Mutah University
Faculty of Graduate Studies

Improvement of Energy Efficiency for Faculty of Engineering in Mutah University

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الآراء الواردة في الرسالة الجامعية

لا تعبر بالضرورة عن وجهة نظر جامعة مؤتة

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College of Graduate Studies

جامعة مؤتـــة

كلية الدراسات العليا

قرار إجازة رسالة جامعية

تقرر إجازة الرسالة المقدمة من الطالب عمر بدر سمور البدور

والموسومة بـ: improvement of energy effeciency for faculty of engineering in mutah university

استكمالاً لمتطلبات الحصول على درجة الماجستير في الإدارة الهندسية/إدارة أنظمة الطاقة الذكية

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أ.د عمر المعايطة

Dedication

This study is wholeheartedly dedicated to our beloved parents, who have been our source of inspiration and gave us strength when we thought of giving up, who continually provide their moral, spiritual, emotional, and financial support. To my brothers, sisters, brother in law, relatives, friends, and classmates who shared their words of advice and encouragement to finish this study.

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All thanks to Allah for his blessings which helped me in completing the preparation of this thesis and I would like to express my deepest appreciation to all of those who provided me with the possibility to complete this thesis.

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List of Abbreviations

Abbreviation	Stand for
CFL	Compact Fluorescent Lamp
KWh	Kilowatt-Hour
LDR	Light Dependent Resistor
LED	Light-Emitting Diode
MWh	Megawatt-Hour
NEPCO	National Electric Power Company
PIR	Passive Infrared
PV	Photovoltaic
SSR	Solid State Relay
UNDP	United Nations Development Programme
USDOE	US Department of Education

List of Symbols

Symbol	Meaning
L_C	Cable Losses Coefficients.
L_M	Module Losses Coefficients.
L_T	Temperature Losses Coefficients.
$P_{demand\ max}$	Maximum Demand Loads.
$P_{inv,in,kWh}$	Total Load Generated via PV.
P_{max}	Module Peak Power at Maximum Irradiance.
$P_{max,actual}$	Power Produced by The Module at each Day.

Abstract

Improvement of Energy Efficiency for Faculty of Engineering in Mutah University

Omar Bader Al-bdour

Mutah University, 2020

Lighting represents a major part of building energy use, therefore, energy savings in a lighting system can be very important to reduce the overall building energy consumption, as choosing the appropriate lighting, and control system, is a key factor for achieving a significant reduction, in energy consumption and thus reducing CO_2 emissions.

In this study, a survey was conducted for lighting users from students, to gather their opinions, regarding the lighting system, and the need for upgrading in faculty of engineering at Mutah University, furthermore, this lighting system was discussed and analyzed, where it found a great opportunity to make a significant saving, by replace the lighting equipment with more efficient bulbs and fixtures, such as LED lamps, and apply building management system, using control system of the motion and light sensors in addition to solar LED lamps to illuminate the external squares of the faculty. The study calculations showed that the annual savings rate of the proposed lighting system reaches 68%, Moreover, a solar energy system has been created to cover the annual consumption of the proposed lighting system with a short payback period.

الملخّص

تحسين كفاءة الطاقة لكلية الهندسة بجامعة مؤتة

عمر بدر البدور

جامعة مؤتة – 2020

تمثل الإضاءة جزءاً كبيراً من استخدام طاقة المباني، لذلك يمكن أن يكون توفير الطاقة في نظام الإضاءة مهمًا جدًا لتقليل استهلاك طاقة المبنى، حيث أن اختيار نظام الإضاءة والتحكم المناسب، هو عامل رئيسي لتحقيق انخفاض كبير في استهلاك الطاقة، وبالتالي تقليل لانبعاثات ثاني اكسيد الكربون الضارة.

في هذه الدراسة ، تم عمل استطلاع لمستخدمي الإنارة من الطلاب في كلية الهندسة في جامعة مؤتة ، لجمع آرائهم حول نظام الإنارة في الكلية، وحاجته للتطوير، كما تم دراسة وتحليل هذا النظام، حيث تبين وجود احتمالية كبيرة لعمل توفير فعّال في استهلاك الطاقة، من خلال استبدال نظام الإنارة بنظام اكثر كفاءه ، مكون من مصابيح الثنائي الباعث للضوء ، وتطبيق نظام إدارة للمبنى ، باستخدام مستشعرات تحكم للحركة وشدة الضوء، بالإضافة لمصابيح تعمل بالطاقة الشمسية ، لإضاءة الساحات الخارجية لمبنى الكلية، حيث اظهرت الحسابات، ان نسبة التوفير السنوية لنظام الإنارة المقترح تصل الى ٦٨%. علاوة على ذلك، تم إنشاء نظام طاقة شمسية لتغطية الاستهلاك السنوي لنظام الإضاءة المقترح، مع فترة استرداد قصيرة.

Chapter One
Introduction

1.1General

The energy in all its forms, is the main engine in the world, as it is used in all aspects of life, and it is the main pillar of the industry, technology, and education, where countries compete to produce the largest amount of energy, to support the economy, and upgrade public industries, and services, hence, the importance of optimal use of energy and reducing waste to a maximum possible.

The importance of energy efficiency, has increased between the objectives of building management, and environmental aspects, improving energy efficiency can make significant cost savings, and reduce emissions, furthermore, could enable comfort, and working environment, and more satisfied users, and better productivity.

The built environment contributes to improving energy efficiency, due to buildings responsible for 30 % up to 40 % of the world's energy consumption, and accounts for 25 % to 36 % of the world's greenhouse gas emissions (UNDP, 2009).

Jordan has faced significant energy challenges recently, that required it to generate and use renewable energy, and other alternative sources, as figure 1.1 shows Contribution of primary and renewable energy to electricity generation in Jordan, furthermore, due to political conflicts in neighboring countries, such as Syria and Iraq, energy import has become less reliable, thus interest in energy saving has become important in Jordan.

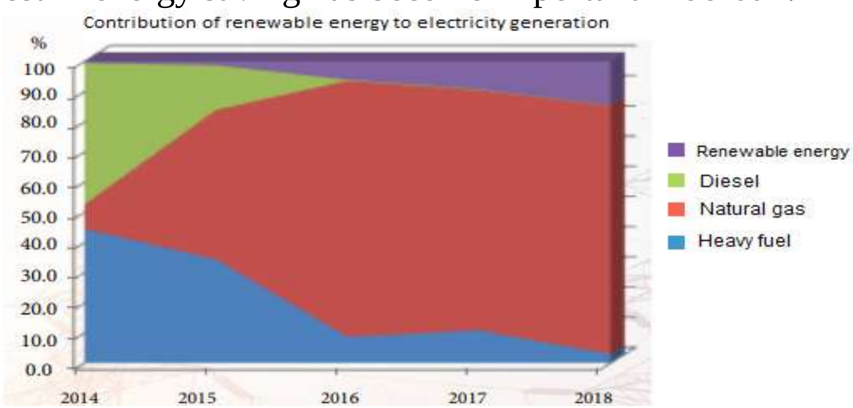


Figure 1.1 Contribution of Primary and Renewable Energy to Electricity Generation in Jordan. (NEPCO Annual Report 2018)

For a country like Jordan, it is important to reduce the wastage of power, that is spending unnecessarily, In conjunction with the growing population at a rapid rate, and the increasing demand for electricity. Nowadays for overcoming global climate change, the users must use a sustainable energy system, along with managing energy consumption. The major problem is that sustainable energy faces multiple challenges, related to growing of energy consumption constantly, which caused by the population growth, and the change standards of living, to minimize the energy consumption as well las the greenhouse gas emissions, energy consumption should be improved and use more efficiently.

Currently, Jordan has the highest energy intensity in the region, where projected annual growth rates for energy demand from 2015 to 2025 (~5%) are some of the highest in the world. (EBRD,2019). Jordan is one of the most countries in the world, in dependency on foreign energy sources, where is 96% of the country energy needs come from abroad, such as imported oil and natural gas from neighboring countries, and this consumes a large amount of Jordan's GDP. (Wikipedia,2019).

However, a huge portion of this energy is used to generate electric power, the following figure 1.2, represented Jordan's consumption of electrical energy, which almost tripled for the past 20 years.

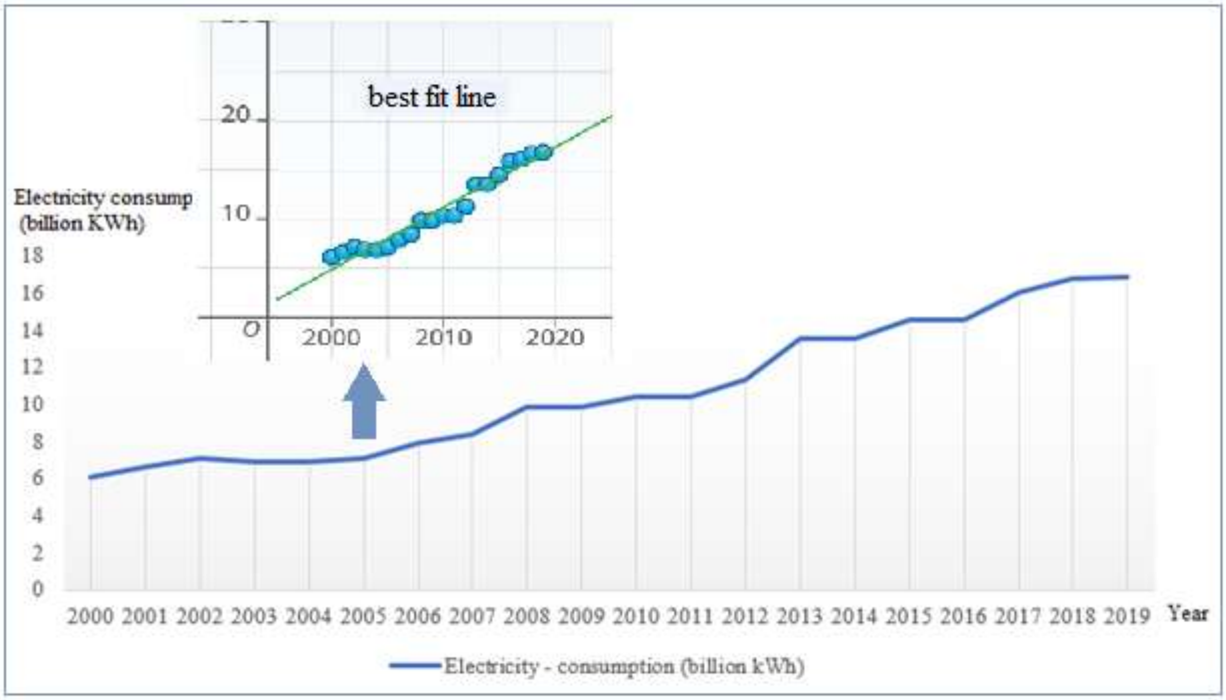


Figure 1.2: Jordan Electricity Consumption for The Past 20 Years (Indexmundi,2019)

According to the statistics, most of the electricity consumption in Jordan, is inside government, and residential buildings according to the figure 1.3, where it was monitored a large electricity consumption in those buildings, including the academic buildings, due to the lack of optimal energy use, as many still use the old lighting techniques that consume a large amount of energy, with Low operating efficiency, as this consumption can be significantly reduced, if electrical lighting systems are developed. (NEPCO, 2018)

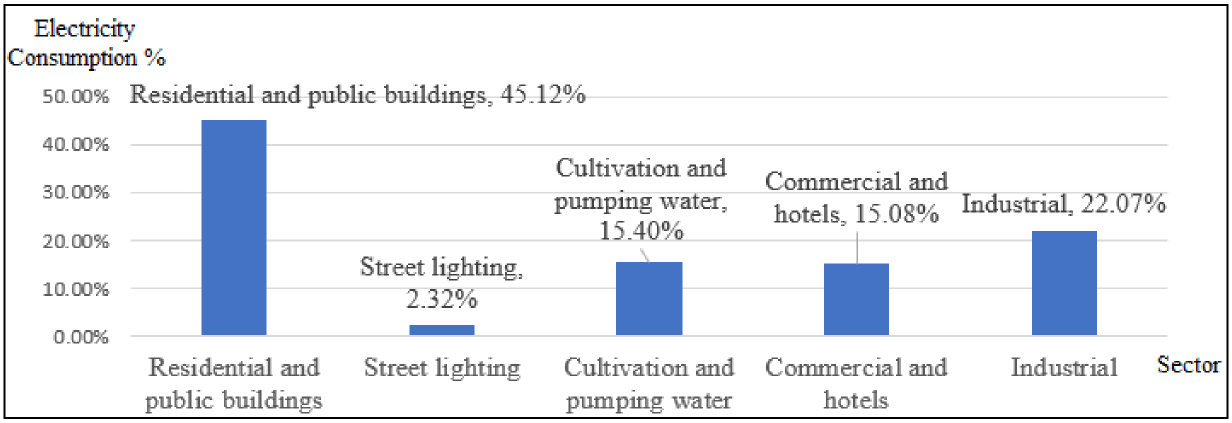


Figure 1.3 Sectoral Distribution of Electricity Consumption in Jordan for Year of 2018. (NEPCO, 2018)

Nowadays, the considerable amount of this electrical consumption is converted to artificial lighting, light is necessary to connect between the activities of people, With the increase in the energy consumption, by different segments of users, concerning the difficulty of energy generation, it is important to find and improve efficient ways of lighting.

On the other hand, the production of electricity by conventional methods, causes great harm to the surrounding environment, as the electricity production in Jordan is classified according to the attached figure 1.4, as the most important component that causes CO_2 emissions. (EBRD,2019).

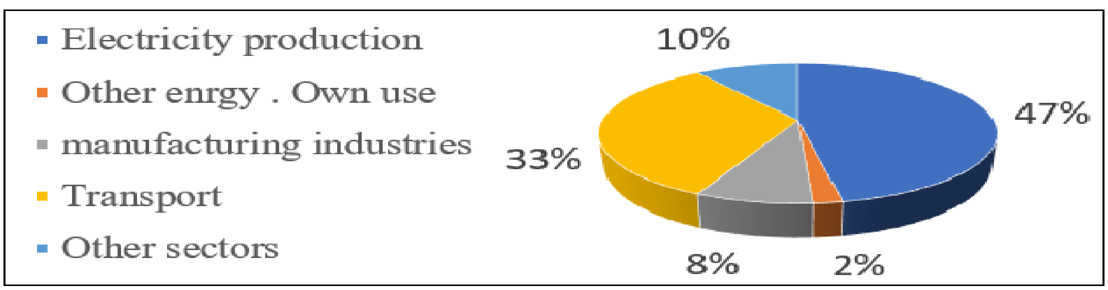


Figure 1.4 CO_2 Emissions by Sector in Jordan 2017 (EBRD,2019).

1.2 Research Background

In Arab countries, buildings energy consumption, presented an average of 35% of overall energy consumption, and responsible for 35-45% of all CO_2 emissions. (AFED,2012). Figure 1.5 presented building sector share of the final energy consumption in some Arab countries.

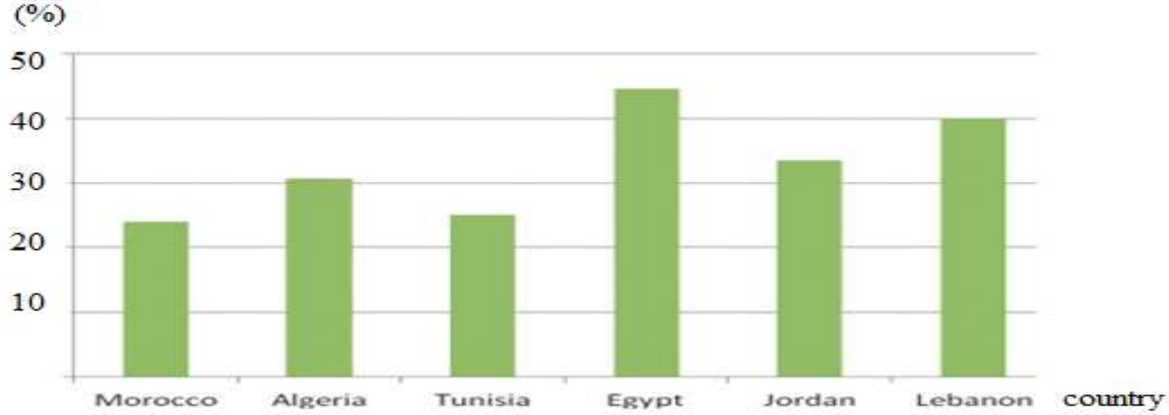


Figure 1.5 Building Sector Share, in The Final Energy Consumption in Some Arab Countries, (Al-Zu bi, M. & Mansour, O. ,2017)

Recently, there has been a significant increase, in the rate of energy consumption inside academic buildings, due to the presence of old and low efficient control systems, that reflecting high energy consumption, compared to their low performance, and this is It causes high costs for these educational institutions, as it consumes most of its budget on energy bills, instead of improving and developing its educational environment, figure 1.6 presented The detailed energy consumption for office building in Arab countries.

