of the control technologies. The energy savings in Case2 is 51.7KWH (17%) when adding the Occupancy Sensor, 94KWH (31%) when adding Daylight Sensor and Dimming Systems, and is 122 KWH (40%) when adding all of the control technologies. The energy savings in Case3 is 69KWH (23%) when adding the Occupancy Sensor, 108 KWH (36%) when adding

Daylight Sensor and Dimming Systems, and is 135 KWH (44%) when adding all control technologies. The energy savings in Case4 is 60.8KWH (20%) when adding the Occupancy Sensor, 102 KWH (33%) when adding Daylight Sensor and Dimming Systems, and is 129 KWH (42%) when adding all of the control technologies. Figure6.25 represents the annual lighting energy consumptions for all cases of changing lighting technologies and Lighting control technologies in the Electromechanical Office. While Figure6.26 represents the lighting energy savings.

Table6.21: Lighting Energy Savings for All Control Technologies in the Corridor

		Occupancy Sensor -10%			Daylight. S and Dim. Sys. -25%			3 Control Systems -35%		
Case Number	Type of Lighting Fixture	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Savings % (KWh)
Case1	CFL	275.18	30.576	10%	229.32	76.44	25%	198.74	107.01	35%
Case2	T5	254.01	51.744	17%	211.68	94.08	31%	183.45	122.30	40%
Case3	T8	236.59	69.168	23%	197.16	108.6	36%	170.87	134.88	44%
Case4	LED	244.94	60.816	20%	204.12	101.64	33%	176.90	128.85	42%

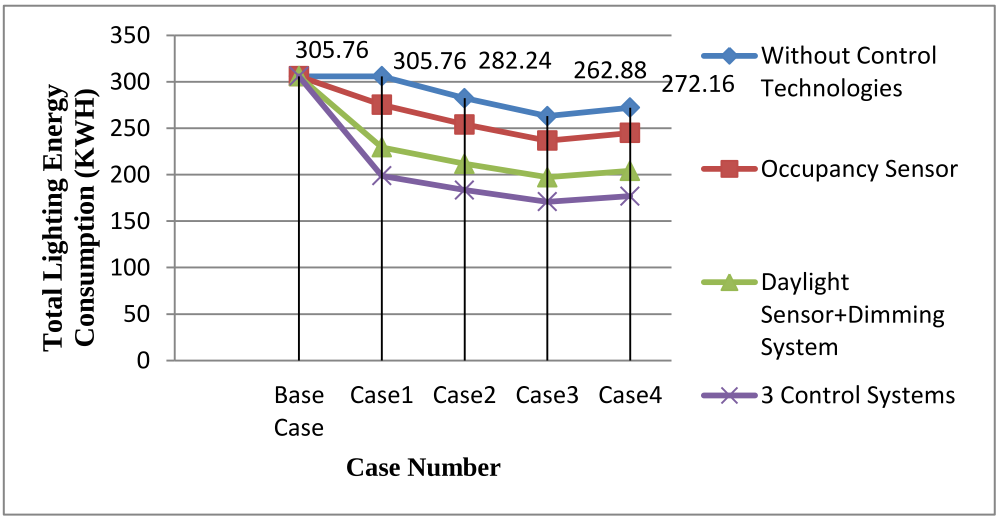


Figure6.25: Annual Lighting Energy Consumptions for All Cases of Lighting and Control Technologies in the Corridor

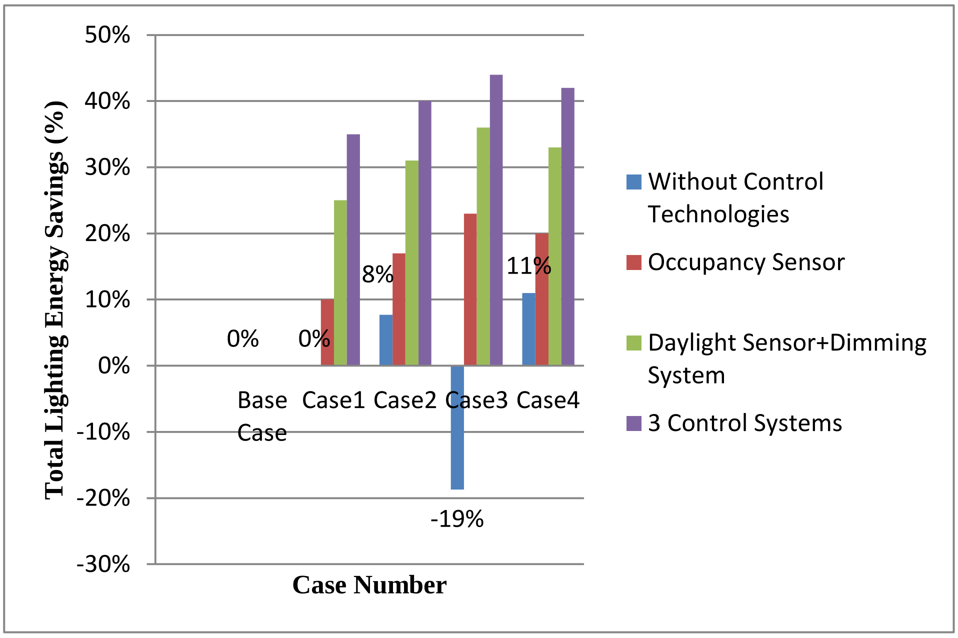


Figure6.26: Lighting Energy Savings for All Cases of Lighting and Control Technologies in Corridor

(B) HVAC Energy (Indirect Energy)

Table6.22 presents the summary of HVAC energy savings when adding each control systems for all cases in the Corridor. It shows that energy savings in Case1 is 91.7KWH (10%) when adding the Occupancy Sensor, 229KWH (25%) when adding Daylight Sensor and Dimming Systems, and is 321 KWH (35%) when adding all of the control technologies. The energy savings in Case2 is 155KWH (17%) when adding the Occupancy Sensor, 282KWH (31%) when adding Daylight Sensor and Dimming Systems, and is 550 KWH (40%) when adding all of the control technologies. The energy savings in Case3 is 207.5KWH (23%) when adding the Occupancy Sensor, 325.5 KWH (36%) when adding Daylight Sensor and Dimming Systems, and is 404.6 KWH (44%) when adding all control technologies. The energy savings in Case4 is 60.8KWH (20%) when adding the Occupancy Sensor, 182.44 KWH (33%) when adding Daylight Sensor and Dimming Systems, and is 386 KWH (42%) when adding all of the control technologies. Figure6.27 represents the annual lighting energy consumptions for all cases of changing lighting technologies and Lighting control technologies in the Corridor. While Figure6.28 represents the HVAC energy savings.

Table6.22: HVAC Energy Consumptions and Energy Savings for All Lighting Control Technologies in Corridor

		Occupancy Sensor -10%			Daylight. S and Dim. Sys. -25%			3 Control Systems -35%		
Case Number	Type of Lighting Fixture	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)	Annual HVAC Energy Consumption (KWh)	Annual HVAC Energy Savings (KWh)	Annual HVAC Energy Savings % (KWh)
Base Case	CFL	917.28	0	0%	917.28	0	0%	917.2	0	0%
Case1	CFL	825.552	91.728	10%	687.96	229.32	25%	596.2	321.04	35%
Case2	T5	762.048	155.23	17%	635.04	282.24	31%	550.3	366.91	40%
Case3	T8	709.776	207.50	23%	591.48	325.8	36%	512.6	404.66	44%
Case4	LED	734.832	182.44	20%	612.36	304.92	33%	530.7	386.56	42%

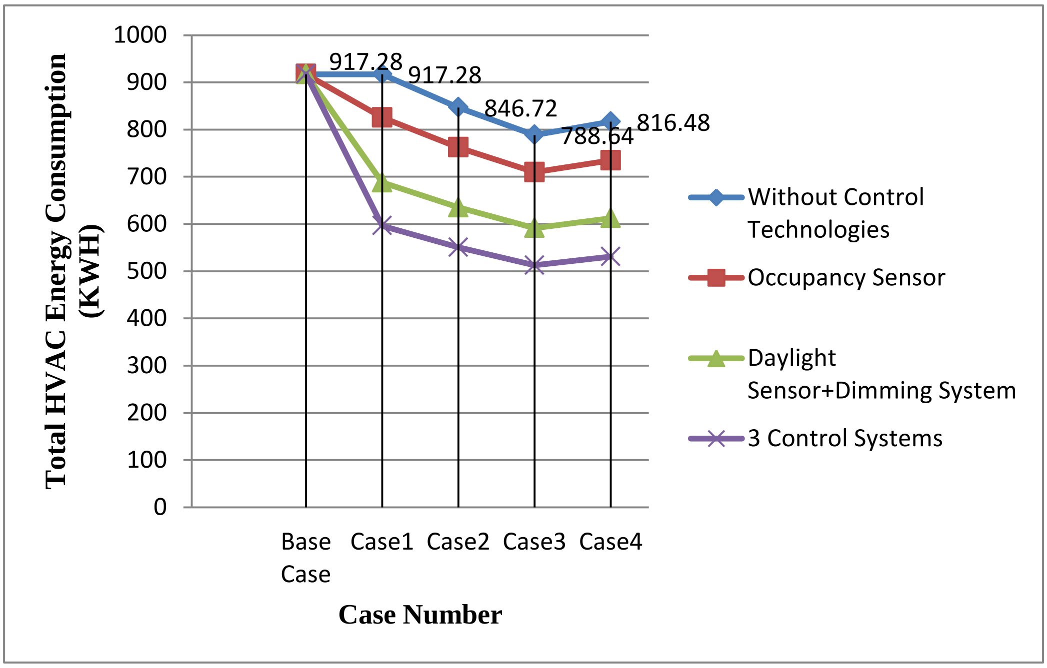


Figure6.27: Annual HVAC Energy Consumptions for All Cases of Lighting and Control Technologies in Corridor

