The Impact of Internal Dynamic Facades on Energy Saving

تأثيرالواجهات المعمارية الداخلية الديناميكية على المباني الموفرة للطاقة

by

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A dissertation submitted in fulfilment

of the requirements for the degree of

MSC OF SUSTAINABLE DESIGN OF BUILT ENVIRONMENT

at

The British University in Dubai

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May 2017

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ABSTRACT

As the world's environment is suffering from excessive problems people are facing nowadays, increase in levels of CO_2 is one of these problems. The building industry is responsible for 40% of greenhouse gas emissions, and multiple solutions are currently taking place to solve these issues. In the construction field, window shading is already an old and common habit that has been used for a long time. Manipulation in these shadings is what is creating new challenges to reduce energy consumption in a building and therefore save the world.

The study focuses on the use of different techniques that act as window shading devices to save energy such as automatic shading, manual shading, and the introduction of glass tinting. All of these are compared to each other through the use of simulation of a typical office space located in the Bank of Housing, Amman, Jordan. The results show that manual shading all in all saves up a total energy of 57.01%, automatic shading saves up 43.08%, and tinted shading saves up 37% of total energy taking into account that all are compared to Base Case scenario.

In the case of economic analysis, manual shading requires a payback period of 5 years. Tinted shading requires 15 years while automatic period is the least economical with a payback period of 17 years.

The purpose of this study is to show which technique saves up more energy and cost. In this case, it is proven that manual shading saves up the greatest amount of energy when comparing it to all other scenarios. This means that in this case in particular, automatic shading or tinted is not favorable.

Keywords: Energy Saving, Automatic Shading, Glass Tinting, Energy Loads, Manual Shading.

الملخص

بما أن البيئة تعاني في هذه الفترة من التحديات المتزايدة التي يواجهها الانسان, تعتبر زيادة نسبة غاز ثاني أكسيد الكربون احدى هذه التحديات. قطاع الإنشاءات مسؤول عن ما نسبته 40% من انبعاث الغازات الدفيئة. هناك عدة وسائل تم تطبيقها لمواجهة هذه التحديات.

في مجال الإنشاءات, تظليل النوافذ يعتبر من الطرق المتداولة والنستخدمة منذ فترة طويلة, التطوير والتغيير في عمليات التظليل هو ما يعتبر تحد في ترشيد وتوفير استهلاك الطاقة في المباني وبذلك تحسين الكوكب.

هذه الدراسة تعنى بالطرق المستخدمة للآليات المختلفة لتظليل النوافذ مثل التظليل الآلي, التظليل اليدوي, وتقديم العواكس المركبة على زجاج النوافذ. كل هذه الطرق سيتم مقارنتها فيما بينها عن طريق المحاكاة لمكتب نموذجي واقع داخل مبنى بنك الإسكان في مدينة عمان, الأردن. نتائج البحث ستظهر أن التظليل اليدوي سيوفر ما نسبته 57.01% بالإجمالي, التظليل الآلي سيوفر ما نسبته 43.08% بالإجمالي, أما العواكس المركبة على الزجاج ستوفر ما نسبته 37% بالإجمالي مع الأخذ بعين الإعتبار بأن جميع المقارنات تمت مع مقارنة الوضع الأصلي (المرجعي) للزجاج.

المغزى من هذه الدراسة هو إظهار الطريقة المثلى لتوفير الطاقة. في هذه الدراسة سيتم إثبات أن التظليل اليدوي سيوفر أقصى نسبة من الطاقة بالمفاضلة مع الطرق الأخرى المذكورة. هذا يعني وبالتحديد, أن التظليل الآلي والعواكس المركبة على الزجاج هي طرق غير مجدية. وفي حالة مقارنة الطرق من ناحية الجدوى الإقتصادية, فإن فترة استرداد الاستثمار للتظليل اليدوي هي 5 سنوات, بينما تكون 15 سنة بالنسبة للعواكس المركبة على الزجاج, بينما تكون الفترة الأطول للتظليل الآلي وهي 17 سنة.

DEDICATION

I dedicate this paper to my husband who has shown me the greatest powers of love and for telling me that the sky is the limit. I thank my mom deeply for never allowing me to give up and my father for providing me with assistance, love, and compassion. Finally, I thank my ten-month-old son Fahed for keeping me up through the night, and demanding constant attention, he has shown me that nothing is impossible and there is always time, patience, and persistence for success.

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CHAPTER 1 **: GENERAL INTRODUCTION**

1.1 The Architect and Sustainability

An architect is a person that is filled with unlimited energy and imagination and is keen to change a world containing constraints and barriers. He/she needs to be tactical and strategic about where to cause that change, how, and what tools to use. Unfortunately, that's the world we live in, and architecture needs to be bounded to reality than in dreams for it to be practical and most of all, sustainable (Harvey, 2000).

Sustainability is a critical word that has been under the spotlight for a while. According to Datta and Hobbs (2013), the field of building emits around 40% of greenhouse gas emissions. The competition that is occurring is to lessen this large percentage by the use of new innovations and by creating awareness. As far as architects dream to create buildings that stand out, they always need to create a liaison between energy performance of a building, function, and its design aesthetics. In the Middle East, for example, CO_2 emissions account for only 6% of the global CO_2 emissions, yet is increasing since the 1950s (Marland, Andres and Boden, 1994). Just considering the fact that there is an increase; means that immediate action needs to take place before it's too late.

According to Selkowitz, (2001); a façade system of a building is the most crucial element that delivers the best performance towards the building occupants and energy saving. He claims that dynamic façades offer better protection against the sun and have the ability to control cooling loads thus providing thermal comfort and a good amount of daylighting. Having the ability to control the façades gives a good amount of natural ventilation so cooling loads will be further reduced. There will be a reduction of operating costs when energy use decreases in regards to heating, lighting, and cooling. Integrating PV systems is a plus and saves a tremendous amount of energy. Finally, thermal comfort provides better health and satisfaction towards the occupants which leads them to deliver a better performance. He adds as well that façade systems must take into consideration lots of other issues such as orientation, location, latitude, fire safety, and earthquakes. Occupant needs and climate are constantly changing, a high-performance façade must be able to simultaneously adapt to these changes.

When looking at sustainable building design, the portrayed buildings have one thing in common, and that is their all glass façade systems. In the past, glazed façades where an architectural icon and many structural progressions were done to make these designs physically real. They are being looked at these days as the solutions towards sustainable design because lots of improved glazing technologies have been carried out to reach what is available in the market (Selkowitz, 2001).

A fenestration system in a building is one of its most critical elements in its design. Not only is it aesthetic from the outside, it provides natural indoor daylight as well. From the building owner's point of view, a fenestration system reduces annual energy costs and keeps unwanted visitors out. From the occupant's perspective, a fenestration system offers distinguished views to the outside and provides good daylight quality to define space. The problem these days is that there are many requirements that a fenestration system needs to accomplish; fenestrations need to provide a view yet at the same time control glare. They must provide daylight yet control cooling loads and solar transmittance. They must provide a certain degree of connection with the world outside and at the same time provide a satisfactory user comfort. They provide natural ventilation yet sometimes cause an air leakage which leads to drafts. In a nutshell, a static glazed façade must respond to a variety of changing and contrasting conditions whether found in the interior or exterior of a building (Selkowitz, 2001). That's when a dynamic façade emerges into the spotlight.

A dynamic façade's interest is to control the transmitted heat and light so that glare and cooling loads be reduced. Another objective is the dynamic optical control; a way which distributes daylighting within a space to moderate the interior changes which change intensely on the outside between the sun and sky. The aim today is to create a dynamic control system which is less complex and less costly. A special importance will not be only laid on the façade system but also on its sensors, software-based algorithms, actuators communications protocol, and maintenance (Selkowitz, 2001).

According to Selkowitz (2001), there are two approaches towards façade control and these are miniaturization and large scale double envelope façades. Within the past 25 years, scientific progressions have been working on developing the thin film glass coating technology. They are low cost and can be spread over wide areas of glazing façades. The aim of using the latter is the ability to reduce heat because of their low emissivity. Later on, they have been known to admit daylight which increases solar heat gain. In the meantime, the smart glazing technology is under the spotlight since it can change and control solar transmittance dynamically. Smart glazing systems have been divided into two categories, passively activated and actively controlled. The passively activated technology are those that are sensitive to heat “thermochromic” and light “photochromic”. The actively controlled are electrochromic technology with the involvement of a small applied voltage (Selkowitz, 2001).

As for the large scale double envelope façades, it is the idea of adding another interior or exterior layer to the façade. It is a more costly approach yet provides a better reliable performance. Usually, the two façades are placed a distance away from each other providing an air gap in between. This is beneficial because it can provide natural ventilation from the outside without the use of mechanical systems. Also, they work as insulators to seize or reject heat (Selkowitz, 2001).

1.2 Façades

In building construction and architectural design, a façade is recognized as the most expensive component in a building. It costs from 15% to 40% of the construction budget. Technology has advanced the way facades behave; now they are lighter and even more transparent. In addition to that, facades became more of an isolated system that is not connected to the building’s structure, and that enables it to become more flexible (Beisi, 2007).

A curtain wall system used to be called an environment filter. It is a barrier separating controlled interior surroundings with variable exterior conditions; this definition is given in the 1950s (Castrillón, 2009). According to Trubiano (2013), building envelopes no longer act as separators yet they create spatial environments that involve the building’s engineering system as a whole. Around the 1990s, a new generation of facades is still used today. They come in different definitions. A Double Façade system is a glazed façade that is added to the original one for exterior noise reduction. A Double Skin Façade system is one that is composed of two glazed facades with an air barrier in between (Castrillón, 2009). Double skin facades are more expensive than single facades, yet on the long run, they are a better solution because they reduce energy by 30% and so lower costs (Beisi, 2007). Integrated Dynamic Facades emphasize control strategies on variables such as daylight control, ventilation, heating and temperature control (Castrillón, 2009).

1.3 The Situation in Jordan

Amman is the capital of Jordan, which is located in its northwest highlands. It has an elevation of about 800 to 100 meters above sea level. Amman is considered to have a Mediterranean climate and that means that it has hot and dry summers and cool winters. It snows occasionally and has an annual precipitation of about 250-480mm (Ray, Kirshen and Watkins, 2012). According to Tarawneh and Şen (2011), Jordan as a country is facing a lot of problems; alongside the fact that has limited water access, it is also facing industrialization, urbanization, and a rapid increase in population which all contribute to the massive amount of energy consumption. Not only that, but Abdelkader et al. (2010) add that people are living a certain quality of life that they cannot change, and this adds a bigger threat on energy consumption.

According to Al-Salaymeh (2006), the country of Jordan still depends on oil for its energy which is non-renewable. Abdelkader et al. (2010) add that after the Gulf war, oil prices have been increased. It is stated that Jordan in 2002; the share of solar energy in the total energy mix is 1.7%. It is expected that in the year 2007 that it would increase to 2.1%. In the year 2004, the Renewable Energy International Conference was held in Germany. Jordan's authority is told that in the next five coming years; 5% of its energy must come from renewable sources (Al-Salaymeh, 2006). Luckily for Jordan, it has vast amounts of wind energy since it's mountainous and solar energy with solar radiation of 300 days a year (Abdelkader et al., 2010). Since then until recently Jordan is working on the implementation of solar energy into new technologies to pursue the use of renewable energy for the upcoming future (Al-Salaymeh, 2006).

1.4 Motivation

A building façade has the most important part when addressing the energy consumption in a building. A façade, in general, is a building's envelope that doesn't exactly act this way; it is one of the building's constituents which contribute to heat loss in the winter and solar gain in the summer. The problem is to design a façade that requires the lowest amount of energy demands for lighting, heating, ventilation, and cooling while at the same time allowing the interference of the exterior weather. A dynamic façade in this condition is very beneficial since it provides both solar shading and insulation to respond to the user needs as adapt to the exterior environment (Johnsen and Winther, 2015).

It is already known that Jordan as a country is suffering from the decrease of energy and water, not only that but with the increase of refugee migration from nearby countries, this has put a struggle on the country even more. Since the year of 1961, the rate of urbanization has increased from 44% all the way to 83.6% in the year 2013. The problem resulting is the increase in the rate of inflation in urban centers, as well as the deficiency of the current services to accommodate this immense growth in population. Unfortunately, this created a lot of challenges on the county such as road congestion, overcrowding, degradation of agricultural land, and lack of greenery (Alnsour, 2016). The answer here is not to question or re-arrange the uncontrolled urban growth, but to look into solutions towards the impacts that this growth is affecting on the limited energy that Jordan has. As the random growth in population is wasting lots of energy, it is imperative to look at methods to save energy such as focusing on the construction industry in Jordan. According to Alnsour (2016), he also suggests that the urban strategy should involve the focus on building design and finding ways to reduce the energy and water consumption in relation to size, finishing, location, and ventilation of the building's characteristics.

Hammad, Ebaid and Al-Hyari (2014), state that in the previous 20 years, energy consumption has doubled in Jordan and is expected to stay like that until the year 2020. That is because as mentioned above the population is increasing and the demand for energy is growing. This scenario is urging Jordan to back sustainable development and improve energy efficiency.

The aim of this research is to introduce a new method to help in creating energy efficient buildings in Jordan. This technology has many names; one of them is defined as Dynamic Shading Devices and are incorporated mainly into the glazed facades of buildings.

The Bank of Housing building, it is the first to incorporate dynamic louvers under the brand name MechoShade in Amman (Badaweih, 2016). The aim here is to propose a more advanced and optimized solution towards the dynamic shading system than the one used in the Bank of Housing Building. The direction is to prove that the updated system saves up more energy than the recently incorporated one. This study will be performed through simulation where the base case will be the actual building modeled with the MechoShade louvers already installed, and different studies will be performed individually to obtain even more energy reductions. As mentioned above the simulation will take place under the weather of the city of Amman. The idea as a whole is not to focus on this building on particular; it is only a model where the experiment will take place on in order to tests the various variations that will be applied regarding dynamic facades.

1.5 Aims and Objectives

Around the globe especially in North America, studies on daily basis cover the issue regarding energy saving in architecture. In the Middle East, however; this is not the cause especially in a Third World Country such as Jordan. In addition to that, its climate is ideal when subjecting those studies towards energy saving because it has a dry and a hot summer.

Everyone knows how window shading behaves. A manual shading device such as static roller blind is usually operated by the person sitting next to the window in an office. The latter opens and closes it randomly depending on the glare or the temperature in the office regardless if it's a clear sky or a cloudy one. Unfortunately, this contributes to major energy waste, not only that but this is usually the case in most of Jordan. Only recently are sustainable projects being erected and green building codes are being established (Badaweih, 2016). Thus the introduction of having automated controlled blinds could be the first step towards major energy reduction in the field of architecture.

The Housing Bank is a major building in Amman that is recently being built. Its aim is to create a sustainable environment and reduce energy consumption. As mentioned earlier it is the first building in Amman to install automatic shading devices under the brand name of MechoShade (Badaweih, 2016).

The aim of this paper is to give a closer analytical look at this recently applied technology and try to find ways to optimize it even further. It focuses on the Housing Bank building in particular since it just installed the automatic shading device. The idea is to propose different scenarios for the behavior of the shades. For example, the studies will for focus on:

-Automatic Top Down Shades: and these are internal shading devices that maneuver from top to bottom like conventional roller shading devices. Their studies will focus on the understanding of energy saving, visual comfort and thermal satisfaction of the occupants.

-Automatic Bottom Up Shades: those are internal automatic shading devices that maneuver from bottom to top. They are ideal when tackling the glare conditions in the office (Kapsis et al., 2010).

-Manual Shading: The latter is essential when comparing to automatic shading in order to see which one saves more energy. The understanding will be based on how much will one benefit from automatic shading over manual, or is it not even worth it?

-Tinted Shading: This study focuses on the idea of removing the shades completely and substituting them with tinted shades of different visual transmittances. It might be not as ideal or energy saving as the application of actual shades; however, it sure it a cheaper approach that requires less maintenance.

The objectives however tend to focus on:

-Understanding how dynamic facades really behave and whether they are the best technology to apply or not.

-Understanding the pros and cons of dynamic systems in general.

-The idea of introducing various scenarios and configurations to understand the behavior of dynamic facades.

-Comparing energy consumptions based on the different configurations selected.

-Comparing through economic analysis the viability of the mentioned scenarios

1.6 Dissertation Outline

The dissertation is divided into seven chapters starting with Chapter 1 as a general introduction to the topic. It involves a basic overview concerning sustainability in relation to architecture and the definition of facades in buildings.

Chapter 2 is literature review which involves the study of previous research while asking questions and discussions about the presented work. In addition to that, it is essential to point out that the research gets narrower in this chapter which studies facades in a closer perspective and focuses on defining what intelligent buildings really are. This chapter intends to shine on the location where the thesis intends to focus on while presenting its climatic data and analyzing them. The chosen city will be the Capital of Jordan: Amman. In addition, light will be shined on the chosen building in this study, its geographical location, and some details about its construction. Finally, this chapter tends to tackle the aims behind the research and the objectives required to achieve those aims.

The research methodology is in Chapter 3. It involves the methodologies taken in previous studies, analyzing them, and then choosing which one to adapt in this particular research.

In Chapter 4, it focuses on the simulation of the model. First, it displays the base case that will be used in this research and then the parameters that will be applied along with their explanation.

Chapter 5 is results and discussions. This chapter tends to assess the data obtained from the previous chapter and illustrate them through tables and graphs. Then discussions will be carried out to analyze the outcomes of the study and to compare them with other studies in relation to this topic in particular.

Chapter 6 is the economic analysis which selects all the cases individually and assesses their cost in relation to the payback period. Their economic efficiencies will be compared to other and discussed.

Finally, Chapter 7 comes up with conclusions based on the studies made in the previous chapters and answers previous questions asked as well. In addition to that, it gives ideas on how to carry out future research in this field.

CHAPTER 2 : **LITERATURE REVIEW**

2.1 Introduction

Nowadays, the envelope is not part of the structural ensemble of a building. In fact, it is a separate skin that might only look as a closure element in a building; however, it ensures a larger responsibility. An envelope regulates the energy streams in relation to light transmission in controlling the interior illumination, heat, cold and it reduces solar radiation when the weather outside is too hot (Cimmino et al., 2016). In addition to that, an envelope is a critical fact that determines the aesthetic behavior of a building.

"The façade is a means of communicating a figure of prestige and power" (Johnsen and Winther, 2015, p.1569). Glass is a material that designers are using in facades since they are aesthetically pleasing, and offer transparency along with elegance and lightness in a building. A glass envelope in general increases the interaction not only between the inside and the outside but between the user and the exterior view as well (Johnsen and Winther, 2015).

Dynamic Facades play a very important role in reducing energy consumption in a building. In order to understand how they work, this chapter tends to identify and point out studies which are related to dynamic facades and intelligent buildings.

2.2 Daylighting

Daylighting is the use of exterior lighting to illuminate interior environments. In 1950 to 1960s, there is an extensive use of fluorescent lighting due to inexpensive electricity in buildings that any requirement for daylighting became unimportant. During the energy crisis in 1970 since energy costs increased, all eyes critiqued the glazed buildings. They emitted huge amounts of uncontrolled daylighting and that contributed to a major increase in cooling loads due to the major increase in solar gain (Heschong, 2002).

Building construction then focused on creating buildings with low ceilings and lower wall to volume ratios. Buildings that are older added dropped ceilings and insulating panels or tinted glass in order to minimize daylight. The aftermath of all of this was not very beneficial and here is why:

First of all, it is found that the use of electricity to light up a building involves more energy consumption than the cooling load offered from daylighting. The latter is more efficient than electric sources because it has more lumens per unit of heat measure. The trick is to manage the use of daylighting appropriately to obtain energy efficiency. Secondly, it is stated that a good amount of daylighting contribute to a better health and productivity for the users occupying a building. The increase in retail sales, better student well-being, and reduction of employee absence are regarded as benefits from the use of daylighting (Heschong, 2002).

2.3 Shading

Shading Devices are imperative if daylighting is present in a building. They help to introduce lighting as well as thermal comfort, and this is done by interrupting solar radiation particularly and by decreasing the unwanted glare inside a building. Most importantly, a shading device helps to reduce the overall energy consumption in a building if used appropriately (Khoroshiltseva, Slanzi and Poli, 2016). Kirimtat et al., (2016) on the other hand state that new buildings are mostly equipped with glazed facades in order to let in daylight and provide a nice view for the building’s occupiers. The risk here is the immense cooling and heating loads that are being consumed. This is when shading devices become an essential element that needs to be considered earlier on when designing a building.

There are several types of shading devices such as external roller shades, Venetian blinds, overhangs, and finally internal shading. Several studies have been performed on them, however, one must keep in mind that all of them serve the same aim, and this is to allow the penetration of direct sunlight and solar gains in the heating period, and preventing direct sunlight and reducing solar gain in a cooling period (Kirimtat et al., 2016).

Many characteristics need to be considered while choosing the best shading device type that suits a building such as a latitude, the projection of natural light, and the building type. In addition, one must consider the shape of the building and its orientation as well. The most suitable type of shading device must follow all of the above in addition to control the penetration of daylight; has a suitable cost, provides thermal comfort as well as visual comfort (Kirimtat et al., 2016).

A fixed shading device can be found on either exterior or interior side of a building. It is crucial to point out that fixed shading devices block daylight entity, prevent solar radiation in the summer, and increase the consumption of artificial lighting. With this said, one must bear in mind that shading devices behavior varies according to which climate they are mounted at. For example in a Mediterranean climate, it is advisable to apply fixed shades in south facades in buildings. They decrease thermal loads in winter period and reduce the strong daylight in the summer (Kirimtat et al., 2016).

Overhangs are surfaces that are mounted horizontally on the exterior top of a window. According to the sun's position and climate, the shape of the overhang must be designed to provide the maximum shade possible. In temperate climates for example, since the sun is higher in the summer than in the winter, overhangs are ideal. Here in the summer, the overhangs reduce solar heat gain and glare whilst in the winter, sun rays can be penetrated to heat a building (Kirimtat et al., 2016).

Horizontal Louvers are found on an exterior of a glazed façade in a building. Usually, louvers extend to a certain distance out to permit the low sun angle during the winter time and block it during the summer. The design of the louvers including their depth depends on the distance between each other, climate type, and the latitude of where the building is situated. It is advisable that louvers be painted a light color to reflect daylight inside the building. Vertical louvers, on the other hand, are ideal when placed on the western and eastern facades on a building. In the winter they act as a wind barrier too. Technology is integrated recently in vertical louvers to make them dynamic towards the sun's position through sensors (Kirimtat et al., 2016).

Speaking of dynamic shading devices, Venetian blinds are an example. They are usually used in commercial buildings and are used to adjust the light levels that are penetrated inside the building. They provide thermal comfort, visual comfort, and offer privacy as well. The factors which affect the design of the Venetian blinds are the solar tilt angle and angle of incidence. Usually, in commercial buildings, Venetian blinds are placed 2.5 cm away from the interior glazing, have a width of 2.5 cm as well. Under the same category of dynamic shades are the Venetian blinds. They are popular because of many reasons. For example, they come in different shapes and sizes, they are easy to install, and at the same time save energy whether they are automated or not (Kirimtat et al., 2016).

Finally, come to the roller shades, they are applied in residential buildings as well as commercial. They can be controlled either manually or automatically. Their benefit is that they can control daylight and at the same time reduce glare. Automatic roller shades have recently undergone a lot of scientific studies, and show that they are adequate in saving energy (Kirimtat et al., 2016).

According to Wankanapon and Mistrick (2011), studies are showing that roller shades especially when working under automatic systems save around 3% of CO_2 emissions when comparing them with manual roller shades. The latter provide poor daylighting and waste of energy with infrequent shading adjustments by the users.

2.4 Intelligent Buildings

Since the 1980s, the idea of intelligent buildings has emerged, until now, however, there is no specific definition of what intelligent building actually means. Many studies have set up a list of indexes and standards in order to evaluate the performance of an intelligent building.

At the beginning, intelligent buildings were defined to be related to building automation only without any user interaction. The Intelligent Building Institution in Washington (1988 in Wong, Li and Wang, 2005) define an intelligent building as one that combines several systems in order to conduct resources all parallel to each other to increase investment, the saving of operating costs, flexibility, and technical performance.

In the mid-1980s however, soon intelligent buildings which were seen as only technological were criticized. Authors such as Robathan (1994 in Wong, Li and Wang, 2005) saw that it is imperative for intelligent buildings to respond to the requirements of the building occupants. Furthermore, Clements-Croome (1997 in Wong, Li and Wang, 2005) argued that certain factors have great benefits towards the human well-being in a building and this is the close relationship between work process management and services systems. He claims that the building environment affects the productivity of the occupant inside the building and his mood.

Recently, however, the definition of intelligent buildings is branched out furthermore; now terms such as performance adjustment and learning ability are greatly looked at. An intelligent building must not only change to satisfy the user's needs but must also be able to learn and adjust its performance in terms of the environment and the building's occupancy. On the other hand, intelligent building definitions keep branching out and different authors come up with different definitions every day (Wong, Li and Wang, 2005).

According to Wong, Li, and Lai (2008) for instance, first, intelligent buildings must be both responsive and dynamic. They should provide a cost effective and operational environment by enhancing their four basic components and these are management, people, places, and process. A successful intelligent building is one that creates a harmony among these four components which will lead to an energy efficient friendly environment, safety, comfort, lower costs, and long-term flexibility. In a nutshell, a successful intelligent building is one that is known to have high values in terms of environment, economy, and sociability.

Perumal, Sulaiman and Leong (2013), define intelligent buildings in another manner. An intelligent building for them is when a building has an environment that tends to be controlled through automation and communication and at the same time suitable to perform through smart activities. It focuses on the comfort of its occupants yet by running basic operational costs.

Finally, according to J.K.W et al (2001 in Wong, Li and Wang, 2005), an accurate definition of an intelligent building is crucial. Without it, any upcoming building will not be designed optimally to meet the requirements of the next century.

2.5 Intelligent and Dynamic Facades

"An intelligent building envelope adapts itself to its environment by means of perception, reasoning, and action. This innate adaptiveness enables an intelligent building envelope to cope with new situations and solve problems that arise in its interaction with the environment" (Aschehoug et al, 2005, p2).

According to Aschehoug et al. (2005), they claim that intelligent facades, in general, have many specific definitions. Advanced facades, innovative, and high-performance facades are identified as better than conventional facades. Smart facades and Intelligent Facades basically mean the same thing; they are facades that work with computer-based controls. Active facades mean facades that are dynamic. Interactive façades are the same as dynamic facades, they both react to external situations and user commands.

Intelligent facades of a building are interpreted in five acts called double loop learning and these are sensory perception, mental model, assessment of information and feedback, strategic thinking, and implementation. In general, it is expected from an intelligent envelope to do three things and these are:

- To manage a changing environment.
- To manage a conflictive environment.
- To manage human behavior.

To explain these in more details, an intelligent building façade must adapt to altering situations in the environment taking into account that the latter is composed of three components. First, there is an indoor component located within the actual shell of the building, an outdoor one which is regarded as site and climate conditions, and the third component is the users of the building including their behavior and what they like and dislike.

Next, it is regarded that an intelligent building envelope must solve issues which arise from the interaction that occurs within the environment. That is why is it preferable that an intelligent envelope can manage equally the set of actions it is asked to do and never optimize on a task over the other. This might bring conflictions later on.

Finally, the acceptance of the building users is considered the most important when incorporating an intelligent façade in a building. Studies are imperative when determining the behavior of the users towards the intelligent system noting that their dissatisfaction can halt its operation or even disrupt it completely.

Intelligent Facades face many technical and architectural challenges in material use, composition, and, form. For instance in glazed facades; there are always conflictive demands of openness versus insulation, privacy versus transparency, solar shading versus daylight access. In a nutshell; the intelligent façade is supposed to consider all of these contradictions and handle them altogether (Aschehoug et al, 2005).

In the past when energy conservation was not clearly looked at, vast amounts of cooled and heated air were lost in commercial buildings, homes, and what not. The architectural design and energy were seen as totally separated things that behaved in isolation to one another. The architectural facades, for example, were designed in a way to optimize the operation of cooling, ventilation, heating, and lighting equipment. When the 1973 energy crisis occurred, architects and engineers thought that increasing the window to wall ratio by 100% in commercial buildings lessened the solar heat gain resulting from the transparent facades. What they did not know was that they were doing the exact opposite.

At the beginning of the 21^{st} century, the energy conservation phenomena are addressed. Architects and engineers finally understand that the building's façade and design must function hand in hand with the mechanical systems of a building. Natural ventilation, light transmission, and heat transfer are now analyzed, studied carefully and simulated to test their effect on the building's façade and equipment to maintain thermal comfort in a building

Dynamic facades are building envelopes that are precisely constructed to gather, examine, and answer to performance based feedback. Their data is analyzed instantaneously, to give feedback on how the exterior envelope is behaving. This alerts the engineer in case of modifications, redesign, and re-engaging its united systems. Usually, double skin facades are given the title of dynamic facades when they are able to monitor, lighting levels, air velocity, temperature, CO_2, and humidity through their voids.

Since dynamic facades tend to measure and compare the exterior environment to the performance of the envelope, it takes certain actions when the performance behaves less than expected. When the data is collected, it is compared to a particular benchmark; here the façade behaves in one of three actions. It can either signal an activation code to keep the system as is, or it can activate an associated component in the system to amend it and return it to its balance, or it adjusts the predicted performance in the future which is being monitored (Trubiano, 2013).

2.6 Previous Studies about Dynamic Facades

This section tends to explore other research papers that study dynamic shading devices into more detail. The objective is to understand how the approaches are perceived and what parameters are changed in order to create the maximum effect of energy efficiency. A comparison is performed amongst them and the best methodology will be mentioned and see what improvements can be done later on.

In the paper of Wankanapon and Mistrick (2011), they tend to focus on the effect of controlled shading and controlled lighting on heating, cooling, and electric lighting energy savings. The Base Case is an office with 3 m width, 4.6 m length, and 3.7 m height. The experiment is performed using the software EnergyPlus and Base Case is modeled taking into account that no lighting control is used or shading control. Not to mention that all orientations are considered and the experiment is performed for the day of July 15th only.

The control strategies that are taken into account are:

-At 95 W/m^2, the shades drop.

-At 189 W/m^2, the shades drop.

-At 400 W/m^2, the shades drop as shown in figure 2.1.

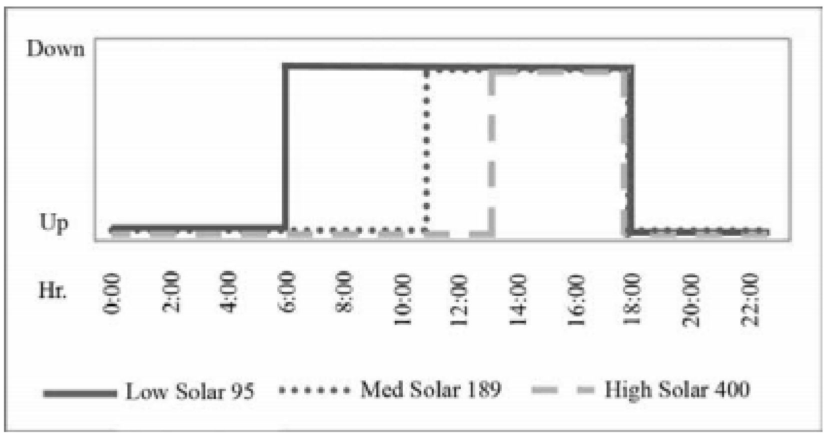


Figure 2.1: The period of time when the shades are lowered according to the control strategies (Wankanapon and Mistrick, 2011).

In addition to that, the lighting control sensor is considered to achieve 538 lux and provide a lighting power density of 9.89 W/m^2.

The experiment is performed in Minneapolis; a heated dominated region as a first scenario, with a white roller shade and a dark gray roller shade. For heating energy, the latter increased by 8 to 14% when both lighting control and shading are applied. Due to the increase in solar loads, it is found that the dark gray shading required less heating energy than the white shading. The maximum cooling energy saving is around 21% with the use of white shades at 189 W/m^2 as set point. The maximum lighting energy saving is around 76% at 400 W/m^2 set point and along the use of white shades. Total energy saving is 11% and occurred at set point 400 W/m^2 with the use of white roller shades.

When the experiment is performed in Huston which is a cooling dominated region; the cooling energy saving is around 13% and happened at 189 W/m^2 with the use of white shades. The maximum lighting energy saving is 81% at 400 W/m^2 with the use of white shades again. When lighting control is applied, the maximum saving occurred at 400 W/m^2, which is 36% when white shades are used.

As a conclusion, it is found out that for Houston climate, maximum energy efficiency occurred at 400 W/m^2 set point and with the use of white roller shades.

According to Kapsis et al., (2010); the aim is to incorporate the use of bottom-up motorized roller shades in an office space. The aim is to prove that the latter save up more energy than the conventional roller shades.