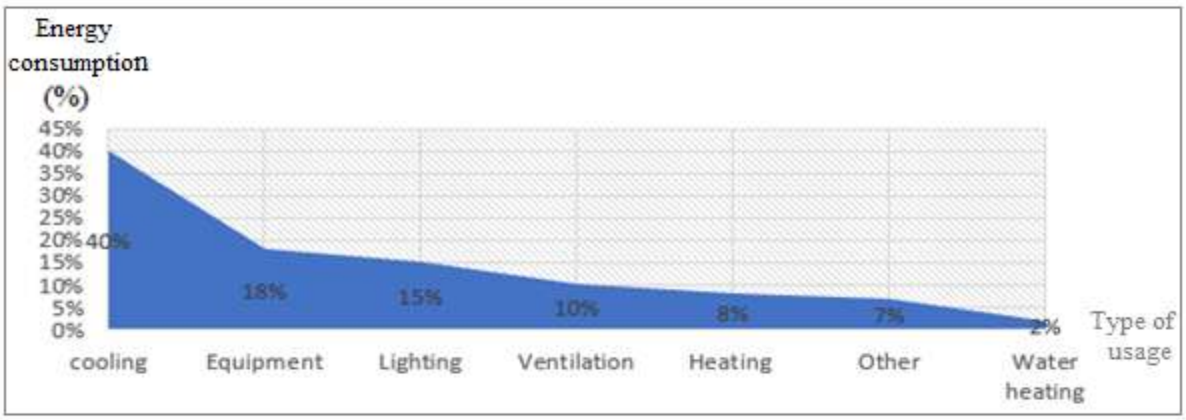


Figure 1.6 Detailed Energy Consumption for Office Building in Arab Countries. (AFED,2012)

Jordanian universities possess the powerful buildings, that encourage sustainable development, as their design is subject to planning suitable, for modern technology, and because these universities are now witnessing massive development in scientific, and engineering disciplines, and great acceptance by students, it has become necessary to develop their internal energy systems, to provide a better study environment for the student, and to take advantage of the wasted energy expenses, in things that would serve the educational process. (UNDP,2009)

Among all the uses of electric energy, the lighting system is considered the simplest and most commonly used, comparing with other electric energy forms, as it continuously used in all annual seasons without exception, Lighting consumed 15-25% of the total energy usage in a large office building in Arab countries, as many buildings still use inefficient lighting systems that already became outdated. (AFED,2012)

In universities and educational institutes, lighting is a significant factor for providing the appropriate learning environment, it not only provides the visual comfort to complete tasks, but also contributes to the aesthetic, psychological, and health aspects of students, teachers, and other users.

However, lighting considerable impact on the environment primarily, because the consumption of electricity generated from coal, it can also be a source of health hazard; for instance, the mercury in fluorescent bulbs and tubes is highly toxic and can accumulate in the body, and can easily be absorbed in the components of the ecosystem. (Steinhauser, G. and Stettner, C., 2014).

In educational buildings, a massive component of the energy is spent in illuminating the building interior, as the energy costs increase day after day, below figure 1.7 shows the huge academic buildings lighting consumption comparing with other sectors buildings as per US department of education.

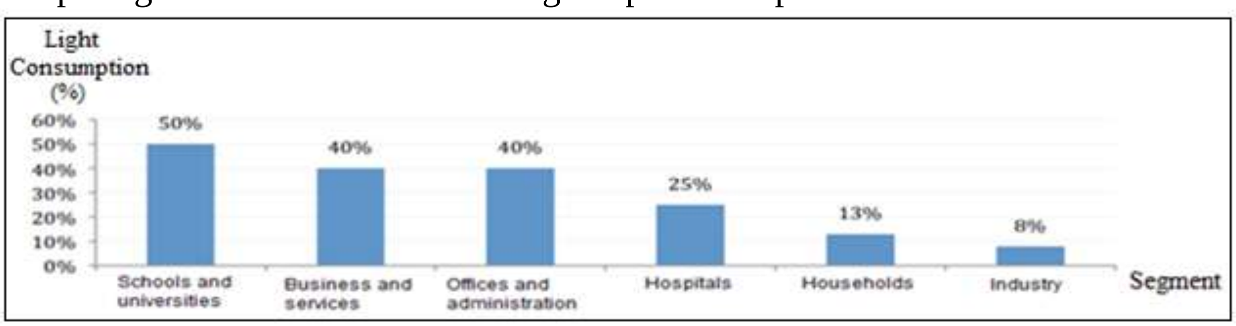


Figure 1.7 United States Lighting Consumption by Segments, (USDOE, 2012)

The most common mistakes, that cause high consumption for the lighting system is to keep light on in unoccupied workspaces and used electric lighting while daylight can provide the same illumination amount at no cost. Moreover, is using an inefficient lighting system that wastes most of the electricity amounts as heat.

The key role for improving lighting efficiency, and reduce its consumption in the building, is done by the owners and users of buildings, the owners are responsible for the operational, and technical and features of the building, and also maintenance as well. On another hand, the users are responsible for any misuse, or overuse for the energy sources.

In response, the Jordanian ministry of energy and mineral resources has motivated the use of LED on the residential, commercial, and industrial levels, as energy economic lamps, to reduce lighting consumption. LEDs are energy-saving tool as they consume less electricity than the incandescent lamps. (Jordan National Energy Action Plan,2013)

On the other hand, it's been noticed in these buildings people, just leaving places without put off the lights, to downgrade the consumption, an automatic system for lighting can be used, where the light becomes on if there is a motion in the room, otherwise, If there is no movement, the light will switch off automatically.

Due to the Lighting importance role in the education institutes, especially, inside the classrooms, for improving concentration, and helps a healthy attitude to learning, this study forced on energy consumption in one of the most important sectors that used the electric energy, which is the universities sector, the faculty of the engineering building at Mut'ah University, was taken as a case study and a great focus was placed on the lighting system, the system improvement for the lighting will be visible and logical, sensible in case the old lighting system is replaced by a more advanced, and energy-saving system.

This research, provides efforts for minimizing the energy consumption of this lighting system in many ways, such as install new more efficient equipment, by replacing the fluorescent lamps with LED lamps, and use building management system as lighting control, with motion and light sensors to enhance energy saving, taking into account the daylight factor and its role in reducing energy use, furthermore, is covering the consumption results with solar energy.

1.2.1 Mutah Engineering Faculty Overview

The Faculty of Engineering was established in 1984, located in Al-Karak Governorate with 152 km to the south of Amman capital of Jordan (31°05 N, 35°43 E, and elevation 1153 m). The faculty building contains three floors with basement, classrooms, academic staff offices, administration, and public facilities, where each floor area is 1102 m^2, the faculty building shown in the figure 1.8.

Figure 1.8 Engineering Faculty in Mutah University

The average total energy consumption in the college is 8 MWh monthly, meaning 96 MWh per year (Alnajideen, M. and Alrwashdeh, S. 2017)

1.3 Statement of the Problem

The main problems of this research are summarized in five main topics:

1. Wasted energy, as a result of using an inefficient lighting system, that consumed large electric energy.
2. The unnecessary electrical energy usage, such as keep lighting in the non-occupied classrooms, and offices.
3. Non-optimal use of daylight, sometimes electric lights are used instead where daylight is available, and gives the same efficiency as electric light.
4. Pollution hazard: in addition to CO_2 emissions increasing, due to excessive energy consumption, the fluorescent lamps contains mercury, which exposes the users to the risk of pollution.
5. The need for an alternative system at low cost, to cover the annual lighting bills.

Therefore, all the above-mentioned point led to the below questions:

A. How the electrical energy performance of Engineering buildings is defined?
B. How to develop a more efficient lighting system, with low energy waste?
C. How to control the lighting system, to reduce unnecessary electricity use?

D. How to make optimum use of daylight?
E. How to reduce CO_2 emissions, and improve the environment?
F. How to create an alternative energy system, to cover the annual lighting cost?

1.4 Significance of the Study

The importance of the study summarized in the following points:

1. Continuing to use the current lighting system, is costing the university an extra annual amount, while installing a new highly efficient, and economist lighting system, could contribute to reduce it to half.
2. The study showed many unnecessary uses of lighting, inside the college campus, this can be controlled, and disposed of, by using control sensors.
3. One of the most important results for energy improvement, is reducing carbon emissions, which, in turn, works to decrease the negative impact on the environment, along of eliminate the mercury component, in CFL lamps.
4. Exploiting empty places, such as car parking lots to producing solar energy which is environmentally friendly, to cover annual lighting cost on the one hand, and give it an aesthetic side on the other hand.
5. This study provided a highly efficient integrated lighting system, with a short payback period.

1.5 Study Scope

The study focused on lighting efficiency in the faculty, because it's considered the simplest and most commonly used compared with other electrical energy forms, as it constantly works in all annual seasons without exception.

The lighting system is a significant factor for providing a proper learning environment, not only provides the visual comfort to complete tasks, but also contributes to the aesthetic, psychological, and health aspects of students, teachers, and other users, and because of the existence of a great opportunity to make a huge saving in energy consumption by upgrading this light system.

The old lighting system has been studied, and its energy consumption calculated for as the first stage, then upgraded the old lighting system to LED system as a second stage and calculate the amount of savings in energy consumption, and as a third stage the control sensor have been added to increase the efficiency of the system and reduce consumption, The fourth stage was dedicated to covering the annual costs, of this new system, by establishing a solar electricity generation system.

1.6 Objectives of the Study

This research has varied targets and objectives to achieve as follows:

1- Defined lighting efficiency needs, and requirements, in the mut'ah engineering faculty.
2- Achieve optimum lighting efficiency, to improve interior environmental quality, with minimum energy usage, without downgrading the comfort or functionality level.
3- Determine the annual savings potential of implementing a new efficient lighting system, using the best lighting fixtures, and lamps, which have been tested worldwide.
4- Reduce unnecessary lighting use, by installing an intelligent automatic control system, with appropriate sensors system.
5- Contribution to keep the environment clean, and reduce the CO_2 emissions.
6- Create an alternative energy system, to cover the annual lighting costs, for the engineering faculty in Mutah University.

1.7 Motivation of Study

A large amount of energy is currently consumed, due to the lack of use of additional tools, and features, that come with low prices, and high operating efficiency, whereas using them leads to improve the efficiency, and reduce a lot of cost at the same time, with short payback period, therefore this study could reduce the consumption up to half, and provide better power factor for the current lighting system, in additional covering all the lighting annual bills, with solar energy project, to minimize these annual bills to zero.

1.8 Research Methodology

To achieve the overall objectives of the research, it is important to have a systematic approach to the framework of research implementation. Therefore, the following approach is adopted in the current research:

1. Literature review: The understanding and evaluation of the current state of the research are some of the most fundamental and important steps in any research activity. This is done by reviewing the various previous works that are done and findings published by other researchers through books, journals, online databases, etc. This will be done to assist in adopt to define the various aspects of the research.

2. Conduct a survey, to collect the students' opinions, and suggestions participation for reducing lighting consumption, here, the results are very important to address aspects that may cause unnecessary energy use.
3. Mathematical calculations, to find the existing energy consumption, and determine the optimum energy-saving that can be proposed.
4. Using the helioscope software, to create a solar energy project that covers the annual costs of the proposed system.

1.9 Thesis Structure

The thesis is composed of four chapters:

In Chapter 1: Introduction described the energy situation in Jordan, and the needs of upgrading the energy efficacy, especially for the lighting system was presented, in addition to the study objectives, the scope, and research methodology.

In Chapter 2: an overview of the previous related work is presented.

In Chapter 3: included data analysis, and energy saving calculations, and discussion.

In Chapter 4: conclusions and recommendations.

Chapter Two
Literature Review

2.1 Literature Reviews Related to Lighting Replacement

Dhingra, A. and Singh, T. (2009), presented study of energy conservation measures adopted in a spinning unit, thy convert old incandescent system with new fluorescent system, they determined the payback period of 6 months, beside of energy saving results led to more benefits to improve the lux levels and decreased the maintenance cost due to the new fixtures lifespan is more than the old fixtures.

Efpraxia, M. (2014), studied the energy performance and the lighting conditions of an industrial building, with focusing on daylight and electrical installation, the researcher introduced a smart lighting technology using LED lamps with taking advantage of the daylight to increase the energy saving, the study shows a huge amount of lights of great wattage would have been used, rendering the lighting installation completely inefficient, Daylight is not used in all rooms, the researcher suggested using an occupancy sensor to reduce constipation and he got the result of reduction of the total energy demand by 32%, as well as reduction of CO_2, with payback period 5.5 years.

Moghimi, S., et al (2015), determined the energy and cost savings after re-lamping the hospital with LED lights, also the emission reduction and payback period. The researcher's results showed that, by applying this strategy, the energy cost saving will be $ 2 million after 3 years with more than 5000 t of CO_2 reduction per year and the payback period is 2.9 years.

Mario, J., et al (2015), presented a comparing between different types of lighting technology to optimize the energy efficiency and reduce energy consumption in the building, In summary, researchers mentioned that LED lighting is more efficient than fluorescent lamps for IPBEN building, but, the fluorescent's payback period is much better than for LEDs, the study results found that The electricity bill for LED lighting is 41% less than CFL lamps. Therefore, LED lamps are the best option to reduce pollution and energy consumption but the investment is more than fluorescent lamps.

2.2 Literature Reviews Related to Building Management for Lighting.

Garg V., Bansal N. (2000), presented a smart occupancy sensor design that can adapt to changing activity levels. A model is also proposed for “human motion” of a person working at a computer. A smart occupancy sensor can learn the variation in the activity level of the occupants with respect to time of the day, researcher results have shown that about 5% more energy can be saved by using a smart occupancy sensor.

Alsa'di, M. (2008), described the huge for energy savings in the Palestinian universities sector (15-25%) by implemented some energy-saving measures with a low payback period and some of the measures are without investment on the most energy equipment such as HVAC and lighting system. researcher achieved a 24% percentage of saving in the lighting system with a low investment amount and 7% in the cooling system with no investment cost and 5% in the heating system with no cost. Also, he developed a new energy management software, which is used to estimate the total energy savings from each opportunity in his study. Researcher in his study also has designed and implemented a new web based automatic light management and control system, in order to reduce the lighting consumption, by considered the classrooms schedule table, the occupancy sensors, and the daylight distribution, this system resulted in extra saving of 45%.

Lakra, M. and Viond kiran, K. (2016), designed a smart saving system for Indian Universities, where every classroom has a passive infrared sensor that responded to movements, and accordingly, devices are switched ON/OFF automatically. All system is controlled and monitored by the central base station, the researcher finds that entire system provided an efficient utilization of the resources and saves the power wastage when compared with the conventional system.

Xu, Lei., et al (2016) presented a study for energy performance in different lighting systems and control strategies applied in open-plan offices. The energy-saving of various lighting control strategies is simulated and analyzed, and a combined lighting control strategy of background dimming lighting plus task lighting is studied. researchers' results shown savings from general lighting control 50% or higher.

Riyanto, I., et al (2018), used a sensor system to reduce the energy consumption of public utilities. They note that there is a big difference in energy consumption with the presence of these sensors. However, the researchers did not use these sensors in the rest of the institution rooms. The results of using the sensors in this study are contributed to reducing the energy cost of a 30% -40%.

Simonian L., Packard M. (2018), presented and discussed how to examine the operation and maintenance of the current lighting system in a university lab classroom, they proposed occupancy sensors system, to reduce the energy consumption. The researcher results determined over $14,000 of wasted energy in the year, moreover, the payback period for the suggestion sensor system is within one year.

2.3 Summary of Literature Review

In below table 2.1, the previous studies were summarized in terms of objectives, results, and imperfections, which have been addressed and managed by the current research.

Table 2.1 Literature Review Summary

Researchers Names & year	Title	Purpose of Study	Study Results	Remarks
1-GargV. 2- Bansal N (2000)	Smart occupancy sensors to reduce energy consumption	Reduce the overuse energy consumption	5% More energy saved by using a smart occupancy sensor.	Using only one sensor category, researcher could add light sensor, to achieve more energy reduction.
Alsa'di, M. (2008)	Study and Design of An Automatic Control System for Electric Energy Management - Case Study An-Najah National University	Control energy use in most university facilities, to improve efficiency, and reduce energy consumption.	The researcher did a great work for improving the energy efficiency, as he achieved 45% energy saving in 2.5 years payback period.	The researcher could have done a solar energy project, to cover the costs of the annual bills of the new annual results.
1- Dhingra, A. 2- Singh, T. (2009)	Energy Conservation with Energy Efficient Lighting	Reduce the energy consumption.	Improved the lux levels, and decreased the maintenance cost, with 6 months payback period.	The researcher didn’t use control sensors to make an additional reduction for the consumption.
Efpraxia, M. (2014)	Energy efficiency in industrial buildings by lighting solutions,	Improve energy performance, and reduce the overuse lighting energy.	Reduced of the total energy demand by 32%, as well as reduced of CO_2, with payback period 5.5 years.	Researcher could have used a motion sensor, to get additional 10% energy saving.

Researchers Names & year	Title	Purpose of Study	Study Results	Remarks
1-Mario, J. 2-De Souza, T. 3-Silveira, J. (2015)	Comparative analysis between fluorescent and LED illumination for improve energy efficiency at IPBEN building	Optimize the energy efficiency, and reduce energy consumption in the building, by replace the current light to LED lamps.	Using LED made the lighting energy bill 41% less than CFL lamps.	The researcher could have made another comparison using LED with control sensors to make additional energy savings
1-Moghimi, S. 2-Azizpour, F. 3-Lim, Chin 4-Salleh, Elias 5-Sohif, Mat 6-Sopian, K. (2015)	Energy Saving and Emission Analysis via Lighting Retrofitting in a Large-Scale Hospital: Case Study in Malaysia	Increase energy and cost savings after re-lamping the hospital with LED	The results energy cost saving reached 2$ million, after 3 years with more than 5000 t of CO_2 reduction per year, and the payback period is 2.9 years.	The researchers did not use control sensors, which will increase the energy savings.
1-Lakra, M. 2-Viond, K. (2016)	Design of Smart and Intelligent Power Saving System for Indian Universities	Adding PIR motion sensors for Indian Universities classrooms, to reduce the energy consumptions.	The researcher finds that entire system provided an efficient utilization of the resources and saves the power wastage when compared with the conventional system	Researchers used only one type of sensor, moreover, they did not give importance for replace the bulbs with more efficient type like LED.
1-Indra Riyanto 2-Margatama 3- H. Hakim 4- Martini, M. (2018)	Motion Sensor Application on Building Lighting Installation for Energy Saving and Carbon Reduction Joint Crediting Mechanism	To use a sensor system, to reduce the energy consumption of public utilities	The results of using the sensors in this study are contributed to reducing the energy cost of a 30% -40%.	The researchers did not use the sensors in the rest of the institution rooms, furthermore they didn't change the light efficiency with more

Researchers Names & year	Title	Purpose of Study	Study Results	Remarks
				efficient light lamps as LED.
1-Simonian, L. 2- Packard M. (2018)	Implementing an Occupancy Sensor Lighting Control System in a University Lab Classroom	Using an occupancy sensor, to examine the operation and maintenance of the current lighting system in a university lab classroom	The researcher results determined over $14,000 of wasted energy in the year within one-year payback period.	Researchers used only one type of sensor; they could use light sensor with addition to changing the light bulbs to more energy-saving type.