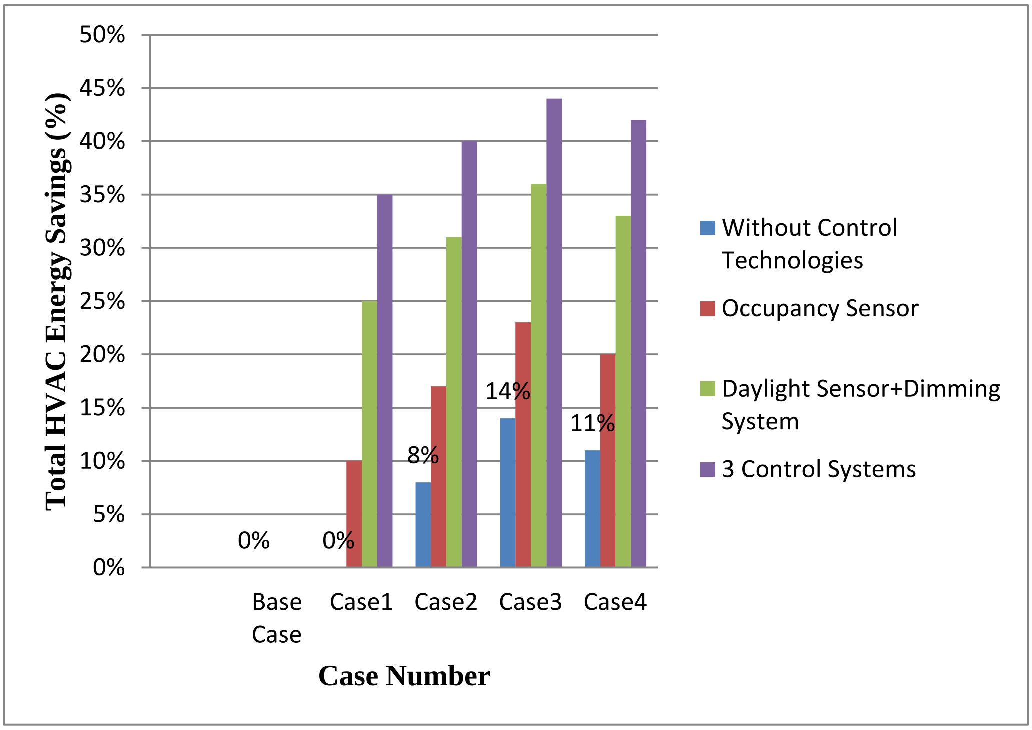


Figure6.28: HVAC Energy Savings for All Cases of Lighting and Control Technologies in Corridor

6.5 Economic Analysis

All economic analysis is based on FEWA electricity rates for Ras Al Khaimah Federal Buildings. It is 0.23 AED/KWH for electricity consumption up to 10,000KHW and 0.37AED/KWH for more than 10,000KWH. In our case we use 0.23AED/KWH since the electricity consumption is less than 10,000KWH

In this section, some calculations will be done to find the most commercial and cost saving from all lighting and control technologies in each selected areas. The calculations based on some equations that were taken from similar studies and from specialists lighting suppliers. The following steps have to be done to get the most commercial lighting and control technologies from all cases:

1) Finding the annual electricity cost payments for each case.

Annual Electricity Cost Payment

= Electricity Consumption (KWH) ***FEWA Electricity Rate 0.23**(AED) (6.7)

2) Finding the cost for changing and replacement of lamps, lamps ballast, and control technologies for each case. This needs to know the following information:

- Average Life Time for each Type of Lighting and Control Technologies.
    - T8:10,000 hrs
    - T5:25,000 hrs
    - CFL:15,000 hrs
    - LED:50,000 hrs
    - Lighting Technologies:25,000 hrs
- Duration for annual changing of lamps, ballasts, and control technologies.

Duration for annual changing of each unit

$$= \frac{\textbf{Average Life Time for each unit (hrs)}}{\textbf{Operation hours (hrs)}} \qquad (6.8)$$

Where Operation hours =7Hrs *5Days * 48 Weeks =1680 Hours

- Total number of lamps for each case. (Example: T8 (4*18) Watt has 4 lamps).
- Lamp ballast for each light fitting is 2 multiplied by the number of lamps in each case except for LED because it use one ballast instead of two as known from lighting specialists and lighting suppliers.
- Total number of lamps, ballasts and control technology that needs to be changed yearly.

Units to be changed yearly

$$= \frac{\textbf{Total number of units in each case}}{\textbf{Duration of changing the units yearly}} \qquad (6.8)$$

- Unit price of each lamp, ballast , light fittings, and control technologies (were taken from Quotations and by Information from Lighting Suppliers):
    - T8 Lamp : 3 (AED)
    - T5 Lamp : 5 (AED)
    - CFL Lamp : 4 (AED)
    - LED Lamp : 31 (AED)
    - Lamp Ballast for T8,T5,CFL : 3.5-5.5 (AED)
    - Lamp Ballast for LED : 25 (AED)
    - T8(4*18) : 280 (AED)
    - T5(4*14) : 420 (AED)
    - CFL(2*13) : 224 (AED)

- CFL(1*13) : 186 (AED)
- CFL(2*26) : 224 (AED)
- CFL(1*26) : 186 (AED)
- LED(40) : 1100 (AED)
- LED(27) : 580 (AED)
- Occupancy Sensor : 550 (AED)
- Daylight Sensor+ Dimming System : 560 (AED)

- Cost of replacement of one lamp, ballast and control technology (According to Lighting Specialists is10AED)
- Cost of changing and replacement of one lamp, ballast and control technologies.

Cost of changing and replacement of one unit

= **Cost of one unit** + **Cost of replacement of one unit** (10AED) (6.9)

- Total annual cost of changing lamps, ballasts, and control technologies for each case.

Total Annual Cost of changing of one unit (6.10)

= **Cost of changing and replacement of one unit** * **Units to be changed yearly**

- Total annual saving costs of changing lamps, ballasts, and control technology for each case.

Total Annual Saving for each case (6.11)

= **(Lighting + HVAC) Payment Savings + Total Annual Cost Saving for Changing (Lamps, Ballasts, Control Technologies)**

3) Finding the Payback period and Finding the Return of Investment (ROI) for each case in each selected area. Payback period is the amount of time in decimal years that will go by before a system upgrade option's energy savings reach the net installation cost (also called Investment Cost). Return of Investment is an internal rate of return, expressed as a percentage, based on the relationship between annual energy savings and the net installation cost. They represent a simple and effective first step at determining whether the new equipment would be a good investment for its owner.

$$\textbf{Payback period} = \frac{\textbf{Cost of Investment}}{\textbf{Total Annual Saving}} \qquad (6.12)$$

$$\textbf{ROI (\%)} = \frac{\textbf{Total Annual Saving}}{\textbf{Cost of Investment}} *(100) \qquad (6.13)$$

Cost of Investment (Initial Cost)

= **Number of light fittings * Unit price for each lighting technology** (6.14)

The results were shifted to Appendix B which is divided to three sections according to the area of the study. From this Appendix, we get many results such as: the best Payback and ROI were for the LED for all cases, The Payback in the Meeting Room using Investment cost of 3920 AED is 8.68 for LED, -17.88 for CFL and 14.06 for T5. ROI (%) is 11.53% for LED, -6% for CFL, and 7% for T5. For Electromechanical Office, The Payback using Investment cost of 1120AED is 4.88 for LED, -5.79 for CFL, and 9.45 for T5. The ROI (%) is 20.5% for LED, -17.5% for CFL, and 10.6% for T5. For Corridor, The Payback using Investment cost of 1302 is 34.49 for LED, -20.9 for CFL, and 48.88 for T5. The ROI (%) is 2.9% for LED, -4.8% for CFL, and 2% for T5. These Payback Period and ROI percentages became better when using Occupancy Sensors, Daylight Sensors and Dimming Systems. The best Payback were the best when using all the three control systems with LED lighting technologies as can be indicated in Appendix B where the Payback for this Case is Payback Period is 3.4

Chapter 7
Conclusions and Recommendations

7.1 Conclusions

This research used to find the best lighting and control technologies that can be used in Federal Buildings in UAE to reduce the total energy consumption by reducing lighting energy consumption as a direct energy and also the HVAC (cooling) energy which is the indirect energy that can be saved depending on saving in lighting energy. Three lighting technology proposal were compared to the existing lighting in MOPW-RAK building. The lighting technologies are T5, CFL, and LED which were compared to the existing lighting technology which is T8 in Meeting and Office and CFL in Corridor. Also, lighting control technologies were also applied to the selected areas in the building and compared to the base case also.