Through their studies, they came across the idea of a three section façade. That meant that the bottom part should be opaque, the middle area is for viewing hence a roller shade is installed, and the upper area must redirect the daylight deep into the space to provide daylight and eliminate glare. It is suggested that the top part of the glazing install a Venetian blind as well in order for the occupant to control the penetration of daylight. The roller shades are suggested for the middle part, hence to provide privacy for the user and reduce glare. Finally, in this paper, the three façade division concept is applied, yet this time with the roller shade installed in the middle part maneuvering from bottom to top instead of the other way around.

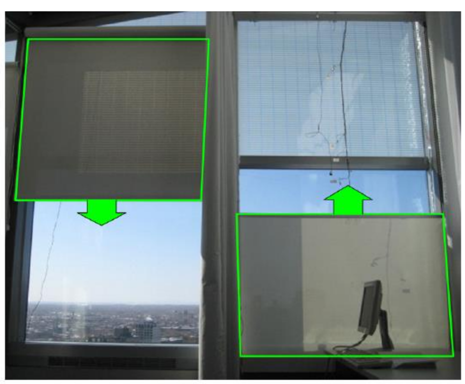


Figure 2.2: Conventional roller blind (left) and bottom up roller shade (right) ,(Kapsis et al. ,2010).

The experiment carried out involved a numerical model in studying the daylight performance of the bottom up shade. This is able to determine the distribution of daylight on the work plane. After that, Radiance through IES is used in order to calculate how many luminaries are needed to achieve a minimum lighting level of 500 lux. The experiment is done in regards to two control strategies, the conventional on/off method where lights turn completely off when illuminance levels are above 500 lux, and turn on when it's lower. Also, the dimming method where the lights are continuously dimming according to the illuminance levels inside the workplace.

Finally, the simulations are tested on real grounds in an office (1.5 m width, 3.2 m length, and 3.4 m height) located in Concordia University, Montreal, Canada. The façade is divided into three sections, an opaque 0.8 m at the bottom, 1.3 m clear glass in the middle, and 1.3 m fritted glass on top. The bottom up shade is mounted 30 cm away from the gazing.

The bottom up shade is white, has a visible transmittance of 18%, reflectance of 74% and its perforation percentage of 5%. Photometers are placed at distances 0.3 m, 0.8 m, 1.3 m, 1.8 m from the façade wall. After monitoring the results for a year, a comparison is performed between the daylight illuminance of the simulation and the experiment. The results are close to each other. A numerical approach and a parametric approach are performed in order to develop a control strategy for the bottom up shades. The aim is to create a Glare Free Zone (GFZ) in the entire room. Finally, the results utilized the three different transmittance values that are 0%, 5%, and 10%.

Transmittances of 10% showed the best performance with Daylight Autonomy DA higher than 0.7, yet this could increase the possibility of glare. That is why transmittance of 5% has the same value which is 0.7 at 2 m away from façade, yet starts to linearly decrease at later distances throughout the office reaching 0.47.

Another comparison is performed regarding the electrical consumption with the use of control dimming lighting strategies. When applying the on/off strategy, it is found that 10% transmittance consumed 47% less energy than 5% and 66% less than base case. When dimming is performed, 10% transmittance consumed 18% less than 5% transmittance and 69% less than base case. In general, dimming saved up around 32% of energy compared to on/off.

Finally, another comparison is performed keeping the same transmittances, yet comparing between an automatic bottom up shade and a conventional roller shade. The results showed that the daylight autonomy DA for automatic bottom up shade is 0.58 higher than conventional roller shade. Another comparison is performed between the two regarding electric lighting energy consumption. With the on/off strategy, automatic bottom up shades consumed 21% less energy than conventional roller shades and 41% when applying dimming control.

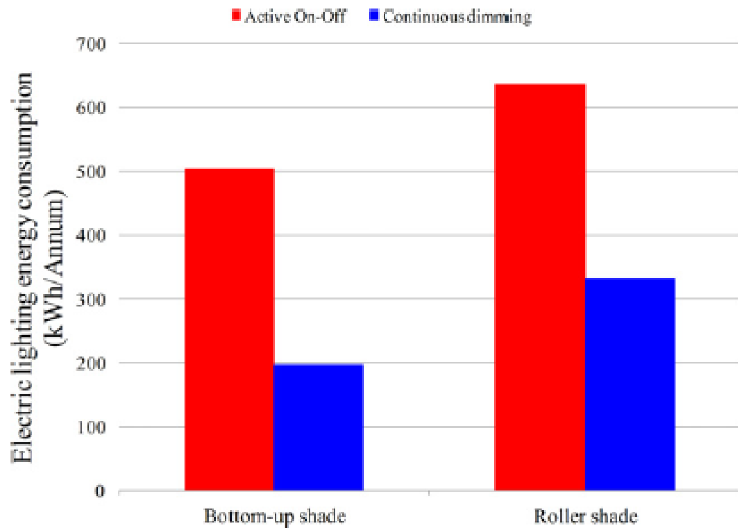


Figure 2.3: Electric energy consumption (Kapsis et al. ,2010)

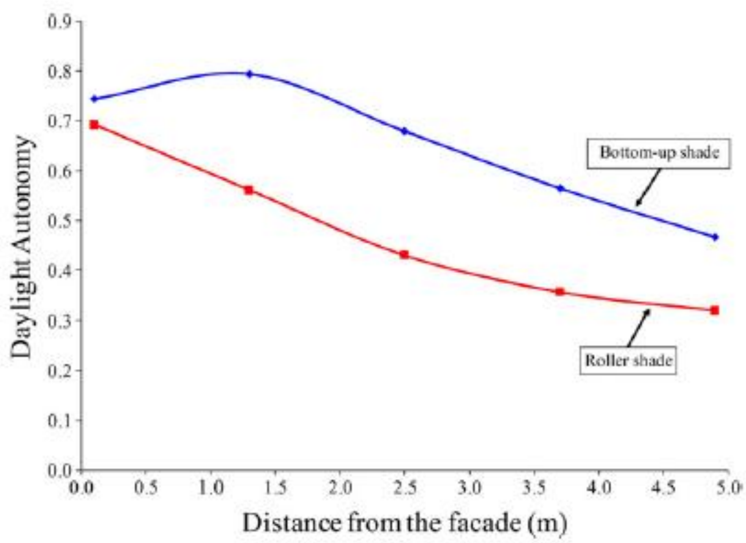


Figure 2.4: Daylight autonomy comparison (Kapsis et al. ,2010)

In another study done by Winther, F., Heiselberg, P., and Jensen, R. (2010), their paper focuses on simulation based on case studies. The aim of the paper is to investigate the effectiveness of a smart façade through the testing of energy storage, mass transport, heat transfer, and irradiation. Using a program known as BSim a comparison is performed assessing a static façade to a dynamic façade. Here the layout and the area of the façade are two parameters that remain constant throughout the study.

The chosen building has an area of 10 000 m^2, windows have a U-value of 1.5 W/m^2K, g value of 0.6, and ventilation unit has an SPF factor of 2.1 kJ/m^3. The total energy demand for this building is 96 kWh/m^2 per year. The first changes that are performed are the g value and U-value on the glazing and the use of smart artificial lighting; this managed to decrease energy consumption from 96 kWh/m^2 to 73 Wh/m^2 per year. Moreover, when applying dynamic facades, the insulating effect of the shutters reduces energy consumption from 96 kWh/m^2 to 76 kWh/m^2 per year. In terms of HVAC; through the combination of both decentralized ventilation and natural ventilation, the entire energy demand reduced from 70 kWh/m^2 to 51 kWh/m^2 per year because pressures on the ductwork are lessened. Finally, through the addition of smart lighting control systems, the total demand went from 51 kWh/m^2 to 40 kWh/m^2 per year.

This proves that dynamic façade deign is a huge contributor to the overall energy reduction of a building (Winther, F., Heiselberg, P., and Jensen, R.,2010).

In the case of using social surveys on the use of dynamic facades to test user satisfaction, Bakker et al. (2014), have done a good paper on this issue. A methodology is performed when 26 participants fill in a survey right after an experiment is performed for each one to test dynamic facades and their satisfaction towards it. The major factors that are incorporated are the visual performance and daylighting. The test is performed in a typical office room, with a glazed opening. An interior intelligent automated roller shade is installed. The constant factors in this experiment are the non-moveable furniture and the nice view to the outside. Sensors are positioned to monitor the daylight inside the office. The positions of the shades are recorded over time and the length of the test is 4.5 hours.

Figure 2.5: shades are fully opened (left). Lower shades are fixed (middle). Upper shades operating only (right) (Bakker et al, 2014).

Moreover, the automatic roller shades are composed of two individually operated shades, one from the bottom and one from the top as shown in the figure 2.5.

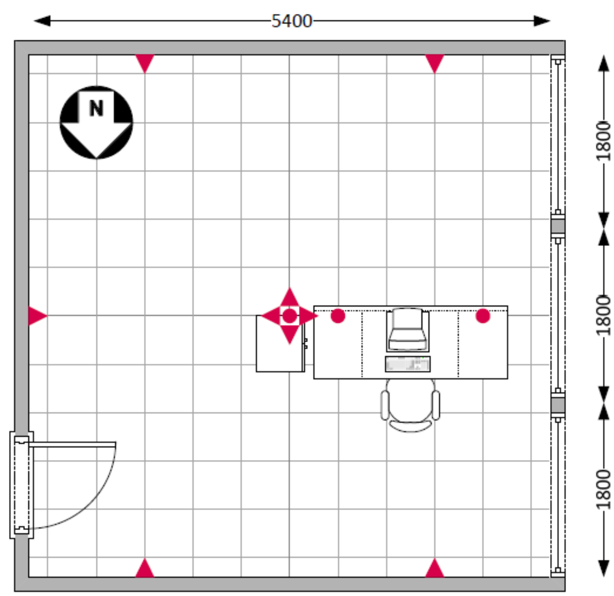


Figure 2.6: Furniture plan of the office space (Bakker et al., 2014)

Four scenarios are carried out in the experiment, all performed with the roller shades being automatic. In scenario 1, the roller shades move 20 cm every ten minutes. In scenario 2, the roller shades move a distance of 5 cm every 2 minutes. In scenario 3, the lower shades are fixed, while the top shade responds to avoid glare keeping the illuminance in the room between 500 to 2000 lux. In the final scenario, the lower shades are fixed and only the upper one moves a distance of 20 cm every ten minutes.

Finally, the people doing the experiment are asked to fill up questionnaires about their experience. 69% of them had a positive feedback on the office conditions operating under a dynamic façade while 31% preferred that they operate the shutters manually.

According to Yao (2014), an experiment through simulation and field measurement is performed to reduce the energy demand of a building in China through the use of external moveable solar shades. The building is six stories high and has an area of 2100 m^2. Field measurements are performed on particular days in the year and the rest is modeled through simulation. The modeled room is 4 x 4 x 3 m with a 100-300 lux illuminance level, composed of 240 mm brick wall, the southern window is 3 mm single pane, HVAC is running through the entire year with 18 degrees for heating and 26 degrees for cooling. All of these conditions are the base case for an energy non-efficient building.

In the case of solar shading, two cases are performed, one with the windows remaining open, and the other with windows containing operable shading controlled by the occupants. When deducting the solar transmittance, it fluctuated widely between 100 to 400 W/m^2 if shading is not used. When shading is used, it got reduced to 50 W/m^2 and became uniform as seen in the table below.

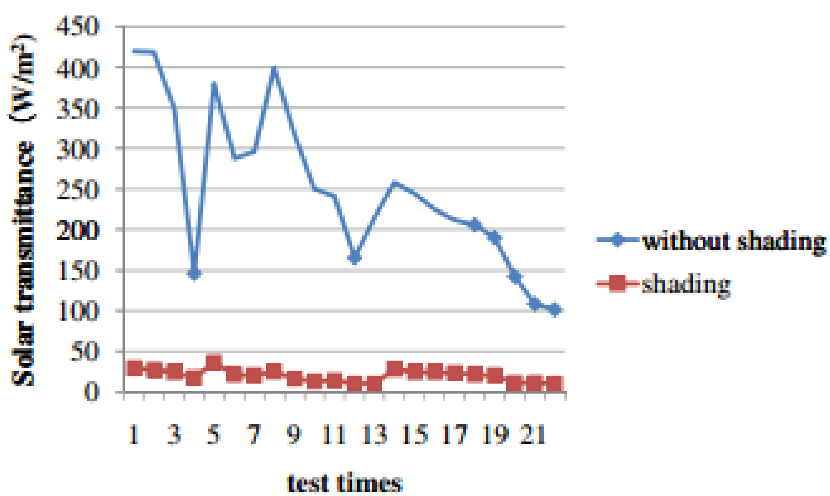


Figure 2.7: Solar Transmittance before and after shading (Yao, 2014)

When testing indoor illuminance to assess the condition of glare in the room; it is found that it is 10 000 lux near the windows when shades are not present, and this causes discomfort for the occupants. When shades are applied, it got reduced to 2000 lux. In the case of the dry bulb temperature inside the room, it got reduced from an average of 5 degrees in the summer and 0.8 degrees in the winter. Moreover, the annual energy performance is also tested when the shades are not applied and when they are. It is found that when shades are applied, there is a total cooling energy reduction of 35.96% and heating energy reduction of 24.23%. This is illustrated below.

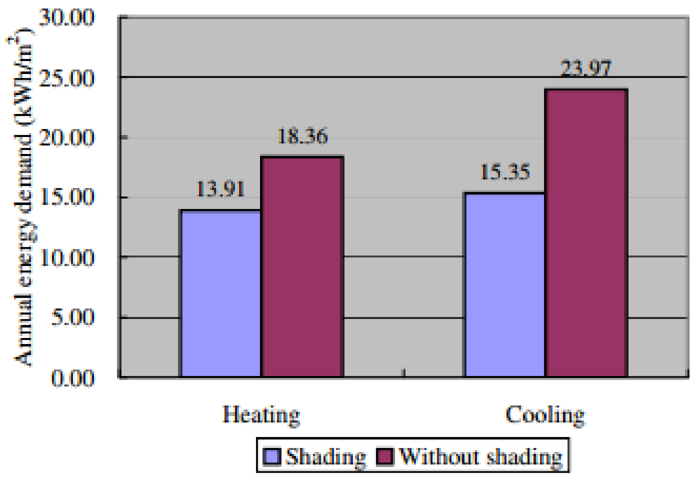


Figure 2.8: Annual Energy Performance (Yao, 2014)

Finally, to conclude, the field tests prove that the external dynamic solar shades reduce solar transmittance to around 8% when comparing them to windows with no available shading. Through building simulation, it is found out that dynamic shading saves energy by 30.87% and improves visual comfort by 19.9%. In a nutshell, dynamic solar shading has a great implication on energy, visual satisfaction, and indoor thermal comfort.

Tzempelikos and Shen (2013), have paid closer attention to the actual control strategies of the roller shades and their outcomes through four experiments. Before explaining this it is essential to point out the office space and its conditions. The latter has one exterior façade containing a 3 m by 1.6 m double clear glazed window that faces south with a window to wall ratio of 0.4. It has a U-value of 6.42 W/m^2. The interior roller shades' transmittance is 10%, their reflectance is 60% on the front and 30% on the back. The dimension of the office space is 4x4x3 m. The working hours are from 9 am to 5 pm. It is essential to point out that the lights are continuously dimmable in order to achieve a daylight illuminance of 500 lux. In addition, cooling and heating exist throughout the year. The office is located in Philadelphia.

The base case scenario is the no shading method. Here illuminance is more than 2000 lux for 86.5% of time and daylight autonomy reaches a maximum of 17.3%. Energy consumption for cooling and heating is 116.9 kWh/m^2 a year.

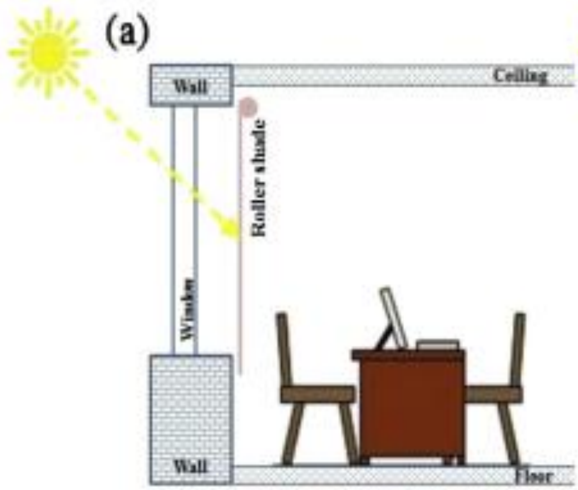


Figure 2.9: Shades close completely (left) and shades close to avoid direct sunlight (right) (Tzempelikos and Shen, 2013)

In the first control strategy known as SC-I, the shades are programmed to close completely when the incident beam radiation hits the façade. After doing calculations, the shades remain open 30% of working hours. Here the daylight autonomy reaches 54% and lighting demand per year of 17.6kWh/m^2. In this case, the heating demand per year is 34.4kWh/m^2 and cooling of 63.9kWh/m^2. This condition seems acceptable are a total energy consumption is 115.9kWh/m2 and daylighting illuminance ranging between 500 to 1000 lux.

In the second shading control strategy SC-II, the shades fully close yet this time when illuminance value reaches more than 2000 lux. When comparing the results with SC-I; there is less daylight autonomy in this method than SC-I and less view to the outside. Not only that but 5% more energy is consumed in terms of heating cooling, and lighting.

In the third shading control strategy SC-III, the shades do not close completely when sunlight hits the façade. On the other hand, they close through a control algorithm at a distance just to prevent direct sunlight from penetrating the working space and that is to maximize the use of daylight. In this case, the users have more view to the outside and enough daylight inside the office. To determine the shade position it follows this equation:

$$h = \frac{d}{\cos(\gamma)} \cdot \tan(\alpha)$$

Where d is the distance between the working area and window, γ is solar azimuth and α is solar altitude while h is the shade height. In this method, the daylight inside the space improves significantly reaching 89.2% yet there is still a risk of glare. Here the shades open for a longer time thus resulting in the higher cooling energy of about 56.1%. This means that the latter is 13.5% higher than SC-II and 11.6% higher than SC-I. On the other hand, the lighting energy used is less than the other methods resulting in more energy saving per year.

Due to the slight increase in the annual energy use found in the third strategy, the fourth strategy SC-IV is more developed and tends to reduce solar heat gain. Here the automatic shades behave the same way, however, they tend to close completely during cooling mode when the exterior solar heat gain resulting from solar radiation is higher than the internal solar heat gain. This method results in terms of annual lighting energy an increase 5.5 kWh/m^2 which is more than SC-III. In terms of cooling energy, however, energy use decreases to 3.6 kWh/m^2 a year when comparing it to SC-III as well.

In order to deduct which control method is best, it all depends on shading properties, the space orientation, the properties and size of the window, and the climate on which the experiment takes place. To obtain a conclusion, the experiment is performed via a case study to obtain a definite answer. In a nutshell, SC-II proved to be better than SC-II because it emitted reduced glare when comparing it to SC-I. SC-II is better than SC-I and SC-II in terms of energy saving yet has an increase in glare. SC-IV is the best however it will not perform well in hot climates because here the cooling load is a concern and will consume the greatest amount of energy.

According to Hammad and Abu-Hijleh (2010); their study focused on the idea of energy saving using an external dynamic louver system in the city of Abu Dhabi. The research performed is done through experimentation and simulation using IES-VE. The collection of the data is achieved over a time duration of 14 months. After carrying out the studies, it is found out that the major disadvantages of dynamic facades are their high costs and long duration.

The office building is modeled, taking into account that no heat transfer occurs outside the partition walls. The experiment will compare energy outcomes in relation to lighting and HVAC resulting through the different effects that the dynamic louver will create. The variables that will be changed within the experiment are:

-The position of the light dimming sensor: The later will measure the daylight inside the office space. It is also connected to luminaries to turn on artificial lighting to achieve the desired luminance.

-Glass shading coefficient: It is significant due to the fact that alters solar heat transmittance of glass. When the latter is changed, then this will cause change on the daylighting inside the office space and on the cooling load thus this will affect the dynamic louvers.

-Slat tilt angle of the louvers: These are important since they tend to affect the cooling loads and the daylighting. The horizontal louvers are assembled on the south facades while the vertical louvers are assembled on the east and west facades.

-Façade orientation: the later will be experimented on individually for each case.

-All the scenarios will experiment at working hour periods are four different times of the year.

For the base case, it is assumed that two desks are assembled in the office; HVAC is operating continuously maintaining a room temperature of 24 degrees. The luminance value inside the office is 500 lux. The experiment will take place at two different locations, one where the light dimming sensor is placed at 2m from the window, and one at 4m. Here when the daylight luminance level exceeds 500 lux, then the fluorescent lights will switch off, otherwise, they are always on. In addition, the U-value of the glazing is 1.95Wk/m^2. The shading coefficient, on the other hand, will be two values which are 0.41 and 0.746. The horizontal louvers are applied on the south façade while the vertical louvers are applied on the west and east facades. The main aim of this study is to find that best slat angle configuration of the louvers that maximizes and energy saving potential.

In order to carry on with the testing, two profiles are established, one which included the light dimming and one without. The latter suggests that the office lights are constantly on, yet the other profile the lights adjust to 500 lux in combination with artificial and natural lighting. This explains that when the level is more than 500 lux, then the artificial lighting switches off. In order to simulate dynamic louvers, the external louvers are modeled at different slat angles that varied among -80°, -60°, -40°, -20°,0°, 20°, 40°, 60°, and 80°. Each angle will; be tested individually. More than 220 angle configurations are obtained. The table below shows a summary of the results for the southern façade where X=2 and SC=0.41. As shown, the optimum energy saving tilt angle is -20°, here the saving reached 31.36%. The experiment is repeated several times with the south façade having X=4 and SC=0.41, also with X=2 and SC=0.746. The same conditions are tested for the western and eastern facades.

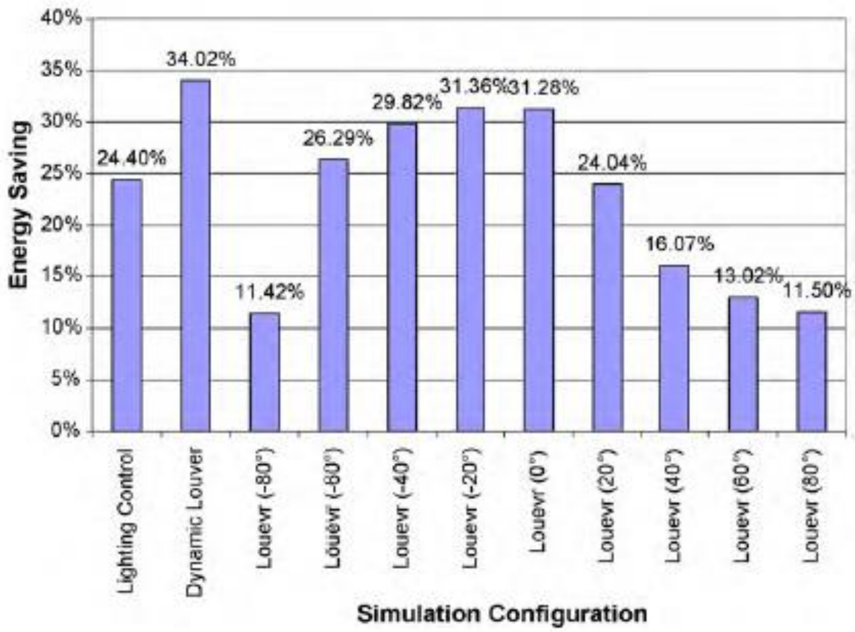


Figure 2.10: Energy savings obtained for different slat angle configurations for the southern façade (Hammad and Abu-Hijleh, 2010)

As observed from the previous researches mentioned above, dynamic louvers are very significant in energy saving. Wankanapon and Mistrick (2011), found out that the application of an automated white shading device helped reduce electrical energy consumption, glare, and cooling/heating demands for two different cities with contrasting weathers. Kapsis et al., (2010), found out that the use of bottom-up automatic shading device consume 21% less energy than conventional roller shades. Winther, F., Heiselberg, P., and Jensen, R. (2010), found out that dynamic facades help reduce energy consumption from 51 kWh/m^2 to 40 kWh/m^2 per year. When testing people’s comfort in relation to dynamic louvers according to the study done by Bakker et al. (2014); 69% of the users are in favor of this new technology. In the case of Yao (2014), he found out that shading in general whether automated or manual help in saving energy by 30.87%. Tzempelikos and Shen (2013) concentrated more on the actual control strategies performed by the automated louvers. They found out that method SC-III and SC-IV are the best in the case of energy savings yet one outperforms the other in terms of glare and cooling loads. Finally, as for Hammad and Abu-Hijleh (2010), they deducted that for each orientation there is an optimum angle that tends to work best in energy saving performance for each case.

2.7 Climate in Amman

The weather in Amman during the day in the summer are usually hot and dry. In the evening, it becomes cool. In the winter through December and January, the temperature reaches as low as 10° C and sometimes it snows. Rainfall‘s annual figure is 25 mm and falls between November and March only (Holiday-weather.com, 2017). Figures 10 to 14 show the climate in Amman throughout the year:

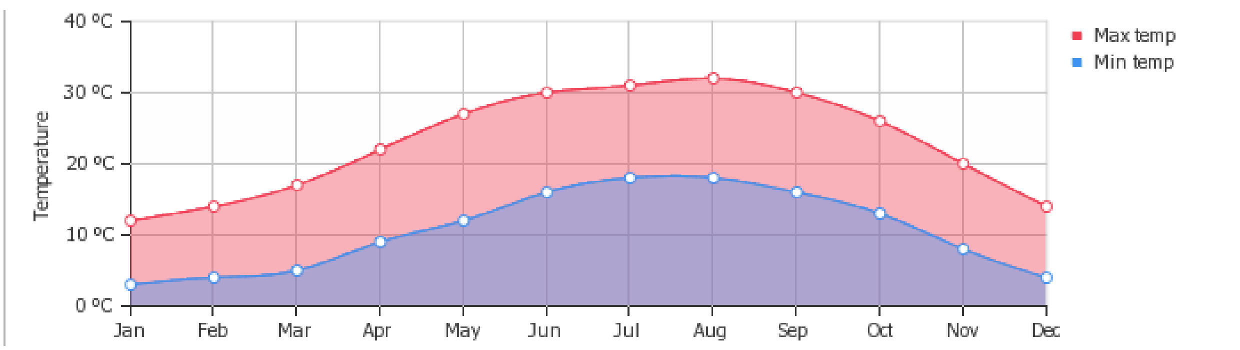


Figure 2.11: Average maximum and minimum temperature in Amman (Holiday-weather, 2017)

As observed, maximum dry bulb temperature is highest in August reaching above 30° C with a lowest of 18° C. In January however, lowest dry bulb temperature is 4° C with a highest of 12° C.

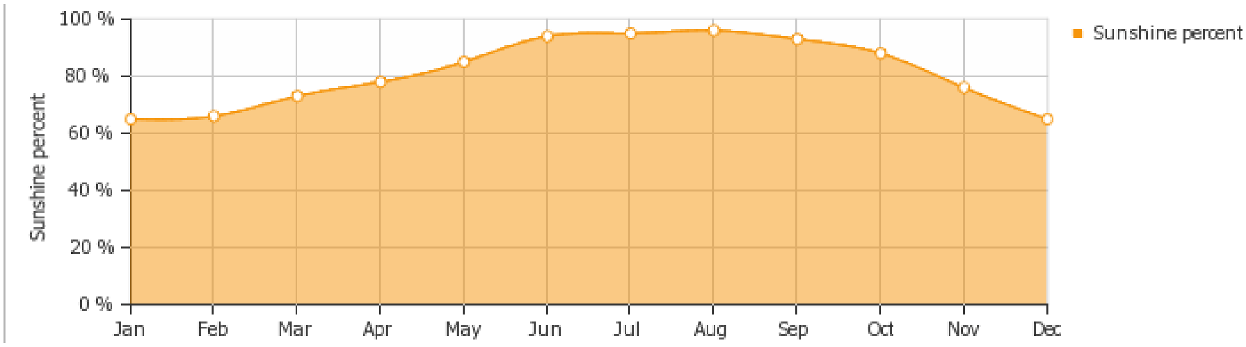


Figure 2.12: Average sunshine in Amman (Holiday-weather, 2017)

Sunshine percentage throughout the year falls greatest between June and September reaching around 80% to 90%. Lowest amount is in December reaching 62% only.

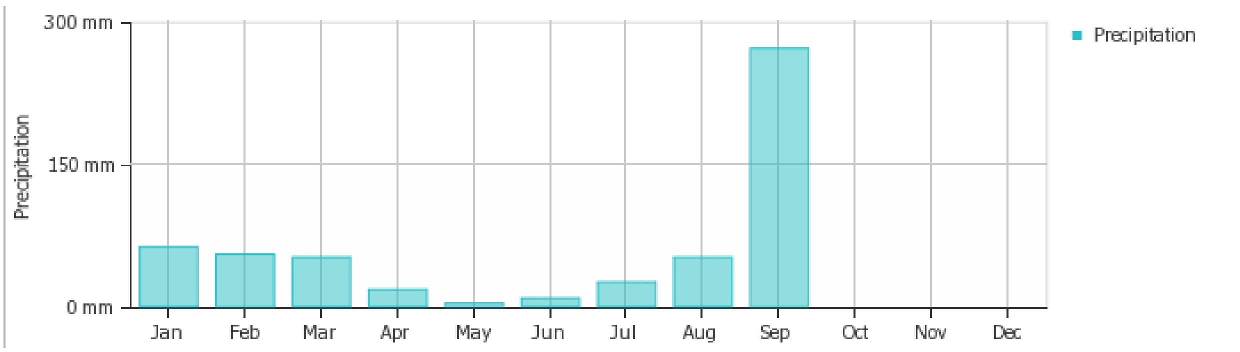


Figure 2.13: Average precipitation in Amman (Holiday-weather, 2017)

In the case of precipitation, the maximum average amount is in September reaching above 225 mm. The lowest amount of precipitation reaches as low as 0 mm in October, November, and December.

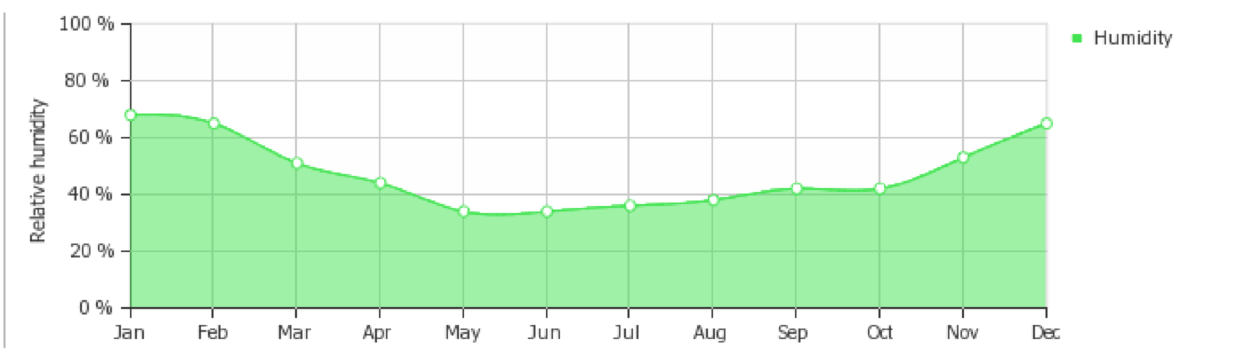


Figure 2.14: Average humidity in Amman (Holiday-weather, 2017)

The relative humidity in Amman reaches a maximum of 68% in January and a minimum of 38% in May. This explains that Amman has mostly a dry climate.

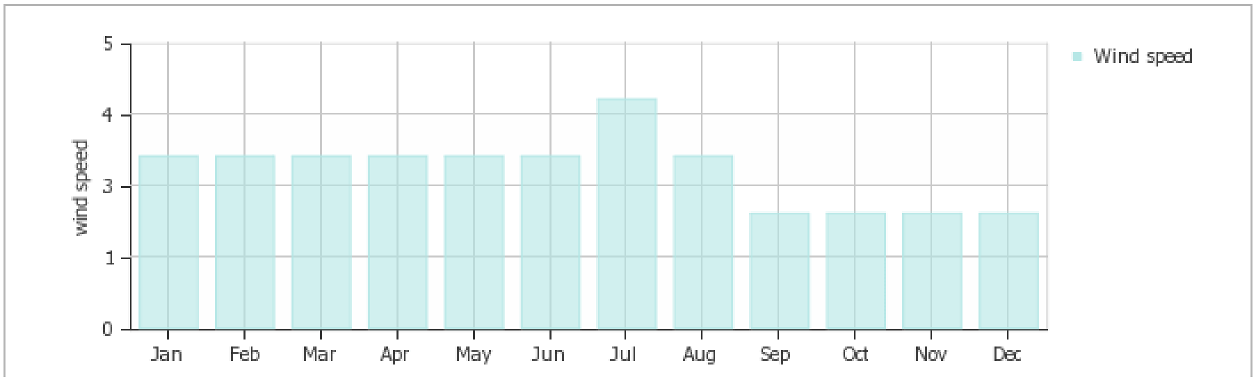


Figure 2.15: Average wind speed in Amman (Holiday-weather, 2017)

The wind speed is mostly constant between January and June reaching around 2.5 m/s. In June it reaches a maximum of 3.2 m/s and between September and December a low of 1.6 m/s (Holiday-weather.com, 2017).