It is apparent that previous studies focused on saving energy, and reducing energy consumption, in the lighting system by following several methods, the most important being replacing old bulbs with more energy-saving bulbs, such as LED, or make building management be installed control sensors, whether motion or light, but, most of the previous studies contain a shortage, some researchers interested in adding sensors only without give importance to replace the inefficient lighting bulbs, and the others did replace the inefficient lighting bulbs, without adding sensors to regulates the energy consumptions.

On other hand, a few researchers did install sensors, and changed the inefficient bulbs, but they didn't cover the new annual bills consumption with solar energy, to reduce the annual bills to zero, in this study, all of that was addressed, and taken into consideration to provide appropriate energy saving solutions.

Chapter Three
Data Analysis and Discussion

3.1 Introduction

This chapter presented the results of energy survey that was prepared for faculty students' opinions, to evaluate the current lighting system, the chapter also provided a comparison between most common lighting types, and a study to develop the lighting system, in terms of tools, and control sensors. The necessary calculations were made, to find the annual savings values, and payback periods, for the developed system, and compared the results with the old system, then a solar energy project was created, to cover the monthly bills of the proposed lighting system.

3.2 Energy Efficacy Survey

Students' opinions considered very important, and helpful in this study, as the students use the classrooms almost daily, which makes manage energy resources such as the current lighting system is their responsibility, therefore, that helps to address aspects, that may cause unnecessary energy use.

The survey focused on the lighting system in the Mut'ah's Faculty of Engineering, and the satisfaction level of student's regarding the lighting system quality, and their opinions for upgrading the lighting system, and adding building management as a sensors, to reduce the energy consumption, furthermore, the survey included student's suggestions, regarding how to improve the faculty's energy efficiency.

3.2.1 Survey Results

To give the survey more accuracy, respondents have been requested to mention their University majors under three categories: electrical engineering students, engineering management students/masters, other majors, due to the nature of the survey related to energy saving.

The survey yielded 104 answers, including 29 electrical engineering students, 17 engineering management, and 58 for other majors. Figure 3.1 shows the results of students' satisfaction for the lighting system. Most of the respondents are dissatisfied with the lighting system, and this represents a strong motivation that the system needs to upgrade.

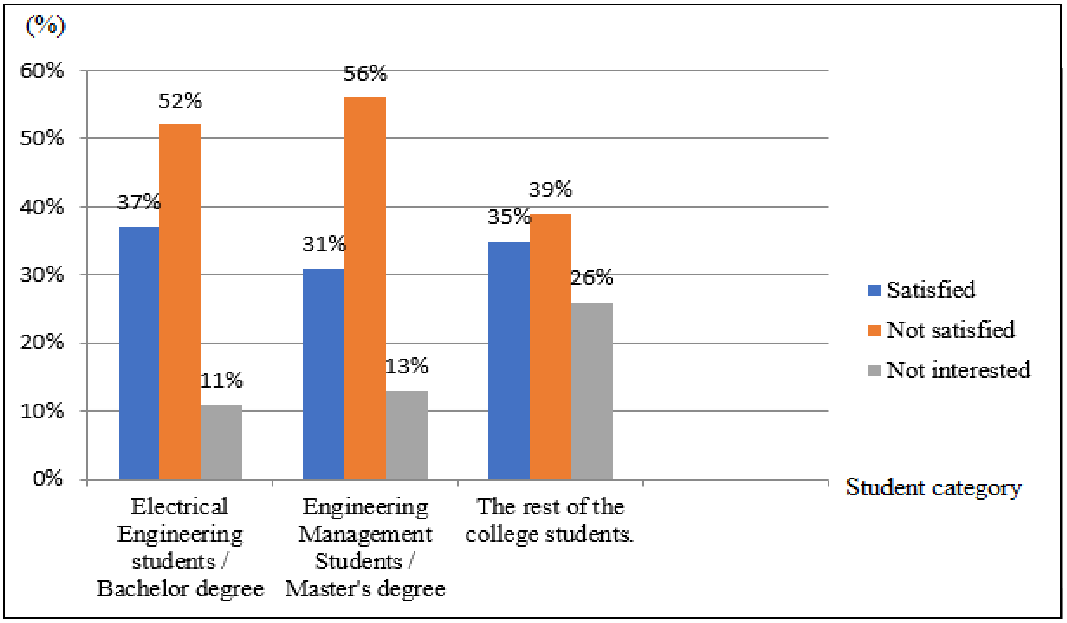


Figure 3.1 Student's Satisfaction Survey for Faculty Lighting system.

One of the most important aims of the survey, is to know the opinions of energy users about stopping unnecessary consumption. Figure 3.2 shows the survey results related to turning off lights, if it not needed. The survey showed negative results, in terms of energy-saving on the part of users, which reflects negatively on energy saving, causing excessive energy consumption.

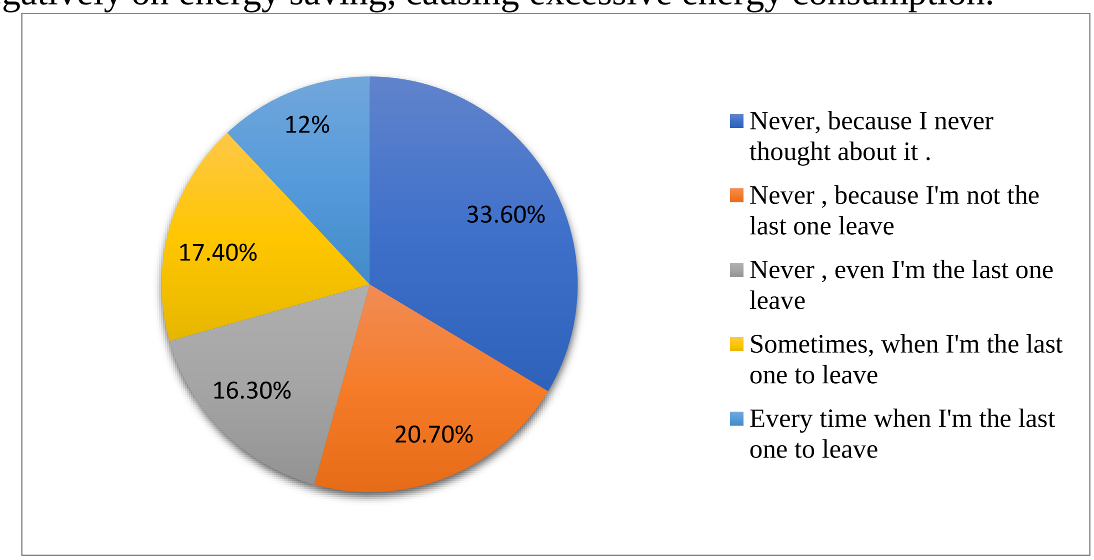


Figure 3.2 Switching the Light Off Survey.

Figure 3.3 shows survey results for students' frequent experiences, and notes about finding illuminated empty classrooms.

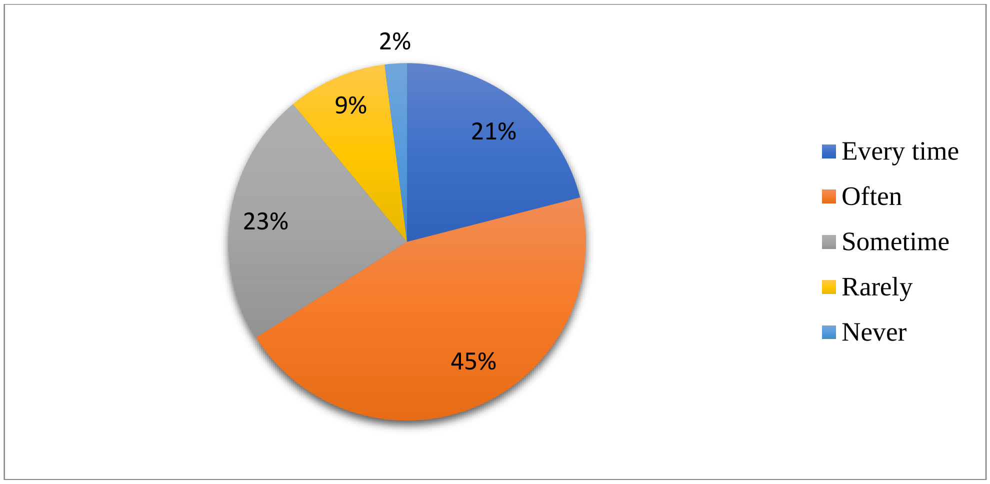


Figure 3.3 Probability of Lights are on in Unoccupied Classrooms.

Most of the solutions proposed by students, regarding energy saving for lighting in the engineering faculty building, were by improve the efficiency of the lighting bulbs, this proposed from 31 respondents out of 104, and 28 respondents suggested to adding motion sensors, to reduce unnecessary lighting consumption, while the rest of the suggestions were divided between holding educational sessions about energy saving for the energy users, and reducing the time difference between the lectures.

3.3 Lighting Lamps and Equipment

The lighting system in the faculty, consists of several bulbs, and fixture tubes, that are controlled by a manual switch, as there is no automatic controller to regulates the lighting process, and reduces consumption.

The old system is using fluorescent bulbs and tubes, this technology could be replaced with LED, which provides more efficacy, and low energy consumption, table 3.1 presented lamps quantity in the Mut'ah Engineering Faculty.

Table 3.1 Lamps Quantity in Mut'ah Engineering Faculty.
(Maintenance Department, Mu'tah University)

Lamps type	Lamps quantity
36-Watt CFL tube	650
18-Watt CFL tube	600
9 & 11 Watt CFL bulb	200
70-Watt CFL bulb	40
Total	1490

3.3.1 Fluorescent Lamps

Fluorescent lights were one of the most cost-effective, and environmentally preferred lighting systems, but due to technology has developed recently, LED takes the first place, despite fluorescent is efficient themselves, where LEDs have more advantages comparing with the fluorescent, fluorescent tube shown in figure 3.4.

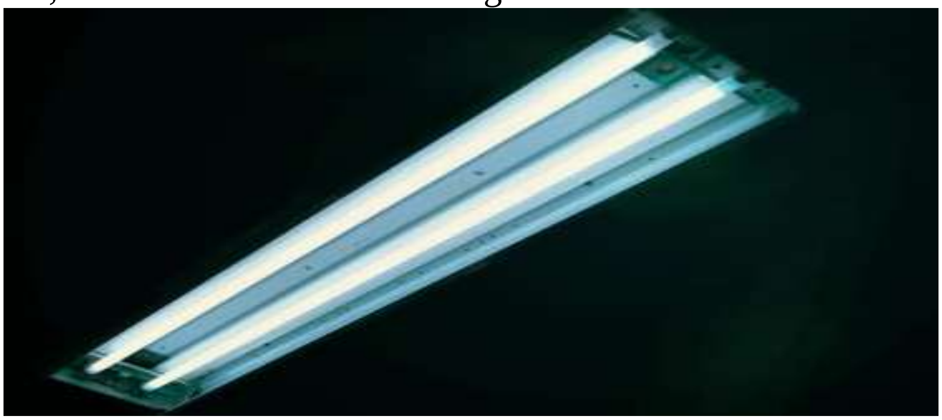


Figure 3.4 Fluorescent Tube Module.

Some fluorescent drawbacks: (George, V., et al ,2011)

1- Light Quality - flickering issues within running time.
2- Dimmable - fluorescent doesn't have dimming features.
3- Energy Efficient - T8 LED lighting tubes are more efficient 30% -40 % than Fluorescent T8 lighting tubes.
4- Mercury content - fluorescent have mercury in its contents, which is very dangerous on the environment and humans.
5- Control features - Fluorescent lights are not appropriate for motion sensor using, where it burns out quickly with frequent use, unlike the LEDs which is not affected by the Off/On times number.
6- Directional Lighting - fluorescents have multi-directional light, therefore some light is lost within the fixture itself, unlike the LED which can illuminate the light only where it is needed.
7- The Lifespan- fluorescent lifespan average is (8000 -30000) hours, while the LED average life 50,000 hours (new models can last up to 85,000 hours).

3.3.2 LEDs Lamps

The Light-Emitting Diode is a highly energy-saving lighting technology, as it uses 75% less energy than traditional lamps in case of bulbs and 50% in the case of tubes. (energy.gov,2019). The LED lamps, last longer than any other types, and offering better light quality, furthermore, LEDs are considered an environmentally friendly, since it does not contain any components of mercury, LED tubes shown in the figure 3.5. LED components made from semiconductors, and emit light without lost heat energy.

Figure 3.5 LED Tubes Module

LEDs are different than other lighting sources, such as incandescent lighting bulbs and Compact Fluorescent lighting Lamps (CFLs), because of many different reasons such as the following: (Schubert, E. F., and Kim, J. K 2005)

1- Long lifetime: LED s' Lamps can last up to 50,000 hours.
2- Rugged: that's why it named Solid State Lighting, because LEDs are made from solid materials that are not able to break easily.
3- No warm-up period: LED's light works instantly (in nano seconds).
4- Directional – LEDs can be directed the light to the wanted area, therefore no light neither energy will be wasted.
5- Excellent Color performance - LED's makes the colors perfect for displays, unlike the other types of lamps.
6- Environmentally friendly - LED's do not contain any hazardous substances such as mercury.
7- Controllable - LED's color and brightness can be controlled.

LED Fixtures Types According to the Installation Method

The methods of replacing, and installing the led are different according to the type of led used, the types are the following (Beciri, D. 2012).

Type A: This type support working with ballast, where it called " plug and play " it has an internal tool to use the existing ballasts of the fixtures.

Advantages: easy to install directly, after removing out the old fluorescent tubes.

Disadvantages:

1- Short lifespans: this type completely deepens on the ballast condition, whenever the ballast gets fail, the LED will stop working, therefore the cost will be increased more in case of replacing the ballast.

2- Not compatible with all types of fluorescents: further check needs to be done, before using this type of LED, to check if it's compatible with the existing fluorescent or no.

3- Low efficient: using ballast consumes more energy, usually, 10% of energy is used by the ballast.

Type B: No need for ballast in this type, where the tube is wired directly to the power using sockets.

Advantages:

1- No power loss since there is no ballast required, power consumption will be reduced.

2- Fewer maintenance costs: eliminating the ballast meaning decreasing the maintenance times to a minimum.

3- Various options: Type B has multiple options of wattage and lumen values Disadvantages: Modifications required: including replace the ballast with socket and make direct the connection between the fixture wire to the socket.

Type C: This type is like type B, for not using the ballast, but in the modification process for bypassing the ballasts is safer.

Advantages: this type is efficient such as type B since no ballast required

Disadvantages: high installing cost due to modification requirement.

3.3.3 Lighting Lamps Comparison

The following table 3.2 represents a comparison, in terms of features between the three most important and available types of lamps, the LED exceeds all types in terms of efficiency, and most of the other features, therefore it is always advisable to replace the other types with LEDs.

Table 3.2 Lamps Comparison of LED and CFL (Khan, N., and Abas, N. 2011)

Parameter	Fluorescent	LEDs
Efficacy [lm/W]	20-60	65-85
Lifetime [hours]	10-20k	50-100k
Startup time [seconds]	1-5	Instantly
Average cost	1.5 JD	JD 2.5-3
Temperature sensitivity	Yes	NO
humidity Sensitivity	Yes	NO

All light sources emit light, and heat in the form of convection, conduction, and radiation, but the amount of light, and heat emitted are varies, depending on the type of the lamp as figure 3.5 shown. (Efpraxia, M. ,2014).

According to figure 3.6, LED makes more light, and less heat compared to the fluorescent, LEDs' luminous output appears to be around five times higher when compared to incandescent lamps, and around two times when compared to fluorescent lamps. On the other hand, radiation, convection, and conduction cover around 92% of the total energy use for lighting in incandescent lamps, 63% in fluorescent lamps, and only 40% in LEDs. (Efpraxia, M. ,2014)

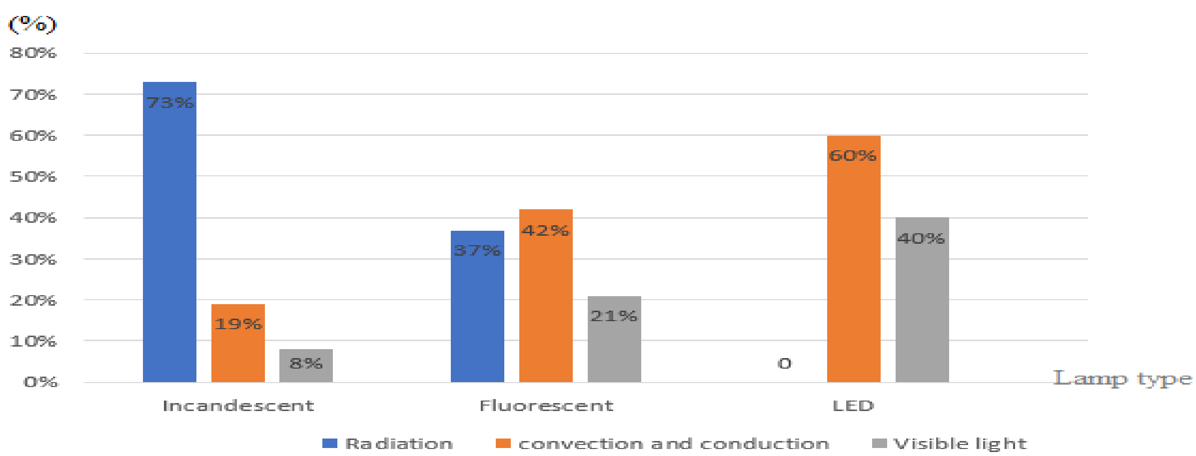


Figure 3.6 Light and Heat Produced by Light Sources (Efpraxia, M. ,2014)

Figure 3.7 shows the illumination efficiency of LED compared to other types, this efficiency is represented by the light intensity per watt of energy consumed, therefore, the LED provides a greater amount of illumination, than any other types, According to figure 3.6, most of the energy lost is shown in figure 3.7 it converted to form of heat radiation.