MOPW-RAK Building was selected for applying the above technologies of saving energy. It was selected to indicate the energy saving in federal building in UAE. The Federal buildings are our interested buildings in this research because it can give clear measurements since the working area of huge comparing with residential buildings. Another reason for choosing the federal buildings is because it includes different purposes rooms and offices that can give us an indication about the best lighting solution for each area according to the occupant needs and purposes. MOPW-RAK was selected because any required data about the MEP systems or any other information or drawings about the different sections, rooms and offices were easy to find because the researcher is working in this building and was one of the team of engineers who build MOPW-RAK building.

The building was simulated in two different simulation software's: Dialux lighting simulation software and IES-VE building energy efficiency modeling software. The study focused on three different purposes areas: Meeting Room, Electromechanical Office, and Corridor. The different information about these three areas was entered to the software's to get the results and analyze them for each area. Some calculations and comparisons between the results were done. From the results, analysis and comparisons we found the followings:

- As a conclusion, all the above lighting and control technologies have advantages and disadvantages, also each one is better to be used in certain area.
- The location, direction, size and many other factors must be taken into consideration in choosing the most suitable type of lighting technologies and lighting control technologies and these factors can make big changes in the results and analysis of the light.
- LED lights is the best because, although the purchasing unit price is higher than the other type of lighting technologies, but it don't need to change the lamp periodically as the long life time, it doesn't need maintenance, replacement of the unit or labor charges. And also by using the return of investment (ROI) and Payback calculation method, we prove that it the best than all other technologies. The entire above are important, but the most important reason for using LED technology in our case study example area is the high amount of saving the lighting energy. LED has the highest possibility savings of energy costs and for CO2 emissions savings possibility.
- CFL is the worst solution for our case because of many reasons such as: CFL uses magnetic ballast whereas, T5 and T8 uses electronic ballast. This is the main reason of the high energy consumption in CFL. The reason is the cheap material components and old electronic design with bad performance of the magnetic ballast. Many lighting manufacturer prefer to use this type of ballast in CFL lighting technology because of its cheap price of light fittings with this type of ballast. They also prefer to remain using this type of ballast in CFL because, although there are better and earlier technologies like T8 and T5, but still many customers prefer to use less price light fittings and they don't care about the better materials and electronic components. They prefer to save the purchasing price for light fittings. Another reason for using the magnetic ballast in CFL is because there are many places that don't need high quality light fittings
- In this study, the following controls were examined: Occupancy sensors, Daylight Sensors, and Dimming System. It was found that with the use of Occupancy sensors, energy savings were 10%, while for Daylight Sensor and Dimming Systems were 25%. The most expensive option is when using the full power lighting without control Systems.

- Using energy savings Lighting technologies not only affects lighting energy consumption, but are also affect HVAC energy savings because of the outcome heat from the Lighting technologies. Lighting Control Technology also have an effects on HVAC energy savings because of the relation between the HVAC and Lighting which is A fact and proved using IES-VE software which show that the Fraction between Lighting and HVAC is 0.33. In another word, each 1KWH of Lighting energy equal 3 KWH of HVAC energy consumptions.

7.2 Recommendations

- While performing the research, the following difficulties were encountered: Problems encountered were in relation to the user's patterns. The occupants had problems with the occupancy sensors. They found that when working at their desk for long periods of time without getting up, the lights are turned off. The occupancy sensor had trouble detecting occupancy whilst occupants were stationary. To counter-act this problem, the pre-set time for the occupancy sensor must do to automatically turn lights off was increased from 5-10 minutes to 15-20 minutes. This led to smaller energy savings that increased user satisfaction and as stated by many authors in the literature review, occupant satisfaction can be linked to higher productivity. Since most of the employees of the MOPW-RAK building which is our case study building are site engineers and site inspectors, which makes the use of the occupancy sensor very important even more than the daylight sensors because occupancy sensors can reduce the lamp life that depends on the switching on/off the lights according to the occupancy and number of times that employees and their customers like consultants and contractors and suppliers are entering and leaving the office during the working day. All these increase the price of doing all the required replacement of the lamp and the fitting. This increased the cost of lights in the offices since the office occupies the largest area of the building.
- It is highly recommended to use LED lighting technology in offices because of its high performance physical features that reduce the glares and give high performance lighting in offices which can increase the comfort ability and productivity for the employees.

- It is highly recommended to not use CFL lighting in offices because of many reasons such as: the bad physical features those results in bad performance because of the bad working environment. Another reason to not use the CFL in offices is the design and shape of the light fitting of the unit that always comes in small size down light shape. This is not suitable in the offices because most of the ceiling of the offices comes with false ceiling that the down light unit not capable to be fitted in this type of ceiling. Another reason is reaching the desired lux level needs to put more units of the light fitting that sometimes as in our case where we increased the number of units to be doubled. This will be ugly, crowded and uncomfortable in the ceiling especially as in our case study office that has small dimensions of the room size. It also can't give the required concentration of the lights on the working surface area that must be included a computer which needs to have a concentrated lighting on this level for better working performance and comfort ability for employee while working with the computer. The other reason that makes CFL technology not suitable for offices is also refereeing to the international standards again which uses yellow color or warm white color for the lamps uses this technology which is not used in office at all. The white color lamp is preferred to be used in offices because it affects the human body by giving more concentration and better working ability.
- CFL lighting technology should be avoided in places where lights are frequently turned on and off because it uses magnetic ballast which is cheap and bad quality comparing to the electronic ballast that is used in latest lighting technologies. This will reduce the life time for the light fitting and this will increase the number of units that have damaged and needs to be replaced. The life of a CFL is significantly shorter if it is turned on and off frequently.
- Although the above features makes the CFL lighting technology very bad choice in offices, but on the other hand it is highly recommended in some other areas that required the above features of the CFL technology such as the open areas and corridors specially in hospitals that doesn't require strong light or high lux level. It also recommended in the surrounding of the outer borders of many special purposes rooms like the Meeting Room. This is because CFL down lights are mostly supported with light dimmers that used to adjust the light brightness as

when having data show with projector presentation as a popular example. This feature is not required in a normal office. Also, CFL is highly recommended in the relaxation areas like: receptions, waiting areas, cafeteria and restaurants …etc. this is because of the International Standard lux level which is low to give relaxation for the occupancy people.

- CFL technology have much more less lamp life and burning hours than the LED technology, on the other hand the life time of the LED lamp can reach 50,000 hrs. This means that the CFL will need more cost for maintenance, labor, and replacement units.
- Some light fittings have differences in uniformity, this is because of the material used in the model or the type of louvers. This might be designed in a different than the UAE standard and this cause glare and some other less or bad uniformity related problems. To solve this problem, it is highly recommended to use the to choose the brands that already used in the UAE or similar Gulf or Middle East countries which have almost the same weather and similar environment. The history of the Lighting manufacturer is very important and the feedback from other customers who were used the same brand and similar models from the same manufacturer are important also. Of course, studying the required features of lights according to purposes of the room is also one of the most important things to be taken into consideration.
- Comparing the uniformity u0 between the four cases, it is noticed that LED has the best uniformity than the other cases. The second is the T5 (Case2), then the CFL (Case3) and last is Base Case (T8). This is reasonable for LED and T5, but it seems not to be true for the other 2 cases of CFL and T8.
- Do not use the occupancy sensor in the meeting room because it is used just in some certain and mostly periodically like monthly or weekly once or twice times.
- Always use Dimmers in meeting room, because it is usually include Projectors, screens, and one or more lab top computers. Dimmers are the best solution for focusing the projectors and screens and to adjust and reduce the lighting brightens for better and more comfortable visible view on screens. Daylight sensor is also important in meeting room because it is a helpful way of saving energy when having with the dimmers.