2.8 The Housing Bank of Trade and Finance

Figure 2.16: The bank’s original headquarters in Shmesani, Amman (almosafr.com)

The Housing Bank of Trade and Finance was established in 1973 and is one of the biggest banks in Jordan and the first to obtain ISO in the Middle East. It has 129 branches.

When the bank was first established in 1973, it was a public shareholding company (PSC). After 24 years, it underwent a transformation to become a full-fledged commercial bank with an increased capital of 100 million JOD in 1997. In 2006, the increased capital reached 252 million JOD.

The Housing Bank of Trade and Finance had a lot of accomplishments. It was the biggest retail bank in Jordan, offering a wide variety of services for its dedicated customers. It has the biggest number of branches in Jordan. It has the largest number of ATM machines and is involved eagerly in e-banking. In 2005, it received the platinum Business Initiative Directors award. In addition to that; since the year 200, it kept receiving awards. It was one of the first banks of Jordan to involve children banking as well (Ar.wikipedia.org, 2017).

CHAPTER 3 : **METHODOLOGY**

3.1 Previous Methodologies carried out in Different Studies

In this section, a couple of previous research are mentioned in order to show what kind of methodologies they used. This would provide some guidance as to what type of methodology must be used in this paper with its pros and cons.

3.11 Studies based on Simulation

Wankanapon and Mistrick (2011) considered using a simulation only approach by Energy Plus as a methodology in their studies. An office with particular dimensions is modeled, and two different types (white and dark gray) of roller blinds are modeled. They idea is that they blinds would descend at three different set points automatically according to the office indoor illumination. The target is the study of how automatic roller blinds affect energy consumption in a building in relation to heating/cooling, electricity consumption, and lighting levels. The experiment is set to study these outcomes yet when the office is located in Minneapolis and Huston, two cities with completely different climates.

Winther, F., Heiselberg, P., and Jensen, R. (2010) applied the only simulation to test the effect of dynamic facades in comparison with static facades using a program known as BSim.

Tzempelikos and Shen (2013), decided to perform their experimentation through simulation. The study focused on the effect of roller shading on the energy consumption of a building. Dimmable lighting existed throughout the whole experiment to obtain a minimum of 500 lux in the office space. Four scenarios took place with the automated shading programmed to either close completely or close partially depending on variously given parameters. Numerical studies are also performed in order to create the algorithm for the shades to behave in considering their sensitivity towards lighting levels and solar heat gain

Hammad and Abu-Hijleh (2010), studied the effect of dynamic external shading louver system based on energy consumption in a building in Abu Dhabi. The study is performed only through simulation using IES-VE while choosing only four days of the year on which results will be obtained. The later took place considering various parameters such as the position of the light sensor, façade orientation, slat tilt angle of the louvers, and glass shading coefficient.

3.12 Studies based on Combined Methodologies

In Kapsis et al., (2010), they wanted to see the effect of bottom up shades in regard to energy efficiency when comparing them with conventional **non-automatic** roller shades. In their paper, their methodology involved literature review at first to study they division of the indoor façade in relation to glare. After that, a numerical study is performed through IES VE in order to find the daylight distribution on the work plane and to introduce sensors in order to control lighting through dimming. That is done in order to compare these results to the actual experiment that took place in Concordia University, Montreal, Canada. Actual roller blinds are mounted in one of the offices from bottom to top. The results of the actual experiment are compared to the simulation in order to approve the results.

Yao (2014), preferred to perform an experiment through both simulation and field measurement. For the field measurement, however, a room in a building in China is where the experiment took place at different days throughout the year. The test is intended to see the effect of moveable roller shades on energy efficiency in a building.

3.13 Studies based on Social Surveys

Bakker et al. (2014), tried to see the effect that daylight and glare would influence the users inside the office when automatic shades are applied. Both types of automatic shading are used including top down and bottom up. A number of users took that experiment while sitting on a desk and performing their usual work on a computer. Next, they are asked to fill up a survey in a form of a questionnaire for their point of view and productivity in relation to glare and daylight throughout their working hours.

3.2 Chosen Methodology for this Paper

From the mentioned experiments above, the most convenient strategy to use for this dissertation would be literature review and simulation.

Automatic shading devices need an accurate method in order to predict their behavior. Not to mention that they need a constant way of observation to predict the sun's movement, and collect lighting levels. In addition, simulation approach allows the user to creatively model his case study regardless of its size, shape, or design. This is a much cheaper approach than doing an actual prototype.

The chosen city to carry out the experiment is Amman; observing its weather files through a computer program will reduce the chances of error that might take place if they are performed on site.

Various scenarios take place that needs to be modeled and remodeled in a precise manner each time. Performing these alterations via software lessens abundantly the time at which the experiment takes place; especially since four different days are chosen through the year at different months to monitor the experiment. In addition to that, one can perform several simulations and record results at all at the same time on one device.

As observed from previous studies, field measurements and actual prototype experiments are always accompanied by simulation tools first. There is always a chance of error that needs to be authenticated through simulation. In addition to that, field measurements and prototype experiments are time-consuming, expensive to create, and produces limited results. In the case of literature review, it is always imperative to use it as a methodology; because one has to perform a background research on his chosen topic before actually testing it. The idea it to develop the area of study based on other research and previous work done in the past. That is not only the case, however; literature review has to be accompanied by another means of methodology in order to show actual results of what one can do.

3.3 Chosen Software Tool

The chosen software tool for the simulation process would be IES-VE. According to Crawley et al. (2008), IES VE is a platform that joins all the application together. The modules usually are:

ModelIT: Involves modeling the project.

ApacheCalc: Provides an analysis of the energy loads.

ApacheSim: Focuses on thermal behavior.

MacroFlo: Studies the effect of natural ventilation.

Apache HVAC: Treats HVAC as a component.

Sun Cast: Provides a shading analysis and observation.

MicroFlo: Is the computation of fluid dynamics in 3D.

FlucsPro/Radiance: Focuses on the design of lighting.

DEFT: Is the optimization of the model.

LifeCycle: Is the energy and cost analysis.

Simulex: Studies the evacuation routes inside a building.

IES VE is detailed software that evaluates the building design and system in a sophisticated manner. It considered all of the optimization with the account of comfort and energy consumption.

The table below gives an overview of the behavior of each of the software tools mentioned by Crawley et al. (2008) and compares them in regards to daylighting and the exterior envelops of a building.

Table 2 ***Building Envelope, Daylighting and Solar*** (9 of the 52 rows from Table 3 in the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Outside surface convection algorithm																				
▪ BLAST/TARP	X								X										X	
▪ DOE-2				X					X	X									X	
▪ MoWiTT									X		X								X	
▪ ASHRAE simple	X					X		X	X				X		X			X	X	
▪ Ito, Kimura, and Oka correlation											X	X								
▪ User-selectable			X						X		X	X	X			X		X	X	X
Inside radiation view factors		X	X						X		X	X	X				P	X		
Radiation-to-air component separate from detailed convection (exterior)		X	X						X	X	X	X	X				X	X	P	X
Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings		P			X				X		X		X			P				X

Figure 3.1: Illustrating a comparison of software tools in regard to daylighting (Crawley et al., 2008).

As observed, the major factors that will be monitored are daylighting and solar gain. In that case, the table shows that the latter are already present in IES VE to measure. In a nutshell, IES VE fits perfectly all the intended factors that are wished to be studied and carried out during the simulation of this dissertation in particular.

The limitation or threats that one can come across when choosing simulation are:

- Obtaining the software license: This can be solved by paying the desired amount on IES VE website and identifying oneself as a student.
- Freezing of the computer device: That is the way the simulation, results, and analyses must always have an external backup device.
- Inaccurate weather files: One must double check the obtained weather files with actual data.
- Limitations of the user to use IES VE because of his lack of knowledge about the program: That can be solved by attending tutorials, viewing tutorial videos, research, and asking people who actually know.

3.4 Introducing the Parameters

A typical office of the Housing Bank is chosen and will be used for the entire research. In order to carry on with the experiment, various variables will be altered in order to create a strong comparison among the cases. The major outcome of this study will be energy efficiency. The parameters of this study are:

-The addition of lighting sensors: The latter are added at different shading scenarios to introduce the idea of dimmable lighting. They measure the light in the space and are directly connected to the luminaries in order to achieve a particular and acceptable lighting level in the office.

-Manual shading: That will be altered only once a day by the building user either completely open or completely closed.

-Automatic Top Down Shading: This will be altered at different shading positions throughout the day according to the light levels inside the office space.

-Automatic Bottom Up Shading: The roller shade will move from bottom to top at different positions throughout the day according to the light levels inside the office space.

-Tinted Glazing: Two scenarios will be studies here having the glazing with the highest visual transmittance at the bottom and decreasing gradually to the top. The second scenario involves the opposite ensemble.

CHAPTER 4 : BUILDING THE SIMULATION MODEL

4.1 Introduction

As a start, the Housing Bank building will be looked at in more details and analyzed right before simulation. The building is currently under construction and is located on Prince Shaker bin Zeid Street in Shmesani area, Amman (Badaweih, 2016). The building is chosen for simulation because it is the first building in Amman to incorporate dynamic shading devices. It is a phenomenal project as well and hosts one of the most important banks in Jordan. It is a modern construction located in an area that was once one of Amman's trendiest spots, now however it has authentic residential buildings and offices (Badaweih, 2016).

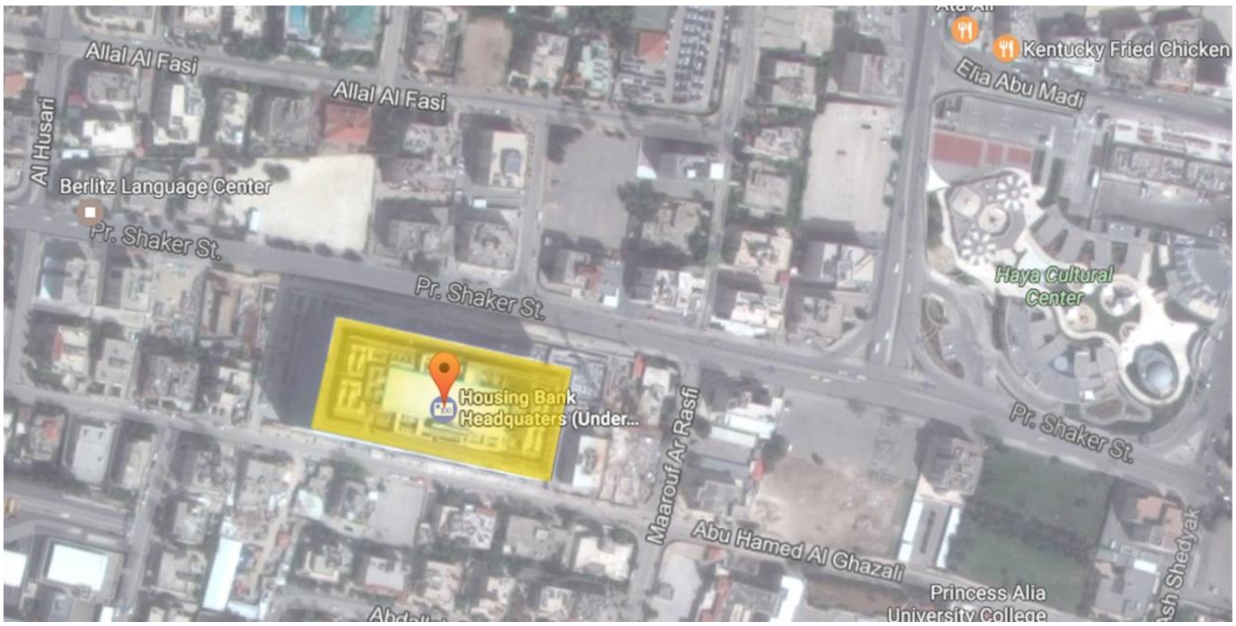


Figure 4.1: Site plan of the building (google.ae, 2017).

The Housing Bank building is composed of 4 lower levels, seven floors above ground, and a roof. The building's height is 33.64 m. Its total built up area is 78737.61 m.

Figure 4.2: Renderings (wikimapia.org, 2017)

The bank is currently under construction as mentioned earlier. Figure 4.2 shows the renderings of the new building.

Figures 4.3 and 4.7 identify the floor plan and a section of the building in order to give a general overview of how the building is constructed.

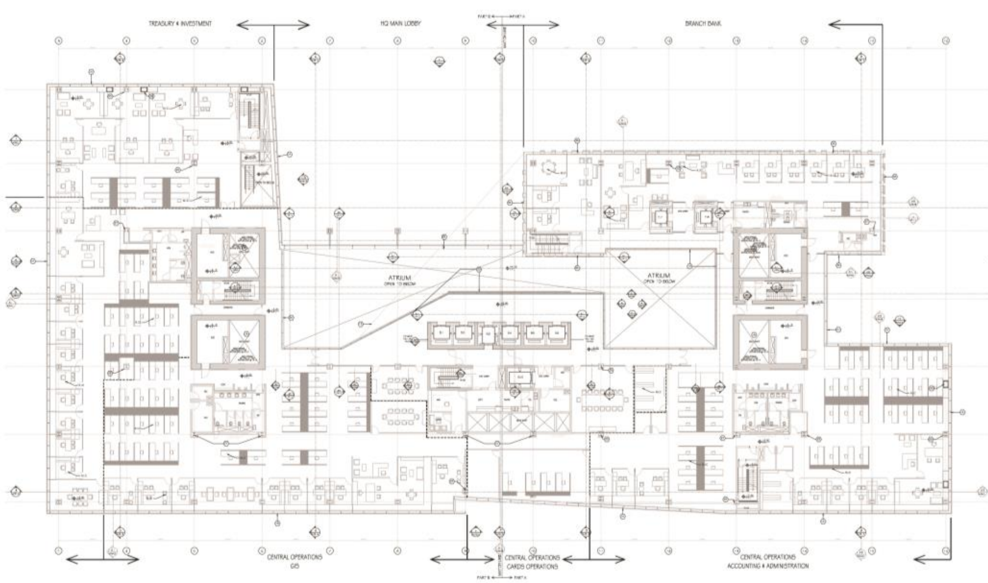


Figure 4.3: First Floor Scale 1:100

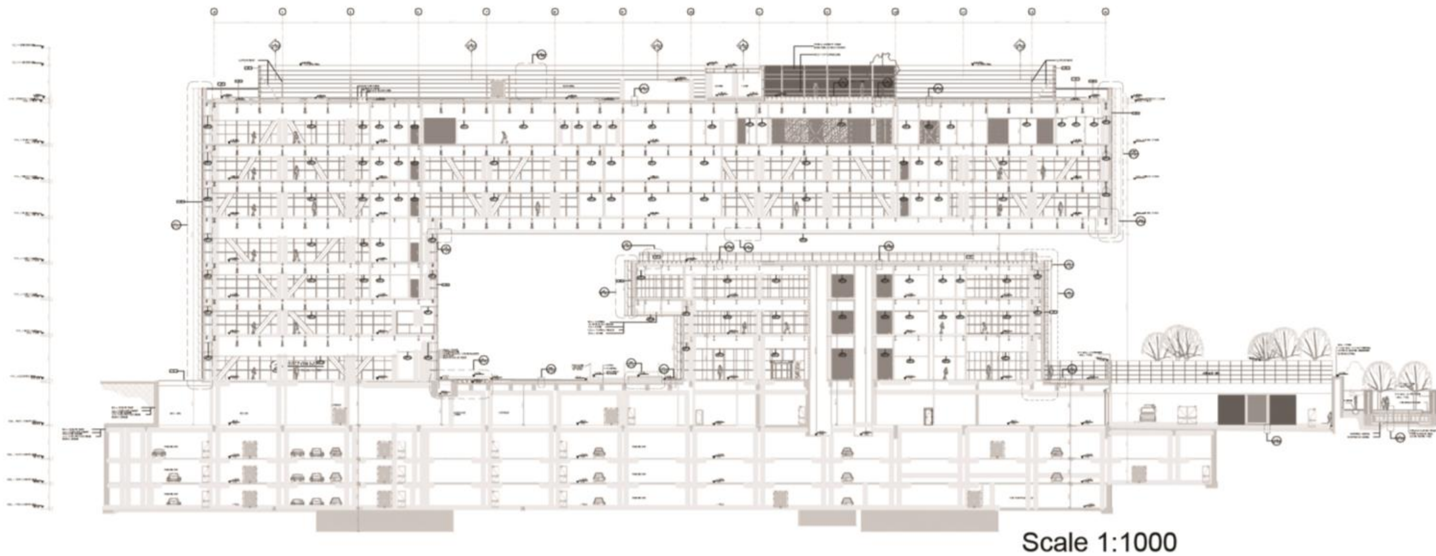


Figure 4.4: Longitudinal Section 2-2

4.2 Mechoshade operated by SolarTrac system

Mechoshade is the brand name for the already installed automatic roller shades inside the Housing Bank building. SolarTrac, on the other hand, is the computer program assigned to control the automatic behavior of the shades. The system is designed to track the position of the sun in order to reduce solar heat gain, glare, and increased brightness. It helps in increasing natural light, thus decreasing artificial lighting use and cost. It reduces air conditioning by reducing solar heat gain, and finally renders a suitable environment through the reduction of glare (Anon, 2017).

The automatic roller shades are programmed to close when the sun rays hit the windows directly and to rise when the window is in shade. It is claimed that the latter saves up 70% lighting costs when installing (Anon, 2017).

The system is already installed in the New York Times headquarters as shown in the figure below. As a case study, the latter is designed by Renzo Piano. By monitoring the shades behavior after installation, they saved up 50% to 60% in lighting costs (Anon, 2017).

Figure 4.5: Cafeteria of the New York Times Headquarters with MechoShades (gettfigures.ae, 2017)

The system of MechoShade is programmed to calculate in each zone of the building the sun's angle on the window. In order to do this, the elevation of the window, solar orientation, profile, and geometry are all taken into account even fins and overhangs. The program helps to adjust the position of the shade at a specified point on the window to block direct sunlight. Radiometers are installed over the roof of the building throughout the year to gather information and then subjected to a computer algorithm through software (Anon, 2017).

4.3 Actual Built Project

Initially, to start with the project, the simulation must comply with the results and work performed by MechoShades regarding the Bank of Housing Building in order to establish a Base Case. Everything that is simulated matches exactly the building properties and materials of the exact project on site.

The building itself is divided into eight zones as displayed below by the engineers already working on the project in order to add the automatic blinds.

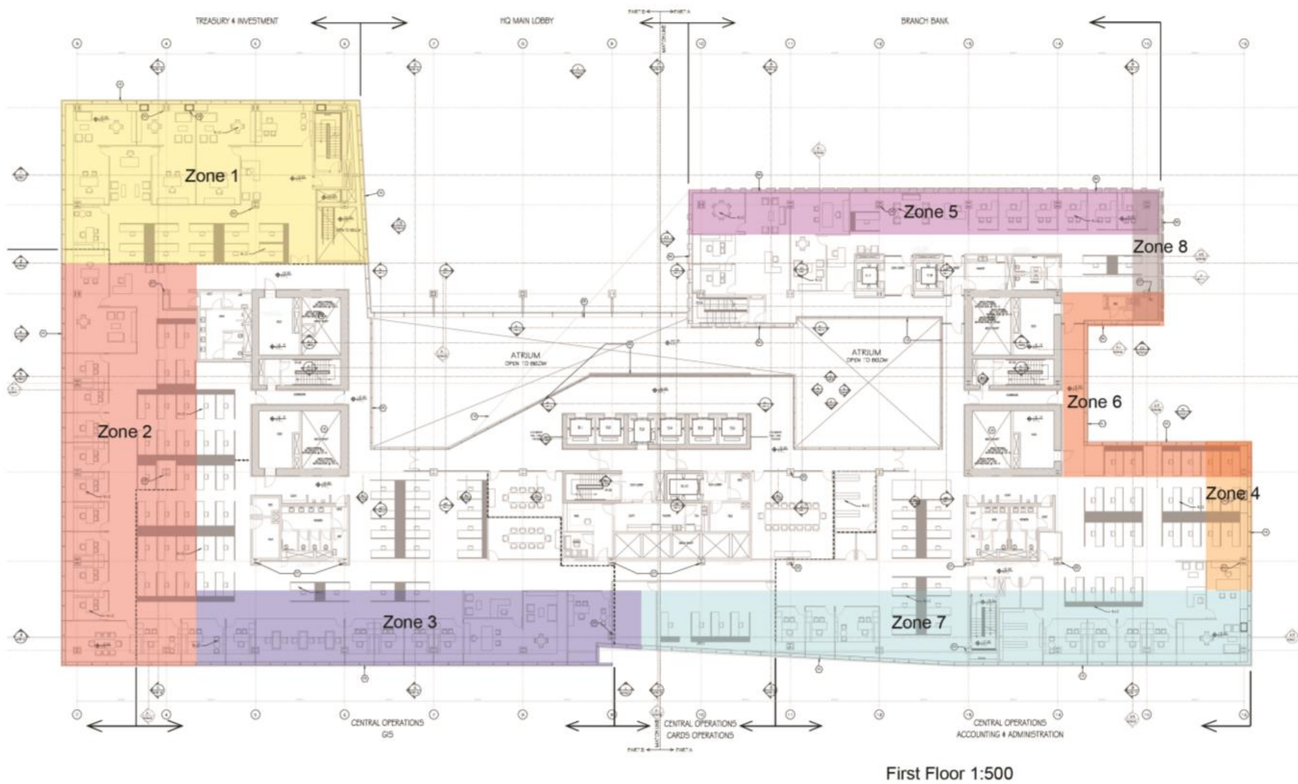


Figure 4.6: Illustrating plan of the first floor with zoning.

One needs to remind that the chosen office is located in Amman, Jordan and is affected by all the climate changes and weather conditions in Amman.

One room is chosen by the author in order to perform the study upon. It is a 3 m width, by 4.7 m length, by 4.8 m height office situated on the first floor. It is located in zone 7 and is on the Southern façade. The room is simulated as a model as observed below in figure 4.10.

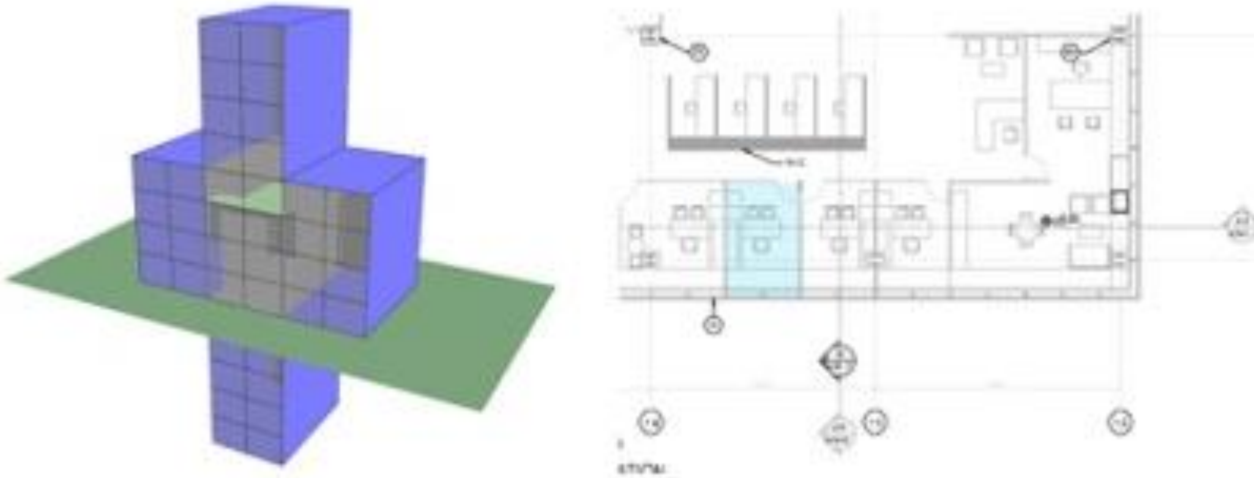


Figure 4.7: Showing the southern model (left) and the chosen office plan (right).

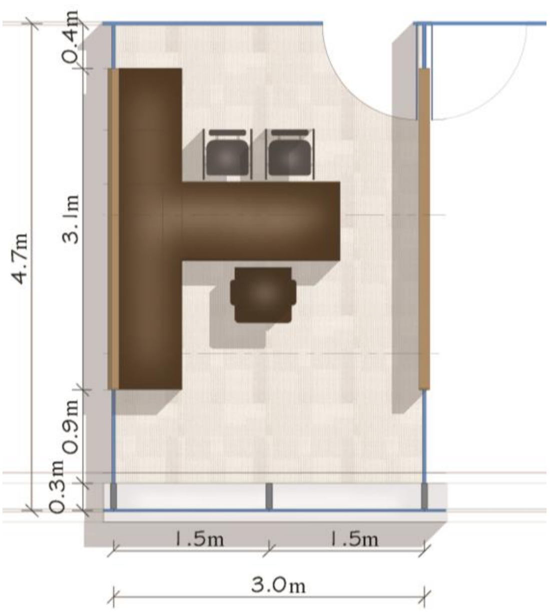


Figure 4.8: Office plan 1:2000

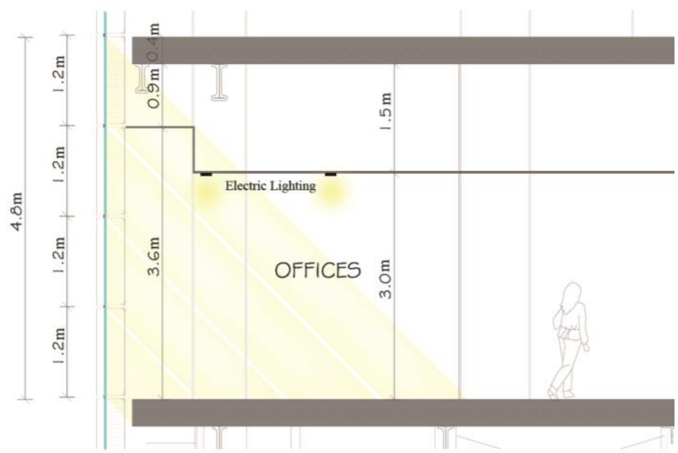


Figure 4.9: Office Section 1:2000

As seen from figures 4.11 and 4.12; the glazing panels have a dimension of 3 m in width with a height of 1.2 m. That means that the window opening is divided into four glazing panels in height and two in width having a total of eight panels. It is assumed the opening is flush with the exterior façade.

As a start, the base case had to be established. In order to do that the author's simulation results must be close to the results performed by MechoShades. The comparisons are regarding solar altitudes, solar azimuth, and solar heat gains with shading and without.

4.4 Construction Material Used

The simulation model is designed to match a portion of the exact building on the site. That is why it is modeled with the same construction materials on IES VE. The table below shows a summary of the entire basic construction material database that is used on the simulated model only.

Table 4.1: Construction materials used in the simulation

	Material Used	Thickness(m)	Density(kg/m^2)	Conductivity(W/mK)	Category	U value (W/m^{2}K)
Internal Partitions	Gypsum Plasterboard	150	950	0.1600	Plaster	0.7129
	Cavity	13	-	-	-	
	Timber Board	19	650	0.1650	Timber	
Internal Ceiling/Flooring	Cast Concrete	200	2100	1.4000	Concrete	1.6429
	Lightweight Concrete	60	1200	2.3076	Concrete	
	Screed	30	1200	0.4100	Screeds and Renders	
	Synthetic Carpet	10	160	0.0600	Carpets	
	Material	Thickness(m)	Transmittance	Visible Light Normal Transmittance	Inside Reflectance	U-Value
Glazing	Clear Float	4	0.820	0.44	0.070	5.7546

4.5 Establishing the Base Case with Validation of the Model

In order to model the base case, a thorough investigation is performed on the actual building through the company MechoShades who have studied the solar gain, solar azimuth, solar altitude and other factors on the actual building for working hours from 8:00 am till 3:00 pm. Only two factors are chosen in order to match them with the simulation of the base case and these are solar gain and solar azimuth with blinds and without for the 21st of December.

Figure 4.13 and table 4.2 show a comparison of solar heat gain when the blinds are not present corresponding to the simulation and MechSahde results. As observed the difference is calculated as a percentage and the minimum reaches 6% with a maximum variation of 33% at the end of the day. Figure 4.14 and table 4.3 show the solar heat gain collected when the blinds are present and automatic per hour. The maximum variation between MechShade results and the simulation occurs at 8:00 which is 43% however reaches a minimum of 8% at 1:00 pm. All in all the visible transmittance of the glass used in the actual building is 0.44; single glazing and the solar gain levels are taken from the center of the room at 1.5 m by 2.35 m.

Figure 4.15, table 4.4, figure 4.16, and table 4.5 illustrate the solar altitude and azimuth respectively. As observed; the simulation readings are close to the ones obtained from MechoSahdes where the visible transmittance of glass is 0.44 and readings are taken from the center of the room at coordinates 1.5 m by 2.35 m.

Table 4.2: Comparison between MechoShade results and simulation results **without** presence of automatic blinds.

Time	MechoShades Results (kW)	Simulation Results (kW)	% Difference
8:00 am	2.92	2.25	23
9:00 am	4.24	3.9	8
10:00 am	5.25	5.6	6
11:00 am	5.92	6.8	13
12:00 pm	6.17	7.25	15
01:00 pm	5.94	7.0	15
02:00 pm	5.08	6.25	19
03:00 pm	3.17	4.7	33

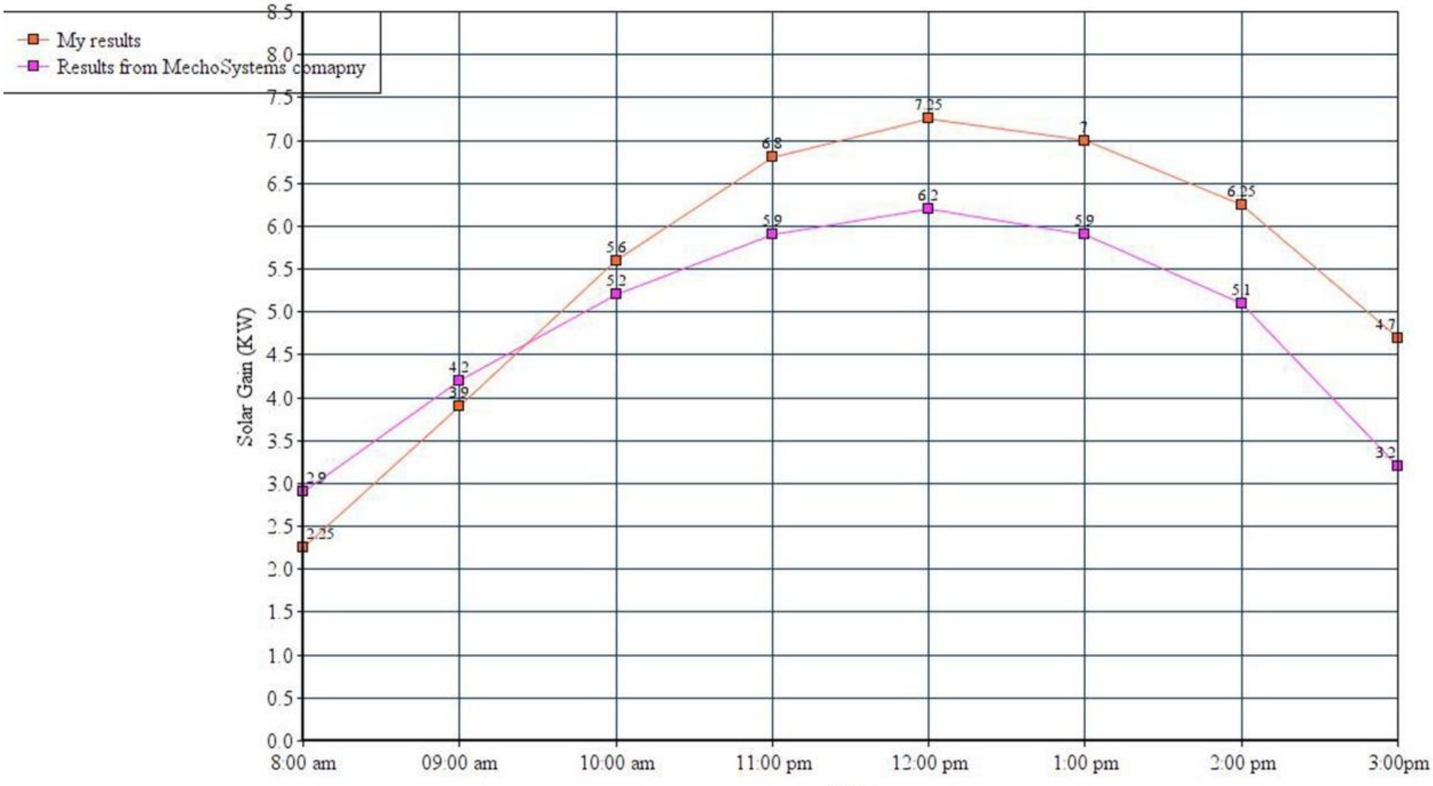


Figure 4.10: Solar Gain without blinds for 21st December

Table 4.3: Comparison between MechShade results and simulation results with presence of automatic blinds.