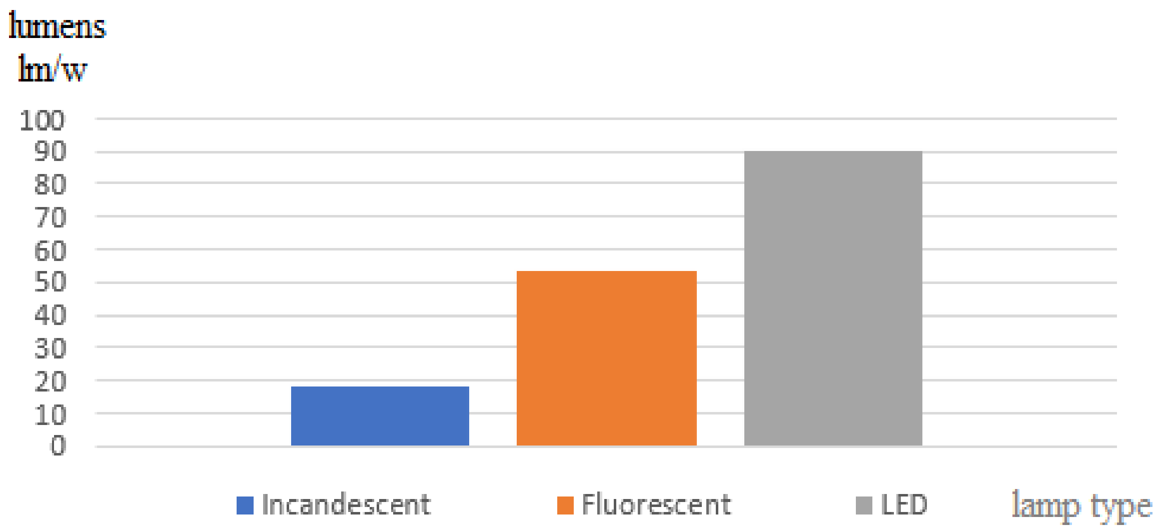


Figure 3.7 Illumination Efficacy of Some Light Types, (Luxreviw, 2020)

3.4 Building Management for Lighting System

The building management for lighting system in the study, is presented as a control system that used sensors, to regulate lighting energy consumption, as it provides the optimal use of energy, and reduces any wastage to the lowest possible value. Automatic control systems are used instead of the manual switch, the most famous types of control devices are motion sensors, light sensors, and ultrasonic, temperature sensors. In this study, two types of controllers were used, a PIR motion sensor and an LDR light sensor.

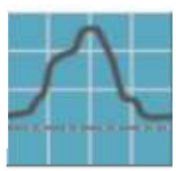
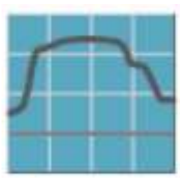
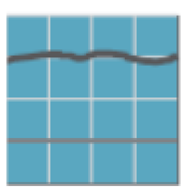
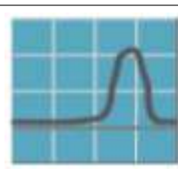
Referring to table 3.3, the annual energy saving for the control devices, is varies depending on the area type, utilize the daylight using the light sensor is makes more saving in classes than offices, and annual saving for PIR occupancy sensor makes more saving in offices, the privet offices usually been controlled by a few numbers of persons, unlike the classrooms.

Table 3.3 Maximum Expected Yearly Energy Saving Examples Using Light and Occupancy Sensors. (lighting controls association, 2013)

Space type & control type	Maximum expected yearly energy saving
Privet offices with occupancy sensor	38%
Privet offices with light sensor	50%
Classrooms with occupancy sensor	55%
Classroom with light sensor	50%

When choosing the appropriate control device for the building, consideration must be given to the nature of the work times for this building, as well as the expected electricity load used, as table 3.4 presented, For example, a light sensor is used more in buildings that operate during daylight hours, while it not necessary for buildings that operate at night hours, as well as, in buildings working for limited occasions, the motion sensor does not make much difference in providing energy to it.

Table 3.4 Selecting Control Devices Based on Lighting Load Profile. (Alsa'di, M. ,2008)

Lighting use profile		Selection	Devices
12 Working hours		Control that reduce the peak demand and utilize the daylight	PIR sensors and LDR sensors for buildings, and Time clock devices for open area
Extended working hours		Control that reduce the overuse energy	PIR sensors and manual switching.
24 Working hours		Control that and utilize the daylight	PIR sensors and LDR sensors & manual switching
Event operation		Manual switch control is enough	Manual switch device

3.4.1 PIR Motion Sensor

PIR sensors is an electronic device that measures infrared radiation, which radiating from objects, PIR measures different air temperatures in its field of view, when a person is in the room, the PIR detector sends a signal or pulse to let the switch pass the current, in order to turn on lights, (Puspita Mouri, S., et al ,2016). This type of motion sensor has selected due to its inexpensiveness and wide usage,

The PIR sensor contains 3 pins as figure 3.8 shown, the first pin for the incoming voltage, usually is 5V, the second is the output pin that sends the signals when the sensor detects motion, the last pin is ground with 0V value.

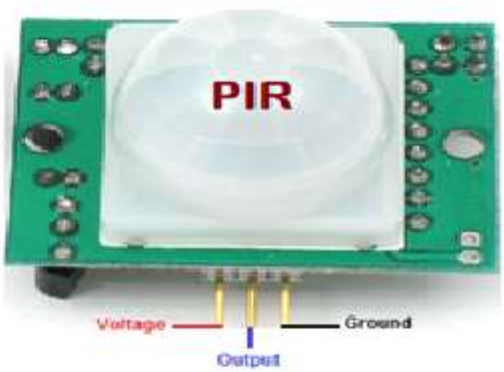


Figure 3.8 PIR sensor Pins

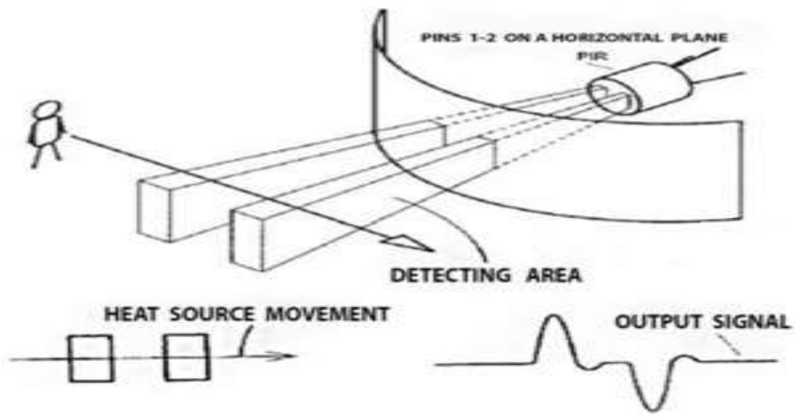


Figure 3.9 Working Concept of PIR Sensor (Puspita Mouri, S., et al ,2016)

As the figure 3.9 shown, the working concept of the PIR sensor, this sensor could detect the infrared radiation of people on the range, if there are some people inside the room, a high current will be passed through switch to the load causing to open lights ON. (Puspita Mouri, S., et al ,2016)

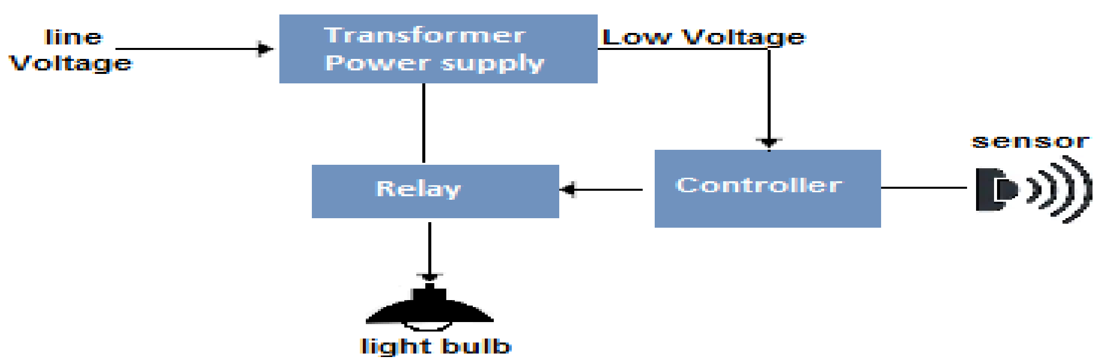


Figure 3.10 Occupancy Sensor Components

As figure 3.10 presented the PIR components ,it contains relay, which working as a switch for bypassing the current, in case the sensor detect any motion in his area range, along of controller who gives the orders to each component and two voltage output, first give low voltage to the relay, and the second have the load voltage which is usually 220V, and is controlled with low voltage since the same voltage control the relay.

3.4.2 Light Dependent Resistor (LDR)

LDR a light-dependent resistor, also known as light sensor, it's a variable resistor which its value changes depend on the light intensity that falls on it, the LDR is made of a high-resistance semiconductor.

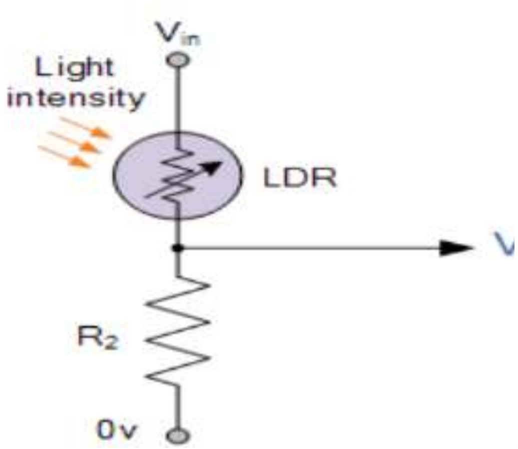


Figure 3.11 LDR Circuit
(Wang, J. and Zhou, Z. 2014)

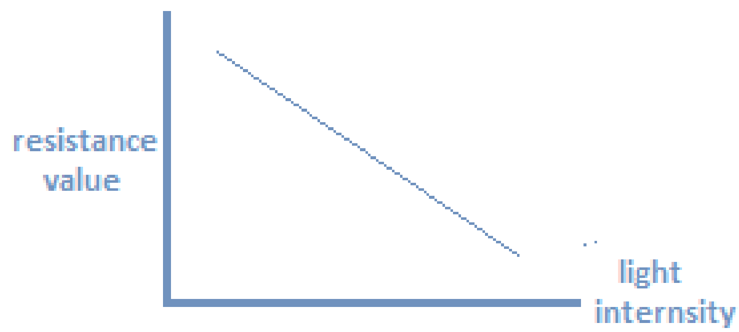


Figure 3.12 LDR Relation between Resistance and Light Intensity

The working principle is if the light that falling on the device is has high enough frequency, the light photons will be absorbed by the LDR semiconductor, which gives the bound electrons adequate energy to jump into the conduction band, therefore, the resulting free electrons conduct electricity, causing lowering of the resistance. (Wang, J. and Zhou, Z. 2014)

LDRs are very helpful, indeed in light/dark sensor circuits, the resistance of the LDR is very high reach up to 1000 000 ohms, but it will become too low when the light falls on its surface, the figure 3.11 shown the LDR circuit. In this study, LDR used to measure the identity of the daylight, and electrical light intensity, which is very helpful to reduce the unnecessary consumption.

Figure 3.12, presented the negative relation between the resistance value, and the falling light intensity, which means, when the falling light increases the resistance value get decreases

3.4.3 Relay

Relay is an electromechanical device, that is actuated only if it connected to electrical current, this device plays an important and essential role in the working principle of the controllers, it works as switches that open and close circuits either electronically (SSR) nor electromechanically (the normal relay).

The electromechanical relays can control one electrical circuit by opening, and closing contacts in another electric circuit, as relay diagrams show in the figure 3.13 below, when the electric current passed through the relay, a magnetic field is created inside the coil that attracts a wire changing the relay state, that causing to pass the current through the other circuit which having the load, while the other type doesn't have a coil and contain diodes, and transistor instead.

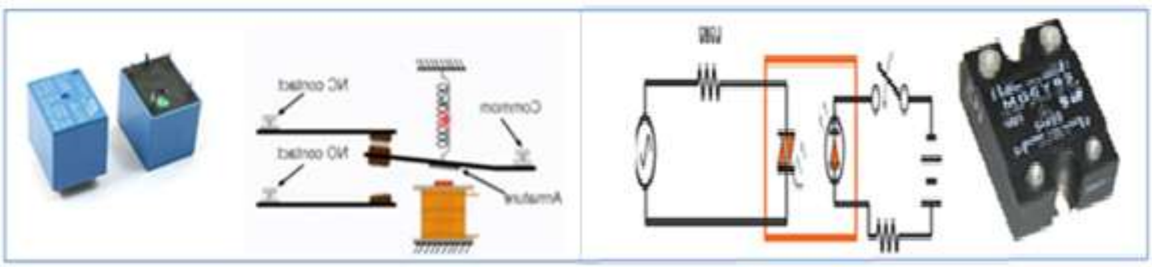


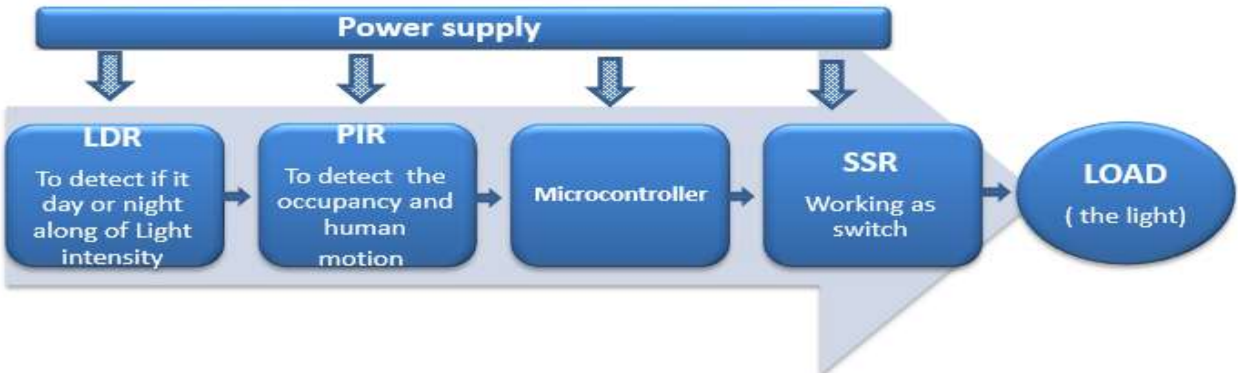
Figure 3.13 Solid State and Electromechanical Relays (Gurevich, V.,2016)

Solid state relay (SSR), is the type that used in this study inside the control devices, because the normal relay got fail quickly, due to infrequent use (on/off), furthermore, normal relay which may fail also as a result of carbon forming resulting from arching for the system design.

In the used system, this solid state relay is connected near to load, and working like a switch, when PIR sensor detects occupancy, and LDR detect low light intensity, the microcontroller will send a signal to the SSR to open the switch, and allow the current pass to load, and opening lights. (Metha,V.K. & Rohi, 2008)

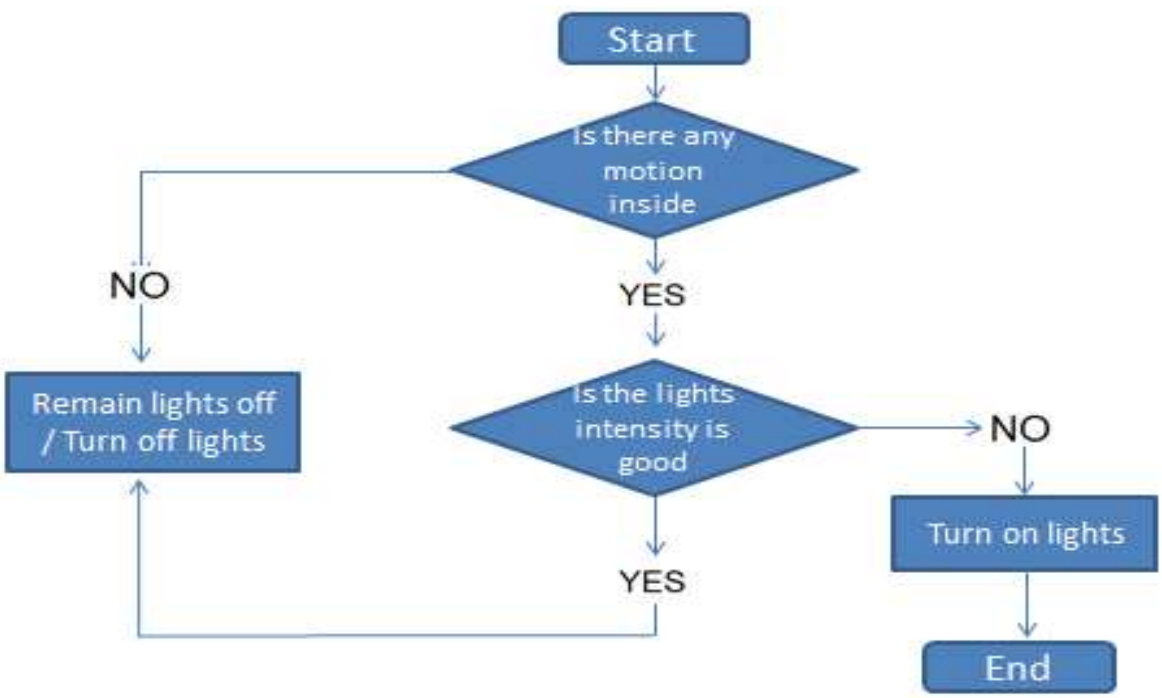
3.4.4 Building Management Components for the Lighting System

The management system component shown in figure 3.14, where the both sensor PIR, and LDR light sensors combined together, in one single device along of relay, and microcontroller.