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APPENDIX A

DIALUX SIMULATION RESULTS

APPENDIX (A-1)

First Simulated Area – Main Meeting Room

Height of Room: 3.000 m, Mounting Height: 3.088 m, Light loss factor: 0.80 Values in Lux, Scale 1:118

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	487	265	665	0.544
Floor	20	389	174	592	0.447
Ceiling	70	83	66	103	0.796
Walls (4)	50	178	70	478	/

Workplane:
Height: 0.750 m
Grid: 7 x 11 Points
Boundary Zone: 0.500 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.371, Ceiling / Working Plane: 0.172.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	TRILUX Enterio M73 RSV 418 E Enterio (1.000)	3352	5200	76.0
2	10	TRILUX Inperla C2 HR 2TCT13 ... E Inperla (1.000)	1323	1800	28.0
			Total: 33343	Total: 49200	736.0

Specific connected load: 13.41 W/m² = 2.75 W/m²/100 lx (Ground area: 54.90 m²)

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Calculation Surface@ 0.75m working table	perpendicular	64 x 64	475	213	671	0.447	0.317

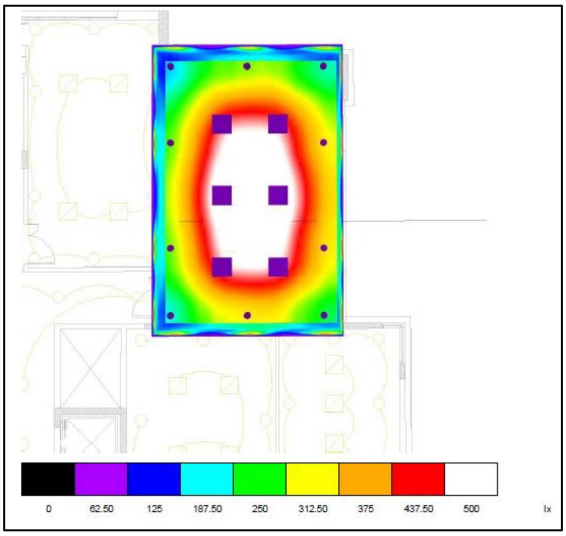
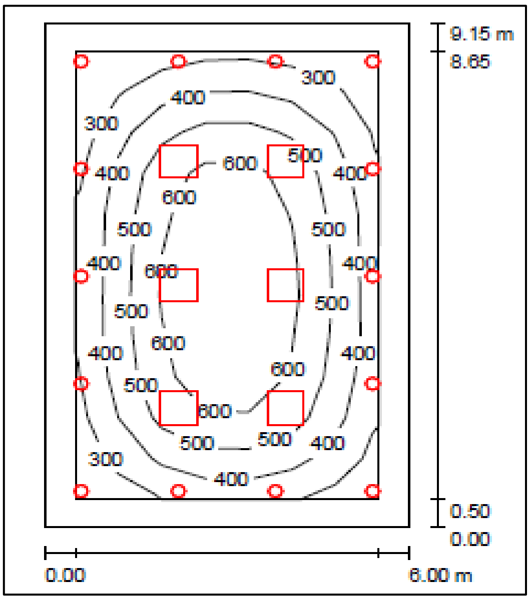
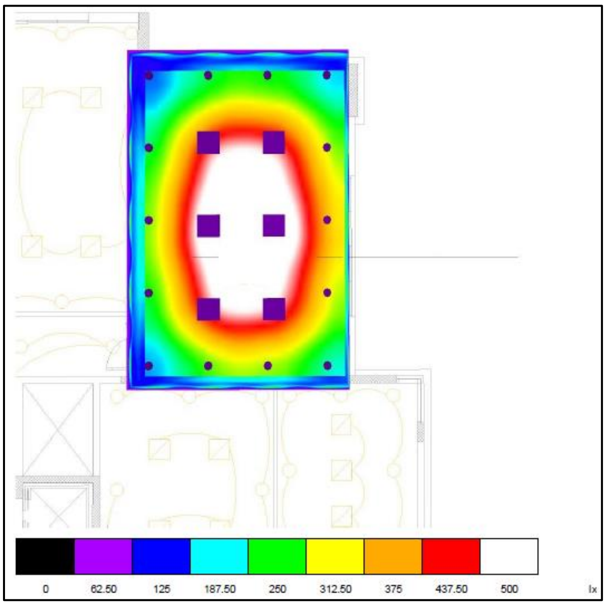


Figure A.1.1: Base Case (T-8 4x18w & CFL 2x13w)





Height of Room: 3.000 m, Mounting Height: 3.088 m, Light loss factor: 0.80 — Values in Lux, Scale 1:118

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	479	220	693	0.460
Floor	20	377	148	616	0.393
Ceiling	70	77	58	89	0.755
Walls (4)	50	157	60	331	/

Workplane:
Height: 0.750 m
Grid: 7 x 11 Points
Boundary Zone: 0.500 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.324, Ceiling / Working Plane: 0.161.

Luminaire Parts List

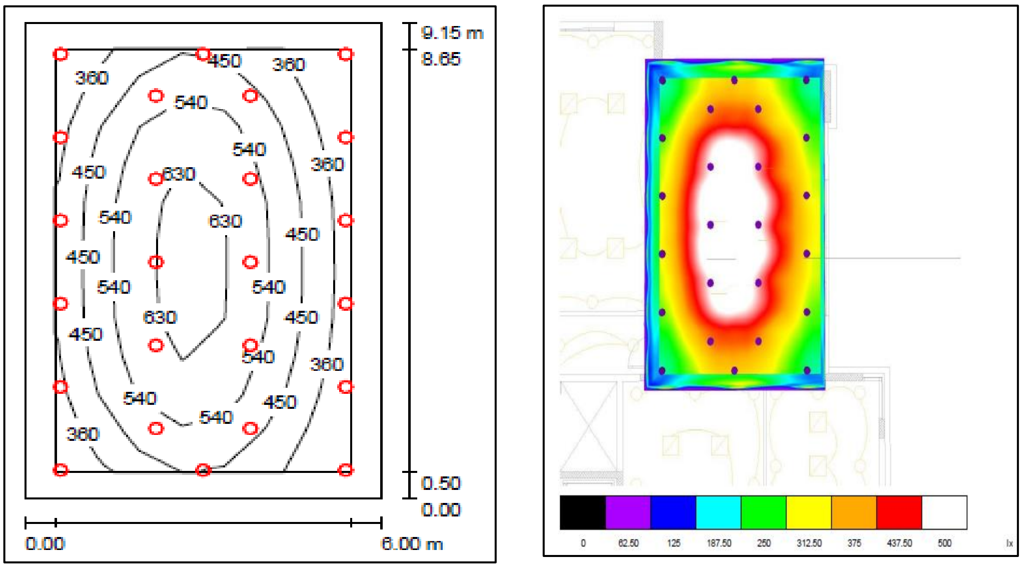
No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	TRILUX Enterio M73 RSV 414 E Enterio (1.000)	3556	4800	61.0
2	14	TRILUX Inperla C2 HR 1TCT13 ... E Inperla (1.000)	713	900	15.0
			Total: 31317	Total: 41400	576.0

Specific connected load: 10.49 W/m² = 2.19 W/m²/100 lx (Ground area: 54.90 m²)

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Calculation Surface@ 0.75m working table	perpendicular	64 x 64	466	160	704	0.342	0.227

Figure A.1.2: Case2 (T-5 4x14w & CFL 1x13w)



Height of Room: 3.000 m, Mounting Height: 3.100 m, Light loss factor: 0.80

Values in Lux, Scale 1:118

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	488	271	690	0.556
Floor	20	391	201	577	0.516
Ceiling	70	85	69	104	0.819
Walls (4)	50	185	68	369	/

Workplane:

Height:	0.750 m
Grid:	7 x 11 Points
Boundary Zone:	0.500 m

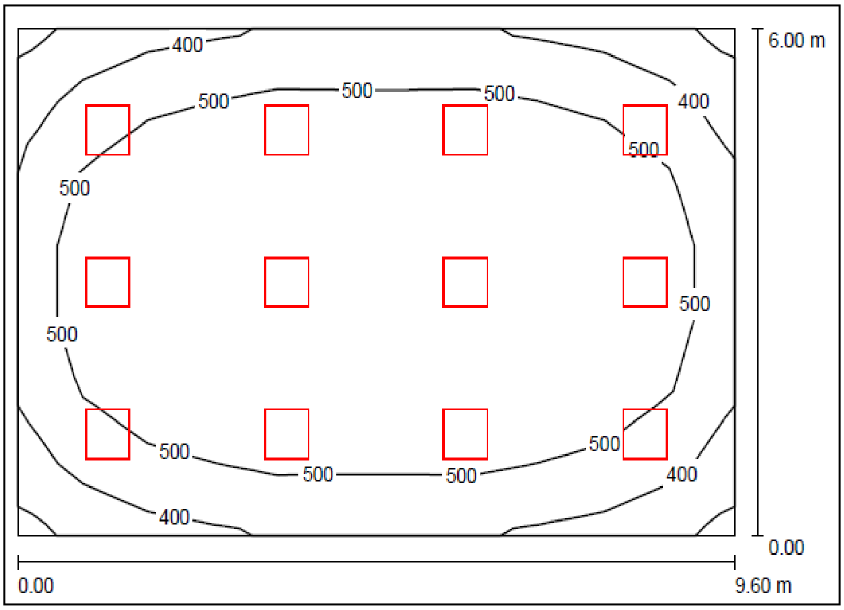
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.372, Ceiling / Working Plane: 0.173.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	14	TRILUX Inperla C2 HR 1TCT13 ... E Inperla (1.000)	713	900	15.0
2	10	TRILUX Inperla C2 HR 2TCT26/32 ... (tc-t..26W) E Inperla (1.000)	2390	3600	56.0
			Total: 33880	Total: 48600	770.0