Time	MechoShades Results (kW)	Simulation Results (kW)	% Difference
8:00 am	1.43	0.82	43
9:00 am	2.08	1.60	23
10:00 am	2.58	2.19	15
11:00 am	2.90	2.55	12
12:00 pm	3.03	2.77	9
01:00 pm	2.91	2.69	8
02:00 pm	2.50	2.34	6.4
03:00 pm	1.56	1.82	14

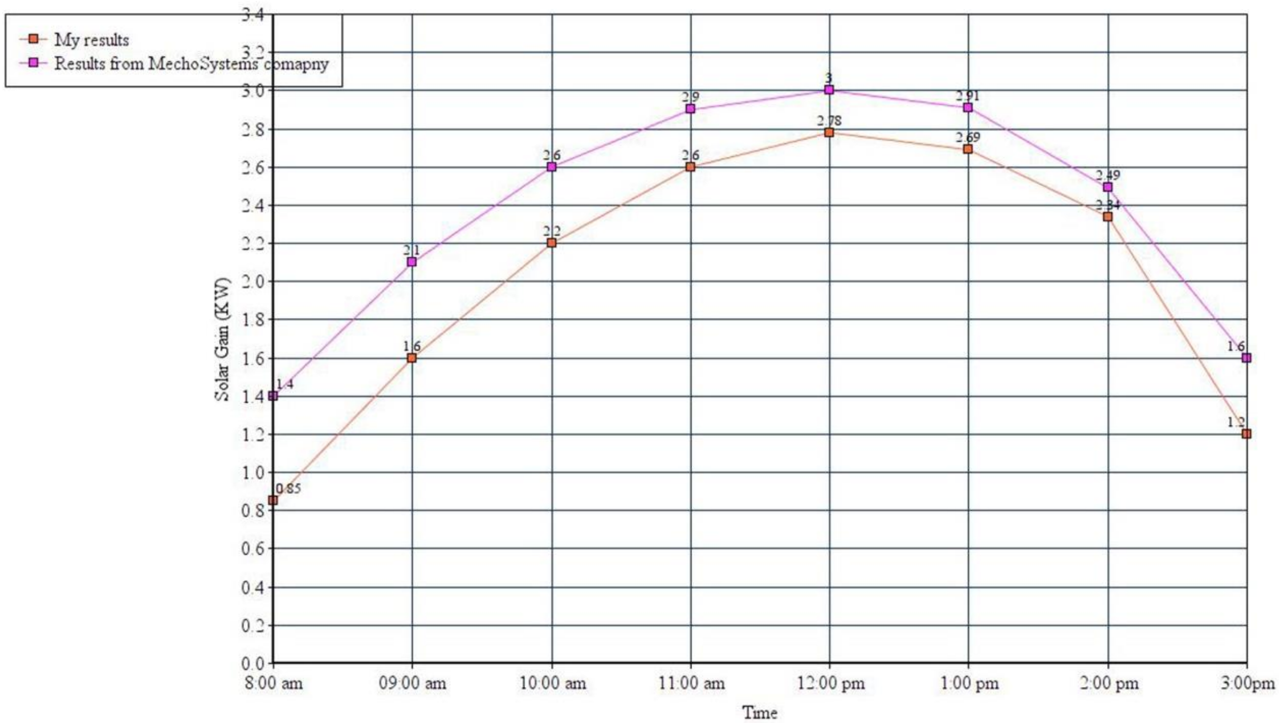


Figure 4.11: Solar Gain with automatic blinds for 21st December

Table 4.4: Comparison of solar altitude between simulation and MechoShade results

Time	MechoShades Results (kW)	Simulation Results (kW)	% Difference
8:00 am	19.9	14	30
9:00 am	27.6	24	13
10:00 am	32.8	30	9
11:00 am	34.6	34	2
12:00 pm	32.8	34	4
01:00 pm	27.6	31	11
02:00 pm	19.9	25	20
03:00 pm	10.3	16	36

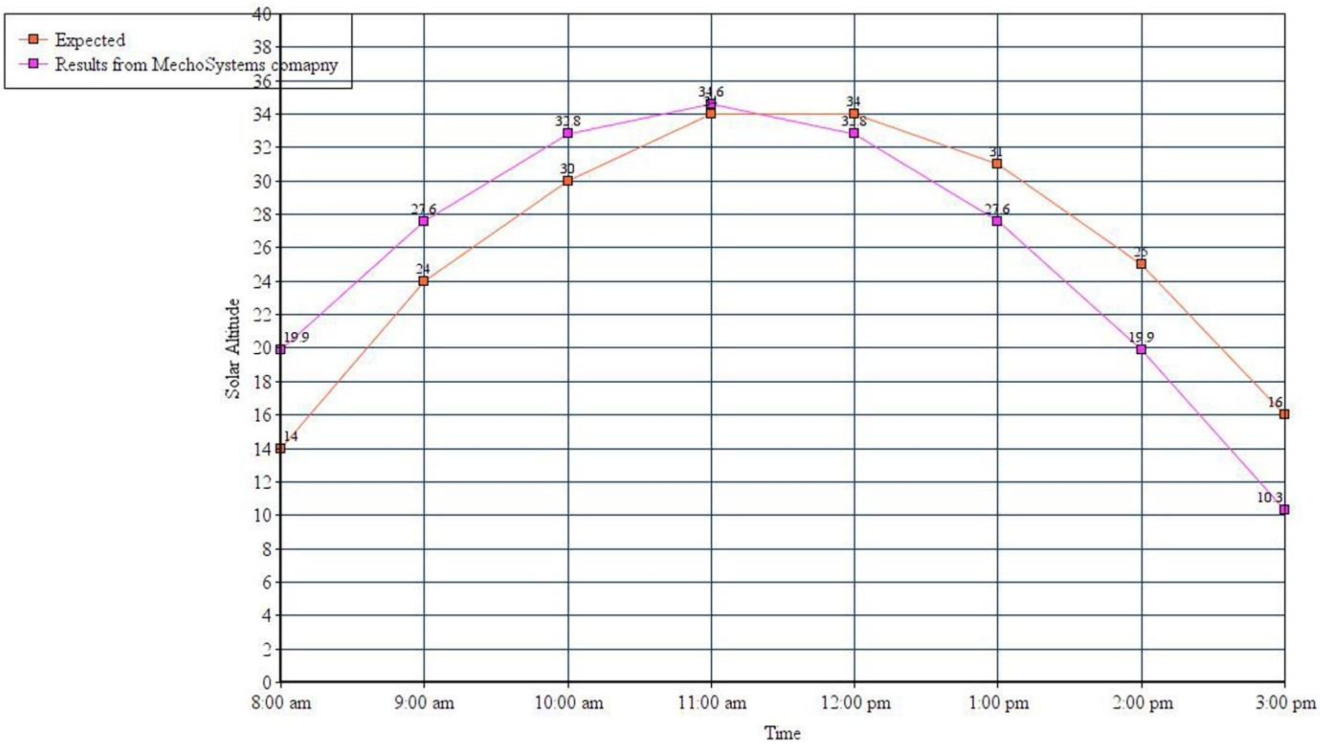


Figure 4.12: Solar Altitude for 21st December

Table 4.5: Comparison of solar azimuth between simulation and MechoShade results

Time	MechoShades Results (kW)	Simulation Results (kW)	% Difference
8:00 am	136.4	141.37	4
9:00 am	148.8	154.82	4
10:00 am	165.6	170.44	3
11:00 am	180	187.08	4
12:00 pm	196.4	202.95	3
01:00 pm	211.2	216.76	3
02:00 pm	220.6	228.21	3
03:00 pm	233.9	237.66	2

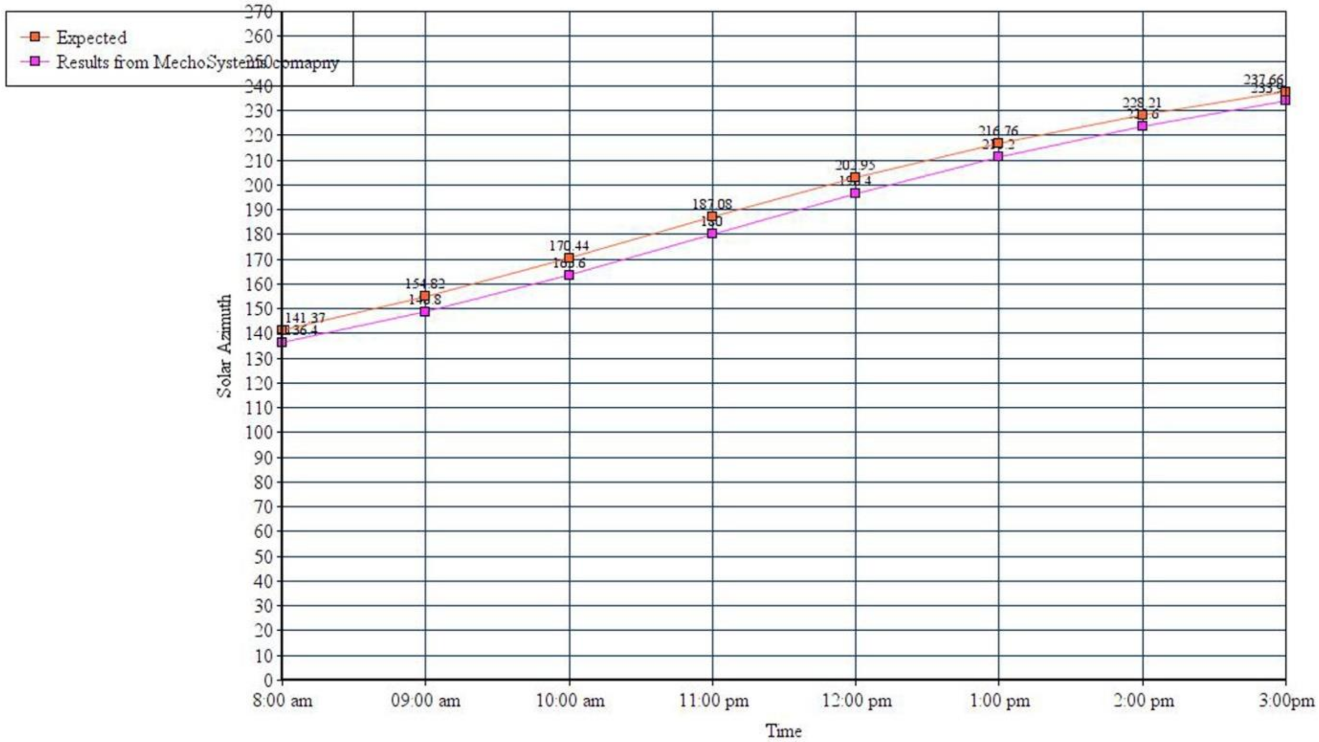


Figure 4.13: Solar Azimuth for 21st of December

Once it is proven that the simulation results are close to the actual results performed by MechoSahdes, the experiment is then carried out through simulation only. Daylight illumination tests are performed on the base case per hour from 8:30 am until 4:30 pm on dates 21st of December 2017, 21st of March 2017, 21st of June 2017, and 21st of September 2017. Note that the base case contains 1/8 inch single exterior glazing of visible transmittance of 0.44. In addition to that, the readings are obtained in the center of the office space at 1.5 m by 2.35 m. Table 4.6, table 4.7, and table, 4.8 illustrate the readings obtained at four days throughout the year considering daylight illumination, solar heat gain, and electrical consumption. Now the Base Case is finally established.

Table 4.6: Illustrating daylight illumination for Base Case

Daylight Illuminance (lux)								
	21st Dec		21st March		21st June		21st Sept	
Time	Illumination	Uniformity	Illumination	Uniformity	Illumination	Uniformity	Illumination	Uniformity
8:30 am	711.49	0.19	775.67	0.18	687.14	0.18	810.71	0.18
9:30 am	929.98	0.19	885.23	0.18	709.26	0.19	911.63	0.19
10:30 am	1098.02	0.21	964.08	0.20	797.77	0.21	993.03	0.21
11:30 am	1199.81	0.26	1029.05	0.22	1133.90	0.23	1061.24	0.23
12:30 pm	1220.06	0.32	1069.69	0.23	913.89	0.23	1096.08	0.23
1:30 pm	1129.08	0.26	1072.89	0.21	812.92	0.20	1084.17	0.20
2:30 pm	915.38	0.23	1010.91	0.19	806.53	0.19	995.50	0.19
3:30 pm	609.37	0.22	844.09	0.18	768.30	0.18	799.28	0.18
4:30 pm	296.23	0.24	583.98	0.19	651.**07**	0.20	524.24	0.20
8:30 am	711.49	0.19	775.67	0.18	687.14	0.18	810.71	0.18
9:30 am	929.98	0.19	885.23	0.18	709.26	0.19	911.63	0.19
Average	901.05	0.24	915.07	0.2	808.98	0.21	919.54	0.2

Table 4.7: Illustrating solar heat gain for Base Case

Solar Heat Gain for (kW) Base Case				
Time	December 21st	March 21st	June 21st	September 21st
8:30 am	3.1532	1.4181	0.7478	0.7907
9:30 am	4.9149	2.5660	0.8509	1.5603
10:30 am	6.3105	3.7981	0.9679	2.6632
11:30 am	7.2242	4.8261	1.2049	3.9538
12:30 pm	7.3988	5.2638	1.6088	4.6286
1:30 pm	6.7159	5.0665	1.8222	4.7842
2:30 pm	5.3920	4.3049	1.6976	4.6933
3:30 pm	3.4021	3.0709	1.3888	3.9466
4:30 pm	0.6347	1.6150	1.0103	2.6459
Total	45.1463	31.9294	11.2992	29.6666

Table 4.8: Illustrating electrical consumption for Base Case.

Electrical Consumption (kW)				
Time	December 21st	March 21st	June 21st	September 21st
8:30 am	0.9291	1.1838	3.6886	4.5198
9:30 am	3.5828	2.7594	3.3861	4.2623
10:30 am	5.9300	4.1182	3.5449	5.2252
11:30 am	7.5880	5.3545	3.7436	6.2798
12:30 pm	8.3581	6.1503	4.0678	6.9972
1:30 pm	8.2782	6.5496	4.3334	7.3511
2:30 pm	7.6722	6.3952	4.3751	7.6611
3:30 pm	6.1712	5.5443	4.1726	7.4927
4:30 pm	2.0465	2.2394	1.9405	3.4284
Average	5.6173	4.4772	3.6947	5.9131

4.6 Weather Data and Daily/Weekly Profiles

In the case for Amman, it is essential to point out its weather data file through IES VE. AP Locate is one of the features used in IES VE and it helps choose a weather data file and represents it per hour 365 days a year. As mentioned earlier four days are chosen to carry out the simulation and that is because they represent days that are close solstices and equinoxes and fall on non-weekend days.

Figures 4.17, 4.18, 4.19, and 4.20 illustrate the charts containing, dry bulb temperature, direct, and diffuse solar radiation for the four individual days mentioned earlier for the entire day. For all of them dry bulb temperature and direct solar radiation peak once at a certain hour and fall back to zero. Diffuse solar radiation has a lower peak value. Cloud cover, on the other hand, changes drastically from day to day. For instance, on 21st December, it is zero most of the time and peaks only once at 8:00 am. Cloud cover is zero on 21st March and stays constant. In 21st of June, the latter is zero yet peaks at 3 pm, falls back to zero, and increases drastically at 6 pm while it stays constant later on. Finally on 21st September, cloud cover is unpredictable since it varies more than once then falls back to zero.

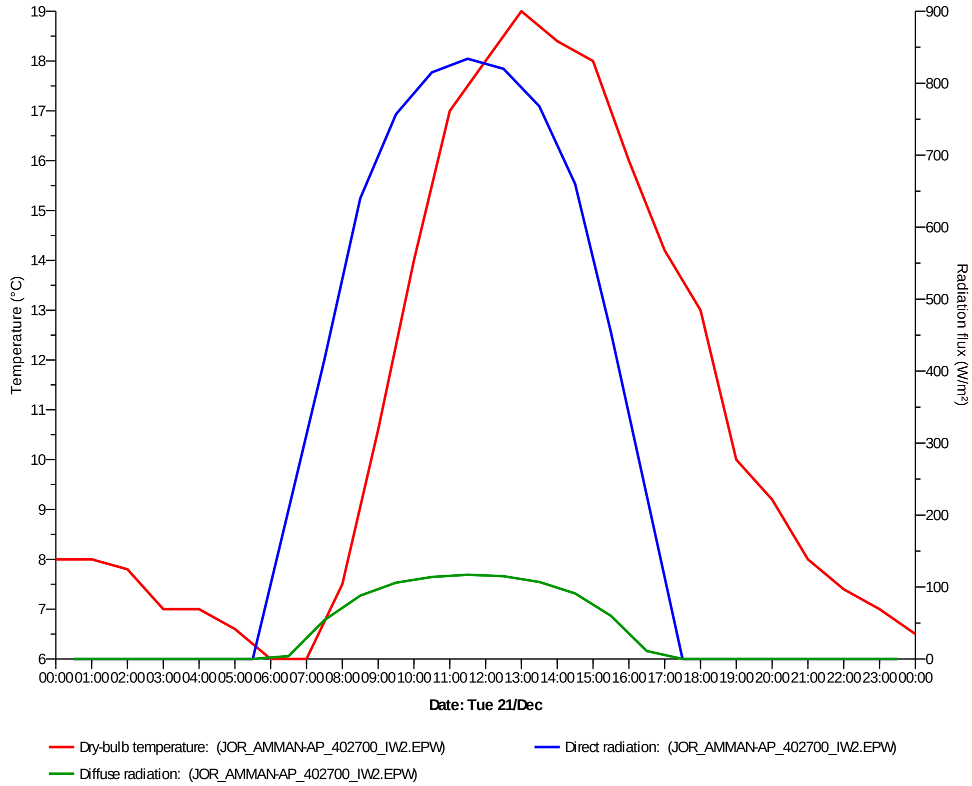


Figure 4.14: Illustrating weather data for Amman on 21st of December (IES VE)

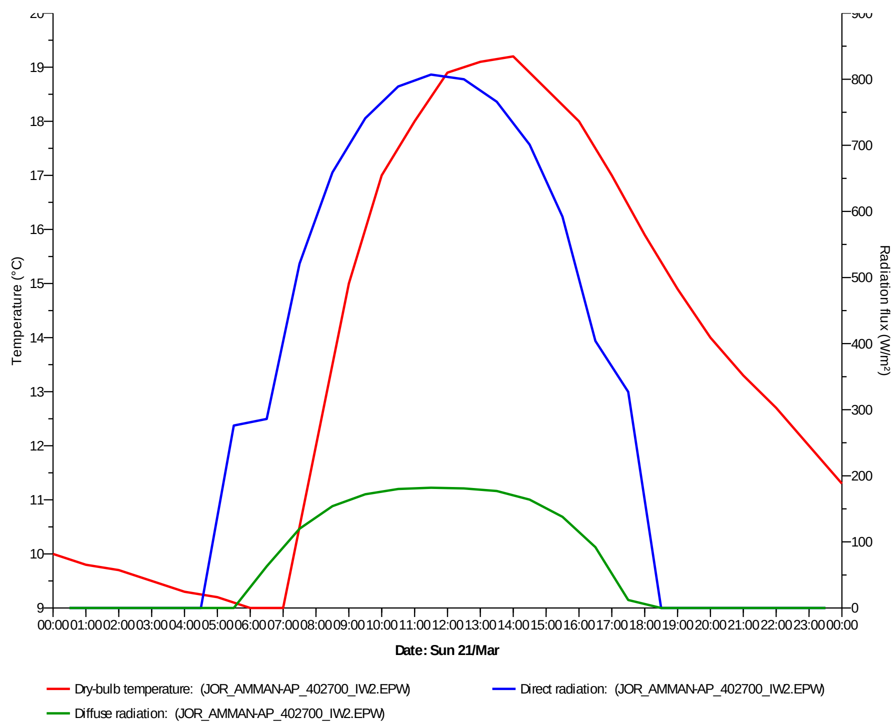


Figure 4.15: Weather data for Amman on 21st March (IES VE)

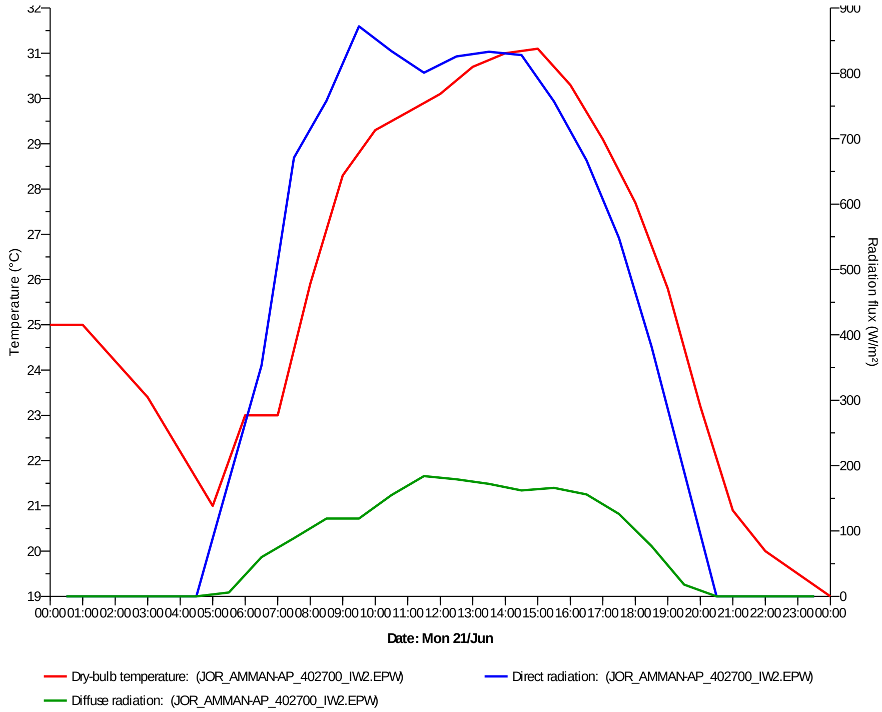


Figure 4.16: Weather Data for Amman 21st June (IES VE)

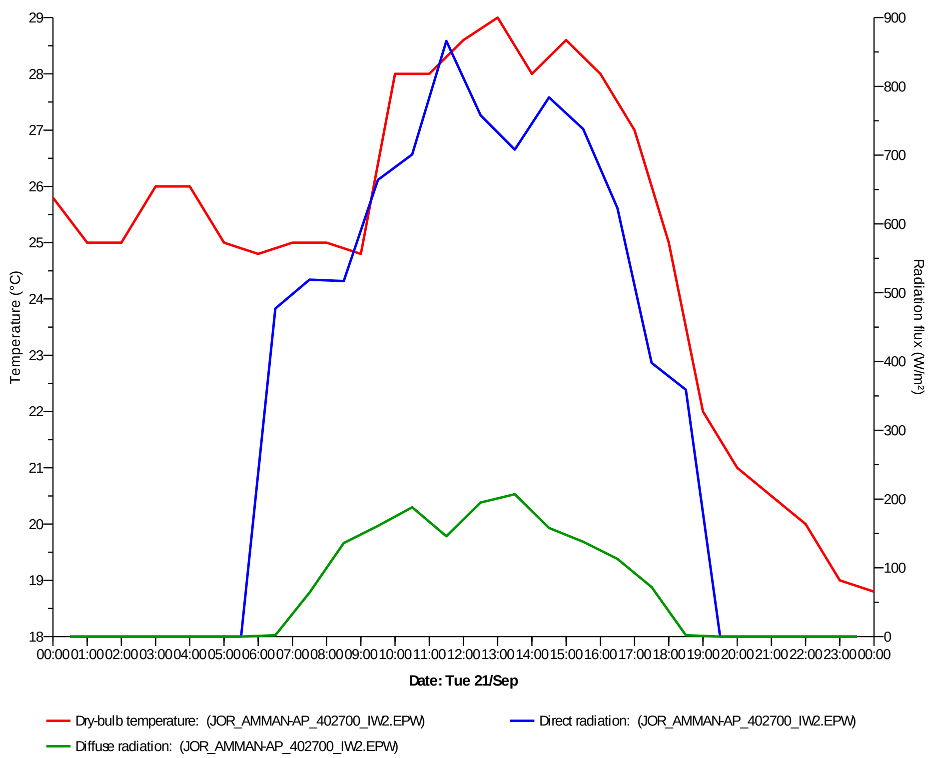


Figure 4.17: Weather Data for Amman 21st September (IES VE)

Figure 4.21 illustrates the daily profile constructed on IES VE to carry on the simulation. Categories such as cooling, daylighting, heating, HVAC, lighting, and occupancy are all affected by the daytime office working hours from 8:30 am until 4:30 pm. The modulating value as shown reaches 1 during working hours whilst it remains 0 for the rest of the day. This profile is called Normal Working Day and has no dimming. The lights and switches are only controlled by on an off. Another daily profile is created containing the dimming profile. The latter is explained in more details later on in the dissertation.

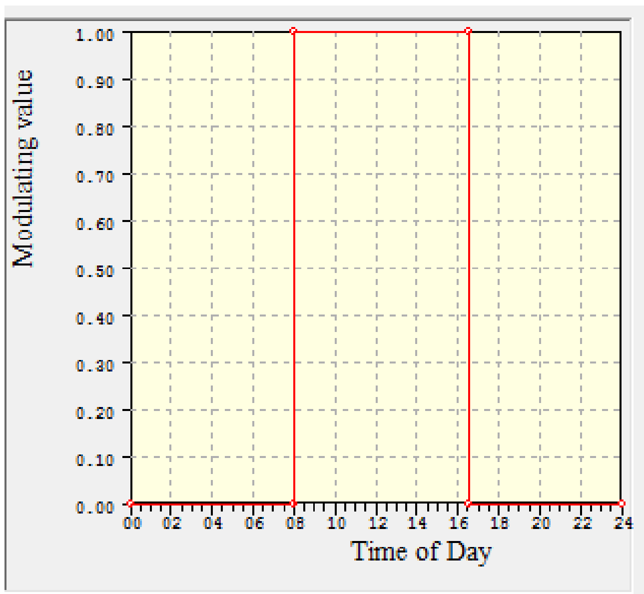


Figure 4.18: Daily profile for a working day (IES VE)

Once the daily profile is created, it is plugged in the weekly profile named by the author as ‘banking week’. As observed in figure 4.22, the daily profile called as a Normal Working Day is activated from Sunday until Thursday. The categories mentioned earlier are considered turned all off during Friday and Saturday which are weekends and on holidays.

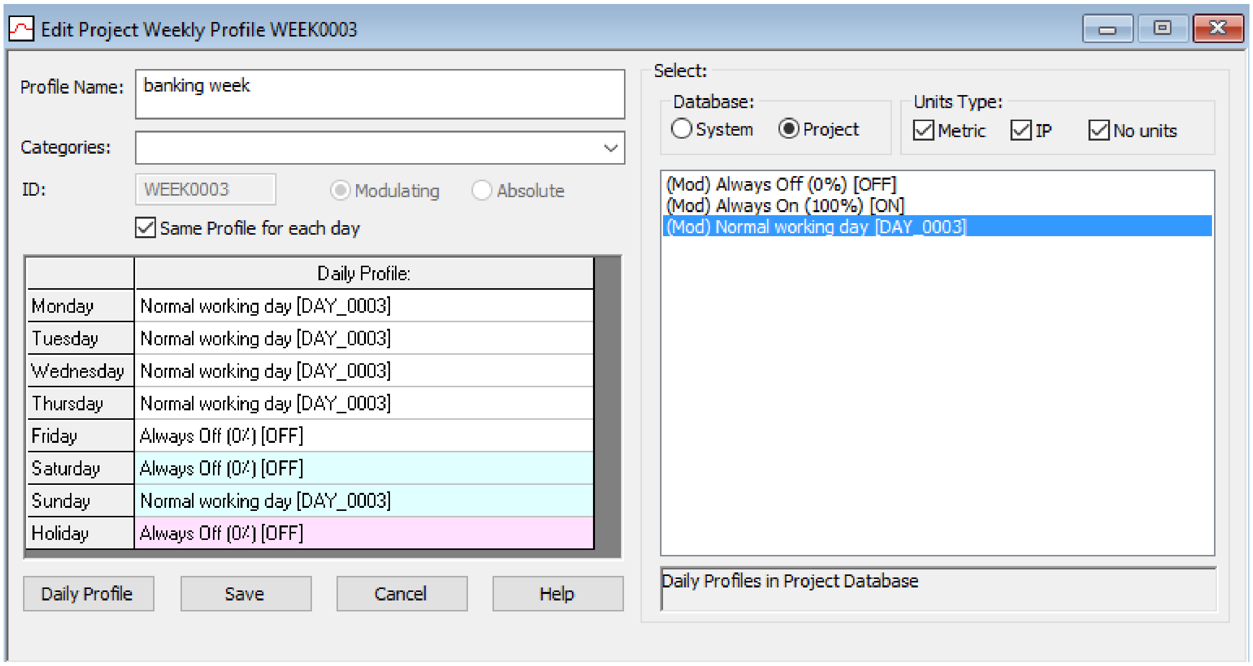


Figure 4.19: Illustrating weekly profile (IES VE)

4.7 Considerations to Take into Account

-It is essential to point out that the office chosen is surrounded by other offices from all directions. Plus surrounding shading and urban shading profile are ignored in this simulation.

-The Base Case is constructed based on studies already performed by MechSahdes Company.

-The materials constructed in the simulation are the same ones used in the actual building. They remain constant throughout the whole simulation.

-The aim of the study is to find out which scenario saves up more energy inside the building and if automatic shading devices are worth to install or not. Human comfort is out of the scope of this study.

-The readings obtained are per hour basis solely at working hours.

4.8 Assessing the Different Scenario Configurations

To carry out the simulation, various scenarios are studied in this paper and are shown in the matrix in table 4.5. They focus on four individual days. Top Down automatic Shading, Bottom Up Automatic Shading, Manual Shading, Tinted Glazing with 0.7 VT at Top and Tinted Glazing with 0.7 VT at Bottom are the parameters. The scenarios are divided into parameters with lighting sensor and without. The studied outcomes are illumination levels, solar heat gain, cooling loads, heating loads, and electricity consumption. The parameters are explained even further below.

Table 4.9: Simulation Matrix

Simulation Matrix												
		Base Case	Top Down Automatic Shading		Bottom Up Automatic Shading		Manual Shading		Tinted Glazing 0.7 VT on top		Tinted Glazing 0.7 VT at bottom	
			No Sensor	Sensor	No Sensor	Sensor	No Sensor	Sensor	No Sensor	Sensor	No Sensor	Sensor
December 21st	Illumination	X	X		X		X		X		X	
	Solar Heat Gain	X	X		X		X		X		X	
	Cooling Load	X	X		X		X		X		X	
	Heating Load	X	X		X		X		X		X	
	Electricity Consumption	X	X	X	X	X	X	X	X	X	X	X
March 21st	Illumination	X	X		X		X		X		X	
	Solar Heat Gain	X	X		X		X		X		X	
	Cooling Load	X	X		X		X		X		X	
	Heating Load	X	X		X		X		X		X	
	Electricity Consumption	X	X	X	X	X	X	X	X	X	X	X
June 21st	Illumination	X	X		X		X		X		X	
	Solar Heat Gain	X	X		X		X		X		X	
	Cooling Load	X	X		X		X		X		X	
	Heating Load	X	X		X		X		X		X	
	Electricity Consumption	X	X	X	X	X	X	X	X	X	X	X
September 21st	Illumination	X	X		X		X		X		X	
	Solar Heat Gain	X	X		X		X		X		X	
	Cooling Load	X	X		X		X		X		X	
	Heating Load	X	X		X		X		X		X	
	Electricity	X	X	X	X	X	X	X	X	X	X	X

4.81 Automatic Shading

For automatic shading, the shading positions are modeled manually. Now the shading positions are separated into four categories according to table 4.6. One must bear in mind that position 0 is when the shades are fully open and position 4.8 m are when they are fully closed.