3.14 Lighting Management Components of PIR and LDR Sensors

For the working concept, as the flow chart in figure 3.15 presented the priority given to LDR to identify whether the light intensity is good enough, or no, if it good the lights will not turn on, otherwise, if the light intensity is low, PIR sensor will check the motion in area range, and upon that either the lights will turn on or off.



3.15 Flow Chart for Integrated LDR and PIR Sensors System

3.5 Upgrading Phases for Lighting System

Lighting upgrading process in this study are divided into 3 phases:

1- Faculty using fluorescent.
2- Faculty using LED.
3- Building management system with LED.

Process of developing the lighting system in the faculty required to determine multiple factors, including the actual working days for the faculty, this factor can be calculated using the following formula:

Actual working days = (No. of weeks per year) × (working days per week) - (annual events & semesters vacation days as per the university calendar) = 52 × 5 – 40 = 220 days.

Another factor needs to determine, this is the lighting hours' number per day, however, the different year seasons, weather, and various temperatures, makes this factor difficult to determine, but it is very necessary in order to complete the consumption calculations, therefore two measures have been adopted for that, the first measure is based on the normal working hours, as shown in table 3.5 below that presented the normal of working hours in various sectors of work, where 12 hours have been adopted for academic buildings.

Table 3.5 The Normal Working Hours for Most Vital Sectors.

Sector	Number of Hours Lights are Used per Day (h)	Used on Weekenc
Offices & Administratior	12	No
Hospitals	24	Yes
Educational Institutes	12	No

The other scale that took into account was the effect of daylight, where it significantly reduces energy consumption and operating costs of the lighting system to about 50% to 40%, daylight is evaluated by calculating the lux amount inside the building, and outside by the lux meter tool, according to European standards for average illuminance level, as the below table 3.6 shown, the amount of lux that expresses the intensity of the light per square meter must be in the classroom between 300-500 while the amount of Lux for direct sunlight is 100,000 lm/m^2,and for diffuse light is 3,000 - 18,000 lm/m^2 (Preto, S. and Gomes, C. 2018)

Table 3.6 European Standards for Average Illuminance Level Regarding Different Tasks in the Commercial Sectors. (Preto, S. & Gomes, C. 2018)

Type of Facility	Type of Area or Task	Em (lx)
General	Entrance Halls and Corridors	100
Offices	Writing, Typing, Reading	500
Offices	Technical Drawing/Working on Computer	750/500
Offices	Conference Rooms/Archives	500/200
Restaurant	Kitchen/Dining Room	500/300
Schools	Classrooms/Library and Laboratories	300/500
Hospital	Waiting Rooms/Operating Theater	200/1000

Faculty working time is from 7 AM up to 7 PM, during this time daylight can cover sometime in summer over 8 hours without needs to electrical light, therefore, the other scale is taking approximately 5 hours in account to operate the light system, the daylight might cover more than 7 hours, however, this assumption adopted based on self-control and individual responsibility, later on, this assumption changed based on the use of light sensor, which is presented in phase 3 of this study.

Therefore, calculations for this phase covered 2 cases:

1- Full energy usages as 12 hours' lights usage daily.
2- Daylight consideration, based on self-control, and individual responsibility, and user's personal estimation of 5 hours' as daily usage.

To find the total Illumination hours annually for both cases:

1. In case of 12 hours (the same of usual working hours): 12 × (actual working days per year) = 12 × 220 = 2640 hours per year.
2. In case of 5 hours (taking daylight in account): 5 × 220 = 1100 h per year.

Note: below information has been provided from local Jordanian markets for Philips lighting company types:

1. Fluorescent T8 36 Watt with 3200 lumens is 1 JD per tube.
2. Fluorescent 18 Watt with 1400 lumens is (0.8 - 1) JD per tube.
3. Fluorescent 9W & 11W with 700 lumens is (1.25 -1.8) JD per bulb.
4. Fluorescent 70 Watt with lumens 5200 is 10 JD per bulb.
5. LED T8 20 Watt with 3200 lumens is 1.8 JD per tube.
6. LED 9 Watt with 1400 lumens is 1.8 JD per tube.
7. LED 6 Watt with 700 lumens is 1.6 JD per bulb.
8. LED 40 Watt with 4800 -5200 lumens is 10 JD per bulb.

Note: Electricity pricing according to the university maintenance department is 0.265 JD/ KWh.

Note: The 40 lamps for the outdoors squires, have fixed working hours with an average of 2 hours daily, 2 ×220 = 440 hours per year.

3.5.1 Phase One (Faculty Using Fluorescent)

The below table 3.7 information Presented the lighting system using fluorescent lamps only.

Table 3.7 Engineering Faculty Fluorescent Lamps Capacity & Quantity.

Lamps Type	Lamps Quantity
36 Watt CFL tube	650
18 Watt CFL tube	600
9 & 11 Watt CFL bulb	200
70 Watt CFL bulb	40
Total	1490

- The annual consumption in case of using 12 lighting hours daily [full usage]:

$0.036 \times 0.265 \times 650 \times 2640 = 16370.64$ JD.
$0.018 \times 0.265 \times 600 \times 2640 = 7555.68$ JD.
$0.009 \times 0.265 \times 100 \times 2640 = 629.64$ JD.
$0.011 \times 100 \times 0.265 \times 2640 = 769.56$ JD.
$0.070 \times 40 \times 0.265 \times 440 = 326.48$ JD.

Total consumption for CFL system with 12 hours lighting daily is = 25652 JD.

- The annual consumption in case of using 5 lighting hours daily:

$0.036 \times 0.265 \times 650 \times 1100 = 6821.1$ JD.
$0.018 \times 0.265 \times 600 \times 1100 = 3148.2$ JD.
$0.009 \times 0.265 \times 100 \times 1100 = 262.35$ JD.
$0.011 \times 0.265 \times 100 \times 1100 = 320.65$ JD.
$0.070 \times 0.265 \times 40 \times 440 = 326.48$ JD.

- Total consumption for CFL system, with 5 hours lighting daily is = 10878.78 JD.

3.5.2 Phase Two (Faculty use LED)

In this phase, all the fluorescent light systems replaced with LED lighting systems to improve the lighting efficiency which will be reflected positively on the monthly bills and the annual saving as well.

To replace the fluorescents lamps with LEDs, there are 4 paths could be following (Beciri, D. 2012) :

1- Bypass the fixture's ballast, the most commonly installed, and considered as cheapest method, here, ballast bypassed due to LEDs tubes do not need to fixtures ballast to work, that’s will save more energy, since the ballasts used 10% of fixtures energy (Hordeski, M., 2005), therefore, this work will require re-wiring the for fixtures, to bypass the ballast, and connect the wires directly to the sockets, that will give an advantage of take off the ballast failures, such as flickering and dimness.

2- Electronics ballast compatible tubes: known as “Plug-n-Play”, it a new option on the markets, this type is required ballast to work, it’s easy to install required just to remove the old tube out, and replace it with new LED tube, but in the other hand, this type has a high upfront cost and the LED will not work in case ballast fails.
3- Hybrid (Ballast Compatible + Ballast Bypass) this type allow providing LED tube that can work with both ballast, and non-ballast case. Hybrid type works with both T8 ballast, and can be wired directly, so using this type gives flexibility when a ballast fails, the LED will continue wok, furthermore, this type can work with both type of light T8 and T12 light.
4- New fixtures, along with new LED tubes: this considered the most expensive option; since new fixtures are required to make the LED tubes work.

The best path to follow is the first option, due to ballast is not required, that’s mean more energy saving, since the ballast consume 10% of fixture tube energy (Hordeski, M., 2005), furthermore, this installation can be done in the same fixture, which means more cost saving.

Below table 3.8, presented the equivalent wattage values for fluorescent and LEDs, it’s clear that a LEDs system needs low energy watts to give the same efficiency as the lighting that a fluorescent system provides.

Table 3.8 Lights Lumens and Equivalent Wattage Values for Fluorescent and LEDs.

Fluorescent	Lumens	LED
36Watt (tube)	3200	20 Watt (tube)
18Watt (tube)	1400	10 Watt (tube)
9&11 Watt (bulb)	700	6 Watt (bulb)
70Watt (bulb)	4800 - 5200	40Watt (bulb)

Lamps Replacement Calculation with Energy Saving.

A- In Case of 12 Lighting Hours per Day (Full Energy Utilization)

Below table, presented the energy saving calculation for full energy usage of 12 hours using LED lamps.

Table 3.9 Energy Saving of Replace 36W CFL Tubes with20W LED Tubes for 12 Hours Daily.

Items and Operations	Calculations	Results in JD
First: Fluorescent Tubes.		
T8 ballast + Starter (1 for each pair) + installation fee	(0.3+ 0.5) × 325 +650 ×1	910 JD
650 T8 fluorescent 36Watt tubes cost	650 ×1	650 JD
Initial cost	910 + 650	1560 JD
(yearly usage cost) 650 of CFL 36W for 2640 hours	650 × 0.036 ×0.265 × 2640	16370.64 JD
Total	1560 + 16370.64	17930.64 JD
Second: LED Tubes.		
(Rewiring fee) T8 ballast + installation fee	0.5 × 325 + 1 × 650	812 .5 JD
650 T8 LED 20 watt tubes cost	650 × 1.8	1170 JD
Initial cost	812.5 JD + 1170	1982.5 JD
(yearly usage cost) 650 of LED20W for 2640h at 0.265JD/ KWh	650 × 0.02 × 0.265 ×2640	9094.80 JD
Total	1982.5 + 9094.80	11077.3 JD
Annual Results		
Upfront savings of using fluorescent tubes	1982.5 -1560	422.5JD
Yearly savings	16370.64 - 9094.80	7275.84 JD
Annual saving percentage	**44.5 %**	

Table 3.10 Energy Saving of Replace 18W CFL Tubes with 9W LED Tubes for 12 Hours Daily.

Items and Operations	Calculations	Results in JD
First: Fluorescent Tubes.		
T8 ballast + Starter (1 for each pair) + installation fee	(0.3+ 0.5) × 300 + 600×1	840
600 T8 fluorescent 18Watt tubes cost	600 ×1	600
Initial cost	840 + 600	1440
(yearly usage cost) 600 of CFL 18W for 2640 hours	600 × 0.018 × 0.265 × 2640	7555.68
Total	1440 JD + 7555.68 JD	8995.68
Second: LED Tubes.		
(Rewiring fee) T8 ballast + installation fee	0.5 × 300 + 600 × 1	750
650 T8 LED 9 watt tubes cost	600 × 1.8	1080
Initial cost	750 JD + 1080 JD	1830
(yearly usage cost) 600 of LED20W for 2640h at 0.265JD/ KWh	600 × 0.009 × 0.265 × 2640	3777.84
Total	1830 + 3777.84	5607.84
Annual Results		
Upfront savings of using fluorescent tubes	1830 - 1440	390 JD
Yearly savings	7555.68 - 3777.84	3777.84
Annual saving percentage	**50 %**	

Table 3.11 Energy Saving of Replace 11W CFL Bulbs with 6W LED Bulbs for 12 Hours Daily

Items and Operations	Calculations	Results in JD
First: Fluorescent Bulbs.		
100 fluorescent 11W bulbs cost	100 ×1	100
installation fee	100 ×1	100
Initial cost	100+100	200
(yearly usage cost) 100 of CFL 11W for 2640 hours	100 × 0.011 × 0.265 × 2640	769.56
Total	200 + 769.56	969.56
Second: LED Bulbs.		
(Rewiring fee) + installation fee	100 × 1	100
100 LED 6 W bulbs cost	100 × 1.6	
Initial cost	260 JD	
(yearly usage cost) 100 of LED 6W for 2640 hours	100 × 0.006 × 0.265 × 2640	419.76
Total	260 + 419.76	679.76
Annual Results.		
Upfront savings of using fluorescent bulbs	260 - 200	60
Yearly savings	769.56 - 419.76	349.8
Annual saving percentage	**45.5 %**	

Table 3.12 Energy Saving of Replace 9W CFL Bulbs with 6W LED Bulbs for 12 Hours Daily.

Items and Operations	Calculations	Results in JD
First: Fluorescent bulbs.		
100 fluorescent 11W bulbs cost	100 × 1	100
Installation fees	100 × 1	100
Initial cost	100 + 100	200
(yearly usage cost) 100 of CFL 9W bulbs for 2640 hours	100 × 0.009 × 0.265 × 2640	629.64
Total	200 + 629.64	829.64
Second: LED Bulbs.		
100 LED 6 W bulbs cost	100 × 1.6	160
Installation fee	100 × 1	100
Initial cost	260 JD	
(yearly usage cost) 100 of LED 6W bulbs for 2640 hours	100 × 0.006 × 0.265 × 2640	419.76
Total	260 JD + 419.76	679.76
Annual results.		
Upfront savings of using fluorescent bulbs	260 - 200	60 JD
Yearly savings	629.64 - 419.76	209.88
Annual saving percentage	**33.5 %**	

Table 3.13 Energy Saving of Replace 70W CFL Bulbs with 40W LED Bulbs for 2 Hours Daily.

Items and Operations	Calculations	Results in JD
First: Fluorescent Bulbs		
40 fluorescent 70W bulbs cost	40 × 10	400
Installation fee	40 × 1	40
Initial cost	400 + 40	440
(yearly usage cost) 40 of CFL 70W bulbs for 440 hours	40 × 0.07 × 0.265 × 440	326.48
Total	440 + 326.48	766.48
Second: LED Bulbs.		
40 LED 40W bulbs cost	40 × 10	400
Installation fee	40 × 1	40
Initial cost	440 + 40	440
(yearly usage cost) 40 of 40W LED bulbs for 440 h at 0.265JD/KWh	40 × 0.04 × 0.265 × 440	186.56
Total	440 + 186.56	626.56
Annual Results.		
Upfront savings of using fluorescent bulbs	440 – 440	0
Yearly savings	326.48 – 186.56	139.92
Annual saving percentage	**43 %**	

Payback period, in case of assuming the lighting hours 12 per day (referring on the yearly saving tables):
The total electricity saving per year equal to:
7275.84 + 3777.84 + 349.8 + 209.88 + 139.92 = 11753.28 JD
The total initial cost = 1982.5 + 1830 + 419.76 + 419.76 + 440 = 5092.02 JD
Payback period: total cost / annual saving = 5092.02 / 11753.28 = 0.433 year
0.433 out of 12 months, meaning payback period approximately 5.19 months.

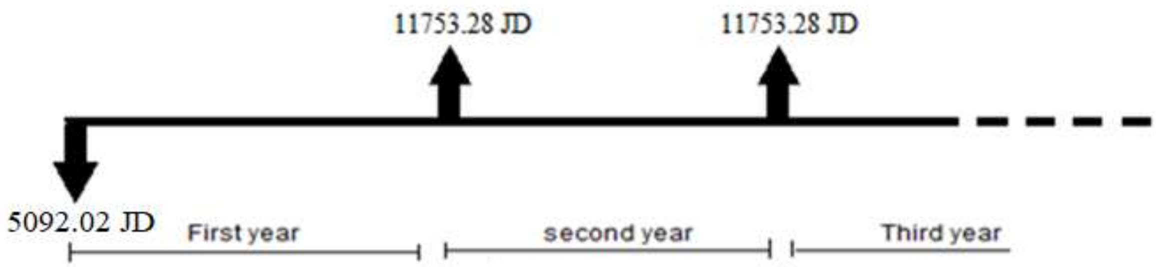


Figure 3.16 Energy cost saving Cash flow in case of 12 hours lighting per day are applied.

B- In Case of 5 Lighting Hours per Day (The Normal Estimation)

Here 5 hours is the normal estimation provided from faculty users, for the daylights, however, this estimation based only in personal opinions, it might include extra energy usage, which can be reduced using control sensors later on in this study, furthermore, this number of hours usually varies and depends only on user responsibility.

Total number of annual working hours is 1100, as the working days annually is 220 hours, and the lighting hours usage is 5 per day.

Table 3.14 Energy Saving of Replace 36W CFL Tubes with 20W LED Tubes for 5 Hours Daily.