Specific connected load: 14.03 W/m² = 2.87 W/m²/100 lx (Ground area: 54.90 m²)

Figure A.1.3: Case 3(CFL 2x26w & CFL 1x13w)



Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	532	343	666	0.644
Floor	20	466	297	584	0.636
Ceiling	80	145	101	244	0.701
Walls (4)	50	302	158	432	/

Luminaire Parts List

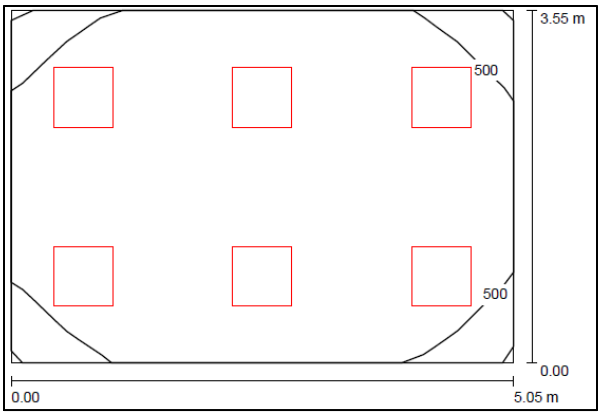
No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	12	TRILUX Liventy Flat 600 OT LED3900nw 01 ETDD Liventy··· (1.000)	3899	3900	40.0
			Total: 46785	Total: 46800	480.0

Specific connected load: 8.33 W/m² = 1.57 W/m²/100 lx (Ground area: 57.60 m²)

Figure A.1.4: Case4 (LED 40w)

APPENDIX (A-2)

Second Simulated Area – Electromechanical Office



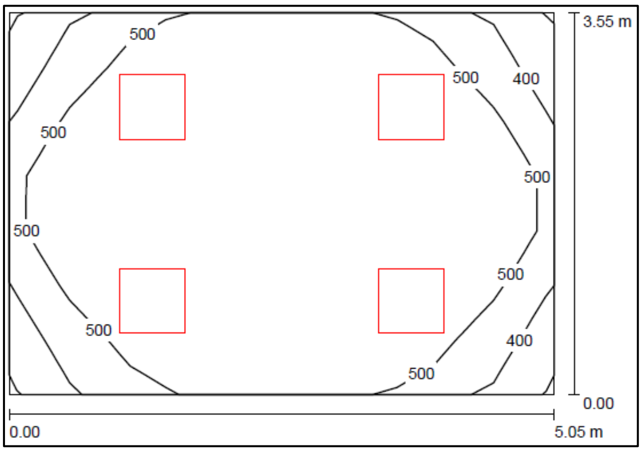
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	659	448	908	0.679
Floor	20	554	390	691	0.704
Ceiling	80	133	109	150	0.822
Walls (4)	50	300	105	557	/

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	TRILUX Enterio M73 RPV 418 E Enterio (1.000)	3381	5200	76.0
			Total: 20287	Total: 31200	456.0

Specific connected load: 25.44 W/m² = 3.86 W/m²/100 lx (Ground area: 17.93 m²)

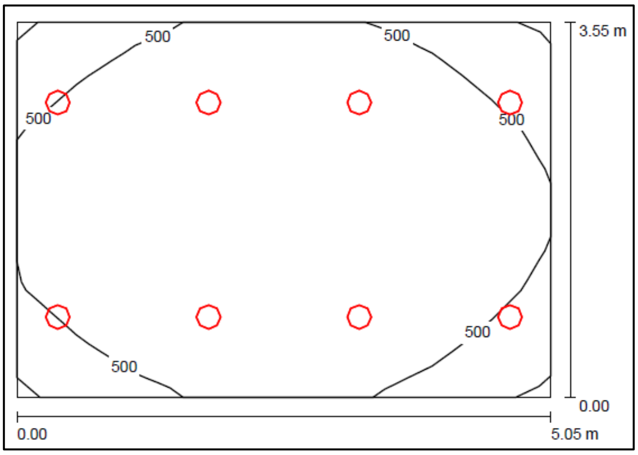
FigureA.2.1: Base Case (T8 4*18 w)



Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	595	360	860	0.605
Floor	20	500	332	645	0.663
Ceiling	80	109	80	126	0.739
Walls (4)	50	248	82	562	/

Workplane:
Height: 0.750 m
Grid: 9 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.414, Ceiling / Working Plane: 0.182.

FigureA.2.2: Case2 (T5 4*14 w)



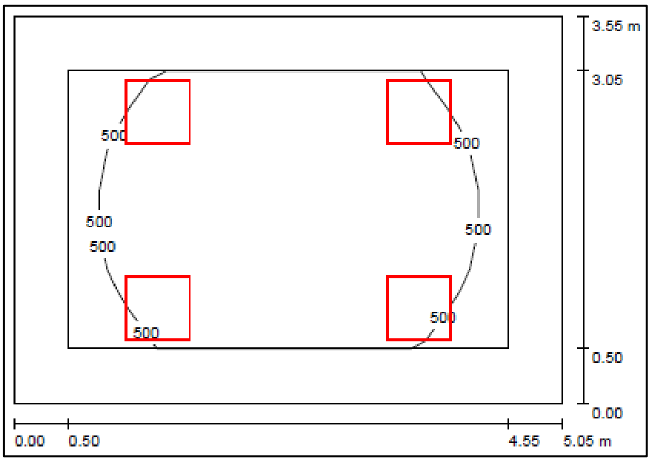
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	561	432	666	0.770
Floor	20	472	345	581	0.731
Ceiling	80	126	108	162	0.858
Walls (4)	50	279	110	1334	/

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	8	TRILUX Inperla C2 HR 2TCT26/32 ... (tc-t..32W) + RA-HR E Inperla (1.000)	2261	4800	70.0
			Total: 18085	Total: 38400	560.0

Specific connected load: 31.24 W/m² = 5.56 W/m²/100 lx (Ground area: 17.93 m²)

FigureA.2.3: Case3 (CFL 2*26 w)



Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	526	457	567	0.869
Floor	20	390	287	461	0.734
Ceiling	80	177	118	287	0.669
Walls (4)	60	303	157	591	/

Workplane:
Height: 0.750 m
Grid: 9 x 7 Points
Boundary Zone: 0.500 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.630, Ceiling / Working Plane: 0.337.

Luminaire Parts List

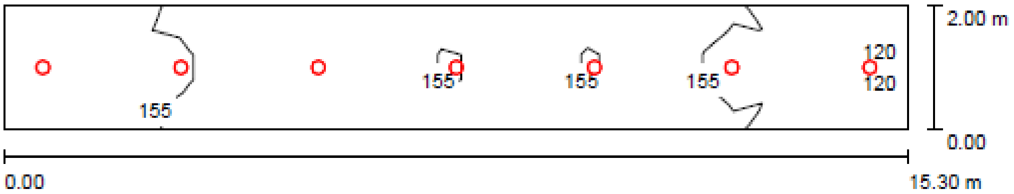
No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	4	TRILUX Liventy Flat 600 OT LED3900nw 01 ETDD Liventy··· (1.000)	3899	3900	40.0
			Total: 15595	Total: 15600	160.0

Specific connected load: 8.92 W/m² = 1.70 W/m²/100 lx (Ground area: 17.93 m²)

FigureA.2.4: Case4 (LED 40 w)

APPENDIX (A-3)

Third Simulated Area – The Corridor



Height of Room: 3.000 m, Mounting Height: 3.100 m, Maintenance factor: 0.80

Values in Lux, Scale 1:110

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	153	115	168	0.749
Floor	20	151	109	166	0.721
Ceiling	80	50	42	68	0.836
Walls (4)	50	116	44	464	/