Table 4.10: Illustrating automatic shading positions according to lighting levels

Light level measured at center of office	Shade Position from top
0 lux - 538.2 lux	0 m (fully open)
538.2 lux – 1076.4 lux	1.2 m
1076.4 lux – 1614.6 lux	2.4 m
1614.6 lux – 2152.78 lux	3.6 m
2152.78 lux and above	4.8 m (fully closed)

The experiment is performed per working hour for 21st December, 21st March, 21st June, and 21st September. The shade positions will alter automatically depending on the illumination inside the room at 1.5 by 2.35 m for each hour. The figure below represents how the shades close from the top at distances of 1.2 m and 2.4 m. Then figure 4.23 shows when automatic top shading is applied, showing how the shades close 1.2 m from the bottom and 2.4 m as well. Figure 4.24 on the other hand occurs when automatic bottom up shading is applied at distances 2.1 m and 2.4 m respectively.

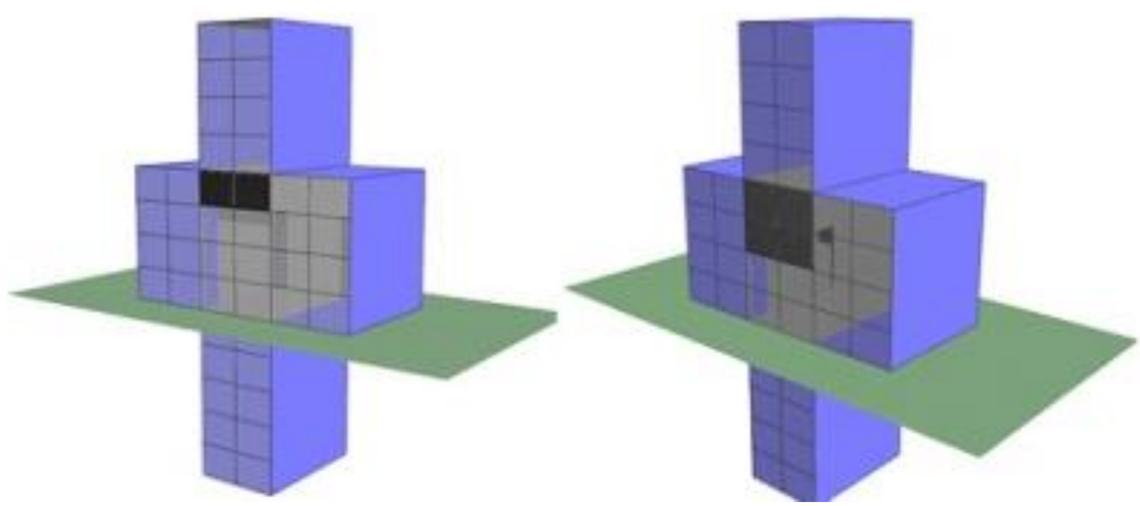


Figure 4.20: Illustrating the use of automatic top down shading at 1.2 m (left) and 2.4 m (right).

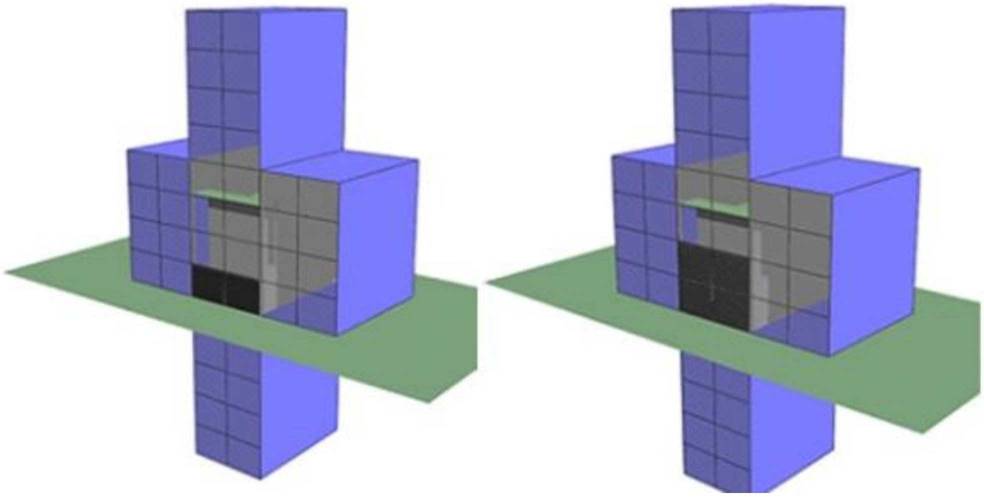


Figure 4.21: Illustrating automatic bottom-up shading at 1.2 m (left) and 2.4 m (right) from below.

4.82 Manual Shading

The simulation is performed again to assess the behavior when manual shading is applied. Here the scenarios are when the shades open completely and that is until 11:30 am, and closed completely until 4:30 pm. This timing is chosen right before the sun is at its highest in position in the sky which is at 12 pm. This scenario will undergo a lighting analysis, electricity consumption, solar heat gain, cooling, and heating load analyses. Not to mention that another test is carried on with the use of a lighting sensor as well. This is shown in figure 4.25.

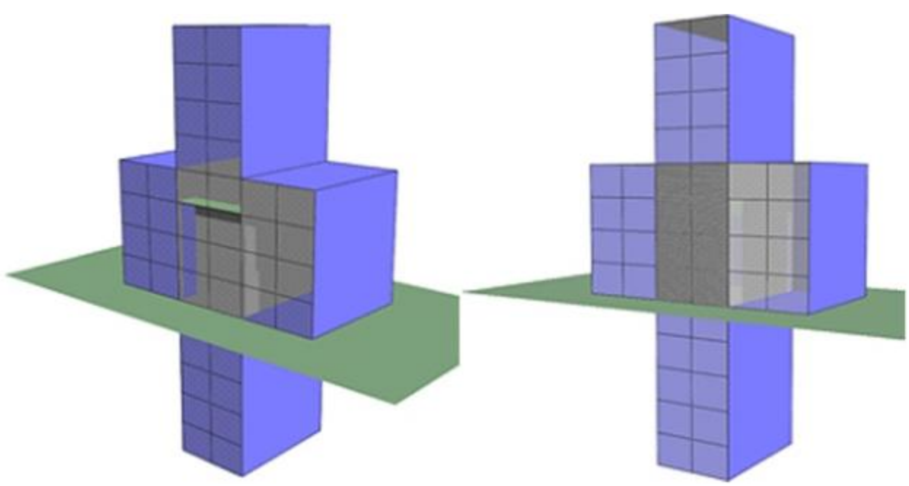


Figure 4.22: Illustrating manual shading when shades are up (left) and completely closed (right)

4.83 Tinted Glazing

Another experiment is carried out with the use of different glazing tints and these are those with Visible Transmittances of 0.7, 0.52, 0.44, and 0.35 (Commercialwindows.org, 2017). The experiment is carried out first when placing on top 0.7 VT and the rest in a descending order. Then it is performed again with 0.7 VT placed at the bottom and the rest are placed also in a descending order as shown in figure 4.26. The tests carried out will undergo illumination levels, solar heat gain, electricity consumption, and cooling and heating loads.

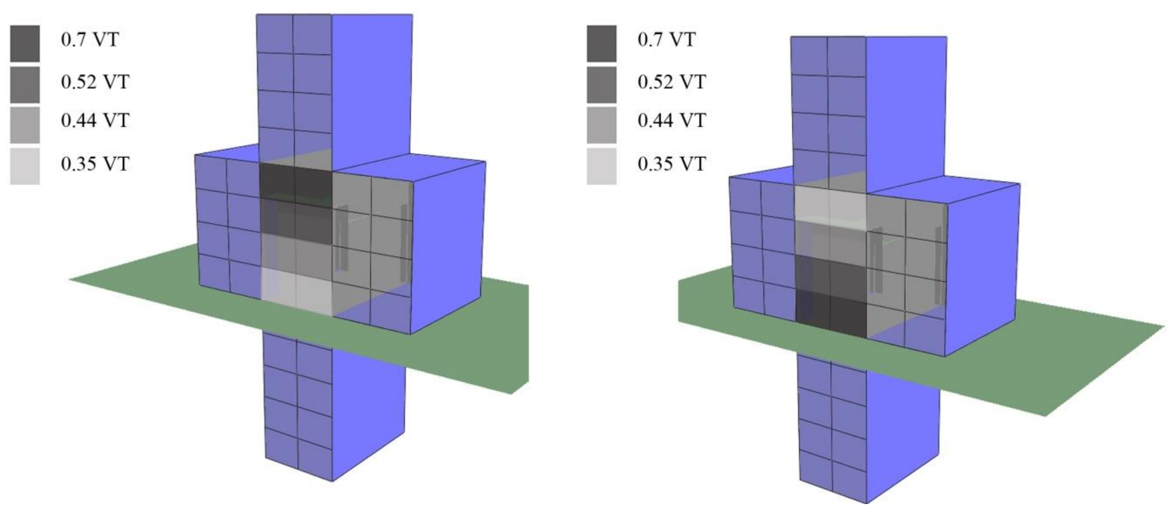


Figure 4.23: Illustrating the use of different tints when 0.7 VT is at the top (left) and 0.7 VT at the bottom (right).

CHAPTER 5 : RESULTS & DISCUSSIONS

5.1 Lighting Levels

Lighting Levels for 21st of December

The tables below illustrate the lighting levels inside the office for each working hour according to different conditions. One must take into account that the four luminaries are considered always on inside the office erected at height 3 m and distributed evenly. As observed, each shade position alters the amount of illumination inside. The conventional top-down shading managed to save up 18.73% of lighting penetration while the bottom up shading saved up 30.88% of lighting. When manual shading is used, it is assumed that the shades stay up until 11:30 am and descend entirely until 4:30 pm. It reduces the lighting level by 56.62% when comparing it to Base Case. One must take into account that in manual shading, most of the time when the shade it closed, the lighting level is less than 500 lux which is less than the conventional lighting level inside an office space. When the tinted glass is used, four different tints with different Visual Transmittances are applied. For instance, in one case the upper glazing has VT of 0.7, the one right below it has VT of 0.52, the one after has VT of 0.44, and the lowest glazing has a VT of 0.35. Here the lighting level is reduced to 15.17% in regard to Base Case. The experiment is performed again with 0.7VT located at the bottom and reduces as it reaches the top. Here the illumination level is reduced to 16.48%. The tables below illustrate the results obtained for each scenario at each hour through the working day.

Table 5.1: Illumination for Automatic Shading for 21st December

Illumination for **Automatic** Shading for 21st December						
Time	Illumination **without shading** (lux) Base Case	Shade Position (m)	Illumination with shading (lux) (Top Down)	Illumination with shading (lux) (Bottom Up)	% of energy saving in regard to Base Case (Top Down)	% of energy saving in regard to Base Case (Bottom Up)
8:30 am	711.49	1.2 m	639.49	615.67	10.12%	13.47%
9:30 am	929.98	1.2 m	888.88	847.75	4.42%	8.84%
10:30 am	1098.02	2.4 m	782.19	558.88	28.76%	49.10%
11:30 am	1199.81	2.4 m	836.71	629.94	30.26%	47.50%
12:30 pm	1220.06	2.4 m	854.37	652.33	29.97%	46.53%
1:30 pm	1129.08	2.4 m	799.48	563.65	29.19%	50.08%
2:30 pm	915.38	1.2 m	905.71	870.45	1.06%	4.91%
3:30 pm	609.37	1.2 m	587.55	569.99	3.58%	6.46%
4:30 pm	296.23	0 m	296.23	296.23	0.00%	0.00%
Average	901.05		732.29	622.77	18.73%	30.88%

Table 5.2: Illumination for Manual Shading for 21st December

Illumination for **Manual** Shading for 21st December				
Time	Illumination **without shading** (lux) (Base Case)	Shade Position (m)	Illumination with shading (lux) (Top Down)	% of energy saving in regard to Base Case
8:30 am	711.49	0 m	711.49	0.00%
9:30 am	929.98	0 m	929.98	0.00%
10:30 am	1098.02	0 m	1098.02	0.00%
11:30 am	1199.81	4.8 m	184.91	84.59%
12:30 pm	1220.06	4.8 m	189.31	84.48%
1:30 pm	1129.08	4.8 m	168.59	85.07%
2:30 pm	915.38	4.8 m	125.14	86.33%
3:30 pm	609.37	4.8 m	75.86	87.55%
4:30 pm	296.23	4.8 m	34.43	88.38%
Average	901.05		390.86	56.62%

Table 5.3: Illumination for Tinted Glass for 21st December

Illumination for **Tinted Glass** for 21st December					
Time	Illumination **without shading** (lux) (Base Case)	Tinted Glass with 0.7VT at top (lux)	Tinted Glass with 0.7VT at bottom (lux)	% of energy saving in regard to Base Case VT from top	% of energy saving in regard to Base Case VT from bottom
8:30 am	711.49	523.05	499.23	26.49%	29.83%
9:30 am	929.98	748.00	742.61	19.57%	20.15%
10:30 am	1098.02	950.08	931.99	13.47%	15.12%
11:30 am	1199.81	1097.15	1118.73	8.56%	6.76%
12:30 pm	1220.06	1126.45	1134.17	7.67%	7.04%
1:30 pm	1129.08	1011.19	966.04	10.44%	14.44%
2:30 pm	915.38	755.94	731.48	17.42%	20.09%
3:30 pm	609.37	460.26	439.21	24.47%	27.92%
4:30 pm	296.23	207.33	209.92	30.01%	29.14%
Average	901.05	764.38	752.6	15.17%	16.48%

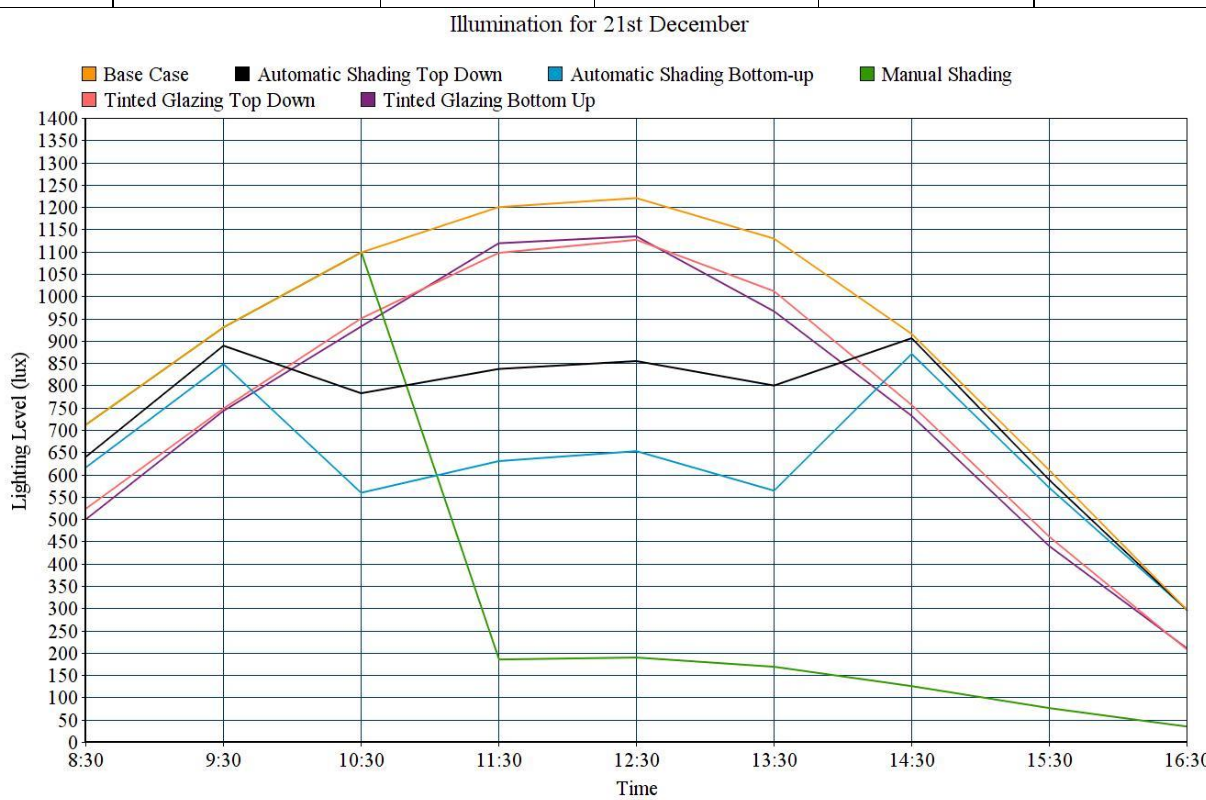


Figure 5.1: Illumination levels for 21st December.

Figure 5.1 shows that the Base Case is the line situated right on top and has the highest peak at 12:30 pm. The tinted glazing with 0.7 VT on top comes right after almost coincides with values with that belonging to tinted glazing with VT at the bottom. The top down automatic shading has a lower peak value than that of the base case and tends to alternate between 9:30 am until 2:30 pm. That is due to the different shade positions that change at each hour. As observed the automatic bottom-up shading alternates also between 9:30 am and 2:30 pm, but seems to have the lowest peak value than the curves above it. Finally, the manual shading follows the same curve as the one belonging to the base case until 11:30 am where a major decrease occurs. The manual shading seems to have the lowest lighting level in average when comparing it to all the other scenarios reaching below 500 lux at times. This means that more artificial lights need to be used.

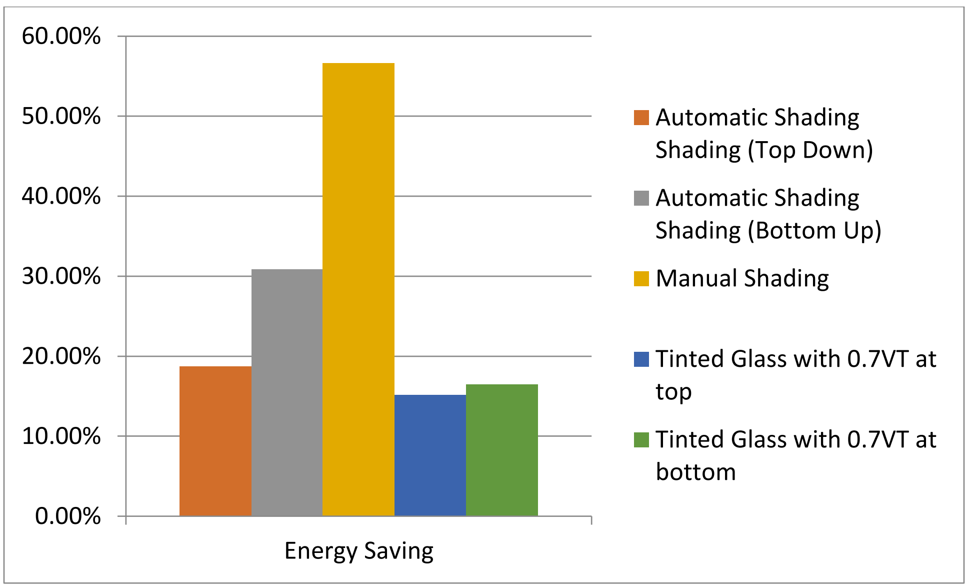


Figure 5.2: Illumination level ratios for 21st December comparing all scenarios.

The figure 5.2 explains overall which scenario reduces the most amount of illumination. Manual Shading wins and then comes bottom up the automatic shading, followed by top-down automatic shading, tinted glass with 0.7 VT at the bottom, and finally tinted glass with 0.7 VT at the top.

Lighting Levels for 21st of March

The tables below show the illumination levels for automatic shading, manual shading, and tinting. It is observed through the results that automatic top down shading reduces lighting by 12.2% and bottom up shading reduce it by 8.72%. In the case of manual shading, it reduces the penetration of lighting inside the office by 58.87% taking into account that most of the time the level of lighting inside the office is below 500 lux as seen by the table. In tinted glazing, lighting level is 32.28% reduced when 0.7 VT is placed on top and 35.73% when 0.7 VT is placed at the bottom.

Table 5.4: Illumination for Automatic Shading for 21st March

Illumination for **Automatic** Shading for 21st March						
Time	Illumination **without shading** (lux)	Shade Position (m)	Illumination with shading (lux) (Top Down)	Illumination with shading (lux) (Bottom Up)	% of energy saving in regard to Base Case (Top Down)	% of energy saving in regard to Base Case (Bottom Up)
8:30 am	775.67	1.2 m	586.56	576.58	24.38%	25.67%
9:30 am	885.23	1.2 m	748.69	742.37	15.42%	16.14%
10:30 am	964.08	1.2 m	868.94	896.62	9.87%	7.00%
11:30 am	1029.05	1.2 m	970.42	1026.79	5.70%	0.22%
12:30 pm	1069.69	1.2 m	1031.24	1071.00	3.59%	-0.12%
1:30 pm	1072.89	1.2 m	1025.08	1068.19	4.46%	0.44%
2:30 pm	1010.91	1.2 m	945.61	941.87	6.46%	6.83%
3:30 pm	844.09	1.2 m	741.12	725.04	12.20%	14.10%
4:30 pm	583.98	1.2 m	488.65	468.68	16.32%	19.74%
Average	915.07		822.92	835.24	10.07%	8.72%

Table 5.5: Illumination for Manual Shading for 21st March

Illumination for **Manual** Shading for 21st March				
Time	Illumination **without shading** (lux)	Shade Position (m)	Illumination with shading (lux) (Top Down)	% of energy saving in regard to Base Case
8:30 am	775.67	0 m	775.67	0.00%
9:30 am	885.23	0 m	885.23	0.00%
10:30 am	964.08	0 m	964.08	0.00%
11:30 am	1029.05	4.8 m	150.66	85.36%
12:30 pm	1069.69	4.8 m	164.70	84.60%
1:30 pm	1072.89	4.8 m	156.10	85.45%
2:30 pm	1010.91	4.8 m	132.39	86.90%
3:30 pm	844.09	4.8 m	98.21	88.36%
4:30 pm	583.98	4.8 m	60.40	89.66%

Average	915.07		376.38	58.87%

Table 5.6: Illumination for Tinted Glazing for 21st March

Illumination for **Tinted Glass** for 21st March					
Time	Illumination **without shading** (lux) (Base Case)	Tinted Glass with 0.7VT at top (lux)	Tinted Glass with 0.7VT at bottom (lux)	% of energy saving in regard to Base Case VT from top	% of energy saving in regard to Base Case VT from bottom
8:30 am	775.67	497.51	483.08	35.86%	37.72%
9:30 am	885.23	653.74	643.15	26.15%	27.35%
10:30 am	964.08	824.12	793.88	14.52%	17.65%
11:30 am	1029.05	925.06	944.41	10.11%	8.23%
12:30 pm	1069.69	1005.05	1003.39	6.04%	6.20%
1:30 pm	1072.89	984.96	964.19	8.20%	10.13%
2:30 pm	1010.91	822.23	828.33	18.66%	18.06%
3:30 pm	844.09	624.92	594.13	25.97%	29.61%
4:30 pm	583.98	395.50	375.32	32.28%	35.73%
Average	915.07	748.12	736.65	16.97%	18.25%

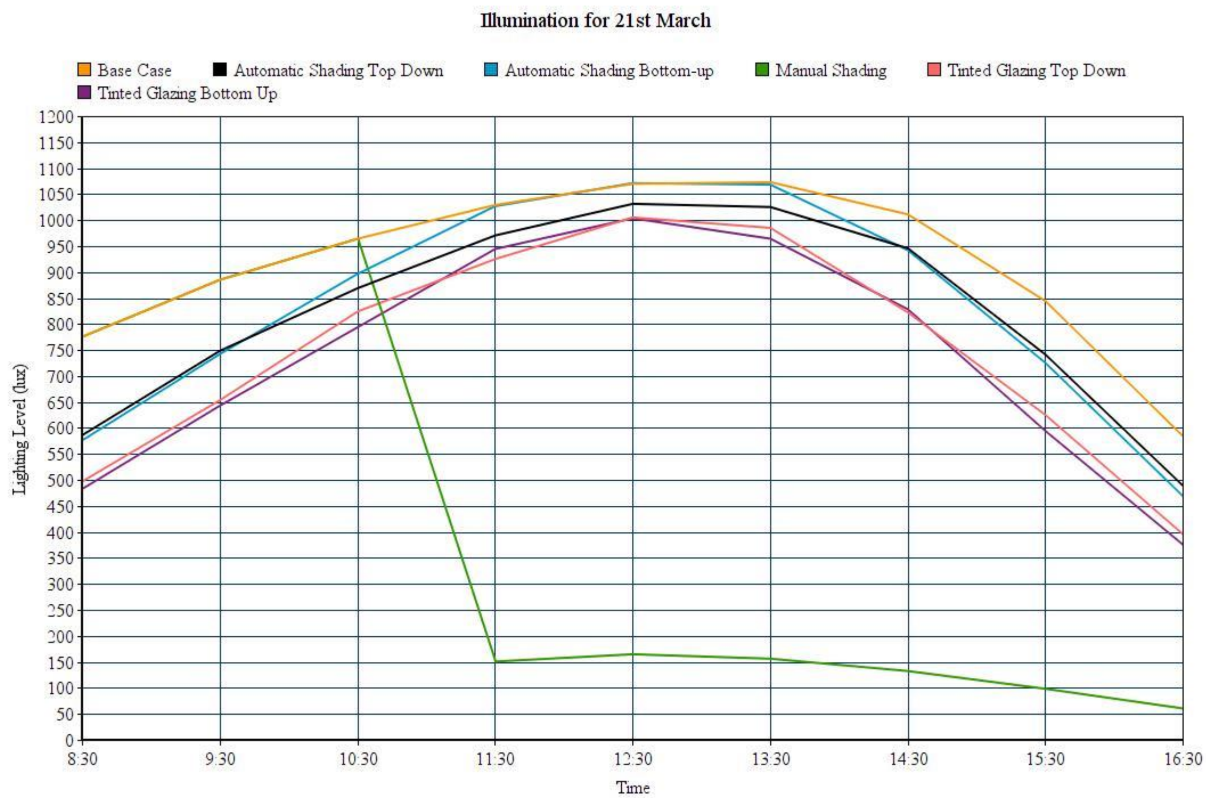


Figure 5.3: Illumination levels for 21st March.

To explain the figure 5.3 the curves are pretty close to each other in value. The base Case scenario is the one that introduces the highest amount of lighting inside the office. It reaches its peak between 12:30 pm and 1:30 pm. Right below it is the automatic bottom-up shading followed by automatic top down shading by few amounts. Tinted glazing follows right beneath with both curves exceeding each other at different hours of the day. Finally is the manual shading; it lets in the same amount of light as Base Case until 11:30 am when a huge slope appears and illumination is greatly reduced.

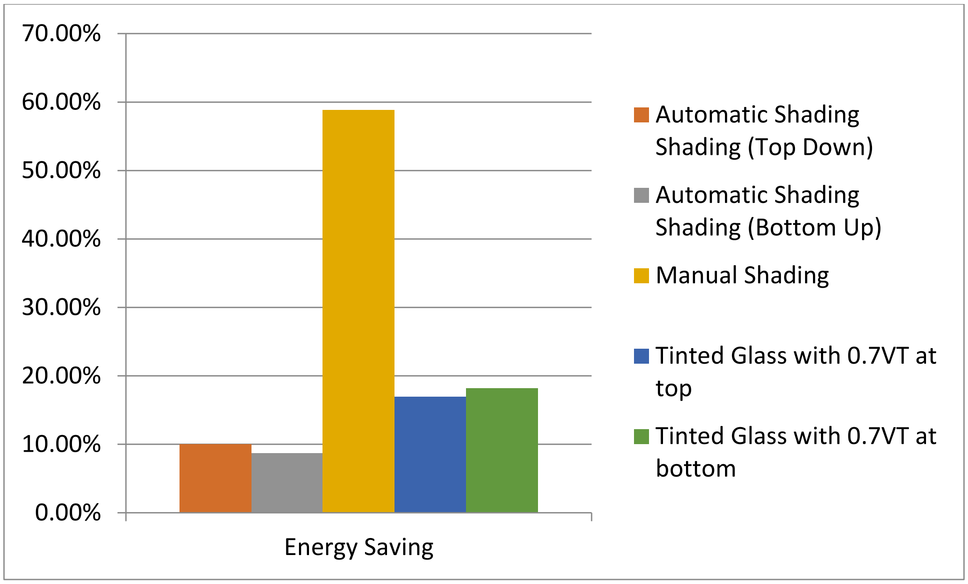


Figure 5.4: Illumination level ratios for 21st March comparing all scenarios.

All in all, for 21st of March, Manual shading saves up the biggest amount of lighting. Next, comes tinted glass with 0.7 VT at the bottom, then tinted glass with 0.7 VT at the top. Following is automatic top down shading. The one that lets in the most amount of lighting is the bar belonging to bottom up the automatic shading.

Lighting Levels for 21st of June

When observing the tables for 21st of June; automatic top down shading seems to reduce lighting level to 26.52%, while 25.53% belongs to automatic bottom-up shading. The results are very close to each other in terms of automatic shading. In manual shading, it reduces illumination to 61.98% when comparing to Base Case as always. Tinted glass with 0.7 VT at top reduces lighting to 44.24% while 0.7 VT at the bottom is 45.82% which are fairly similar.