Items and Operations	**Calculations**	**Results in JD**
First: Fluorescent Tubes.		
T8 ballast + Starter (1 for each pair) + installation fee	(0.3+ 0.5) ×325 +650× 1	910
650 T8 fluorescent 36Watt tubes cost	650 ×1	650
Initial cost	910 + 650	1560
(yearly usage cost) 650 of CFL 36W for 1100 hours	650 ×0.036 × 0.265 ×1100	6821.1
Total	1560 + 6821.1	8381.1
Second: LED Tubes.		
(Rewiring fee) T8 ballast + installation fee	0.5 × 325 + 1 × 650	812 .5
650 T8 LED 20 watt tubes cost	650 × 1.8 = 1170	
Initial cost	812.5 + 1170	1982.5
(yearly usage cost) 650 of LED20W for 1100 hours at 0.265JD/KWh	650 × 0.02 × 0.265 × 1100	3789.5
Total	1982.5 + 3789.5	5772
Annual Results.		
Upfront savings of using fluorescent tubes	1982.5 - 1560	422.5
Yearly savings	6821.1 - 3789.5	3031.6
Annual saving percentage	**45 %**	

Table 3.15 Energy Saving of Replace 18W CFL Tubes with 9W LED Tubes for 5 Hours Daily.

Items and Operations	Calculations	Results in JD
T8 ballast + Starter (1 for each pair) + installation fee	(0.3+ 0.5) × 300 + 600× 1	840
600 T8 fluorescent 18Watt tubes cost	600 × 1	600
Initial cost	840 + 600	1440
(yearly usage cost) 600 of CFL 18W tubes for 1100 h	600 × 0.018 × 0.265 × 1100	3148.2
Total	1440 + 3148.2	4588.2
Second: LED Tubes.		
(Rewiring fee) T8 ballast + installation fee	0.5 × 300 + 600 ×1	750
600 T8 LED 9 watt tubes cost	600 × 1.8	1080
Initial cost	750 + 1080	1830
(yearly usage cost) 600 of LED 9W tubes for 1100 h	600 × 0.009 × 0.265 × 1100	1574.1
Total	1830 + 1574.1	3404.1
Annual Results.		
Upfront savings of using fluorescent tubes	1830 - 1440	390
Yearly savings	3148.2 -1574.1	1574.1
Annual saving percentage	**50 %**	

Table 3.16 Energy Saving of Replace 11W CFL Bulbs with 6W LED Bulbs for 5 Hours Daily.

Items and Operations	Calculations	Results in JD
First: Fluorescent Bulbs.		
100 fluorescent 11W bulbs cost	100 × 1	100
Installation fee	100 × 1	100
Initial cost	100 +100 = 200 JD	
(yearly usage cost) 100 of CFL 11W bulbs for 1100 h	100 × 0.011 × 0.265 × 1100	320.65
Total	200 + 320.65	520.65
Second: LED Bulbs.		
(Rewiring fee) + insulation fee	1× 100	100
100 LED 6 W bulbs cost	100 × 1.6	160
Initial cost	100 + 160	260
(yearly usage cost) 100 of LED 6W bulbs for 1100 h	100 × 0.006 × 0.265 ×1100	174.9
Total	260 + 174.9	434.9
Annual Results.		
Upfront savings of using fluorescent bulbs	260 - 200	60
Yearly savings.	320.65 - 174.9	145.75
Annual saving percentage	**45.5 %**	

Table 3.17 Energy Saving of Replace 9W CFL Bulbs with 6W LED Bulbs for 5 Hours Daily.

Items and Operations	Calculations	Results in JD
100 fluorescent 11W bulbs cost	100 × 1	100
Installation fee	100 × 1	100
Initial cost	200 JD	
(yearly usage cost) 100 of CFL 9W bulbs for 1100 h	100 × 0.009 × 0.265 × 1100	262.35
Total	200 + 262.35	462.35
Second: LED Bulbs.		
100 LED 6 W bulbs cost	100 × 1.6	160
Installation fee	100 × 1	100
Initial cost	160 + 100	260
(yearly usage cost) 100 of 6W LED bulbs for 1100 h	100 × 0.006 × 0.265 × 1100	174.9
Total	260 + 174.9	434.9
Annual Results.		
Upfront savings of using fluorescent bulbs	260 - 200	60
Yearly savings	262.35 - 174.9	87.45
Annual saving percentage	**33.5 %**	

Table 3.18 Energy Saving of Replace 70W CFL Bulbs with 40W LED Bulbs for 2 Hours Daily.

Items and Operations	Calculations	Results in JD
40 fluorescent 70W bulbs cost	40 × 10	400
Installation fee	40 × 1	40
Initial cost	400 + 40	440
(yearly usage cost) 40 of CFL 70W bulbs for 440 h	40 × 0.07 × 0.265 × 440	326.48
Total	440 + 326.48	766.48
Second: LED Bulbs.		
40 LED 40 W bulbs cost	40 × 10	400
Installation fee	40 × 1	40
Initial cost	400 + 40	440
(yearly usage cost) 40 of 40W LED bulbs for 440 h	40 × 0.04 × 0.265 × 440	186.56
Total	440 + 186.56	626.56
Annual Results.		
Upfront savings of using fluorescent bulbs tubes	440 - 440	0
Yearly savings	326.48 -186.56	139.92
Annual saving percentage	**43 %**	

The payback period in case of the lighting hours are 5 per day (Referring to the calculation's tables):

The total electricity saving per year equal to: 3031.6 + 1574.1 + 145.75 + 87.45 + 139.92 = 4978.82 JD

The total initial cost= 1982.5 +1830 + 260 + 260 + 440 = 4772.5 JD

Payback period: 4772.5 / 4978.82 = 0.958 approximately 1 year.

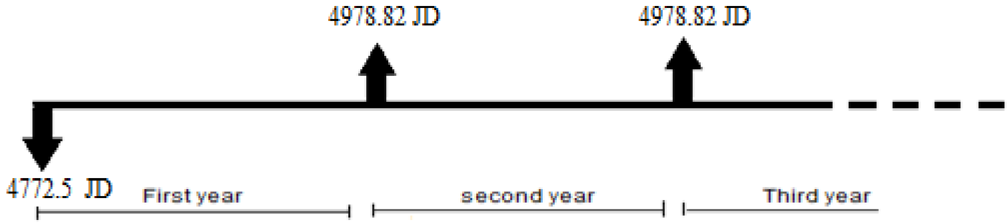


Figure 3.17 Energy Cost Saving Cash Flow in case of 5 Hours Lighting per day Applied.

3.5.3 Phase Three (Building Management System with LED)

As mentioned earlier, the motion sensor turns lights on after making sure that there is a movement in the desired location, but the light will not work unless the illumination level is low, and this is the function of the light sensor, that measures the lighting intensity and accordingly allows the light to work.

Figure 3.18 MDSEN-IR-24V Motion & Day Light Sensor

After communicating with the local markets, they suggested and advised a sensor device that shown in figure 3.18 ,this control device has an advantage of performs both functions of PIR motion sensor and daylight sensor using LDR features, together with a local price of 10 dinars, the device is available, and easy to install where it contains only two ports, and gives a horizontal range detection of 10 meters, and vertical range detection of 3 meters, at this phase, this device added to all offices and classroom and corridors in the faculty.

Depending on the faculty engineering plan, 110 sensor devices could cover all the offices, classrooms, and corridors, with the upfront cost of 1100 JD for devices and 440 JD for installation in an average of 4JD installation fees for each sensor.

Jordan switches between summertime, and wintertime every year, however, summertime considered as daylight saving time, due to the clock set forward 1-hour meaning more extra of daylight is available, in the current year

2020 the summertime started in 27 of march, therefore this change must be taken in account in calculations.

The light sensor depends on daylight, but sometimes the light distribution appears heterogeneous, as the levels of daylight inside the classrooms are varies depending on the distance from the windows, and depending on the seasons, and the state of the sky, whether clear or cloudy, and the condition of blinds, and shading, the following figure 3.19 presented the lighting distribution that measured by BST-LX05 light meter for classroom number 10.

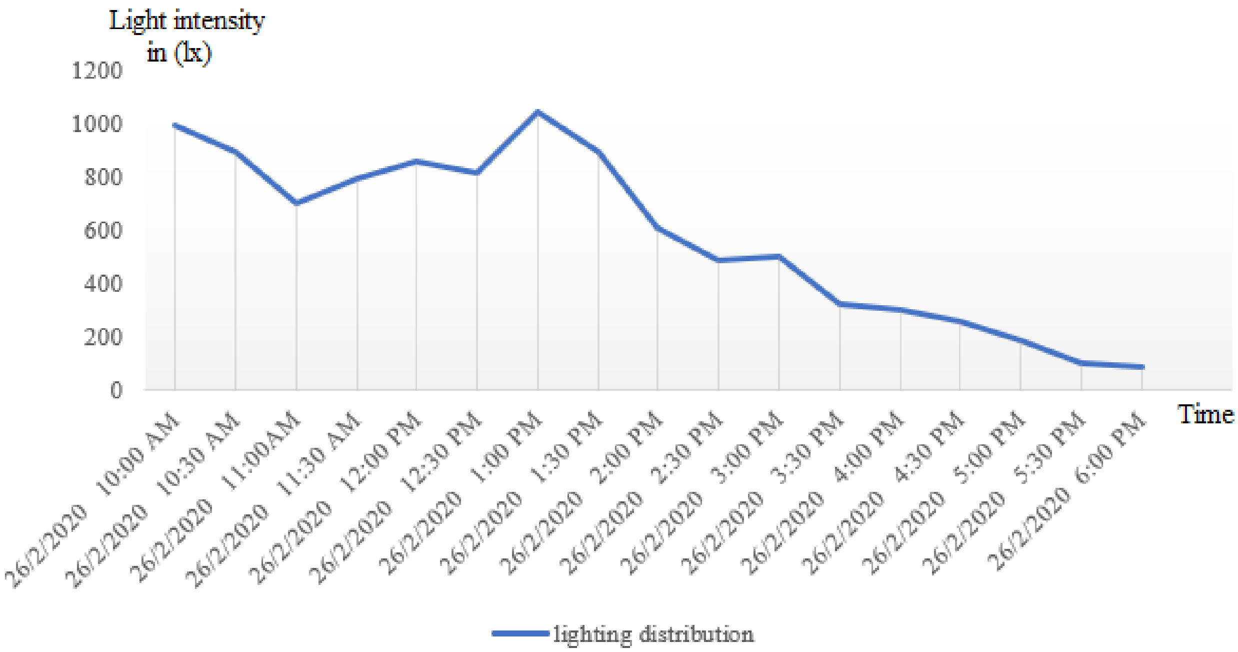


Figure 3.19 Lighting Distribution for Classroom (10) in Lux Unit

The figure shows the high potential for daylight in the classroom 10, as it exceeded European standards, in the required lighting rate, in vital sectors in term of light intensity. According to the previous table 3.6, this will reduce energy consumption, when the daylight utilized correctly, however, it was noted that at 4 PM, the level of illumination was less than required, so here it is assumed that the light sensor will allow illumination, after the PIR sensor detected mention inside the room.

Therefore, depending on the figure 3.19, the available daylight using the light sensor will reduce the light consumption 1 hour in wintertime, and 2 hours in summertime, because of the 1-hour shift between the 2 timing.

For motion sensor calculations, it is difficult to install the sensors currently and calculate the difference saving between the bills. Therefore, the occupancy calculations in this study depended on the study schedule set in the engineering college.

Based on the information available from the admission and registration department, the classroom occupations have a rate of 5 lectures daily, including both bachelor’s and master's students. The average lecture time period for all majors is assumed to be 90 minutes, taking into account that there are lectures last for an hour and there are 3 hours, so The approximate average is 90 minutes, accordingly, the full occupancy time will be $90 \times 5 = 450$ minutes, meaning (7 – 7.5) hours of real occupancy, including two to three hours, in which students will need electrical lights according to the previous study of classroom 10 using the light meter, the same scenario applied to private offices since they are almost subject to the amount of measured daylight.

However, due to the varies of daylight strength, because of the different in temperatures, weathers, using the classroom for other activities, and other factors, another lighting hour will be added under the name of precision coefficient so that the maximum value for daily lighting hours using the control devices (light and motion) is 4 hours in wintertime, and 3 hours as average in the summertime.

Figure 3.20 Solar LED Lamp Module

In this phase, in synchronism with the use of control devices for indoor lighting, the lights of the external square lamps, were replaced with solar LED lamps as in the figure 3.20, it has an internal daylight sensor that controls the lamp upon the outside light intensity and provides the same efficiency of the lights used previously, therefore, their energy usage will be excluded, from the future annual bills. This lamps price is 180 JD per Lamp, with 150 W capacity, that equivalent to 70W fluorescent and 40W electrical lamp.

Calculations.

As mentioned earlier, the light working hours are 3-4, using the control system where 3 adopted for summertime, and 4 for winter time, the calculations covered using sensors in both old CF Land new system of LED, to compare between the annual saving, and select the optimum choice.

A- In case of winter timing with 4 lighting hours: Due to varies between the two timing, summer time has more advantage for extra 1 daylight, where the total annual lighting hours are 4×220 = 880 hours per year in winter.

Table 3.19 Energy Saving of Replace 36W CFL Tubes with 20W LED Tubes for 4 Hours Daily.

Items and Operations	Calculations	Results in JD
First: Fluorescent Tubes		
T8 ballast + Starter (1 for each pair) + installation fee	(0.3+ 0.5) ×325 +650×1	910
650 T8 fluorescent 36Watt tubes cost	650 × 1	650
Initial cost	910 + 650	1560
(yearly usage cost) 650 of CFL 36W tubes for 880 h at 0.265JD/KWh using control sensors	650 × 0.036 × 0.265 × 880	5456.88
Total	1560 + 5456.88	7016.88
Second: LED Tubes with Sensors		
(Rewiring fee) T8 ballast + installation fee	0.5 ×325 + 1 × 650	812 .5
650 T8 LED 20 watt tubes cost	650 × 1.8	1170
Initial cost	812.5 JD + 1170	1982.5
(yearly usage cost) 650 of LED20W tubes for 880 at 0.265JD/KWh using control sensors	650 × 0.02 × 0.265 × 880	3031.6
Total	1982.5 + 3031.6	5014.1
Annual Results		
Upfront savings of using fluorescent tubes	1982.5 - 1560	422.5
Yearly savings	5456.88 - 3031.6	2425.28
Annual saving percentage	**44.5 %**	

Table 3.20 Energy Saving of Replace 18W CFL Tubes with 9W LED Tubes for 4 Hours Daily with Sensors.

Items and Operations	Calculations	Results in JD
First: Fluorescent Tubes		
T8 ballast + Starter (1 for each pair) + installation fee	(0.3+ 0.5) × 300 + 600×1	840
600 T8 fluorescent 18Watt tubes cost	600×1	600
Initial cost	840 + 600	1440
(yearly usage cost) 600 of CFL 18W tubes for 880 hours	600 × 0.018 × 0.265 × 880	2518.56
Total	1440 + 2518.56	3958.56
Second: LED Tubes with Sensors		
(Rewiring fee) T8 ballast + installation fee	0.5 × 300 + 600 ×1	750
600 T8 LED 9 watt tubes cost	600 × 1.8	1080
Initial cost	750 + 1080	1830
(yearly usage cost) 600 of LED 9W tubes for 880 h at 0.265JD/KWh	600 × 0.009 × 0.265 × 880	1259.28
Total	1830 + 1259.28	3089.28
Annual Results.		
Upfront savings of using tubes	1830 - 1440	390
Yearly savings	2518.56 -1259.28	1259.28
Annual saving percentage	**50 %**	

Table 3.21 Energy Saving of Replace 11W CFL Bulbs with 6W LED Bulbs for 4 Hours Daily with Sensors.

Items and Operations	Calculations	Results in JD
First: Fluorescent Bulbs with Sensors.		
100 fluorescent 11W bulbs cost	100 × 1	100
Installation fee	100 × 1	100
Initial cost	100 +100	200
(yearly usage cost) 100 of CFL 11W bulbs for 880 h	100 × 0.011 × 0.265 × 880	256.52
Total	200 + 256.52	456.52
Second: LED Bulbs with Sensors.		
(Rewiring fee) + insulation fee	1× 100	100
100 LED 6 W bulb cost	100 × 1.6	160
Initial cost	100 + 160	260
(yearly usage cost) 100 of LED 6W bulbs for 8080 h	100 × 0.006 × 0.265 × 880	139.92
Total	260 + 139.92	399.92
Annual Results		
Upfront savings of using fluorescent bulbs	260 - 200	60
Yearly savings	256.52 - 139.92	116.6
Annual saving percentage	**45.5 %**	

Table 3.22 Energy Saving of Replace 9W CFL Bulbs with 6W LED Bulbs for 4 Hours Daily with Sensors.

Items and Operations	**Calculations**	**Results in JD**
First: Fluorescent Bulbs with Sensors.		
100 fluorescent 11W bulb cost	100 ×1	100
Installation fee	100 ×1	100
Initial cost	200 JD	
(yearly usage cost) 100 of CFL 9W bulbs for 880 h	100 × 0.009 × 0.265 ×880	209.88
Total	200 + 209.88	409.88
Second: LED Bulbs with Sensors.		
100 LED 6 W bulbs cost	100 × 1.6	160
Installation fee	100 × 1	100
Initial cost	160 + 100	260
(yearly usage cost) 100 of 6W LED bulbs for 880 h	100 × 0.006 × 0.265 × 880	139.92
Total	260 + 139.92	399.92
Annual Results.		
Upfront savings of using fluorescent bulbs	260 - 200	60
Yearly savings	209.88 - 139.92	69.96
Annual saving percentage	**33.5 %**	

Table 3.23 Energy Saving of Replace 70W CFL Bulbs with 150W Solar LED Bulbs for 2 Hours Daily.