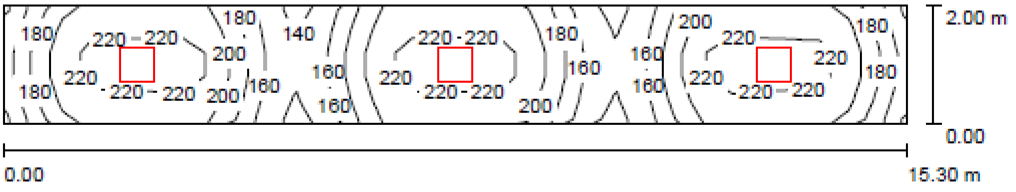
Workplane:
Height: 0.050 m
Grid: 31 x 5 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.763, Ceiling / Working Plane: 0.325.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	7	TRILUX Inperla C2 HR 1TCT26/32 ... (tc-t..32W) E Inperla (1.000)	1799	2400	35.0
			Total: 12592	Total: 16800	245.0

Specific connected load: 8.01 W/m² = 5.22 W/m²/100 lx (Ground area: 30.60 m²)

FigureA.3.1: Base Case (CFL 1*26 w)



Height of Room: 3.000 m, Mounting Height: 3.057 m, Maintenance factor: 0.80

Values in Lux, Scale 1:110

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	194	134	231	0.690
Floor	20	192	132	227	0.688
Ceiling	80	45	31	63	0.698
Walls (4)	50	105	33	408	/

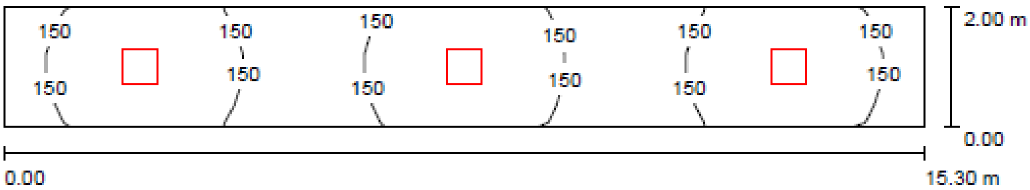
Workplane:
Height: 0.050 m
Grid: 31 x 5 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.544, Ceiling / Working Plane: 0.229.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	3	TRILUX 3694D-RPX/14 E Recessed louvre luminaires 368···, 369··· (1.000)	4369	4800	61.0
			Total: 13108	Total: 14400	183.0

Specific connected load: 5.98 W/m² = 3.08 W/m²/100 lx (Ground area: 30.60 m²)

FigureA.3.2: Case2 (T5 4*14 w)



Height of Room: 3.000 m, Mounting Height: 3.088 m, Maintenance factor: 0.80

Values in Lux, Scale 1:110

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	152	114	180	0.750
Floor	20	151	110	176	0.728
Ceiling	70	33	24	43	0.720
Walls (4)	50	79	25	269	/

Workplane:

Height:	0.050 m
Grid:	31 x 5 Points
Boundary Zone:	0.000 m

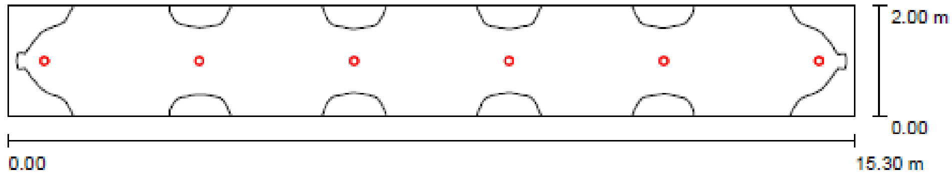
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.517, Ceiling / Working Plane: 0.216.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	3	TRILUX Enterio M73 RPV 418 E Enterio (1.000)	3381	5200	76.0
			Total: 10143	Total: 15600	228.0

Specific connected load: 7.45 W/m² = 4.89 W/m²/100 lx (Ground area: 30.60 m²)

FigureA.3.3: Case 3 (T8 4*18 w)



Height of Room: 3.000 m, Mounting Height: 3.100 m, Maintenance factor: 0.80

Values in Lux, Scale 1:110

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	177	131	222	0.738
Floor	20	176	129	216	0.734
Ceiling	80	32	28	37	0.875
Walls (4)	50	79	26	411	/

Workplane:
Height: 0.050 m
Grid: 256 x 32 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.450, Ceiling / Working Plane: 0.182.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	TRILUX InperlaL C05 BR LED2000ww 01 ET InperlaL··· (1.000)	1799	1800	27.0
			Total: 10796	Total: 10800	162.0

Specific connected load: 5.29 W/m² = 2.98 W/m²/100 lx (Ground area: 30.60 m²)

FigureA.3.4: Case 4 (LED 27 w)

APPENDIX B

Economic Calculations and Results

APPENDIX (B-1)

First Simulated Area – Meeting Room

TableB-1.1: Annual Lighting Electricity Cost Savings for different Lighting Technologies in Meeting Room

Case Number	Type of Lighting Fixture	Lighting Wattage for Each Type of Light (W)	Luminaires Quantities	Unit Price for Each Lighting Fixture (AED)	Total Price for Each Case (AED)	Total Savings in Lighting Fixture Unit Price for Each Case (AED)	Annual Lighting Energy Consumption (KWh)	Annual Electricity Cost for Each Case (*0.23 AED)	Annual Lighting Electricity Cost Savings for Each Case (AED)	Annual Lighting Electricity Cost Savings Percentage for Each Case (AED)(%)
Case 1 **Base Case**	T8	(4*18) T8=72	6	280	3920	_	1162.5	267.39	_	_
	CFL	(2*13) CFL=26	10	224						
Case 2	T5	(4*14) T5=56	6	420	5124	-1204	870.24	200.16	67.23	25.14%
	CFL	(1*13) CFL=13	14	186						
Case 3	CFL	(2*26) CFL=52	10	224	4844	-924	1179.3	271.25	-3.86	-1.45%
		(1*13) CFL=13	14	186						
Case 4	LED	(40) LED=40	12	1100	13200	-9280	806.4	185.47	81.92	30.64%

TableB-1.2: Cost of Changing Lamps for Each Case in the Meeting Room

Case Number	Type of Lighting Fixture	Average Lamp Life Time (Hrs.)	Duration of Annual Changing of Lamps	Total Number of Lamps	Number of Lamps Needs to be Changed Annually	Cost of One Lamp (AED)	Cost of Replacement for One Lamp (AED)	Cost of Changing and Replacement for One Lamp(AED)	Total Annual Cost of Changing Lamps (AED)	Savings for Total Annual Cost of Changing Lamps (AED)
Case1 **Base Case**	T8	10,000	7.44	44	6	3	10	13	76.88	_
	CFL	15,000								
Case2	T5	25,000	11.9	38	3	5		15	47.88	29.00
	CFL	15,000								
Case3	CFL	15,000	8.93	34	4	4		14	53.31	23.56
Case4	LED	50,000	29.7	12	0.4	31		41	16.53	60.35

TableB-1.3: Cost of Changing Lamps Ballast for Each Case in the Meeting Room

Case Number	Type of Lighting Fixture	Average Lamp Ballast Life Time (Hrs.)	Duration of Annual Changing of Lamps Ballast	Total Number of Lamps Ballast	Number of Lamps Ballast Needs to be Changed Annually	Cost of One Lamp Ballast (AED)	Cost of Replacement for One Lamp Ballast (AED)	Cost of Changing and Replacement for One Lamp Ballast (AED)	Total Annual Cost of Changing Lamps Ballast (AED)	Savings for Total Annual Cost of Changing Lamps Ballast (AED)
Case1 **Base Case**	T8 CFL	30,000	17.86	32	2	5	10	15	26.88	–
Case2	T5 CFL	35,000	20.83	40	2	5.5		15.5	29.76	-2.88
Case3	CFL	30,000	17.86	48	3	3.5		13.5	36.29	-9.41
Case4	LED	50,000	29.76	12	0.4	25		35	14.11	12.77

TableB-1.4: Payback Period and ROI for the Meeting Room

Case Number	Type of Lighting Fixture	Annual Lighting Electricity Cost Savings (AED)	Total Annual Cost Savings for Changing Lamp (AED)	Total Annual Cost Savings for Changing Lamps Ballast (AED)	Annual HVAC Cost Savings (AED)	Annual Cost Savings (AED)	Total Investment Cost in Changing Lights (AED)	Payback Period (AED)	ROI (AED)
Case1 **Base Case**	T8 CFL	–	–	–	–	–	3920	–	–
Case2	T5 CFL	67.23	29.00	-2.88	185.47	278.82		14.06	7%
Case3	CFL	-3.86	23.56	-9.41	-229.52	-219.23		-17.88	-6%
Case4	LED	81.92	60.35	12.77	296.76	451.79		8.68	11.53%

TableB-1.5: Lighting Energy Cost Payment Savings for the Lighting Control Technologies in Meeting Room