Table 5.7: Illumination for Automatic Shading for 21st June

Illumination for **Automatic** Shading for 21st June						
Time	Illumination **without shading** (lux) (Base Case)	Shade Position (m)	Illumination with shading (lux) (Top Down)	Illumination with shading (lux) (Bottom Up)	% of energy saving in regard to Base Case (Top Down)	% of energy saving in regard to Base Case (Bottom Up)
8:30 am	687.14	1.2 m	465.62	466.68	32.24%	32.08%
9:30 am	709.26	1.2 m	527.11	533.73	25.68%	24.75%
10:30 am	797.77	1.2 m	637.50	662.33	20.09%	16.98%
11:30 am	1133.90	2.4 m	643.14	534.39	43.28%	52.87%
12:30 pm	913.89	1.2 m	767.41	808.98	16.03%	11.48%
1:30 pm	812.92	1.2 m	674.30	687.47	17.05%	15.43%
2:30 pm	806.53	1.2 m	631.95	642.95	21.65%	20.28%
3:30 pm	768.30	1.2 m	556.75	649.94	27.53%	15.41%
4:30 pm	651.07	1.2 m	445.82	435.46	31.53%	33.12%
Average	808.98		594.4	602.44	26.52%	25.53%

Table 5.8: Illumination for Manual Shading for 21st June

Illumination for **Manual** Shading for 21st June				
Time	Illumination **without shading** (lux) (Base Case)	Shade Position (m)	Illumination with shading (lux) (Top Down)	% of energy saving in regard to Base Case
8:30 am	687.14	0 m	687.14	0.00%
9:30 am	709.26	0 m	709.26	0.00%
10:30 am	797.77	0 m	797.77	0.00%
11:30 am	1133.90	4.8 m	141.00	87.57%
12:30 pm	913.89	4.8 m	116.00	87.31%
1:30 pm	812.92	4.8 m	97.84	87.96%
2:30 pm	806.53	4.8 m	89.50	88.90%
3:30 pm	768.30	4.8 m	72.38	90.58%
4:30 pm	651.07	4.8 m	57.36	91.19%
Average	808.98		307.58	61.98%

Table 5.9: Illumination for Tinted Glazing for 21st June

Illumination for **Tinted Glass** for 21st June					
Time	Illumination **without shading** (lux) (Base Case)	Tinted Glass with 0.7VT at top (lux)	Tinted Glass with 0.7VT at bottom (lux)	% of energy saving in regard to Base Case VT from top	% of energy saving in regard to Base Case VT from bottom
8:30 am	687.14	399.67	390.32	41.84%	43.20%
9:30 am	709.26	454.75	457.94	35.88%	35.43%
10:30 am	797.77	593.11	581.03	25.65%	27.17%
11:30 am	1133.90	882.82	889.00	22.14%	21.60%
12:30 pm	913.89	722.70	725.34	20.92%	20.63%
1:30 pm	812.92	618.05	623.00	23.97%	23.36%
2:30 pm	806.53	551.64	559.65	31.60%	30.61%
3:30 pm	768.30	462.38	476.48	39.82%	37.98%
4:30 pm	651.07	363.05	352.74	44.24%	45.82%
Average	808.98	560.91	561.72	30.66%	30.56%

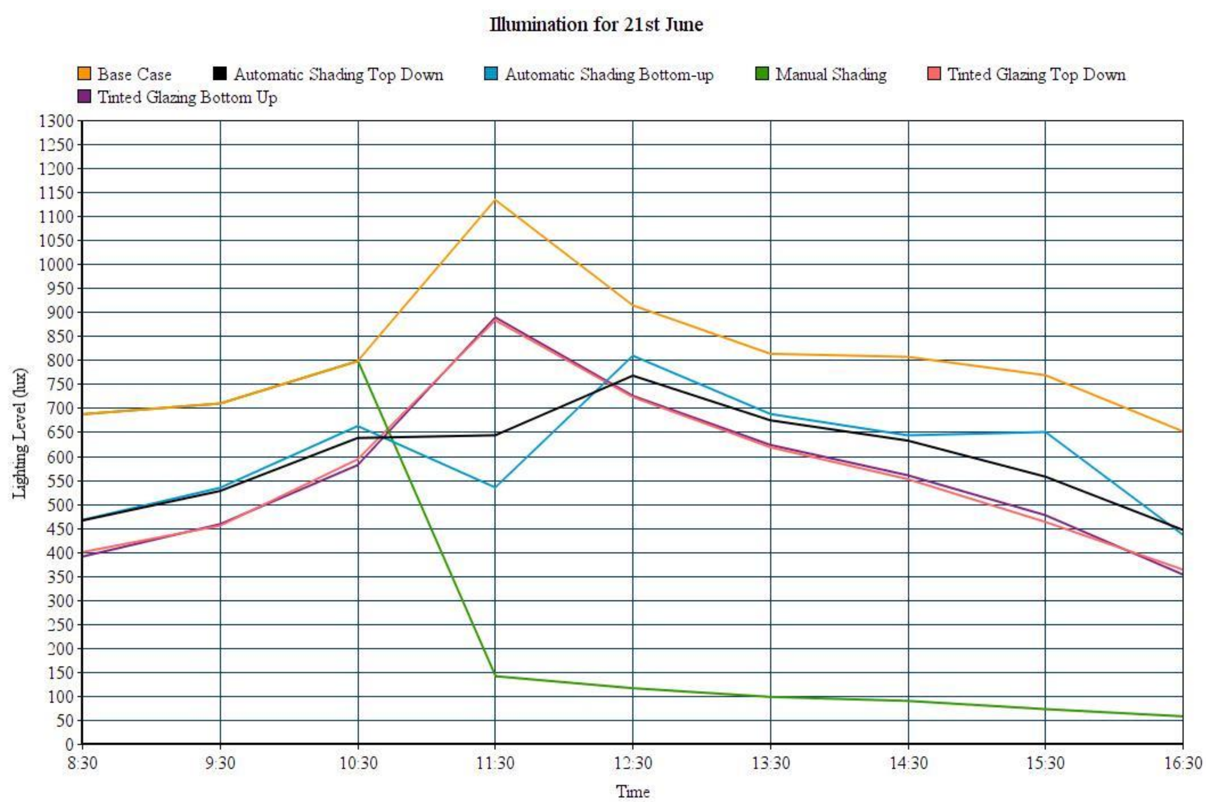


Figure 5.5: Illumination levels for 21st June

For this day in June, Base Case reaches its peak value at 11:30 am. Automatic top down shading drops also at 11:30 am while it peaks up at 12:30 pm. Automatic bottom up shading peaks down even further at 11:30 am while peaking up even more than the top down shading also at 12:30 pm. Tinted glazing belonging to 0.7 VT at the top and 0.7 VT at the bottom seem to be fairly equal, and lower than both automatic shading. On the other hand, it peaks up majorly also at 11:30 am out leveling automatic shading. Manual Shading, however, slopes down big time at 11:30 am and continues until 4:30 pm.

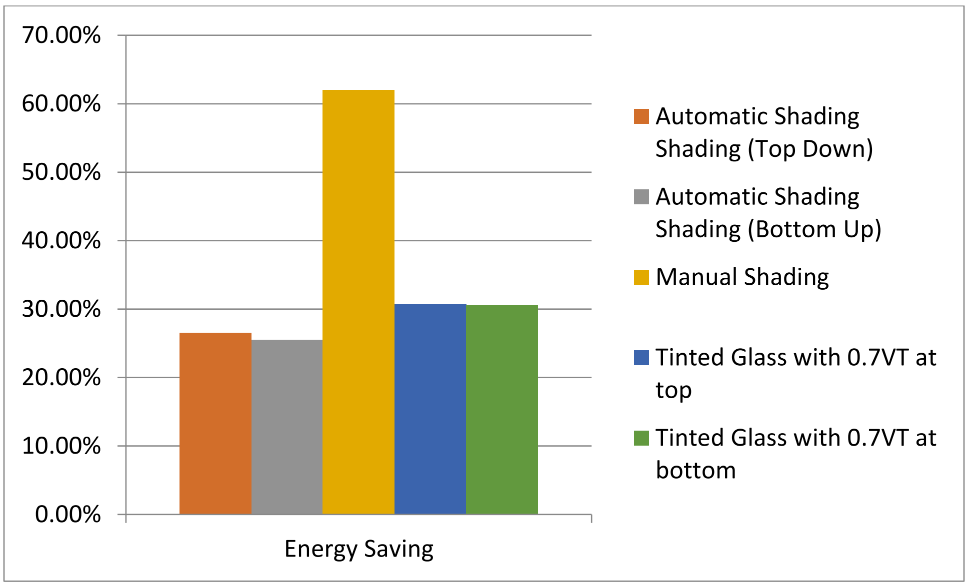


Figure 5.6: Illumination level ratios for 21st June comparing all scenarios

As usual, manual shading seems to be the winner followed by the tinted glass with 0.7 VT at the top, then 0.7 VT at the bottom. Following this is top down automatic shading and finally bottom up automatic shading seems to be the least in lighting level reduction.

Lighting Levels for 21st of September

As the tables portray, automatic top down shading reduces illumination by 18.83% while automatic bottom-up reduces it even further by 21.71%. Manual shading in average reduces lighting level by 58.40% taking into account that most of the time the levels are below 500 lux. For tinted glazing, 0.7 VT on top reduces lighting by 20.03% and the one at the bottom by 20.11%. In general, both tinted glazing configurations give the same result.

Table 5.10: Illumination for Automatic Shading for 21st September

Illumination for **Automatic** Shading for 21st September						
Time	Illumination **without shading** (lux)	Shade Position (m)	Illumination with shading (lux) (Top Down)	Illumination with shading (lux) (Bottom Up)	% of energy saving in regard to Base Case (Top Down)	% of energy saving in regard to Base Case (Bottom UP)
8:30 am	810.71	1.2 m	620.70	613.93	23.44%	24.27%
9:30 am	911.63	1.2 m	768.61	784.87	15.69%	13.90%
10:30 am	993.03	1.2 m	871.13	914.79	12.28%	7.88%
11:30 am	1061.24	1.2 m	967.52	1049.08	8.83%	1.15%
12:30 pm	1096.08	2.4 m	689.50	589.95	37.09%	46.18%
1:30 pm	1084.17	2.4 m	696.98	550.64	35.71%	49.21%
2:30 pm	995.50	1.2 m	882.08	901.49	11.39%	9.44%
3:30 pm	799.28	1.2 m	696.72	665.48	12.83%	16.74%
4:30 pm	524.24	0 m	524.24	409.35	0.00%	21.92%
Average	919.54		746.39	719.95	18.83%	21.71%

Table 5.11: Illumination for Manual Shading for 21st September

Illumination for **Manual** Shading for 21st September				
Time	Illumination **without shading** (lux) (Base Case)	Shade Position (m)	Illumination with shading (lux) (Top Down)	% of energy saving in regard to Base Case
8:30 am	810.71	0 m	810.71	0.00%
9:30 am	911.63	0 m	911.63	0.00%
10:30 am	993.03	0 m	993.03	0.00%
11:30 am	1061.24	4.8 m	154.90	85.40%
12:30 pm	1096.08	4.8 m	160.28	85.38%
1:30 pm	1084.17	4.8 m	149.82	86.18%
2:30 pm	995.50	4.8 m	121.83	87.76%
3:30 pm	799.28	4.8 m	89.48	88.80%
4:30 pm	524.24	4.8 m	51.17	90.24%
Average	919.54		382.54	58.40%

Table 5.12: Illumination for Tinted Glazing for 21st September

Illumination for **Tinted** Glass for 21st September					
Time	Illumination **without shading** (lux) (Base Case)	Tinted Glass with 0.7VT at top (lux)	Tinted Glass with 0.7VT at bottom (lux)	% of energy saving in regard to Base Case VT from top	% of energy saving in regard to Base Case VT from bottom
8:30 am	810.71	523.03	525.12	35.48%	35.23%
9:30 am	911.63	697.39	668.88	23.50%	26.63%
10:30 am	993.03	817.13	830.32	17.71%	16.39%
11:30 am	1061.24	963.07	953.59	9.25%	10.14%
12:30 pm	1096.08	1007.93	1012.19	8.04%	7.65%
1:30 pm	1084.17	936.92	940.81	13.58%	13.22%
2:30 pm	995.50	778.55	802.78	21.79%	19.36%
3:30 pm	799.28	557.78	550.38	30.21%	31.14%
4:30 pm	524.24	336.22	327.12	35.87%	37.60%
Average	919.54	735.34	734.58	20.03%	20.11%

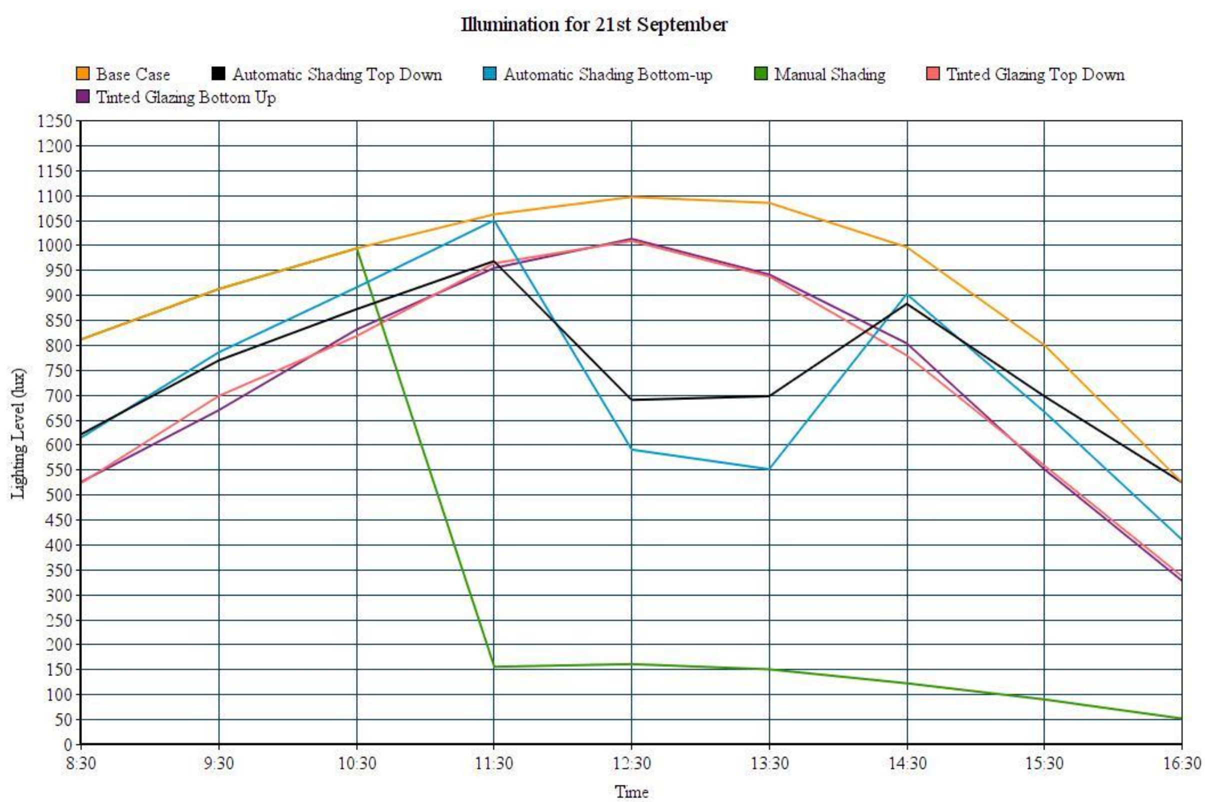


Figure 5.7: Illumination levels for 21st September

Base Case peaks up at 12:30 pm, followed by automatic bottom shading and automatic top down shading. Both of them coincide at different hours throughout the day. They both peak up at 11:30 am yet automatic bottom up is higher than top down. At the same time, they both peak down at 1:30 pm again with the automatic bottom-up shading being lower. Following them is the tinted glazing belonging to both 0.7 VT and top and bottom. They seem to be parabolic just like the Base Case. Manual Shading as always slopes down majorly at 11:30 am and keeps descending even lower until 4:30 pm.

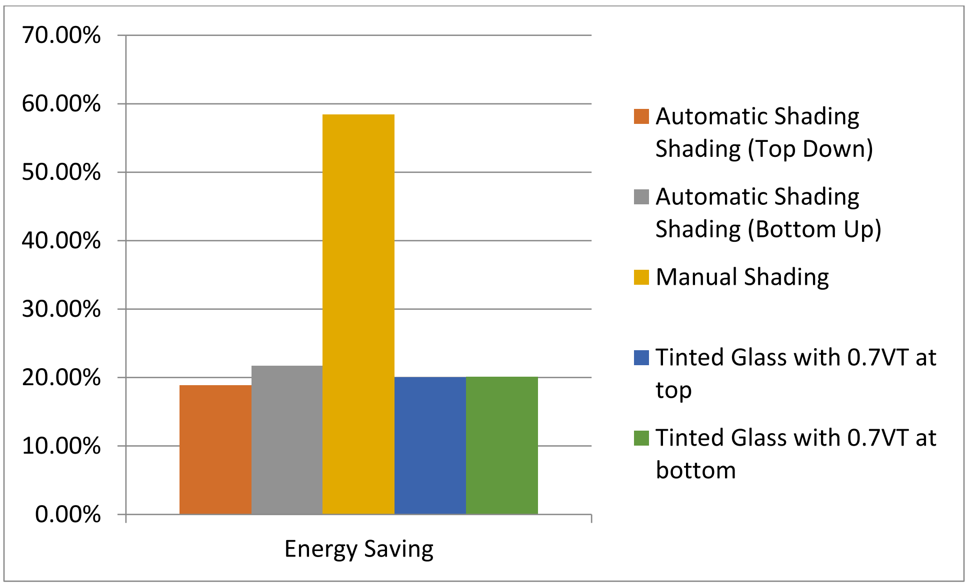


Figure 5.8: Illumination level ratios for 21st September comparing all scenarios

In average for 21st of September, manual shading reduces the highest amount of lighting throughout the day. Following it is bottom up the automatic shading. Right after are both tinted glazing configurations which give the same value, and finally, the top down automatic shading reduces the least amount of lighting throughout the day.

5.2 Solar Heat Gain

Solar Heat Gain for 21st of December

The tables below measure the solar heat gain inside the office space at multiple scenarios. For instance, top down automatic shading saved up to 64.57% of energy while automatic bottom-up shading saved even more and that is 65.21%. The manual shading, on the other hand, saved

50.93% of energy while tinted glazing for both 0.7 VT on top and bottom gave the same result and that is 43.90%.

Table 5.13: Solar Heat Gain for Automatic Shading for 21st December

Solar Heat Gain (kW) for 21st December Automatic Shading						
Time	Base Case	Shade Position (m)	Automatic Shading (Top Down)	Automatic Shading (Bottom Up)	% of energy saving in regard to Base Case (Top Down)	% of energy saving in regard to Base Case (Bottom Up)
8:30 am	3.1532	1.2 m	1.3495	1.3715	57.20%	56.50%
9:30 am	4.9149	1.2 m	2.0915	2.1105	57.45%	57.06%
10:30 am	6.3105	2.4 m	1.8911	1.8934	70.03%	70.00%
11:30 am	7.2242	2.4 m	2.1266	2.1173	70.56%	70.69%
12:30 pm	7.3988	2.4 m	2.1474	2.1405	70.98%	71.07%
1:30 pm	6.7159	2.4 m	1.9965	1.9824	70.27%	70.48%
2:30 pm	5.3920	1.2 m	2.2975	2.3129	57.39%	57.10%
3:30 pm	3.4021	1.2 m	1.4587	1.4867	57.12%	56.30%
4:30 pm	0.6347	0 m	0.6347	0.2895	0.00%	54.39%
Average	5.0163		1.7771	1.745	64.57%	65.21%

Table 5.14: Solar Heat Gain for Manual Shading for 21st December

Solar Heat Gain (kW) for Manual Shading for 21st December				
Time	Base Case	Shade Position (m)	Manual Shading	% of energy saving in regard to Base Case
8:30 am	3.1532	0 m	3.1532	0.00%
9:30 am	4.9149	0 m	4.9149	0.00%
10:30 am	6.3105	0 m	6.3105	0.00%
11:30 am	7.2242	4.8 m	1.8584	74.28%
12:30 pm	7.3988	4.8 m	1.8450	75.06%
1:30 pm	6.7159	4.8 m	1.6338	75.67%
2:30 pm	5.3920	4.8 m	1.3400	75.15%
3:30 pm	3.4021	4.8 m	0.8957	73.67%
4:30 pm	0.6347	4.8 m	0.2003	68.44%
Average	5.0163		2.4613	50.93%

Table 5.15: Solar Heat Gain for Tinted Glazing for 21st December

Solar Heat Gain (kW) Tinted Shading for 21st December					
Time	Base Case	Tinted Glass with 0.7VT at top	Tinted Glass with 0.7VT at bottom	% of energy saving in regard to Base Case VT from top	% of energy saving in regard to Base Case VT from bottom
8:30 am	3.1532	1.7488	1.7488	44.54%	44.54%
9:30 am	4.9149	2.7177	2.7177	44.70%	44.70%
10:30 am	6.3105	3.4903	3.4903	44.69%	44.69%
11:30 am	7.2242	3.9846	3.9846	44.84%	44.84%
12:30 pm	7.3988	4.0526	4.0526	45.23%	45.23%
1:30 pm	6.7159	3.6930	3.6930	45.01%	45.01%
2:30 pm	5.3920	2.9886	2.9886	44.57%	44.57%
3:30 pm	3.4021	1.9086	1.9086	43.90%	43.90%
4:30 pm	0.6347	0.3709	0.3709	41.56%	41.56%
Average	5.0163	2.7728	2.7728	44.72%	44.72%

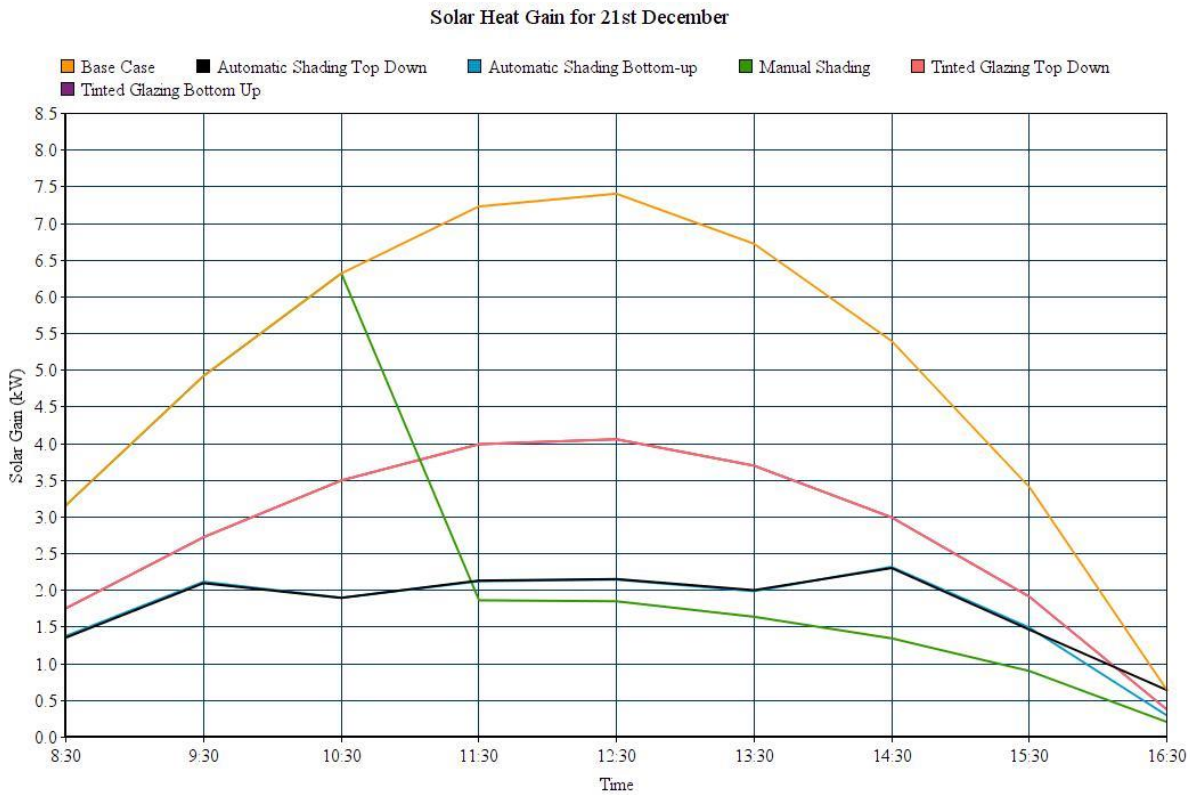


Figure 5.9: Solar Heat Gain for 21st December

As observed from the figure 5.9, Base Case is taken as the greatest contributor to excessive solar gain. Following that is the tinted glazing with both itself and the base case peaking at 12:30 pm. Automatic top down shading peaks at 2:30 pm along with bottom up, only at 4:30 pm the latter has a fewer amount of solar gain. Manual shading slopes down at 11:30 am, and keeps descending until 4:30 pm at the end of the day.

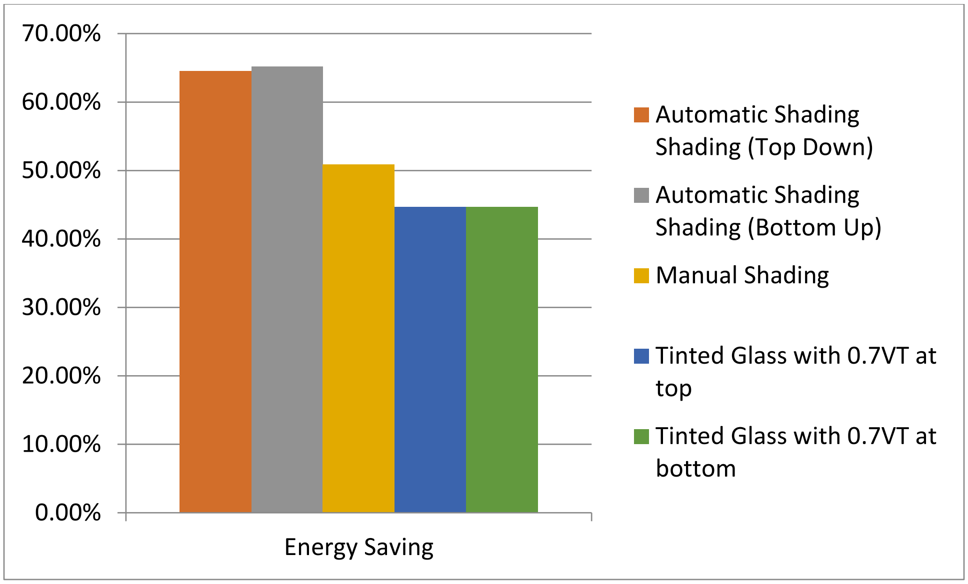


Figure 5.10: Solar Heat Gain saving for 21st December comparing all scenarios

From the figure 5.10, one can deduce that bottom up automatic shading saves the biggest amount of energy when comparing it to the rest. Automatic top down shading comes next, followed by manual shading. The least energy savers are tinted glazing with 0.7 VT at top and bottom.

Solar Heat Gain for 21st March

In the case of 21st of March, automatic top down shading saves up 59.34% of energy. Automatic bottom up shading saves slightly more and that is 57.87%. In the case of manual shading, it saves up 56.80% of energy and that is less than the values above. Tinted glazing belonging to 0.7 VT at top and bottom save up the least amount of energy which is 47.38%.

Table 5.16: Solar Heat Gain for Automatic Shading for 21st March

Solar Heat Gain (kW) for 21st March Automatic Shading						
Time	Base Case	Shade Position (m)	Automatic Shading (Top Down)	Automatic Shading (Bottom Up)	% of energy saving in regard to Base Case (Top Down)	% of energy saving in regard to Base Case (Bottom Up)
8:30 am	1.4181	1.2 m	0.5801	0.5708	59.09%	59.75%
9:30 am	2.5660	1.2 m	1.0620	1.0400	58.61%	59.47%
10:30 am	3.7981	1.2 m	1.5300	1.5135	59.72%	60.15%
11:30 am	4.8261	1.2 m	1.9183	1.9113	60.25%	60.40%
12:30 pm	5.2638	1.2 m	2.0938	2.0913	60.22%	60.27%
1:30 pm	5.0665	1.2 m	2.0565	2.0540	59.41%	59.46%
2:30 pm	4.3049	1.2 m	1.7809	1.7827	58.63%	58.59%
3:30 pm	3.0709	1.2 m	1.2845	1.2938	58.17%	57.87%
4:30 pm	1.6150	1.2 m	0.6774	0.6916	58.06%	57.18%
Average	3.5477		1.4426	1.4388	59.34%	59.44%

Table 5.17: Solar Heat Gain for Manual Shading for 21st March

Solar Heat Gain (kW) Manual Shading for 21st March				
Time	Base Case	Shade Position (m)	Manual Shading	% of energy saving in regard to Base Case
8:30 am	1.4181	0 m	1.4181	0.00%
9:30 am	2.5660	0 m	2.5660	0.00%
10:30 am	3.7981	0 m	3.7981	0.00%
11:30 am	4.8261	4.8 m	1.1705	75.75%
12:30 pm	5.2638	4.8 m	1.2763	75.75%
1:30 pm	5.0665	4.8 m	1.2504	75.32%
2:30 pm	4.3049	4.8 m	1.0880	74.73%
3:30 pm	3.0709	4.8 m	0.7953	74.10%
4:30 pm	1.6150	4.8 m	0.4306	73.34%
Average	3.5477		1.5326	56.80%

Table 5.18: Solar Heat Gain for Tinted Glazing for 21st March

Solar Heat Gain (kW) Tinted Shading for 21st March					
Time	Base Case	Tinted Glass with 0.7VT at top	Tinted Glass with 0.7VT at bottom	% of energy saving in regard to Base Case VT from top	% of energy saving in regard to Base Case VT from bottom
8:30 am	1.4181	0.7430	0.7430	47.61%	47.61%
9:30 am	2.5660	1.3514	1.3514	47.33%	47.33%
10:30 am	3.7981	1.9684	1.9684	48.17%	48.17%
11:30 am	4.8261	2.4940	2.4940	48.32%	48.32%
12:30 pm	5.2638	2.7308	2.7308	48.12%	48.12%
1:30 pm	5.0665	2.6723	2.6723	47.26%	47.26%
2:30 pm	4.3049	2.3053	2.3053	46.45%	46.45%
3:30 pm	3.0709	1.6600	1.6600	45.94%	45.94%
4:30 pm	1.6150	0.8765	0.8765	45.73%	45.73%
Average	3.5477	1.8669	1.8669	47.38%	47.38%

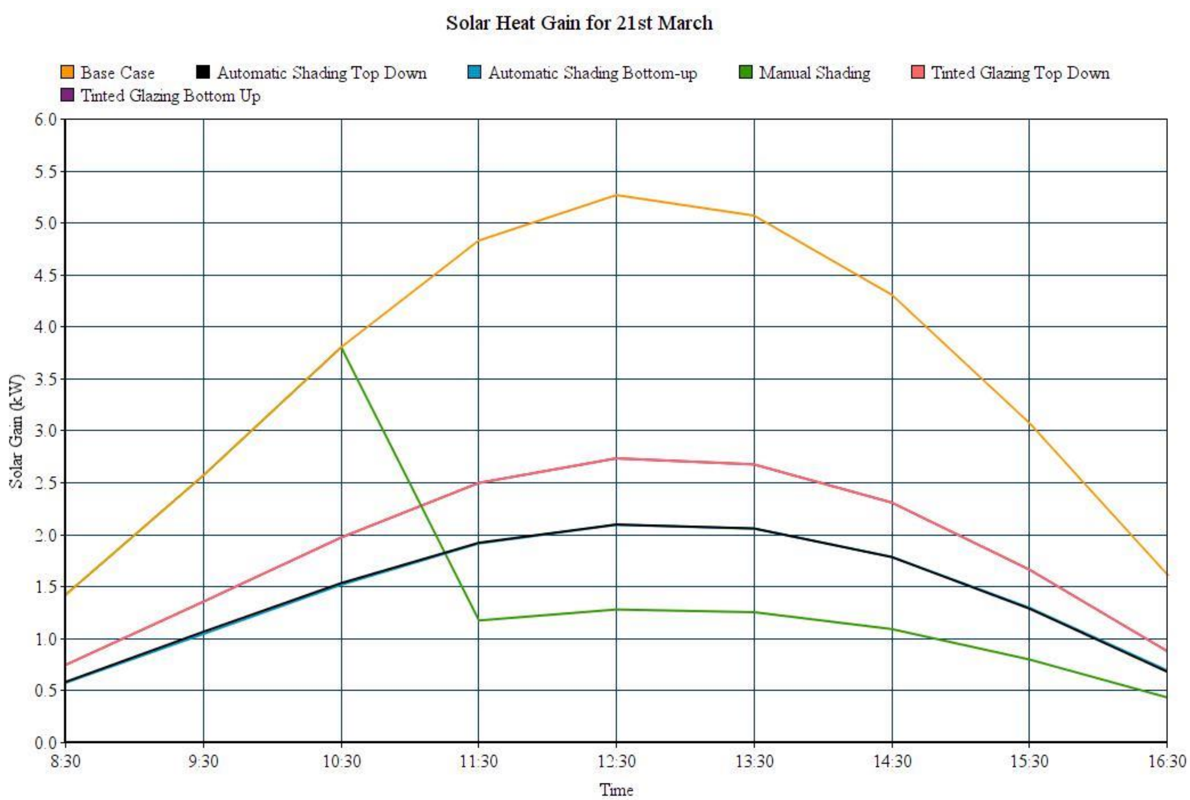


Figure 5.11: Solar Heat Gain for 21st March

The figure 5.11 identifies the base case right on top followed by tinted glazing belonging to 0.7 VT on top and 0.7 VT at the bottom. They both are parabolic and tend to peak up at 12:30 pm. Following them are automatic top down and bottom up shading where their curves overlap. In the case of manual shading, it rises up at 10:30, and drops down majorly at 11:30, then keeps descending in a parabolic manner.

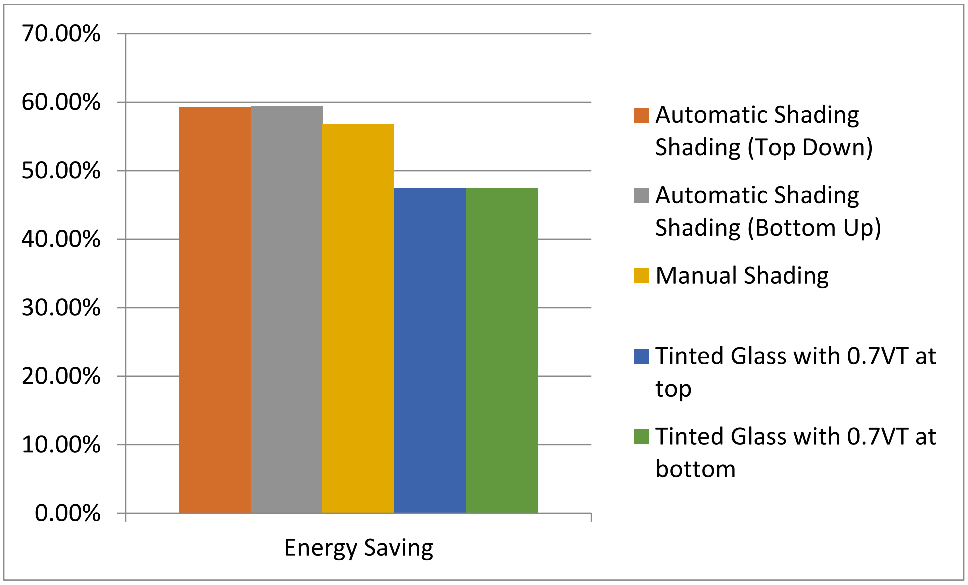


Figure 5.12: Solar Heat Gain saving for 21st March comparing all scenarios

In the figure 5.12, the greatest contributor to energy saving is automatic shading in general. Both top down and bottom up save up almost the same energy amount. Following them is the manual shading, and finally the tinted shading.