Items and Operations	**Calculations**	**Results in JD**
First: Fluorescent Bulbs		
40 Fluorescent 70W bulbs cost	40 × 10	400
Installation fee (1JD for Each)	40 × 1	40
Initial cost	400 + 40	440
(yearly usage cost) 40 of CFL 70W bulbs for 440 h	40 × 0.07 × 0.265 × 440	326.48
Total	440 + 326.48	766.48
Second: LED Solar Bulbs.		
40 LED 150 W solar LED cost	40 × 180	7200
Installation fee (5 JD for Each)	40 × 5	200
Initial cost	7200 + 200	7400
(yearly usage cost) 40 of 150W solar LED bulbs for	(solar energy)	0
Total		7400
Annual Results		
Upfront savings of using fluorescent bulbs	7400 -440	6960
Yearly savings	326.48 JD – 0 JD	326.48
Annual saving percentage	**100 %**	

Payback period the all integrated system (LEDs + Sensors) with 4 hours daily lighting:

– Sensor devises costs: 10JD (per sensor) × 110 JD (number of suggested sensors) + 440 JD (installation fees) = 1100 + 440 = 1540 JD.

– LEDs total initial cost: 1982.5 + 1830 + 260 + 260 = 4332.5 JD

– Cost for solar LED lamps: 7200 JD + installation fee (5×40) = 7400 JD

– Total cost: 1540 JD + 4332.5 JD + 7400 = 13272.5 JD

– Total annual saving (referring to calculations tables): 2425.28 + 1259.28 + 116.6 +69.96 + 326.48 = 4197.6 JD

Payback period: 13272.5 / 4197.6 = 3.16 (approximately 3 years)

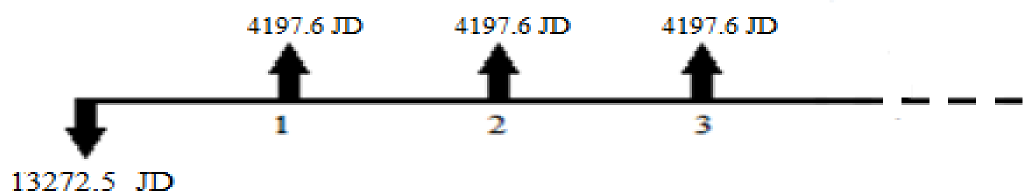


Figure 3.21 Energy Cost Saving Cash Flow for LED & Sensors in case of 4 Lighting Hours Daily Applied.

B- In case of summer timing.

In summer time, 3 hours as lighting hours applied, as summer time is has the maximum capacity of available day light, the total working hours are 3× 220 = 660 hours.

Table 3.24 Energy Saving of Replace 36W CFL Tubes with 20 W LED Tubes for 3 Hours Daily with Sensor.

Items and Operations	**Calculations**	**Results in JD**
First: Fluorescent Tubes with Sensors		
T8 ballast + Starter (1 for each pair) + installation fee	(0.3+ 0.5) × 325 +650×1	910
650 T8 fluorescent 36Watt tubes cost	650×1	650
Initial cost	910 + 650	1560
(yearly usage cost) 650 of CFL 36W tubes for 660 h	650 × 0.036 × 0.265 × 660	4092.66
Total	1560 JD + 4092.66	5652.66
Second: LED Tubes with Sensors		
(Rewiring fee) T8 ballast + installation fee	0.5 × 325 + 1 × 650	812 .5
650 T8 LED 20 watt cost	650 × 1.8	1170
Initial cost	812.5 + 1170	1982.5
(yearly usage cost) 650 of LED 20W tubes for 660 h	650 × 0.02 × 0.265 × 660	2273.7
Total	1982.5 + 2273.7	4256.2
Annual Results		
Yearly savings	4092.66 - 2273.7	1818.96
Annual saving percentage	**44.5 %**	

Table 3.25 Energy Saving of Replace 18W CFL Tubes with 9W LED Tubes for 3 Hours Daily with Sensors.

Items and Operations	Calculations	Results in JD
First: Fluorescent Tubes with Sensors.		
T8 ballast + Starter (1 for each pair) + installation fee	(0.3 + 0.5) × 300 + 600 ×1	840
600 T8 fluorescent 18Watt tubes cost	600 ×1	600
Initial cost	840 + 600	1440
(yearly usage cost) 600 of CFL 18W tubes for 660 hours	600 × 0.018 × 0.265 × 660	1888.92
Total	1440 + 1888.92	3328.92
Second: LED Tubes with Sensors.		
(Rewiring fee) T8 ballast + installation fee	0.5 × 300 + 600 ×1	750
600 T8 LED 9 watt tubes cost	600 × 1.8	1080
Initial cost	750 + 1080	1830
(yearly usage cost) 600 of LED 9W tubes for 600 hours	600 × 0.009 × 0.265 × 660	944.46
Total	1830 + 944.46	2774.46
Annual Results		
Yearly savings	1888.92 - 944.46	944.46
Annual saving percentage	**50 %**	

Table 3.26 Energy Saving of Replace 11W CFL Bulbs with 6W LED Bulbs for 3 Hours Daily with Sensors.

Items and Operations	Calculations	Results in JD
First: Fluorescent Bulbs with Sensors.		
100 fluorescent 11W bulbs cost	100 × 1	100
Installation fee	100 × 1	100
Initial cost	100 +100	200
(yearly usage cost) 100 of 11W CFL bulbs for 660 h	100 × 0.011 × 0.265 × 660	192.39
Total	200 + 192.39	392.39
Second: LED Bulbs with Sensors.		
(Rewiring fee) + insulation fee	1× 100	100
100 LED 6 W bulbs cost	100 × 1.6	160
Initial cost	100 + 160	260
(Yearly usage cost) 100 of LED 6W bulbs for 660 h at 0.265JD/KWh	100 × 0.006 × 0.265 × 660	104.94
Total	260 JD + 104.94	364.94
Annual Results		
Upfront savings of using fluorescent bulbs	260 - 200	60
Yearly savings	192.39 - 104.94	87.45
Annual saving percentage	**45.5 %**	

Table 3.27 Energy Saving of Replace 9W CFL Bulbs with 6W LED Bulbs for 3 Hours Daily with Sensors.

Items and Operations	Calculations	Results in JD
First: Fluorescent with Sensors		
100 fluorescent 11W bulbs cost	100 × 1	100
Installation fee	100 × 1	100
Initial cost	100 + 100	200
(yearly usage cost) 100 of CFL 9W bulbs for 660	100 × 0.009 × 0.265 × 660	157.41
Total	200 + 157.41	357.41
Second: LED Bulbs with Sensors.		
100 LED 6 W bulbs cost	100 × 1.6	160
Installation fee	100 × 1	100
Initial cost	160 + 100	260
(yearly usage cost) 100 of 6W LED bulbs for 660 h	100 × 0.006 × 0.265 × 660	104.94
Total	260 + 104.94	364.94
Annual Results		
Upfront savings of using fluorescent bulbs	260 - 200	60
Yearly savings	157.41 - 104.94	52.74
Annual saving percentage	**33.5 %**	

Table 3.28 Energy Saving of Replace 70W CFL Bulbs with 150W Solar LED Bulbs for 2 Hours Daily.

Items and Operations	Calculations	Results in JD
First: Fluorescent Bulbs with Sensors.		
40 Fluorescent 70W bulbs cost	40 × 10	400
Installation fee (1 JD for Each)	40 × 1	40
Initial cost	400 + 40	440
(yearly usage cost) 40 of CFL 70W bulbs for 440 h	40 × 0.07 × 0.265 × 440	326.48
Total	440 JD + 326.48 JD	766.48
Second: LED Bulbs with Sensors.		
Cost of 40 150W solar LED	180 × 40	7200
Installation fee (5 JD for Each)	400 × 5	200
Initial cost	7200 + 200	7400
(yearly usage cost) 40 of 150W solar LED bulbs for 440 h at 0.265JD/KWh	Solar energy	0
Total		7400
Annual Results		
Upfront savings of using fluorescent bulbs	7400 -440	6960
Yearly savings	326.48 - 0	326.48
Annual saving percentage	**100 %**	

Payback period the all integrated system (LEDs + Sensors)

– Sensor devises costs: 10 JD (per sensor) × 110 JD (number of suggested sensors) + 440 JD (installation fees) = 1100 + 440 = 1540 JD.
– LEDs initial cost: 1982.5 + 1830 + 260 + 260 = 4332.5 JD.
– Cost for solar LED lamps: 7200 + installation fee (5 × 40) = 7400 JD.
– Total cost: 1540 + 4332.5 + 7400 = 13272.5 JD
– Total annual saving (referring to calculations tables):
1818.96 +944.46 + 87.45 + 52.74 + 326.48 = 3230.09 JD
Payback period: 13272.5 / 3230.09 = 4.1 (approximately 4 years)

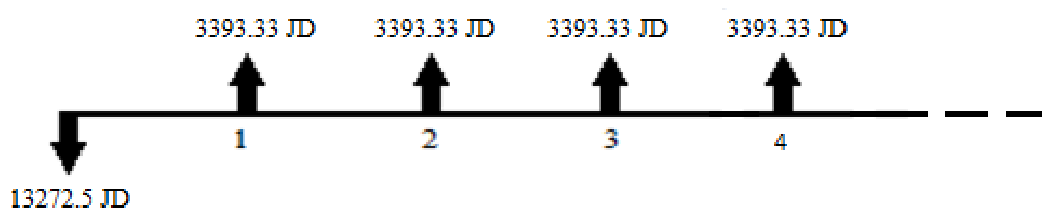


Figure 3.22 Energy Cost Saving Cash Flow for LED & Sensors in case of 3 Lighting Hours Daily Applied.

3.5.4 Energy Cost and Saving Results for The New Lighting System

According to the previous calculations, it was found that there is a large amount of savings, when converting from fluorescent to LED, and then this estimate was increased, by strengthening the LED system with sensor controllers, the table 3.29 shows the consumption values and the annual cost of the lighting system in several upgrading phases for the light system.

Table 3.29 Annual Energy Cost and Consumptions of Several Phases for Upgrading Lighting System., where WT: Wintertime, ST: Summertime.

Lamps Type & Wattage	Annual Energy Consumptions (KWh)	Annual Energy Cost (JD)
36W Fluorescent	25740	6821.1
18W Fluorescent	11880	3148.2
11W Fluorescent	1210	320.65
9W Fluorescent	990	262.35
70W Fluorescent	1232	326.48
20W LEDs / No sensors	14300	3789.5
9W LEDs / No sensors	5940	1574.1
6W LEDs / No sensors	660	174.9
6W LEDs / No sensors	660	174.9
40W LEDs / No sensors	704	186.56
20W LEDs with sensors/ ST	8580	2273.7

Lamps Type & Wattage	Annual Energy Consumptions (KWh)	Annual Energy Cost (JD)
9W LEDs with sensors / ST	3564	944.46
6W LEDs with sensors / ST	396	104.94
6W LEDs with sensors / ST	396	104.94
150W solar LEDs with sensors /ST	0	0
20W LEDs with sensors/ WT	11400	3031.6
9W LEDs with sensors / WT	4752	1259.28
6W LEDs with sensors / WT	528	139.92
6W LEDs with sensors / WT	528	139.92
150W solar LEDs with sensors /WT	0	0
Total of Fluorescent	41052	10878.78
Total of LEDs system	22264	5899.96
Total of LEDs with sensors / ST	12936	3428.04
Total of LEDs with sensors / WT	17208	4570.72

To know the economic feasibility of upgrading the lighting, the most workable cases will be calculated to compare the results, and determine the best annual saving method and to find the final saving rate. The five-hour system for the LED and fluorescent systems will be adopted as normal lighting hours in the following calculations.

1- Replace the full indoor fluorescent system with LED, and adding controller sensors, along of replace the outdoor fluorescent with solar LED lamps (in summertime)

Total energy annual saving cost: (referring to table 3.29) is equal to
(total consumption cost of using CFL) **-** (total consumption cost using LED with sensor in summer)
10878.78 - 3428.08 = 7311.38 JD
Annual saving percentage: 68%
Payback period: (referring to calculation tables)
Total cost for the developed system is: 13272.5 JD
Payback period = Total cost for the new lighting system / energy annual saving
= 13272.5 / 7311.38 = 1.8 years (approximately 1year and 9 months).

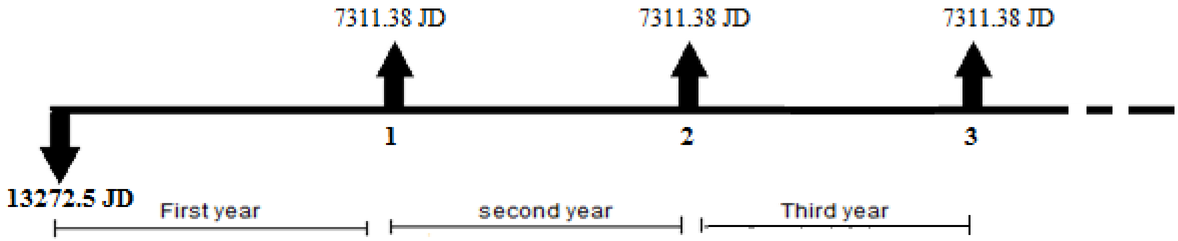


Figure 3.23 Energy Cost Saving Cash Flow of Replace Fluorescent with LED, Control Devices and Solar LED in Summertime.

2- Replace the full indoor fluorescent system with LEDs and controller sensors and replace outdoor fluorescent with solar LED lamps (in Wintertime)

Total energy annual saving cost: (referring to the calculation tables and table 3.29)

(total consumption cost of using CFL) **-** (total consumption cost using LED with sensor in wintertime)

10878.78- 4570.72 = 6168.74 JD

Annual saving percentage 57.5%

Payback period = Total cost for the new lighting system / energy annual saving

13272.5 / 6168.74 = 2.15 years (approximately 2 year and 2 months).

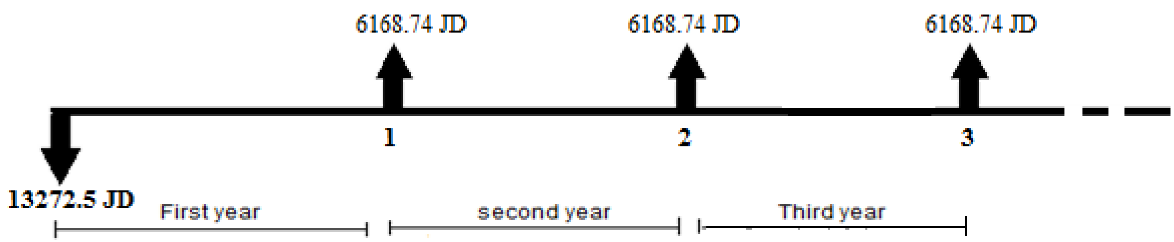


Figure 3.24 Energy Cost Saving Cash Flow of Replace Fluorescent with LED, Control Devices and Solar LED in Wintertime.

3- Replace the full fluorescent system with LEDs only for normal use (5hours)
(referring to tables 3.14 to 3.18 and table 3.29)

Total energy annual saving cost = 10878.78 - 5899.96 = 4839.5 JD

The saving percentage is 45 %.

Referring to calculations tables the total cost was: 5132.5 JD

Payback period = 5132.5 / 4839.5 = 1.06 (approximately 1 year)

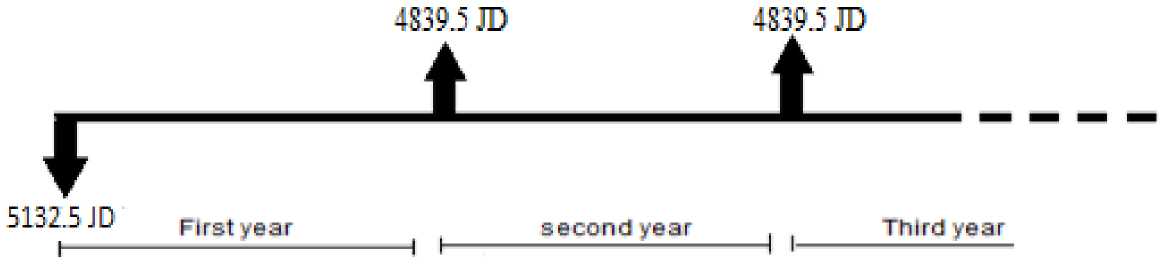


Figure 3.25 Energy Cost Saving Cash Flow for Replace Fluorescent with LED Only.

4- Using only the fluorescent Lamps with control system.
(referring to calculation tables and table 3.29).
The annual saving cost: 10878.78 – 6657.86 = 4220.92 JD
Saving percentage is: 38 %
Payback period: (sensors total cost) / (annual energy saving) =
1540 / 4220.92 = 0.36 (approximately 4 months)

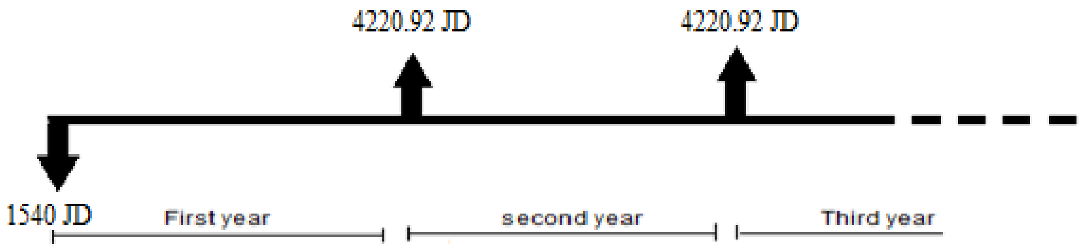


Figure 3.26 Energy Cost Saving Cash Flow for Adding Sensor to Fluorescent.

The above calculations showed that the best option to get the most annual cost and consumption savings is to switch to internal LEDs light with sensor and External solar LED light, this option can provide annual saving cost 68 % with less than 1.9 years' payback period.

The figure 3.27 shows the annual energy cost values in three lighting systems, where the lowest annual cost is in case of using LEDs with controller sensors.