Case Number	Type of Lighting Fixture	Annual Lighting Energy Cost Payment (AED)	Annual Lighting Energy Cost Savings (AED)	Annual Lighting Energy Cost Payment (AED)	Annual Lighting Energy Cost Savings (AED)	Annual Lighting Energy Cost Payment (AED)	Annual Lighting Energy Cost Savings (AED)
Base Case	T8	267.39	-	267.39	-	267.3	-
Case1	T8	240.65	26.74	240.65	66.85	755.6	406.90
Case2	T5	180.14	87.25	180.14	117.27	565.6	596.90
Case3	CFL	244.13	23.26	244.13	63.95	766.5	395.98
Case4	LED	166.92	100.46	166.92	128.28	524.1	638.40

TableB-1.6: HVAC Energy Cost Payment Savings for the Lighting Control Technologies in Meeting Room

Case Number	Type of Lighting Fixture	Annual HVAC Energy Cost Payment AED)	Annual HVAC Energy Cost Savings (AED)	Annual HVAC Energy Cost Payment AED)	Annual HVAC Energy Cost Savings (AED)	Annual HVAC Energy Cost Payment AED)	Annual HVAC Energy Cost Savings (AED)
Base Case	T8	853.17	-	853.17	-	853.17	-
Case1	T8	767.86	85.32	639.88	213.29	554.56	298.61
Case2	T5	600.93	252.24	500.77	352.40	434.00	419.17
Case3	CFL	974.42	-121.2	812.02	41.15	149.42	703.75
Case4	LED	500.77	352.40	435.86	417.31	491.50	361.67

TableB-1.7: Total Annual Cost of Changing Control Systems for All Cases

Case Number	Type of Lighting Fixture	Average Life Time for all the control systems (Hrs)	Duration of Annual Changing of control sys.	Total Number of control sys. For each case	Number of control sys. that's Needs to be Changed Annually	Cost of Replacement for One control sys. (AED)	Cost of One Occupancy Sensor (AED)	Cost of Changing and Replacement for One control sys(AED)	Total Annual Cost of Changing control sys. for Each Case (AED)	Cost of One (Daylight sensor with Dimming System) (AED)	Cost of Changing and Replacement for One control sys(AED)	Total Annual Cost of Changing control sys. for Each Case (AED)	Cost of (O.S +Daylight S. +Dim. Sys.) (AED)	Cost of Changing and Replacement for One control sys(AED)	Total Annual Cost of Changing control sys. for Each Case (AED)
Case1	T8	25000	14.88	1	0.67	10	550	560	37.63	650	660	44.35	1200	1210	81.31
Case2	T5														
Case3	CFL														
Case4	LED														

TableB-1.8: Total Annual Cost Savings without Using Control Technologies

Case Number	Type of Lighting Fixture	Annual Lighting Electricity Cost Savings (AED)	Annual HVAC Electricity Cost Savings (AED)	Total Annual Cost Savings for Changing Lamps (AED)	Total Annual Cost Savings for Changing Lamps Ballast (AED)	Annual Cost Savings for Each Case (AED)
Base Case	T8	_	_	_	_	_
Case1	T8	_	_	_	_	_
Case2	T5	67.23	185.47	29	-2.88	278.82
Case3	CFL	-3.86	-229.52	23.56	-9.41	-219.23
Case4	LED	81.92	296.76	60.35	12.77	451.8

TableB-1.9: Total Annual Cost Savings When Using Occupancy Sensors in Meeting Room

Case Number	Type of Lighting Fixture	Annual Lighting Electricity Cost Savings (AED)	Annual HVAC Electricity Cost Savings (AED)	Total Annual Cost Savings for Changing Lamps (AED)	Total Annual Cost Savings for Changing Lamps Ballast (AED)	Savings for Total Annual Cost of Changing control sys. for Each Case (AED)	Annual Cost Savings for Each Case (AED)
Case1	T8	26.74	85.32	_	_	37.63	149.69
Case2	T5	87.25	252.24	29	-2.88	37.63	403.24
Case3	CFL	23.26	-121.25	23.56	-9.41	37.63	-46.21
Case4	LED	100.46	352.4	60.35	12.77	37.63	563.61

TableB-1.10: Total Annual Cost Savings When Using Daylight S.and Dim.Sys.

Case Number	Type of Lighting Fixture	Annual Lighting Electricity Cost Savings (AED)	Annual HVAC Electricity Cost Savings (AED)	Total Annual Cost Savings for Changing Lamps (AED)	Total Annual Cost Savings for Changing Lamps Ballast (AED)	Savings for Total Annual Cost of Changing control sys. for Each Case (AED)	Annual Cost Savings for Each Case (AED)
Case1	T8	66.85	213.29	_	_	44.35	324.49
Case2	T5	117.27	352.4	29	-2.88	44.35	540.14
Case3	CFL	63.95	41.15	23.56	-9.41	44.35	163.6
Case4	LED	128.28	417.31	60.35	12.77	44.35	663.06

TableB-1.11: Total Annual Cost Savings When Using the Three Control Systems

Case Number	Type of Lighting Fixture	Annual Lighting Electricity Cost Savings (AED)	Annual HVAC Electricity Cost Savings (AED)	Total Annual Cost Savings for Changing Lamps (AED)	Total Annual Cost Savings for Changing Lamps Ballast (AED)	Savings for Total Annual Cost of Changing control sys. for Each Case (AED)	Annual Cost Savings for Each Case (AED)
Case1	T8	406.9	298.61	_	_	81.31	786.82
Case2	T5	596.9	419.17	29	-2.88	81.31	1123.5
Case3	CFL	395.98	307.75	23.56	-9.41	81.31	799.19
Case4	LED	638.4	361.67	60.35	12.77	81.31	1154.5

TableB-1.12: Payback Period and ROI without Control Technologies

Case Number	Type of Lighting Fixture	Total Investment Cost in Changing the Lights for base case (AED)	Annual Total Cost Savings (Without Cont. Sys.) (AED)	Payback Period for Each Case (AED)	ROI for Each Case (AED)
Base Case	T8	3920	_	_	_
Case1	T8		_	_	_
Case2	T5		278.82	14.06	7.1%
Case3	CFL		-219.23	-17.88	-5.6%
Case4	LED		451.8	8.68	11.5%

TableB-1.13: Payback Period and ROI when Using Occupancy Sensor

Case Number	Type of Lighting Fixture	Total Investment Cost in Changing the Lights for base case (AED)	Annual Total Cost Savings (O.S) (AED)	Payback Period for Each Case (AED)	ROI for Each Case (AED)
Base Case	T8	3920	_	_	_
Case1	T8		149.69	26.19	3.8%
Case2	T5		403.24	9.72	10.3%
Case3	CFL		-46.21	-84.83	-1.2%
Case4	LED		563.61	6.96	14.4%

TableB-1.14: Payback Period and ROI when Using Daylight. S. and Dim. Sys.

Case Number	Type of Lighting Fixture	Total Investment Cost in Changing the Lights for base case (AED)	Annual Total Cost Savings (Daylight .S +Dim. Sys.) (AED)	Payback Period for Each Case (AED)	ROI for Each Case (AED)
Base Case	T8	3920	_	_	_
Case1	T8		324.49	12.08	8.3%
Case2	T5		540.14	7.26	13.8%
Case3	CFL		163.6	23.96	4.2%
Case4	LED		663.06	5.91	16.9%

TableB-1.15: Payback Period and ROI when Using the Three Control Systems

Case Number	Type of Lighting Fixture	Total Investment Cost in Changing the Lights for base case (AED)	Annual Total Cost Savings (O.S +Daylight S. +Dim. Sys.) (AED)	Payback Period for Each Case (AED)	ROI for Each Case (AED)
Base Case	T8	3920	_	_	_
Case1	T8		786.82	4.98	20.1%
Case2	T5		1123.5	3.49	28.7%
Case3	CFL		799.19	4.90	20.4%
Case4	LED		1154.5	3.40	29.5%

APPENDIX (B-2)

Second Simulated Area – Electromechanical Office

TableB-2.1: Annual Lighting Electricity Cost Saving for the different Lighting Technologies

Case Number	Type of Lighting Fixture	Lighting Wattage for Each Type of Light (W)	Luminaires Quantities	Unit Price (AED)	Total Cost of the Case (AED)	Annual Lighting Energy Consumption (KWh)	Annual Electricity Cost for Each Case (*0.23 AED)	Annual Lighting Electricity Cost Savings for Each Case (AED)	Annual Lighting Electricity Cost Savings Percentage for Each Case (AED)(%)
Case1 (Base Case)	T8	(4*18) T8=72	4	280	1120	483.84	111.28	_	_
Case2	T5	(4*14) T5=56	4	420	1680	376.32	86.55	24.73	22%
Case3	CFL	(2*26)CFL=52	8	224	1792	698.88	160.74	265.3	-44%
Case4	LED	(40) LED=40	4	1100	4400	268.8	61.82	49.46	44%