<u>Solar Heat Gain for 21st of June</u>

On the day of 21st of June, automatic top down shading saves up 62.37% of solar heat gain while automatic bottom-up shading is pretty close which is 62.91%. Manual shading saves up 59.80% which is a bit lower than the automatic shading in all. Tinted glazing with 0.7 VT located at the bottom and top save up 50.90% of solar heat gain.

Table 5.19: Solar Heat Gain for Automatic Shading for 21st June

Solar Heat Gain (kW) for 21st June Automatic Shading						
Time	Base Case	Shade Position (m)	Automatic Shading (Top Down)	Automatic Shading (Bottom Up)	% of energy saving in regard to Base Case (Top Down)	% of energy saving in regard to Base Case (Bottom Up)
8:30 am	0.7478	1.2 m	0.3061	0.3061	59.07%	59.07%
9:30 am	0.8509	1.2 m	0.3472	0.3472	59.20%	59.20%
10:30 am	0.9679	1.2 m	0.3945	0.3945	59.24%	59.24%
11:30 am	1.2049	2.4 m	0.3549	0.3293	70.55%	72.67%
12:30 pm	1.6088	1.2 m	0.5932	0.5913	63.13%	63.25%
1:30 pm	1.8222	1.2 m	0.6695	0.6637	63.26%	63.58%
2:30 pm	1.6976	1.2 m	0.6454	0.6322	61.98%	62.76%
3:30 pm	1.3888	1.2 m	0.5417	0.5304	61.00%	61.81%
4:30 pm	1.0103	1.2 m	0.3991	0.3966	60.50%	60.74%
Average	1.2555		0.4724	0.4657	62.37%	62.91%

Table 5.20: Solar Heat Gain for Manual Shading for 21st June

Solar Heat Gain (kW) Manual Shading for 21st June				
Time	Base Case	Shade Position (m)	Manual Shading	% of energy saving in regard to Base Case
8:30 am	0.7478	0 m	0.7478	0.00%
9:30 am	0.8509	0 m	0.8509	0.00%
10:30 am	0.9679	0 m	0.9679	0.00%
11:30 am	1.2049	4.8 m	0.2759	77.10%
12:30 pm	1.6088	4.8 m	0.3584	77.72%
1:30 pm	1.8222	4.8 m	0.4058	77.73%
2:30 pm	1.6976	4.8 m	0.3854	77.30%
3:30 pm	1.3888	4.8 m	0.3191	77.02%
4:30 pm	1.0103	4.8 m	0.2311	77.13%
Average	1.2555		0.5047	59.80%

Table 5.21: Solar Heat Gain for Tinted Glazing for 21st June

Solar Heat Gain (kW) Tinted Shading for 21st June					
Time	Base Case	Tinted Glass with 0.7VT at top	Tinted Glass with 0.7VT at bottom	% of energy saving in regard to Base Case VT from top	% of energy saving in regard to Base Case VT from bottom
8:30 am	0.7478	0.3966	0.3966	46.96%	46.96%
9:30 am	0.8509	0.4497	0.4497	47.15%	47.15%
10:30 am	0.9679	0.5109	0.5109	47.22%	47.22%
11:30 am	1.2049	0.6121	0.6121	49.20%	49.20%
12:30 pm	1.6088	0.7688	0.7688	52.21%	52.21%
1:30 pm	1.8222	0.8640	0.8640	52.58%	52.58%
2:30 pm	1.6976	0.8227	0.8227	51.54%	51.54%
3:30 pm	1.3888	0.6895	0.6895	50.35%	50.35%
4:30 pm	1.0103	0.5145	0.5145	49.07%	49.07%
Average	1.2555	0.6254	0.6254	50.19%	50.19%

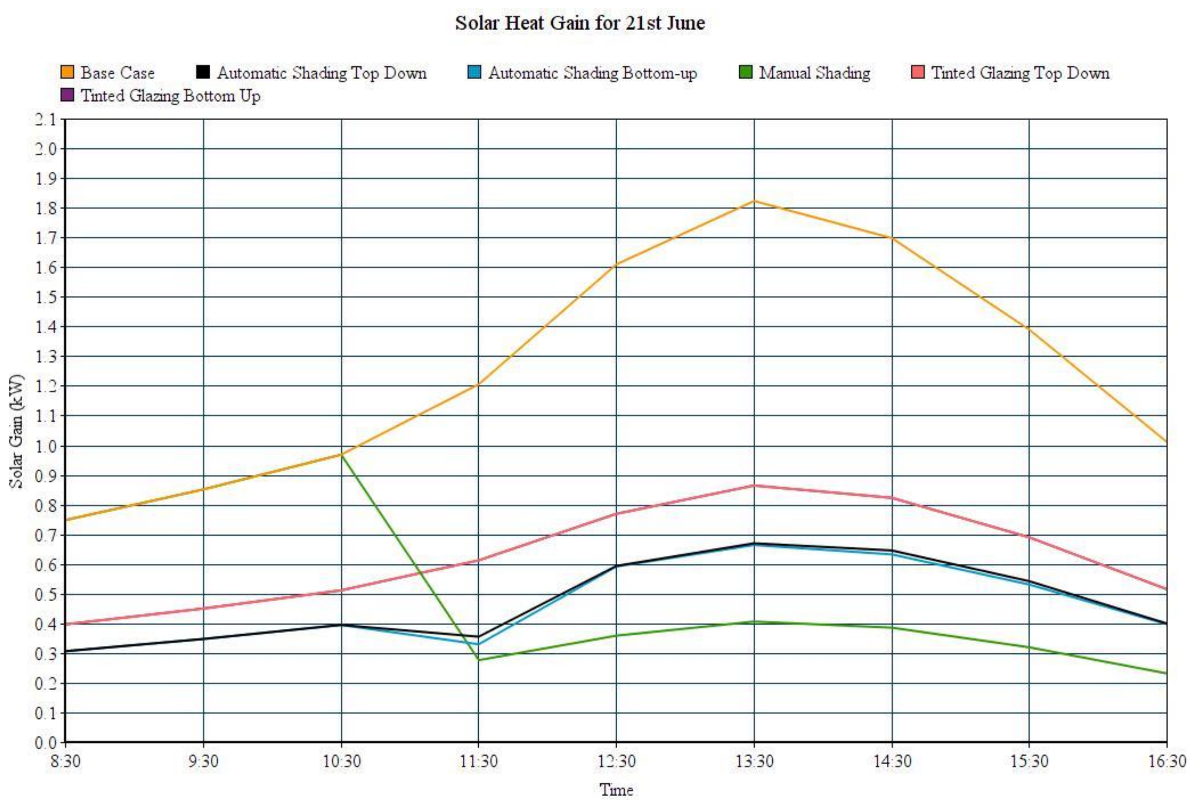


Figure 5.13: Solar Heat Gain for 21st June

In the figure 5.13 it is observed that tinted glazing, automatic, and manual shading have a much lower slope than that belonging to Base Case. When talking about the peak hour and this is at 1:30 pm, tinted glazing has the most solar gain, followed by both automatic shades, and finally, the lowest solar gain is the manual shading which slopes downwards until 4:30 pm.

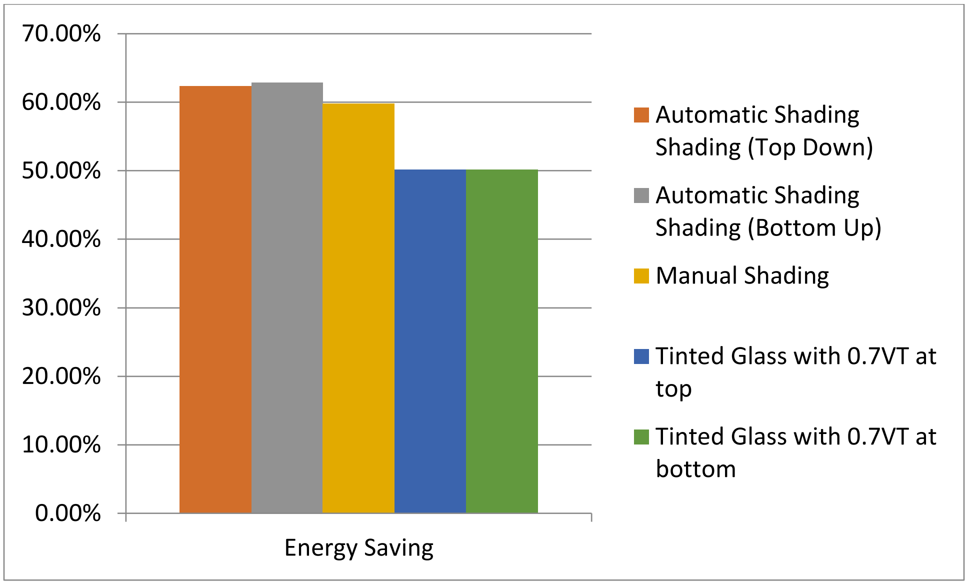


Figure 5.14: Solar Heat Gain saving for 21st June comparing all scenarios

According to the figure 5.14, bottom up automatic shading saves most of the energy; slightly below it is top down automatic shading, followed by manual shading. The least energy conserving are both tinted glazing belonging to 0.7 VT situated at top and bottom.

Solar Heat Gain for 21st of September

In the tables below, automatic top down shading seems to save up 58.23% of solar heat gain followed by bottom-up automatic shading which saves slightly above it by only 0.36%. The manual shading here saves up 64% while tinted glazing saves the least and that is only 48%.

Table 5.22: Solar Heat Gain for Automatic Shading for 21st September

Solar Heat Gain (kW) for 21st September Automatic Shading						
Time	Base Case	Shade Position (m)	Automatic Shading (Top Down)	Automatic Shading (Bottom Up)	% of energy saving in regard to Base Case (Top Down)	% of energy saving in regard to Base Case (Bottom Up)
8:30 am	0.7907	1.2 m	0.3157	0.3141	60.07%	60.28%
9:30 am	1.5603	1.2 m	0.6223	0.6061	60.12%	61.15%
10:30 am	2.6632	1.2 m	1.0976	1.0643	58.79%	60.04%
11:30 am	3.9538	1.2 m	1.5824	1.5592	59.98%	60.56%
12:30 pm	4.6286	2.4 m	1.2634	1.2548	72.70%	72.89%
1:30 pm	4.7842	2.4 m	1.3153	1.3102	72.51%	72.61%
2:30 pm	4.6933	1.2 m	1.9083	1.8977	59.34%	59.57%
3:30 pm	3.9466	1.2 m	1.6409	1.6335	58.42%	58.61%
4:30 pm	2.6459	0 m	2.6459	2.6459	0.00%	0.00%
Average	3.2963		1.3769	1.3651	58.23%	58.59%

Table 5.23: Solar Heat Gain for Manual Shading for 21st September

Solar Heat Gain (kW) Manual Shading for 21st September				
Time	Base Case	Shade Position (m)	Manual Shading	% of energy saving in regard to Base Case
8:30 am	0.7907	0 m	0.7907	0.00%
9:30 am	1.5603	0 m	1.5603	0.00%
10:30 am	2.6632	0 m	2.6632	0.00%
11:30 am	3.9538	4.8 m	0.9062	77.08%
12:30 pm	4.6286	4.8 m	1.0379	77.58%
1:30 pm	4.7842	4.8 m	1.0760	77.51%
2:30 pm	4.6933	4.8 m	1.0779	77.03%
3:30 pm	3.9466	4.8 m	0.9292	76.46%
4:30 pm	2.6459	4.8 m	0.6400	75.81%
Average	3.2963		1.1868	64.00%

Table 5.24: Solar Heat Gain for Tinted Glazing for 21st September

Solar Heat Gain (kW) Tinted Shading for 21st September					
Time	Base Case	Tinted Glass with 0.7VT at top	Tinted Glass with 0.7VT at bottom	% of energy saving in regard to Base Case VT from top	% of energy saving in regard to Base Case VT from bottom
8:30 am	0.7907	0.4075	0.4075	48.46%	48.46%
9:30 am	1.5603	0.7891	0.7891	49.43%	49.43%
10:30 am	2.6632	1.3839	1.3839	48.04%	48.04%
11:30 am	3.9538	2.0297	2.0297	48.66%	48.66%
12:30 pm	4.6286	2.3580	2.3580	49.06%	49.06%
1:30 pm	4.7842	2.4573	2.4573	48.64%	48.64%
2:30 pm	4.6933	2.4629	2.4629	47.52%	47.52%
3:30 pm	3.9466	2.1053	2.1053	46.66%	46.66%
4:30 pm	2.6459	1.4332	1.4332	45.83%	45.83%
Average	3.2963	1.7141	1.7141	48.00%	48.00%

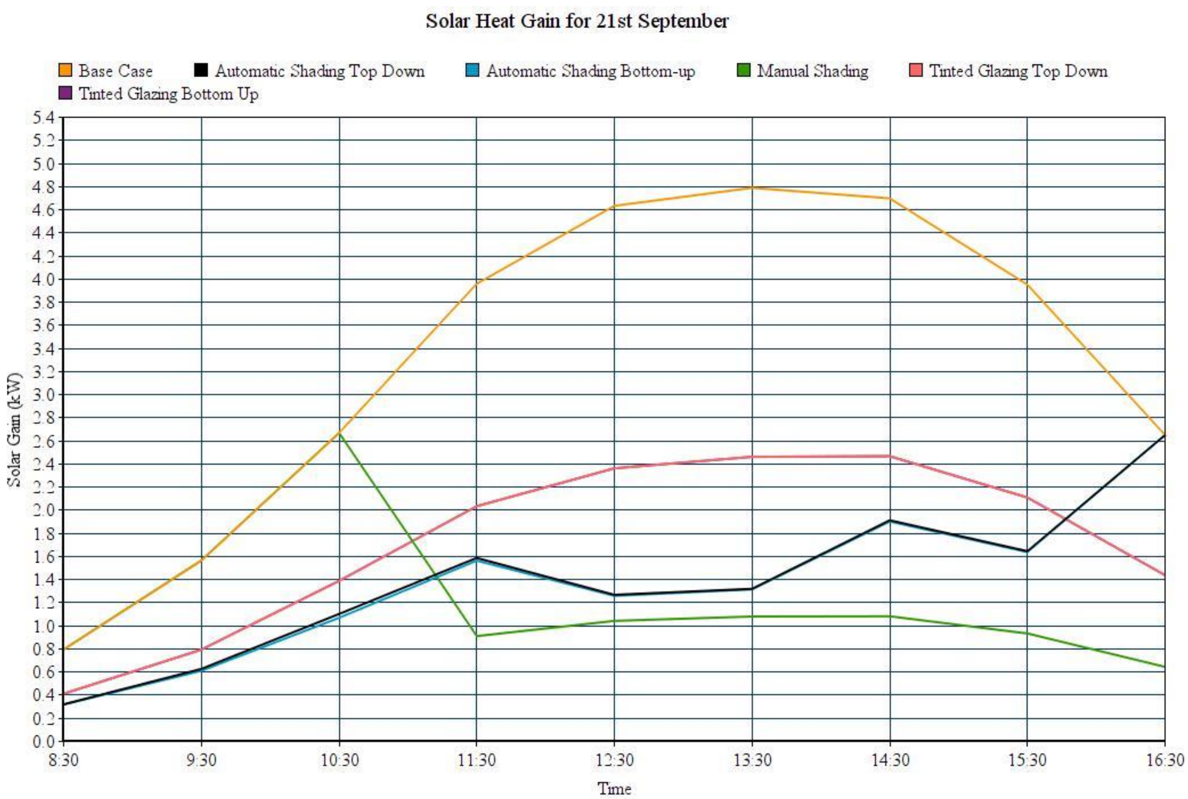


Figure 5.15: Solar Heat Gain for 21st September

Observing the figure 5.15; energy consumption peaks most at 1:30 for Base Case. Right below it is the tinted shading belonging to 0.7 VT located at both bottom and top of the glazing. Following them are the automatic shadings which overlap each other. They peak at 2:30 and at 4:30 where the shading disappears and solar heat gain return to Base Case. Finally, in manual shading, there is a huge slope that occurs at 11:30 am as usual and keeps sloping downwards.

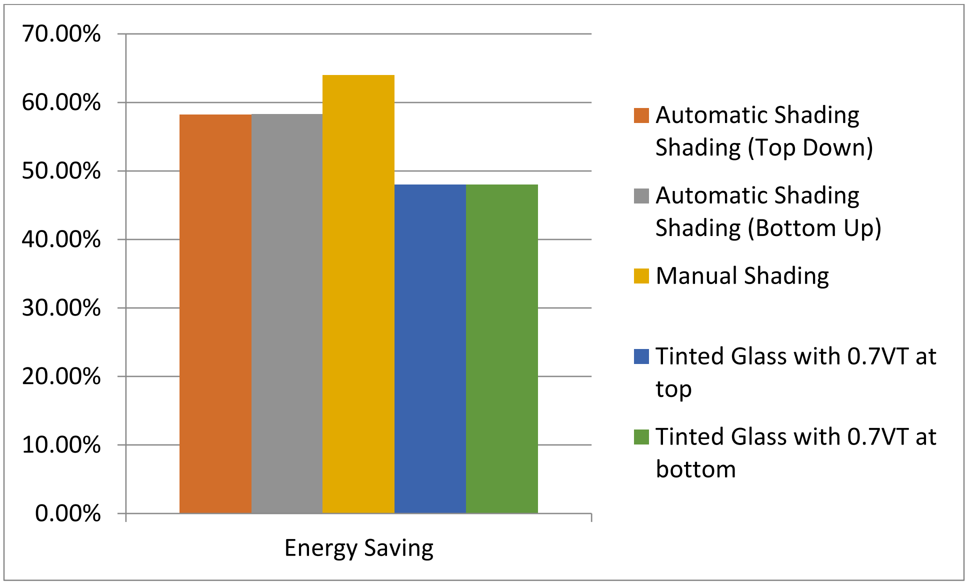
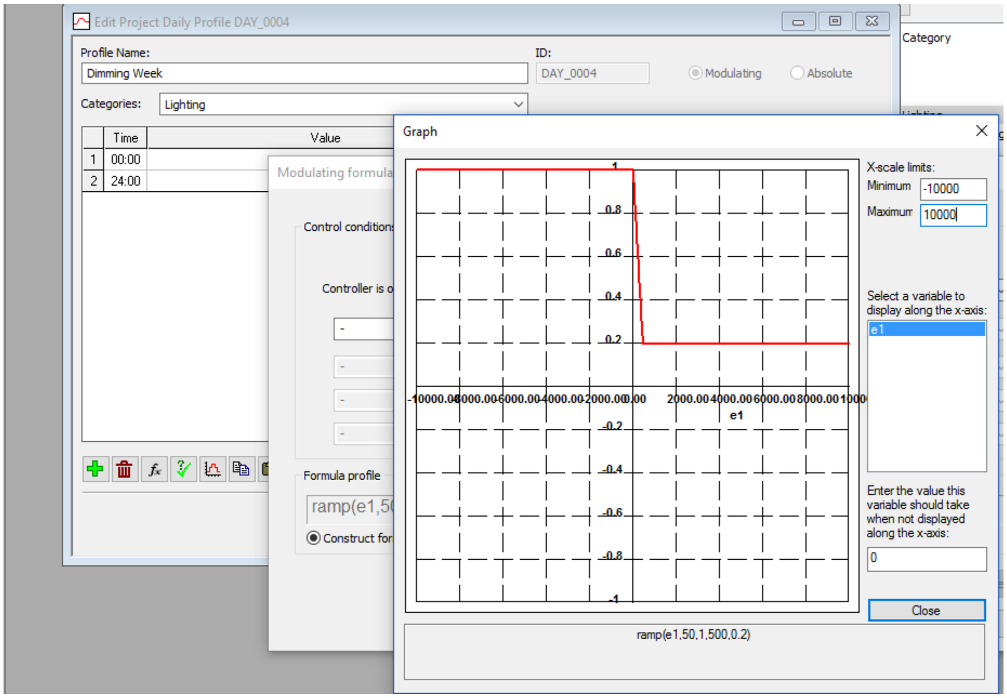


Figure 5.16: Solar Heat Gain saving for 21st September comparing all scenarios

According to the figure 5.16, Manual shading saves the greatest amount of solar heat gain inside the office space. Following that are both top down and bottom up automatic shadings. Finally are both tinted shading configurations.

5.3 Electrical Consumption

In the results below; three new columns have been added. They are the ones which include a light sensor which is responsible for the dimming of light whenever the light level reaches above 500 lux in the office. It is imperative to add that in the experiment above where **no light sensor is used**, it is expected that the electric lights in the office are turned on continuously. In order to carry out that experiment, a new daily profile is created on IES VE which took into consideration the dimming of lights following this formula: ramp(e1,50,1.0,500,0.2) figure 5.17. It explains that when the light level in the office is 500 lux or below, all the lights in the office are turned on. When it reaches 500 lux or above, only 0.2% of the electric lighting emitted from the luminaries is present. Not to mention that a light sensor is added to the office space right in the middle of it. That is performed in Radiance IES and an Apache analysis is performed on it.



	Time	Value
1	00:00	ramp(e1,50,1,500,0.2)
2	24:00	ramp(e1,50,1,500,0.2)

Figure 5.17: Displaying the graph corresponding to formula ramp(e1,50,1.0,500,0.2)

<u>Electrical Consumption for 21st of December</u>

The tables below portray the electrical consumption that took place from 8:30 am till 4:30 pm and the percentage of energy saving that occurred in regard to Base Case results. Now automatic top down shading saved 12.44% of electricity while automatic top down shading with sensor saved up more and that is 13.32%. Automatic bottom up shading saved up 12.12% and that is less than the above two, while automatic bottom-up shading with sensor saved up 12.42%. In the case of manual shading, it saved up 52.26% of electricity, the one with sensor saved up 52.46% which is more. Tinted glazing belonging to 0.7 VT situated at the top and 0.7 VT situated at the bottom gave the result; 4.96%. This explains that they consumed the most of the electricity when comparing them to all of the above.

Table 5.25: Electrical Consumption for Automatic Shading for 21st December

Electrical Consumption (kW) for 21st December Automatic Shading						
Time	Base Case	Shade Position (m)	Automatic Shading (Top Down)	Automatic Shading (**with light sensor**) (Top Down)	Automatic Shading (Bottom Up)	Automatic Shading **(with light sensor)** (Bottom Up)
8:30 am	0.9291	1.2 m	0.9920	0.9754	0.9824	0.9658
9:30 am	3.5828	1.2 m	3.3046	3.2856	3.2856	3.2666
10:30 am	5.9300	2.4 m	5.0042	4.9104	5.0195	5.0005
11:30 am	7.5880	2.4 m	6.4460	6.3527	6.4852	6.4664
12:30 pm	8.3581	2.4 m	7.1262	7.0332	7.1827	7.1640
1:30 pm	8.2782	2.4 m	7.0256	6.9328	7.0879	7.0692
2:30 pm	7.6722	1.2 m	6.8247	6.8061	6.8449	6.8263
3:30 pm	6.1712	1.2 m	5.4962	5.4777	5.4923	5.4738
4:30 pm	2.0465	0 m	2.0465	2.0465	2.0465	2.0465
Average	5.6173		4.9184	4.8689	4.9363	4.9199
% of energy saving in regard to Base Case	0%		12.44%	13.32%	12.12%	12.42%

Table 5.26: Electrical Consumption for Manual Shading for 21st December

Electrical Consumption for Manual Shading for 21st December (kW)				
Time	Base Case	Shade Position (m)	with Manual Shading (kW)	With Manual Shading **and sensor** (kW)
8:30 am	0.9291	0 m	0.9291	0.9291
9:30 am	3.5828	0 m	3.5828	3.5828
10:30 am	5.9300	0 m	5.9300	5.9300
11:30 am	7.5880	4.8 m	2.5856	2.5645
12:30 pm	8.3581	4.8 m	3.1204	3.1001
1:30 pm	8.2782	4.8 m	2.9751	2.9552
2:30 pm	7.6722	4.8 m	2.6384	2.6186
3:30 pm	6.1712	4.8 m	1.9150	1.8954
4:30 pm	2.0465	4.8 m	0.4604	0.4580
Average	5.6173		2.6819	2.6704
% of energy saving in regard to Base Case	0%		52. 26%	52.46%

Table 5.27: Electrical Consumption for Tinted Glazing for 21st December

Electrical Consumption for Tinted Glass for 21st December (kW)			
Time	Base Case	Tinted Glass with 0.7VT at top	Tinted Glass with 0.7VT at bottom
8:30 am	0.9291	1.1301	1.1301
9:30 am	3.5828	3.5640	3.5640
10:30 am	5.9300	5.6667	5.6667
11:30 am	7.5880	7.1882	7.1882
12:30 pm	8.3581	7.8908	7.8908
1:30 pm	8.2782	7.7671	7.7671
2:30 pm	7.6722	7.1519	7.1519
3:30 pm	6.1712	5.7502	5.7502
4:30 pm	2.0465	1.9389	1.9389
Average	5.6173	5.3387	5.3387
% of energy saving in regard to Base Case	0%	4.96%	4.96%

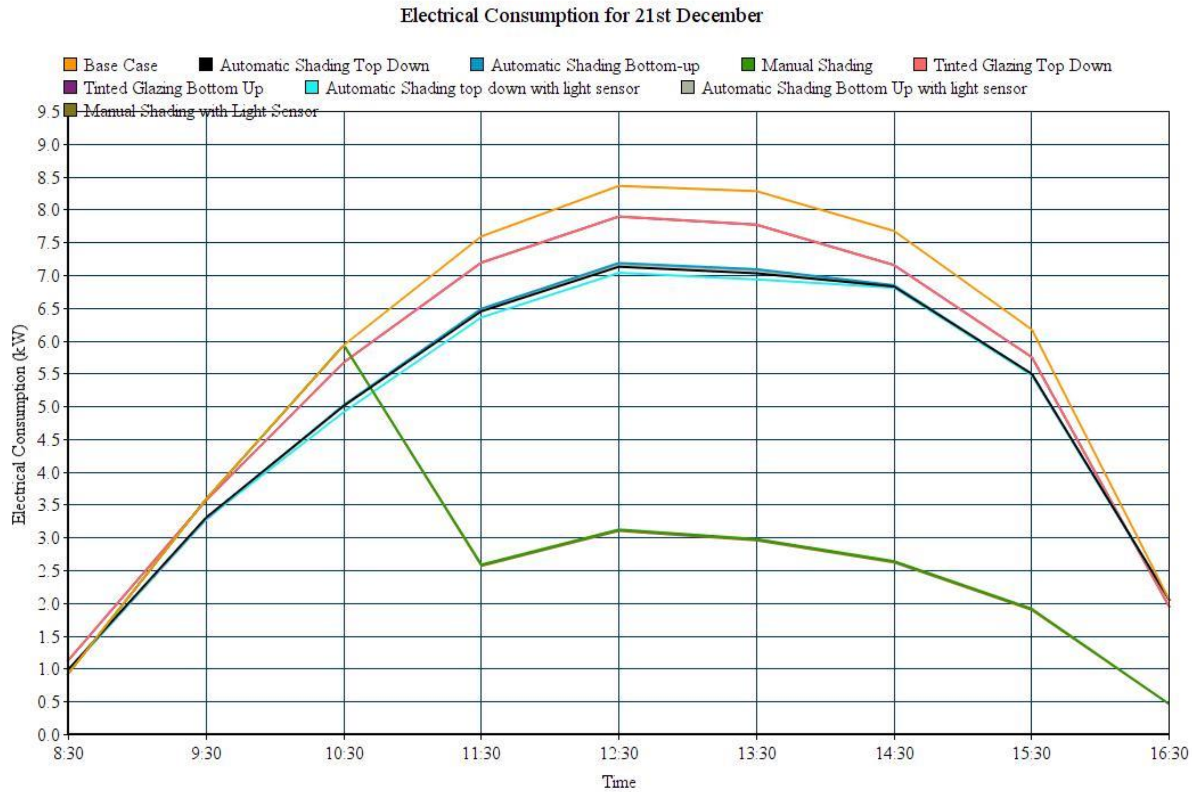


Figure 5.18: Electrical Consumption for 21st December

Base Case uses up most of the electricity which peaks at 12:20 pm. Following it is the tinted glazing, and then the automatic shadings right below. They all seem to be consuming electricity in ranges that are not too far away from each other. Manual glazing with a light sensor and without seem to overlap. They consume the least electrical output and slope downwards until 4:30 pm.

One needs to take into account that here the shades fully close between 11:30 am until 4:00 pm. Then they remain open for the rest of the day. Perhaps if they alternate or close at a different time the results would change. In this case in particular the following figure is added to explain the results. Figure 5.19 shows the contrast between manual shading with sensor each in comparison and daylight illuminance on 21st of December.

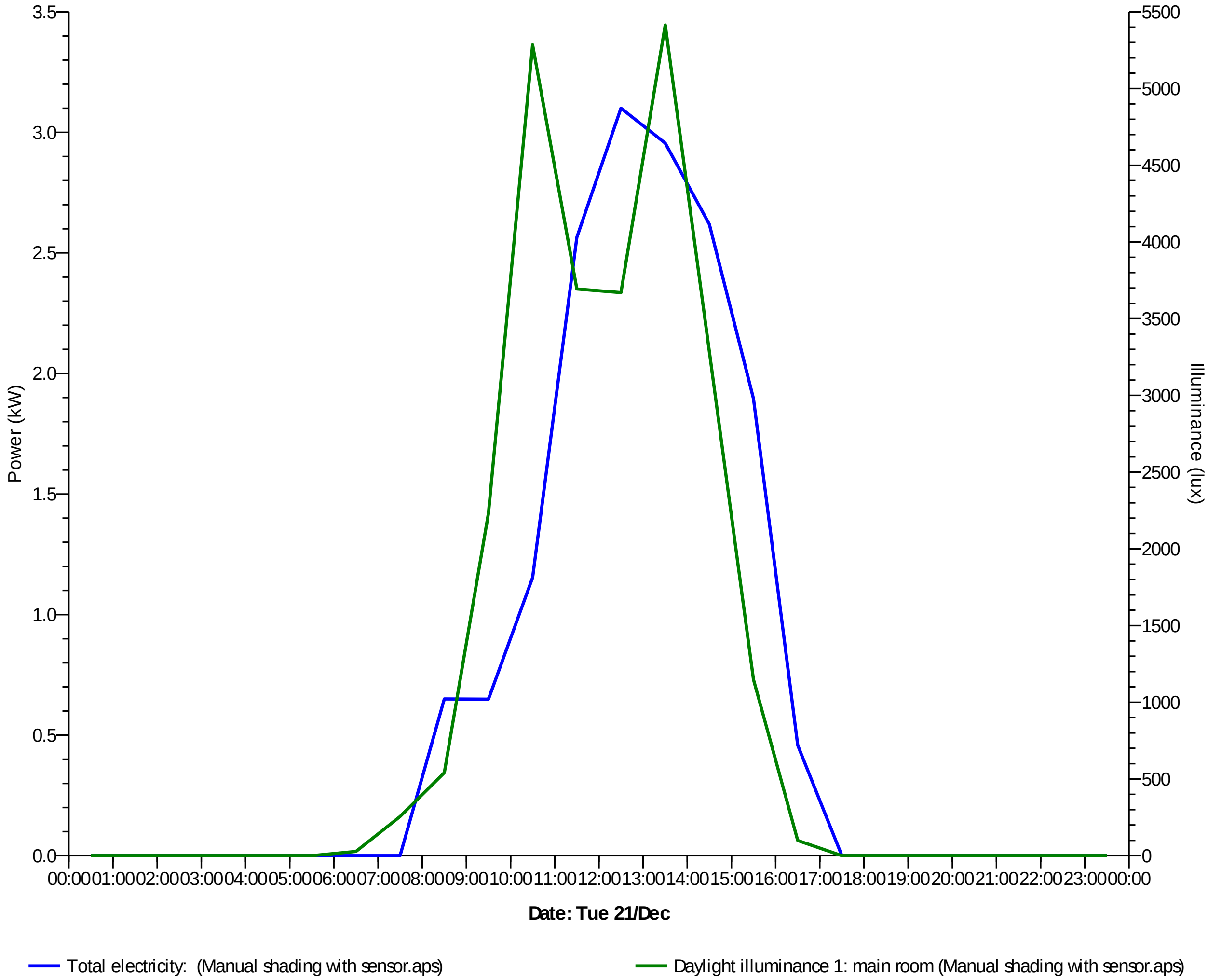


Figure 5.19 : Total electricity consumption for manual shading with light sensor for 21st Dec.