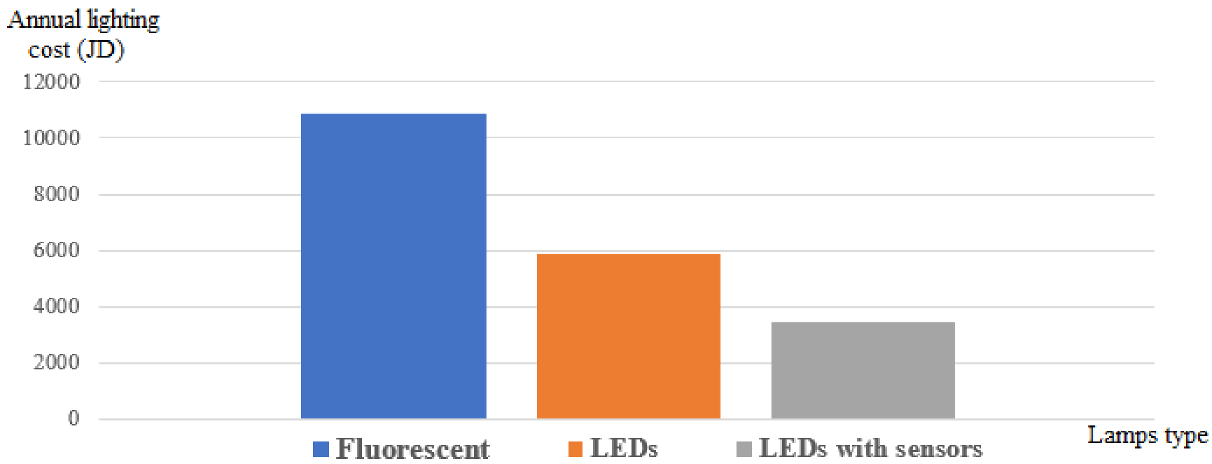


Figure 3.27 Annual Energy Cost for The Three Lighting System Phases.

3.6 Solar Energy Project.

After improving the lighting system, and reduced energy consumption, at this stage, a solar system was added to cover the annual energy consumption of the new lighting system.

3.6.1 Solar Analysis

Jordan is well-positioned for setting up solar energy projects in terms of annual daily average insolation intensity, figure 3.28 presented the global solar radiation map of Jordan in Wh/m^2/Day.

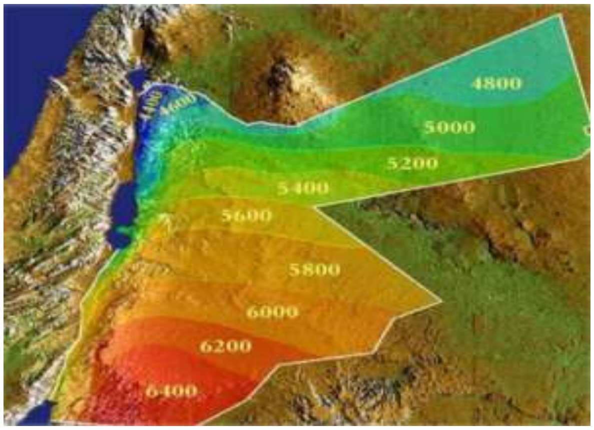


Fig. 3.28: Global Solar Radiation Map of Jordan in Wh/m^2/Day, (Alrwashdeh, S. & Al-saraireh, F. & Saraireh, M. 2018)

The peak sun hours (PSH) selected to be about 6 hours, at standard test conditions in *Alkarak- Mutah*, (Alnajideen, M. & Alrwashdeh, S. 2017)

3.6.2 System Design.

The annual energy consumption of the new lighting system was calculated in the previously, and it was 12.936 MWh /year in summertime, and 17.208 MWh in wintertime, so the average is 15.072 MWh, since the two timing have almost the same duration.

The solar system used in the project is on grid, as the figure 3.29 shown, used to cover the energy usage, contained 315W Mono-crystalline modules with efficiency of 19.3 %, and this PV modules specifications presented in appendix C, where the selected inverter was 5 K SMA Sunny Tripower 5.0 with efficiency of 97.6% - 98.2%, where its specifications presented in appendix D.

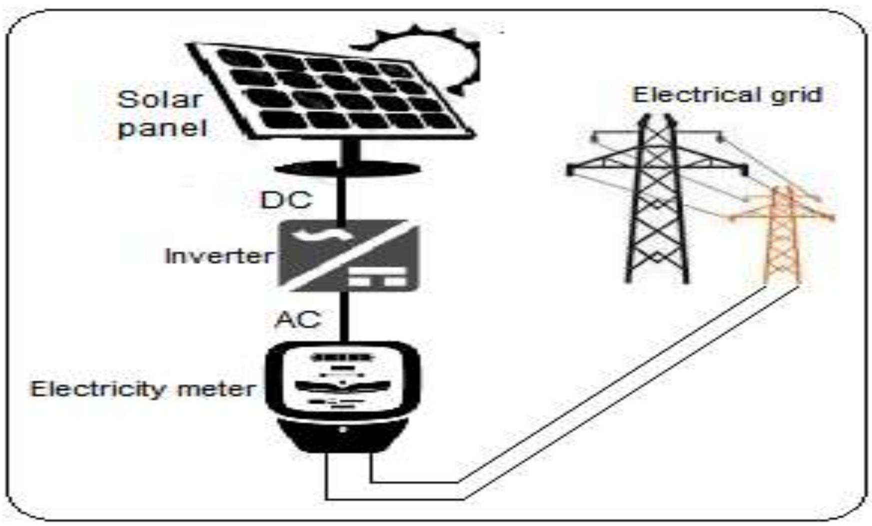


Figure 3.29 On Grid Model

In the first stage of solar electricity generation, the energy generated in the panels is on DC current form, after using inverter the current is converted to AC current, as figure 3.29 shown, the extracted DC value depend on inverter efficiency (Borgstein, E. & Lamberts, R. & Hensen, J. 2016), because of this, the value of the energy generated by the panels must be greater than the value of the annual consumption, as the below equation described (I.E.A.)

$$P_{inv,in,kWh} = P_{demand\,\max} / \eta_{inv} \quad (3.1)$$

Where, η_{inv} : The inverter efficiency

$P_{demand\,max}$: The maximum demand load.

$P_{inv,in,kWh}$: Total load generated via PV.

Using the above equation, where the annual load is 15.072 MWh and selected inverter efficiency 97.6% - 98.2%, as maximum value, the total generated load via PV using equation 3.1, with inverter efficiency of 97.6 % is

15.442 MWh. The numbers of PV panels required to generate 15.442 MWh is given by the following formula: (J.R. Fanchi,2004)

$$No.\ of\ PV\ Panels = P_{in\,v,in,kWh} \,/\, P_{max,actual} \qquad (3.2)$$

Where, $P_{max,actual}$: The power produced by the module at each day given by the following equation: (Gormally, A., et al 2016)

$$P_{\mathrm{max,actual}} = [\,(1 - L_T)\times(1 - L_C)\times(1 - L_M)\,]\times P_{max}\times PSH \qquad (3.3)$$

Where, L_T : The temperature losses coefficients.

L_C : The cable losses coefficients.

L_M : The module losses coefficients.

P_{max} : The module peak power at maximum irradiance.

Using the equations (1.3), (3.2) and (3.3) along of appendix C, D:

$P_{inv,in,kWh}$ = 15.442 MWh.

$P_{\mathrm{max,actual}}$ = 548 ($kW_p h$)

No. of PV Panels = 28

The system size of 28 PV with 315W capacity is 8820 KW, is required 2 of 5 KW inverter.

3.6.3 PV Location Overview

Helioscope software was used to calculate the area size, and distribution of solar panels in the proposed location, in the college parking lots, and determined the shading effect for the faculty building, the panels allocated in zone of faculty car parking lots, to give protection to cars, and an aesthetic aspect at the same time.

Figure 3.30 Proposed PV Location for PV System Via Helioscope Software

Figure 3.30 shown, the proposed area for placing solar panels, which has an area of about 106.5 m^2, according to the figure 3.31, the chosen area is not affected by the shadows of the college building, which gives the site the advantage of producing the largest amount of solar energy.

Figure 3.31 Location Area and Shading Via Helioscope Software

Figure 3.32 Solar System Specifications Via Heliscope Software

As per the website latitude.to, Mutah latitude angle is 31°, using this as a tilt angle for the PV system, contributes to give high solar energy compared with other angles.

The selected row spacing is 0.5m with 2×2 solar panels frame size, with 3 m high for the cars parking, as the helioscope software figure 3.32 shown, azimuth angle 180° with fixed tilt racking.

3.6.4 Solar Energy Project Cost and Results Analysis

The proposed solar project covered the annual costs of the developed lighting system, for 15.072 MWh annual lighting consumption, with 3994.08 JD annual cost. PV project, and the payback period were presented on table 3.30.

Table 3.30 PV Project Cost.

Item	Cost
28 of 315W PV panels	3700 JD
Inverters ×2	2200 JD
Cables	400 JD
Miscellaneous	1000 JD
Parking Roof & Design	3500 JD
Total PV Cost	10800 JD
Electricity Bill Cost/ Year	3994.08 JD
Payback Period	2.7 Years

3.6.5 Total System Result (Sensors, LED, Solar Energy Project).

In this last stage, the new lighting system was combined with the solar panels system, to cover the annual bills, and find the overall system payback period.

The cost of the lighting system with the building management of control sensors in previous calculations was 13272.5 JD, in addition to the cost of the solar system 10800 JD, the total becomes 24072.5 JD, while the annual bills cost for the previous light system was 10878.78 JD as per the table 3.29 presented .

1. payback period of applying (LED & control sensors) without solar panels: 13272.5 / (10878.78 – 3994.08) = 1.9 years.
2. Payback period for the overall system before applied the new lighting system:

   24072.5 /10878.78 = 2.2 years. (with regard to the old high annual lighting bill).
3. Payback period for the overall system after applied the new lighting system:

   24072.5 /3994.08 = 6 years. (with regard to the new low annual lighting bill).

Chapter Four
Conclusions and Recommendations

4.1 Conclusions

The conclusions and results of this research, after analyses and the discussions, are the following:

1. The survey presented a negative result, in terms of energy-saving on the users' part, where significant proportion of the faculty-student are not aware about the importance of energy-saving, and the large role of the lighting system in energy consumption.
2. The study demonstrated that building management using a control system can provide a large amount of energy- saving in a lighting system, where the light sensors utilized the waste daylight hours, to provide the same electric light efficiency, and the occupancy sensor eliminates the unnecessary lighting use.
3. The study took into account the difference in conditions between summertime, and wintertime, where the number of daylight hours available is more in the summertime, therefore, lower energy was used, as the study achieved 68% energy saving as maximum, when using the complete system, consisting of indoor LED with control sensors, and outside solar LED in the summertime, while achieved 57.5% energy saving in wintertime, with average of 63% for the 2 timing, with payback period of 2 years, which produced 15.072 MWh annually with cost estimation of 3994.08 JD.
4. The study achieved results of lower energy saving in case of LED lighting was used without sensors, where the saving was 45.5 % annually, with 1 year payback period ,and achieved more low results of 38% energy-saving, in case of using fluorescents lamps with control sensors, with a short payback period (4 months).
5. The proposed solar energy project covered the new annual energy consumption of with short payback period of 2.2 years.

4.2 Recommendations

Based on this research, the following recommendations are proposed for future studies:

1- Apply similar energy management studies, in the other facilities, whether it's academic, commercial or any other sector.

2-Establishing energy centers in academic buildings, for monitoring energy Consumption, and holding educational sessions for students on the importance of energy-saving, and the effect of excessive energy consumption on the environment.

3-Use advanced techniques to monitor the performance of the lighting system remotely.

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Appendices

A- Survey sample

Mutah University.
Faculty of engineering.

Survey for Faculty students' opinions on the current lighting system.
(Related to master thesis work)

Dear student kindly, select your study major form one of the following:

A. Engineering management B. Electrical engineering C. Other major.

1- Have you ever turned off the classroom lights after lecture is over?

A-Never, because I never thought about it.
B-Never, because I'm not the last one leave.
C-Never, even I'm the last one leave.
D-Sometimes when I'm the last one leave.
E-Usually I do that.

2- How many times have you seen the lights on in unoccupied classrooms?

A-Never. B- Rarely. C- sometimes. D- Often. E-Every time.

3- Are you satisfied with the current faculty lighting system?

A-Satisfied.
B-Not satisfied.
C-Not interested.

4- Do you have any suggestion that could help to reduce the energy consumption in the faculty?

Thank you for participation in the survey.

(A) Energy survey for Engineering faculty students.

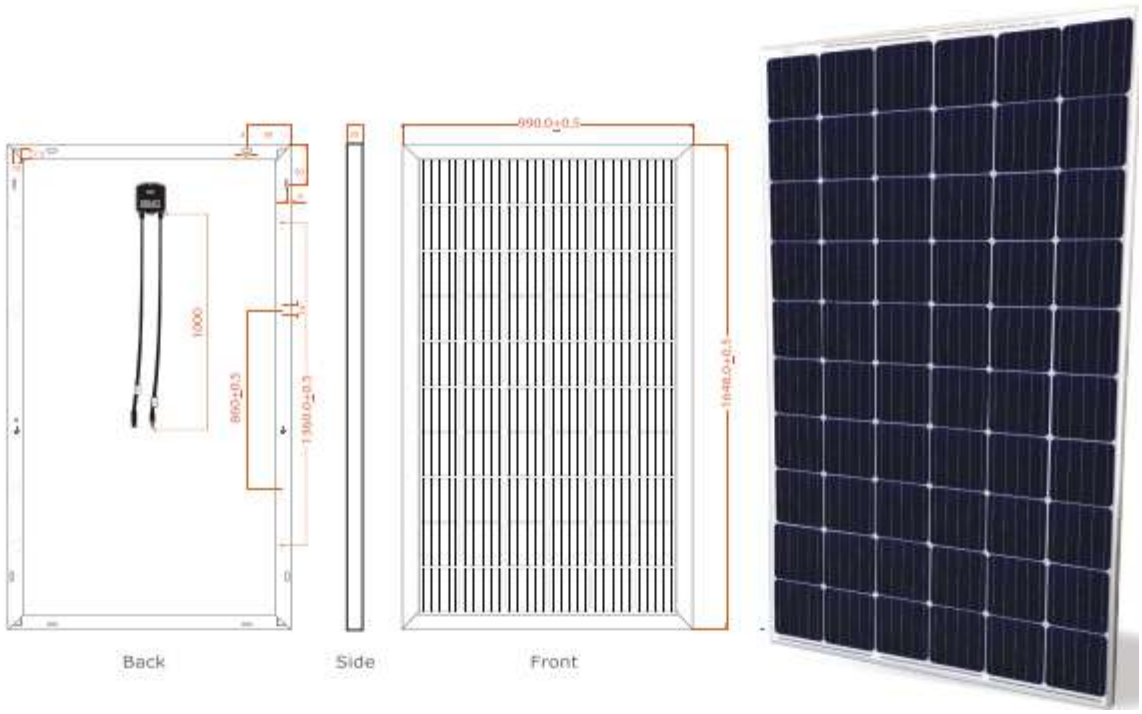
B- MDSEN-IR-24V Sensor Specifications

This motion and daylight detecting sensor that automatically turns on an attached light fixture when motion is detected, or the level of daylight drops. This motion sensor can also detect ambient lighting and tell whether it is night or day outside.

(B)MDSEN-IR-24V sensor specifications, (www.larsonelectronics.com)

Specifications	
Detection Distance	2 to 11 Meters (Adjustable)
Detection Range/Field	180 Degrees
Power Source:	120V AC, 12V DC, or 24V DC
Rated Load	800 Watts
Device Draw	1 Watt
Working Temperature	10 Degrees C to 40 Degrees C
Time Delay	5 sec to 7 min (Adjustable)
Ambient-Light	<10 to 2000 Lux (Adjustable)
Installation Height	1.8m to 2.5m
Housing Color	White, Brown

C- PS-M60 Mono Crystalline Module 315 specifications



(C) 315 PV Panels Specifications, (Philadelphia-Solar)

Characteristics (STC)	STC
Peak Power – P_{max} (W)	315
Open Circuit Voltage - Voc (V)	40.67
Short Circuit Current - Isc (A)	9.90
Maximum Power Voltage - Vmpp (V)	33.59
Maximum Power Current - Impp (A)	9.38
Maximum Power - Pmax (W)	315
Module Efficiency - (%)	19.3
Voltage Temperature Coefficient (%/°C)	- 0.30
Current Temperature Coefficient (%/°C)	+ 0.06
Power Temperature Coefficient (%/°C)	- 0.39
NOCT (°C)	45 + 2

Values at Standard Test Conditions STC (Air Mass AM1.5, Irradiance 1000W/m², Cell Temperature °25C).

D- SMA Sunny Tripower 5.0 Inverter Specifications

(D) SMA Sunny Tripower 5.0 Inverter Specifications, (SMA.de)

Technical Data	
Input (DC)	
Max. recommended PV power	9000 Wp
Max. DC voltage	1000 V
MPP voltage range / rated input voltage	245 V to 800 V
Min. input voltage / start input voltage	150 V / 188 V
Max. input current input A / input B	11 A / 10 A
Max. DC short-circuit current input A / input B	17 A / 15 A
Output (AC)	
Max. AC apparent power	5000 W
Nominal AC voltage	3 / N / PE; 230 / 400 V
AC grid frequency / range	50 Hz / -5 Hz to +5 Hz
Rated power frequency / rated grid voltage	50 Hz / 230 V
Max. output current	7.3 A
Power factor at rated power	1
Adjustable displacement power factor	0.8 overexcited to 0.8
Feed-in phases / connection phases	3/3
Max. efficiency	97.6% - 98.2%,

المعلومات الشخصية

الاسم: عمر بدر البدور

التخصص: ماجستير إدارة هندسية

الكلية: الهندسة

سنة التخرج: 2020