TableB-2.2: Cost of Changing Lamps for All Cases

Case Number	Type of Lighting Fixture	Average Lamp Life Time (Hrs)	Duration of Annual Changing of Lamps	Total Number of Lamps	Number of Lamps that's Needs to be Changed Annually	Cost of One Lamp (AED)	Cost of Replacement for One Lamp (AED)	Cost of Changing and Replacement for One Lamp (AED)	Total Annual Cost of Changing Lamps (AED)	Savings for Total Annual Cost of Changing Lamps (AED)
Case1	T8	10000	5.952381	16	3	3	10	13	34.94	_
Case2	T5	25000	14.880952	16	1	5		15	16.13	18.82
Case3	CFL	15000	8.9285714	16	2	4		14	25.09	9.86
Case4	LED	50000	29.76	4	0.13	31		41	5.51	29.43

TableB-2.3: Cost of Changing Lamps Ballast for All Cases

Case Number	Type of Lighting Fixture	Average Lamp Ballast Life Time (Hrs)	Duration of Annual Changing of Lamps Ballast	Total Number of Lamps Ballast	Number of Lamps Ballast that's Needs to be Changed Annually	Cost of One Lamp Ballast (AED)	Cost of Replacement for One Lamp Ballast(AED)	Cost of Changing and Replacement for One Lamp Ballast (AED)	Total Annual Cost of Changing Lamps Ballast (AED)	Savings for Total Annual Cost of Changing Lamps Ballast (AED)
Case1	T8	30000	17.86	8	0.4	5	10	15	6.72	_
Case2	T5	35000	20.83	8	0.4	5.5		15.5	5.95	0.77
Case3	CFL	30000	17.86	16	0.9	3.5		13.5	12.10	-5.38
Case4	LED	50000	29.76	4	0.1	25		35	4.70	2.02

TableB-2.4: Payback Period and ROI for the Electromechanical Office

Case Number	Type of Lighting Fixture	Annual Lighting Electricity Cost Savings (AED)	Total Annual Cost Savings for Changing Lamps (AED)	Total Annual Cost Savings for Changing Lamps Ballast (AED)	Annual HVAC Cost Savings (AED)	Annual Cost Savings (AED)	Total Investment Cost in Changing Lights (AED)	Payback Period (AED)	ROI (AED)
Case1	T8	–	–	–	–	–	1120	–	–
Case2	T5	24.73	74.19	18.82	0.77	118.51		9.45	11%
Case3	CFL	265.3	795.9	9.86	-5.38	1065.68		1.05	95%
Case4	LED	49.46	148.38	29.43	2.02	229.29		4.88	20%

TableB-2.5: Lighting Energy Consumptions for Lighting Control Technologies

Case Number	Type of Lighting Fixture	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)
Base Case	T8	111.28	-	111.28	-	111.3	-
Case1	T8	100.15	11.13	83.46	27.82	72.3	38.95
Case2	T5	88.25	23.04	64.92	46.37	55.0	56.26
Case3	CFL	144.67	-33.38	120.56	-9.27	104.5	6.80
Case4	LED	55.64	55.64	46.37	64.92	40.2	71.10

TableB-2.6: HVAC Energy Consumptions for Lighting Control Technologies

Case Number	Type of Lighting Fixture	Annual Energy Consumption (KWh)	Annual Energy Savings (KWh)	Annual Energy Consumption (KWh)	Annual Energy Savings (KWh)	Annual Energy Consumption (KWh)	Annual Energy Savings (KWh)
Base Case	T8	333.85	-	333.8496	-	333.850	-
Case1	T8	300.46	33.39	250.3872	83.4624	217.002	116.85
Case2	T5	264.74	69.11	194.7456	139.104	165.069	168.78
Case3	CFL	434.00	-100.15	361.6704	-27.8208	313.448	20.40
Case4	LED	58.64	275.21	139.104	194.7456	120.557	213.29

APPENDIX (B-3)

Third Simulated Area – The Corridor

TableB-3.1: Annual Lighting Electricity Cost Savings for All Lighting Technology

Case Number	Type of Lighting Fixture	Lighting Wattage for Each Type of Light (W)	Luminaires Quantities	Unit Price (AED)	Total Cost of the Case(AED)	Annual Lighting Energy Consumption(KWh)	Annual Electricity Cost for Each Case (*0.23 AED)	Annual Lighting Electricity Cost Savings for Each Case (AED)	Annual Lighting Electricity Cost Savings Percentage for Each Case (AED)(%)
Case1 **(Base Case)**	CFL	(1*26) CFL=26	7	186	1302	305.76	70.32	_	_
Case2	T5	(4*14) T5=56	3	420	1260	282.24	64.92	5.41	7.7%
Case3	T8	(4*18) T8=72	3	280	840	362.88	83.46	-13.14	-18.7%
Case4	LED	(27) LED=27	6	580	3480	272.16	62.6	7.73	11%

TableB-3.2: Cost of Changing Lamps in the Corridor

Case Number	Type of Lighting Fixture	Average Lamp Life Time (Hrs)	Duration of Annual Changing of Lamps	Total Number of Lamps	Number of Lamps that's Needs to be Changed Annually	Cost of One Lamp (AED)	Cost of Replacement for One Lamp (AED)	Cost of Changing and Replacement for One Lamp (AED)	Total Annual Cost of Changing Lamps (AED)	Savings for Total Annual Cost of Changing Lamps (AED)
Case1	CFL	15000	8.92	7	1	4	10	14	10.98	_
Case2	T5	25000	14.88	12	1	5		15	12.10	-1.12
Case3	T8	10000	5.95	12	2	3		13	26.21	-15.23
Case4	LED	50000	29.76	6	0.20	28		38	7.66	3.32

TableB-3.3: Cost of Changing Lamps Ballast in the Corridor

Case Number	Type of Lighting Fixture	Average Ballast Life Time (Hrs)	Duration of Annual Changing of Ballast	Total Number of Ballast	Number of Ballast that's Needs to be Changed Annually	Cost of One Ballast (AED)	Cost of Replacement for One Ballast(AED)	Cost of Changing and Replacement for One Ballast (AED)	Total Annual Cost of Changing Ballast (AED)	Savings for Total Annual Cost of Changing Ballast (AED)
Case1	CFL	30000	17.86	14	0.8	3.5	10	13.5	10.584	_
Case2	T5	35000	20.83	6	0.3	5.5		15.5	4.46	6.12
Case3	T8	30000	17.86	6	0.3	5		15	5.04	5.54
Case4	LED	50000	29.76	6	0.2	25		35	7.06	3.53

TableB-3.4: Payback Period and ROI for the Corridor

Case Number	Type of Lighting Fixture	Annual Lighting Electricity Cost Savings (AED)	Total Annual Cost Savings for Changing Lamps (AED)	Total Annual Cost Savings for Changing Lamps Ballast (AED)	Annual HVAC Cost Savings (AED)	Annual Cost Savings (AED)	Total Investment Cost in Changing Lights (AED)	Payback Period (AED)	ROI (AED)
Case1	CFL	–	–	–	–	–	1302	–	–
Case2	T5	5.41	-1.12	6.12	16.23	26.64		48.88	2.0%
Case3	T8	-13.14	-15.23	5.54	-39.41	-62.24		-20.92	-4.8%
Case4	LED	7.73	3.32	3.53	23.18	37.76		34.49	2.9%

TableB-3.5: Lighting Energy Consumptions for Lighting Control Technologies

Case Number	Type of Lighting Fixture	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Saving (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Saving (KWh)	Annual Lighting Energy Consumption (KWh)	Annual Lighting Energy Savings (KWh)
Base Case	CFL	70.3	-	70.3	-	70.3	-
Case1	CFL	63.3	7.0	52.7	17.6	45.7	24.6
Case2	T5	58.4	11.9	48.7	21.6	42.2	28.1
Case3	T8	75.1	-4.8	62.6	7.7	54.3	16.1
Case4	LED	56.3	14.0	46.9	23.4	40.7	70.3

TableB-3.5: HVAC Energy Consumptions for Lighting Control Technologies

Case Number	Type of Lighting Fixture	Annual Energy Consumption (KWh)	Annual Energy Savings (KWh)	Annual Energy Consumption (KWh)	Annual Energy Savings (KWh)	Annual Energy Consumption (KWh)	Annual Energy Savings (KWh)
Base Case	CFL	210.9	-	210.9	-	210.9	-
Case1	CFL	189.9	21.1	158.2	52.7	137.1	73.8
Case2	T5	175.3	35.7	146.0	64.9	126.6	84.3
Case3	T8	225.4	-14.4	187.7	23.2	162.8	48.2
Case4	LED	169.0	41.9	140.8	70.1	122.1	210.9