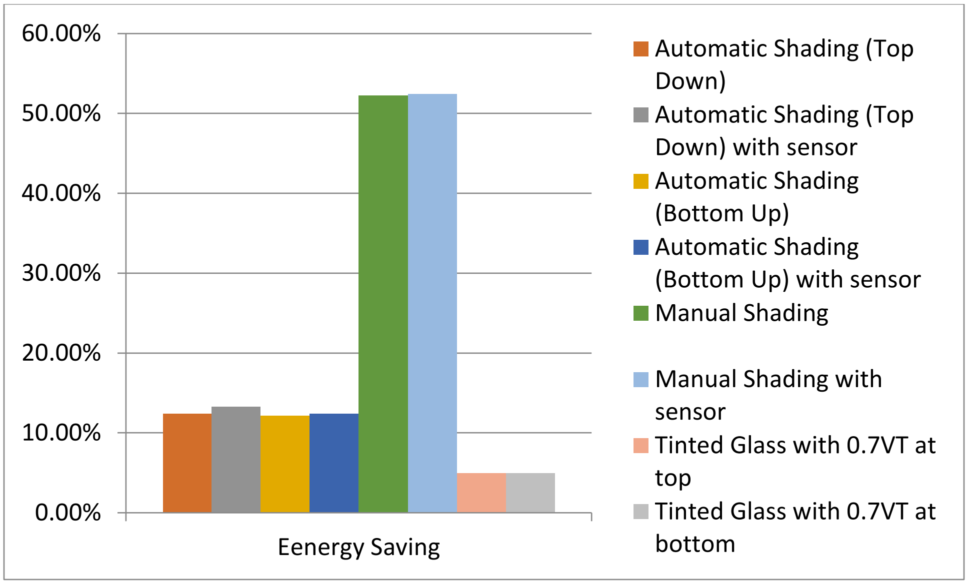


Figure 5.20: Energy saving for 21st December comparing all scenarios

According to the figure 5.19, manual shading with light sensor saves most of the electricity consumption. Slightly below it is the manual shading. After them is the top down automatic shading with a light sensor. Following them, almost the same level are automatic top down shading without the light sensor, automatic bottom-up shading with a light sensor and without.

<u>Electrical Consumption for 21st of March</u>

The following tables show that automatic top down shading saves up 7.99% of electricity, while the later yet with a light sensor saves up 8.28% of electricity. Automatic bottom up shading saves 7.83% while the one with sensor saves 8.23%. In the case of manual shading, it saves 55.07% of electricity and 55.35% when the sensor is added. Tinted glazing saves up 22.26%.

Table 5.28: Electrical Consumption for Automatic Shading for 21st March

Electrical Consumption (kW) for 21st March Automatic Shading						
Time	Base Case	Shade Position (m)	Automatic Shading (Top Down)	Automatic Shading **(with light sensor)** (Top Down)	Automatic Shading (Bottom Up)	Automatic Shading **(with light sensor)** (Bottom Up)
8:30 am	1.1838	1.2 m	1.3632	1.3442	1.3601	1.3412
9:30 am	2.7594	1.2 m	2.6421	2.6231	2.6453	2.6264
10:30 am	4.1182	1.2 m	3.8277	3.8089	3.8381	3.8193
11:30 am	5.3545	1.2 m	4.9314	4.9127	4.9395	4.9208
12:30 pm	6.1503	1.2 m	5.6430	5.6244	5.6457	5.6270
1:30 pm	6.5496	1.2 m	5.9413	5.9662	5.9510	5.9323
2:30 pm	6.3952	1.2 m	5.7344	5.7158	5.7529	5.7343
3:30 pm	5.5443	1.2 m	4.9657	4.9471	4.9787	4.9601
4:30 pm	2.2394	1.2 m	2.0253	2.0160	2.0275	2.0182
Average	4.4772		4.1193	4.1065	4.1265	4.1088
% of energy saving in regard to Base Case	0%		7.99%	8.28%	7.83%	8.23%

Table 5.29: Electrical Consumption for Manual Shading for 21st March

Electrical Consumption for 21st March (kW) Manual Shading				
Time	Base Case	Shade Position (m)	with Manual Shading (kW)	With Manual Shading and sensor (kW)
8:30 am	1.1838	0 m	1.1838	1.1838
9:30 am	2.7594	0 m	2.7594	2.7594
10:30 am	4.1182	0 m	4.1182	4.1182
11:30 am	5.3545	4.8 m	1.1430	1.1230
12:30 pm	6.1503	4.8 m	1.9503	1.9282
1:30 pm	6.5496	4.8 m	2.2807	2.2597
2:30 pm	6.3952	4.8 m	2.2295	2.2090
3:30 pm	5.5443	4.8 m	1.8020	1.7818
4:30 pm	2.2394	4.8 m	0.6357	0.6269
Average	4.4772		2.0114	1.9989
% of energy saving in regard to Base Case	0%		55.07%	55.35%

Table 5.30: Electrical Consumption for Tinted Glazing for 21st March

Electrical Consumption for Tinted Glass for 21st March (kW)			
Time	Base Case	Tinted Glass with 0.7VT at top	Tinted Glass with 0.7VT at bottom (lux)
8:30 am	0.9291	1.5958	1.5958
9:30 am	3.5828	2.8770	2.8770
10:30 am	5.9300	4.0857	4.0857
11:30 am	7.5880	5.2114	5.2114
12:30 pm	8.3581	5.9313	5.9313
1:30 pm	8.2782	6.2383	6.2383
2:30 pm	7.6722	6.0246	6.0246
3:30 pm	6.1712	5.2134	5.2134
4:30 pm	2.0465	2.1242	2.1242
Average	5.6173	4.3669	4.3669
% of energy saving in regard to Base Case	0%	22.26%	22.26%

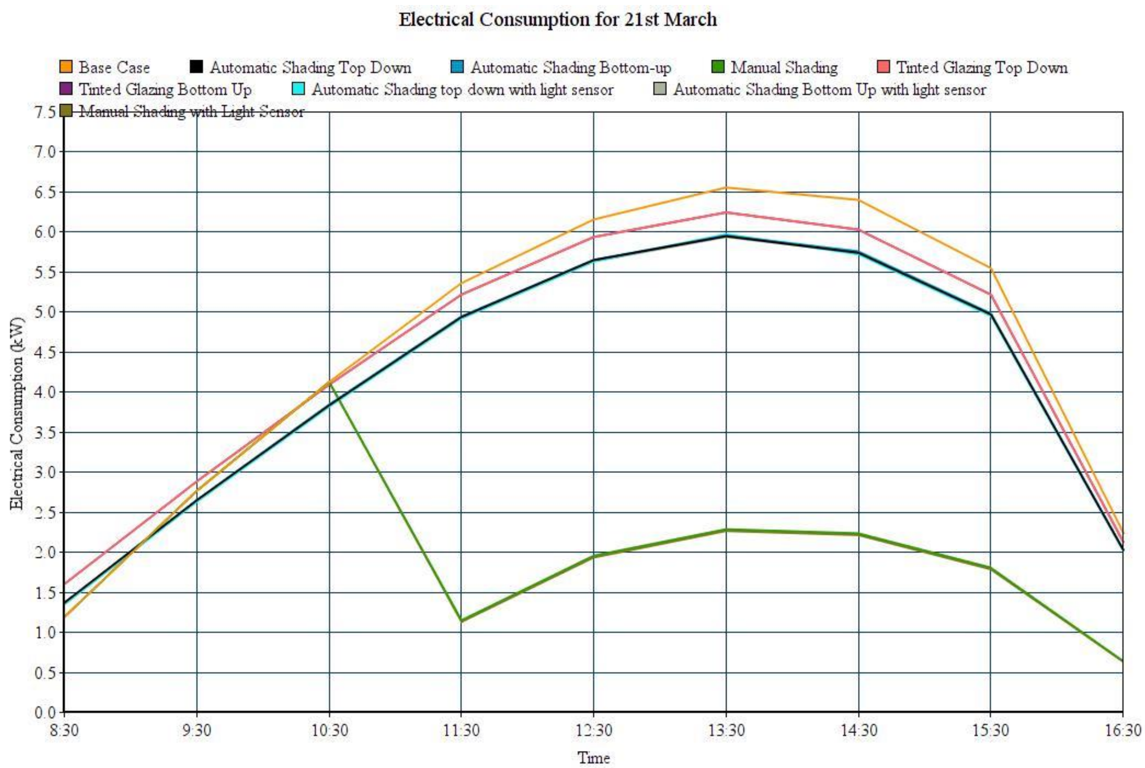


Figure 5.21: Electrical Consumption for 21st March

According to figure 5.20, electricity consumption peaks up for all scenarios at 1:30 pm, and descend downwards later on. All of them are almost in the same range as Base Case yet slightly below it with the exception of manual shading with and without sensor which consumes the least amount of electricity throughout the day.

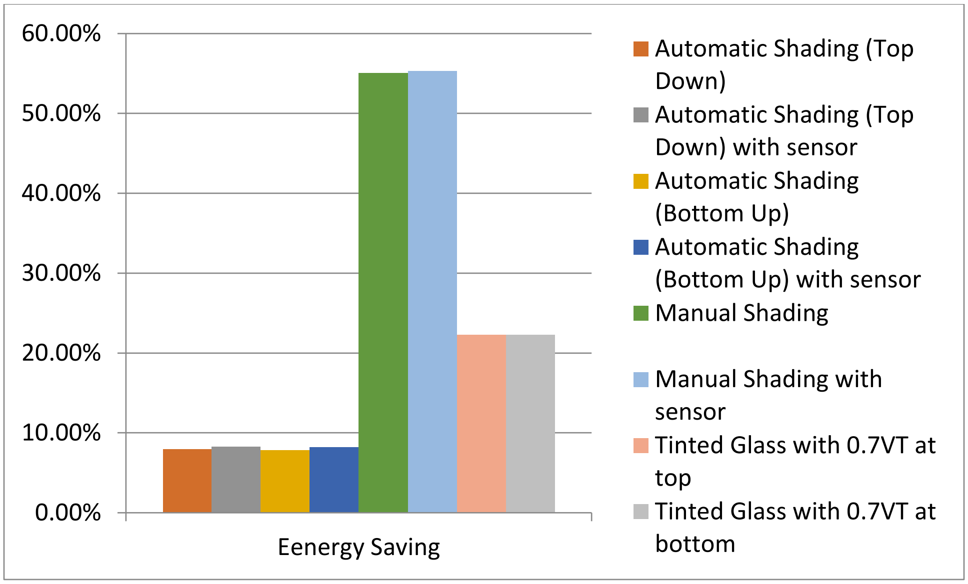


Figure 5.22: Energy saving for 21st March comparing all scenarios

In the figure 5.21, manual shading with sensor saves up most of the electrical consumption through the day and slightly below it is the manual shading without any sensor. After that are the tinted glazing and next comes the automatic top down shading with the sensor. In the end is the automatic top down shading, automatic bottom-up shading with and without the sensor.

Electrical Consumption for 21st of June

Automatic Shading saves up 7.11%, with sensor saves furthermore and that is 7.79% of electricity consumption. Automatic bottom up shading saves 7.10% and with sensor saves up more and that is 7.57%. In the case of manual shading; without sensor saves up 21.02% and with sensor 21.12%. Tinted glazing saves up the least and that is 4.62%.

Table 5.31: Electrical Consumption for Automatic Shading for 21st June

Electrical Consumption (kW) for 21st June Automatic Shading						
Time	Base Case	Shade Position (m)	Automatic Shading (Top Down)	Automatic Shading **(with light sensor)** (Top Down)	Automatic Shading (Bottom Up)	Automatic Shading **(with light sensor)** (Top-Bottom)
8:30 am	3.6886	1.2 m	3.6070	3.5891	3.6053	3.5874
9:30 am	3.3861	1.2 m	3.2411	3.2232	3.2401	3.2221
10:30 am	3.5449	1.2 m	3.3505	3.3325	3.3496	3.3316
11:30 am	3.7436	2.4 m	3.4200	3.3296	3.4192	3.4011
12:30 pm	4.0678	1.2 m	3.7636	3.7455	3.7635	3.7455
1:30 pm	4.3334	1.2 m	3.9676	3.9495	3.9684	3.9503
2:30 pm	4.3751	1.2 m	3.9733	3.9552	3.9761	3.9580
3:30 pm	4.1726	1.2 m	3.7882	3.7701	3.7909	3.7727
4:30 pm	1.9405	1.2 m	1.7760	1.7669	1.7764	1.7674
Average	3.6947		3.4319	3.4068	3.4322	3.4151
% of energy saving in regard to Base Case	0%		7.11%	7.79%	7.10%	7.57%

Table 5.32: Electrical Consumption for Manual Shading for 21st June

Electrical Consumption for 21st June (kW) Manual Shading				
Time	Base Case	Shade Position (m)	with Manual Shading (kW)	With Manual Shading and sensor (kW)
8:30 am	3.6886	0 m	3.6886	3.6886
9:30 am	3.3861	0 m	3.3861	3.3861
10:30 am	3.5449	0 m	3.5449	3.5449
11:30 am	3.7436	4.8 m	2.6419	2.6365
12:30 pm	4.0678	4.8 m	2.8507	2.8452
1:30 pm	4.3334	4.8 m	2.9936	2.9878
2:30 pm	4.3751	4.8 m	2.9844	2.9781
3:30 pm	4.1726	4.8 m	2.8405	2.8328
4:30 pm	1.9405	4.8 m	1.3323	1.3281
Average	3.6947		2.9181	2.9142
% of energy saving in regard to Base Case	0%		21.02%	21.12%

Table 5.33: Electrical Consumption for Tinted Glazing for 21st June

Electrical Consumption for Tinted Glass for 21st June (kW)			
Time	Base Case	Tinted Glass with 0.7VT at top	Tinted Glass with 0.7VT at bottom
8:30 am	3.6886	3.6896	3.6896
9:30 am	3.3861	3.3127	3.3127
10:30 am	3.5449	3.4265	3.4265
11:30 am	3.7436	3.5876	3.5876
12:30 pm	4.0678	3.8565	3.8565
1:30 pm	4.3334	4.0685	4.0685
2:30 pm	4.3751	4.0755	4.0755
3:30 pm	4.1726	3.8820	3.8820
4:30 pm	1.9405	1.8170	1.8170
Average	3.6947	3.524	3.524
% of energy saving in regard to Base Case	0%	4.62%	4.62%

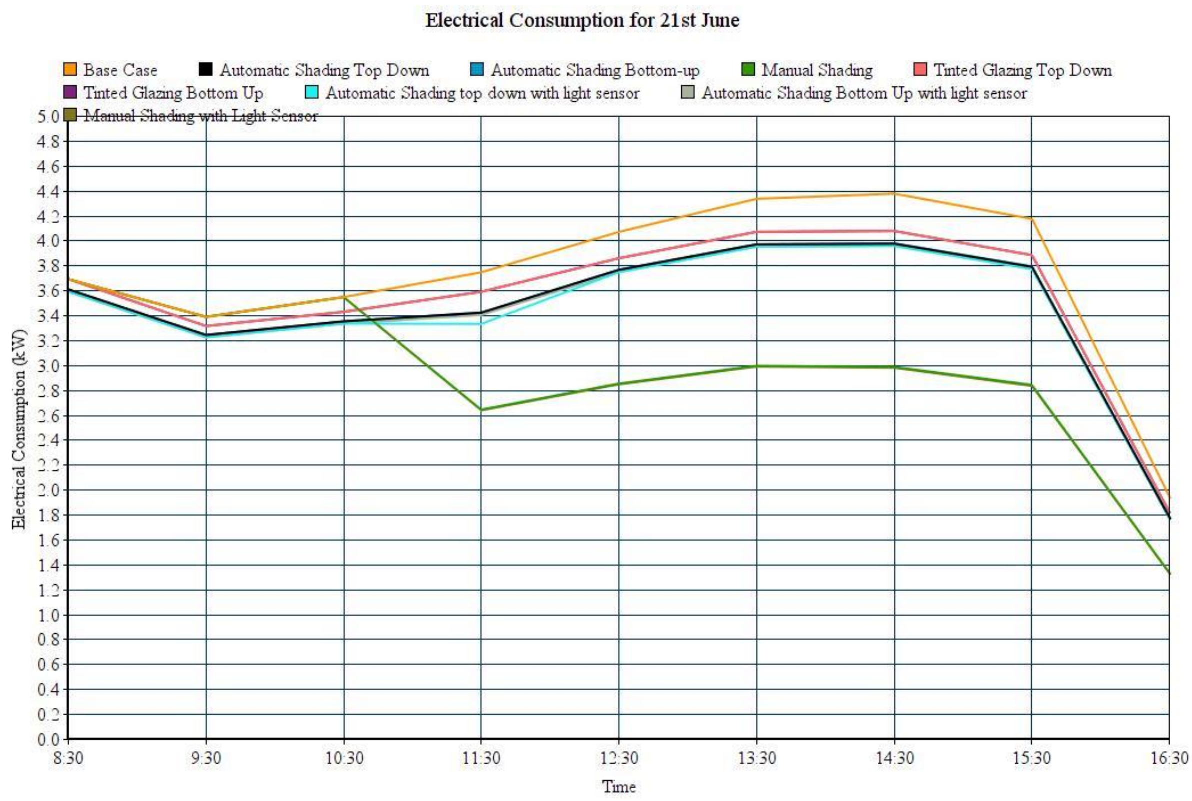


Figure 5.23: Electrical Consumption for 21st June

In figure 5.22, all the scenarios peak at 2:30 pm, and they seem to be in close range to each other with the exception of manual shading which consumes the least amount of electricity and slopes furthermore at 4:30 pm as well.

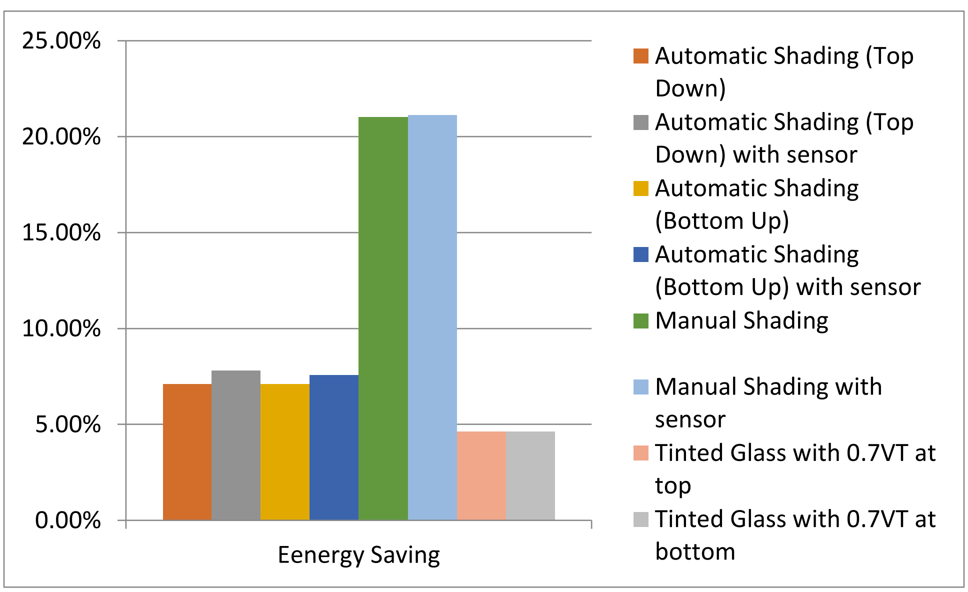


Figure 5.24: Energy saving for 21st June comparing all scenarios

In the figure 5.23, manual shading with sensor saves above 20% of electricity following it is the manual shading with no sensor. Later comes automatic top down shading with the sensor and bottom up with sensor respectively. Automatic top down and bottom up seems to be in the same range. Finally; the least saving is the tinted glazing.

Electrical Consumption for 21st of September

According to the tables below, they identify that automatic top down shading saves 9.76% of electricity, and with sensor save 10.31%. Automatic bottom up saves 9.71% and with sensor saves 9.99%. Manual shading saves 32.59% and with sensor 32.76%. In the end is the tinted glazing which save up only 6.78% of electricity.

Table 5.34: Electrical Consumption for Automatic Shading for 21st September

Electrical Consumption (kW) for 21st September Automatic Shading						
Time	Base Case	Shade Position (m)	Automatic Shading (Top Down)	Automatic Shading **(with light sensor)** (Top Down)	Automatic Shading (Bottom Up)	Automatic Shading **(with light sensor)** (Bottom Up)
8:30 am	4.5198	1.2 m	4.3195	4.3014	4.3054	4.2874
9:30 am	4.2623	1.2 m	3.9708	3.9527	3.9662	3.9482
10:30 am	5.2252	1.2 m	4.7430	4.7250	4.7472	4.7291
11:30 am	6.2798	1.2 m	5.6590	5.6409	5.6674	5.6493
12:30 pm	6.9972	2.4 m	6.0955	6.0047	6.0989	6.0808
1:30 pm	7.3511	2.4 m	6.3965	6.3056	6.3951	6.3769
2:30 pm	7.6611	1.2 m	6.8196	6.8014	6.8308	6.8126
3:30 pm	7.4927	1.2 m	6.5897	6.5715	6.6092	6.5910
4:30 pm	3.4284	0 m	3.4284	3.4284	3.4284	3.4284
Average	5.9131		5.3358	5.3035	5.3387	5.3226
% of energy saving in regard to Base Case	0%		9.76%	10.31%	9.71%	9.99%

Table 5.35: Electrical Consumption for Manual Shading for 21st September

Electrical Consumption for 21st September (kW) Manual Shading				
Time	Base Case	Shade Position (m)	with Manual Shading (kW)	With Manual Shading and sensor (kW)
8:30 am	4.5198	0 m	4.5198	4.5198
9:30 am	4.2623	0 m	4.2623	4.2623
10:30 am	5.2252	0 m	5.2252	5.2252
11:30 am	6.2798	4.8 m	3.6696	3.6577
12:30 pm	6.9972	4.8 m	4.0234	4.0065
1:30 pm	7.3511	4.8 m	4.1541	4.1362
2:30 pm	7.6611	4.8 m	4.2037	4.1857
3:30 pm	7.4927	4.8 m	4.0075	3.9895
4:30 pm	3.4284	4.8 m	1.8077	1.7990
Average	5.9131		3.9859	3.9758
% of energy saving in regard to Base Case	0%		32.59%	32.76%

Table 5.36: Electrical Consumption for Tinted Glazing for 21st September

Electrical Consumption for Tinted Glass for 21st September (kW)			
Time	Base Case	Tinted Glass with 0.7VT at top	Tinted Glass with 0.7VT at bottom
8:30 am	4.5198	4.4414	4.4414
9:30 am	4.2623	4.0872	4.0872
10:30 am	5.2252	4.8967	4.8967
11:30 am	6.2798	5.8493	5.8493
12:30 pm	6.9972	6.5126	6.5126
1:30 pm	7.3511	6.8312	6.8312
2:30 pm	7.6611	7.0544	7.0544
3:30 pm	7.4927	6.8259	6.8259
4:30 pm	3.4284	3.1110	3.1110
Average	5.9131	5.5122	5.5122
% of energy saving in regard to Base Case	0%	6.78%	6.78%

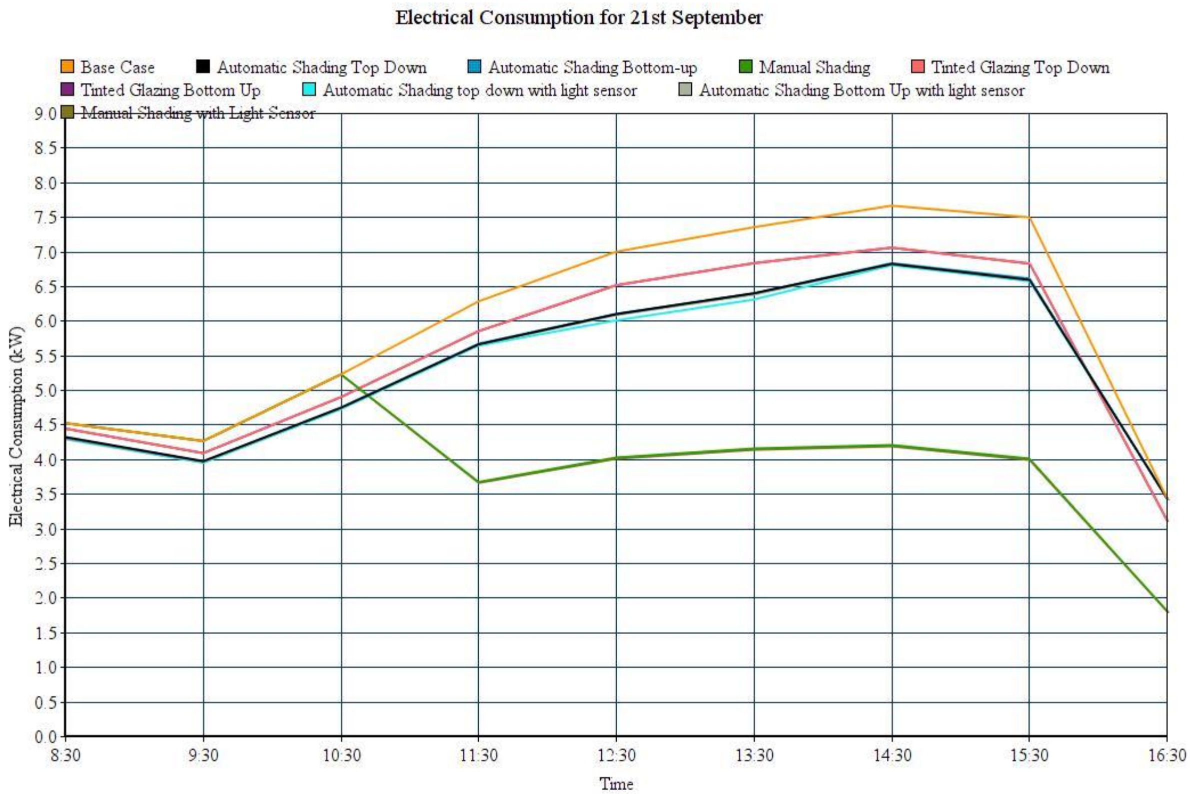


Figure 5.25: Electrical Consumption for 21st September

The figure 5.24 represents how all the scenarios except for manual shading peak up at 2:30 pm. The most electricity consuming scenario is the tinted glazing, then automatic shading. The least electricity consuming is the manual shading. It peaks up at 10:30 am, then slopes down and slopes down again at 3:30 pm.

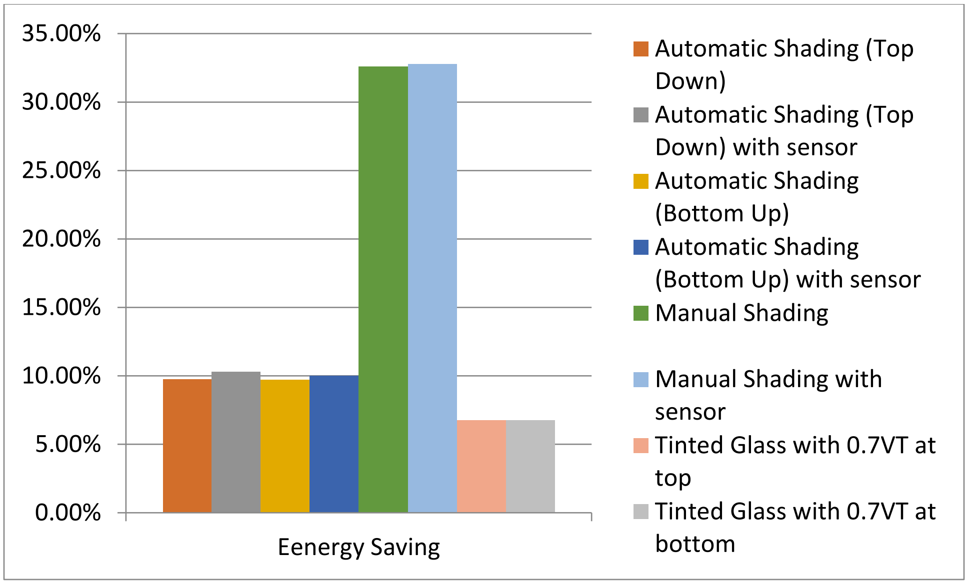


Figure 5.26: Energy saving for 21st September comparing all scenarios

According to the figure 5.25, manual shading with the sensor is the most electricity saving followed by manual shading without shading. Next, comes automatic top down shading with sensor followed by the rest automatic shadings. The least energy conserving are both tinted glazing with 0.7 VT at top and bottom.

5.4 Cooling Loads

In the case of cooling loads, a thorough analysis is performed per working hour regarding external conduction gain and internal conduction gain. The energy saving percentage, however, is calculated by comparing the ratio between the plant sensible load associated with the base case to plant a sensible load of automatic shadings, manual, and tinted glazing individually.

Negative conduction gains occur when the outside temperature is less than the interior temperature. This usually occurs in the cold days in Amman. Positive conduction gain occurs when the exterior air temperature is greater than the interior temperature usually in the summer. In some situations both negative and positive cooling loads occur on the same day; that is because the temperature varies during the day. Some cases in the morning, the exterior temperature is less than the interior, thus resulting in a negative cooling load. While the temperature starts to rise in the later hours, the cooling load becomes positive again. It is essential to point out that the cooling system is set to start automatically when the temperature in the office reaches 25°C.

<u>Cooling Loads for the 21st June</u>

As seen from the tables, automatic top down shading saved up 71.52% and that is considered more than the automatic bottom-up shading which saved up 62.6%. Manual shading saved 73.20% while tinted glazing saved 64.78%. The major energy saving scenario is the manual shading.

Table 5.37: Cooling Loads for Automatic Shading for 21st of June

Cooling Loads (kW) for Automatic Shading in June						
Time	Base Case		Automatic Shading (Top Down)		Automatic Shading (Bottom Up)	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
8:30 am	-0.0568	0.2300	0.0877	0.3829	0.1896	0.5471
9:30 am	0.1300	0.1819	0.1163	0.3944	0.2136	0.5654
10:30 am	0.2844	0.0621	0.1338	0.3145	0.2221	0.8545
11:30 am	0.2844	0.0621	0.1486	0.2904	0.1480	0.2895
12:30 pm	0.6014	-0.5008	0.2190	0.2198	0.2952	0.2050
1:30 pm	0.7166	-0.5954	0.2546	0.0821	0.3272	0.1328
2:30 pm	0.7896	-0.4356	0.2804	0.1029	0.3522	0.1590
3:30 pm	0.8161	-0.1757	0.2955	0.1663	0.3682	0.2378
4:30 pm	0.5938	-0.3739	0.2176	-0.0008	0.2729	0.0223
Average	0.4622	-0.1717	0.1948	0.2169	0.2654	0.3348
Plant Sensible Load	4.265		1.2145		1.594	
% of energy saving in regard to Base Case	0%		71.52%		62.62%	

Table 5.38: Cooling Loads for Manual Shading for 21st of June

Cooling Loads (kW) for Manual Shading in June				
Time	Base Case		Manual Shading	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
8:30 am	-0.0568	0.2300	-0.0568	0.2300
9:30 am	0.1300	0.1819	0.1300	0.1819
10:30 am	0.2844	0.0621	0.2844	0.0621
11:30 am	0.2844	0.0621	0.2264	0.1871
12:30 pm	0.6014	-0.5008	0.2894	0.1208
1:30 pm	0.7166	-0.5954	0.3353	0.0924
2:30 pm	0.7896	-0.4356	0.3604	0.0969
3:30 pm	0.8161	-0.1757	0.3647	0.1211
4:30 pm	0.5938	-0.3739	0.2912	-0.0417
Average	0.4622	-0.1717	0.2472	0.1167
Plant Sensible Load	4.265		1.143	
% of energy saving in regard to Base Case	0%		73.20%	

Table 5.39: Cooling Loads for Tinted Glazing for 21st of June

Cooling Loads (kW) for Tinted Glass in June						
Time	Base Case		VT from top 0.7		VT from bottom 0.7	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
8:30 am	-0.0568	0.2300	0.0581	0.3575	0.0581	0.3575
9:30 am	0.1300	0.1819	0.1075	0.3625	0.1075	0.3625
10:30 am	0.2844	0.0621	0.1438	0.2747	0.1438	0.2747
11:30 am	0.2844	0.0621	0.2056	0.1848	0.2056	0.1848
12:30 pm	0.6014	-0.5008	0.2631	0.0497	0.2631	0.0497
1:30 pm	0.7166	-0.5954	0.3075	-0.0026	0.3075	-0.0026
2:30 pm	0.7896	-0.4356	0.3355	0.0386	0.3355	0.0386
3:30 pm	0.8161	-0.1757	0.3461	0.1258	0.3461	0.1258
4:30 pm	0.5938	-0.3739	0.2562	-0.0618	0.2562	-0.0618
Average	0.4622	-0.1717	0.2248	0.1477	0.2248	0.1477
Plant Sensible Load	4.265		1.502		1.502	
% of energy saving in regard to Base Case	0%		64.78%		64.78%	

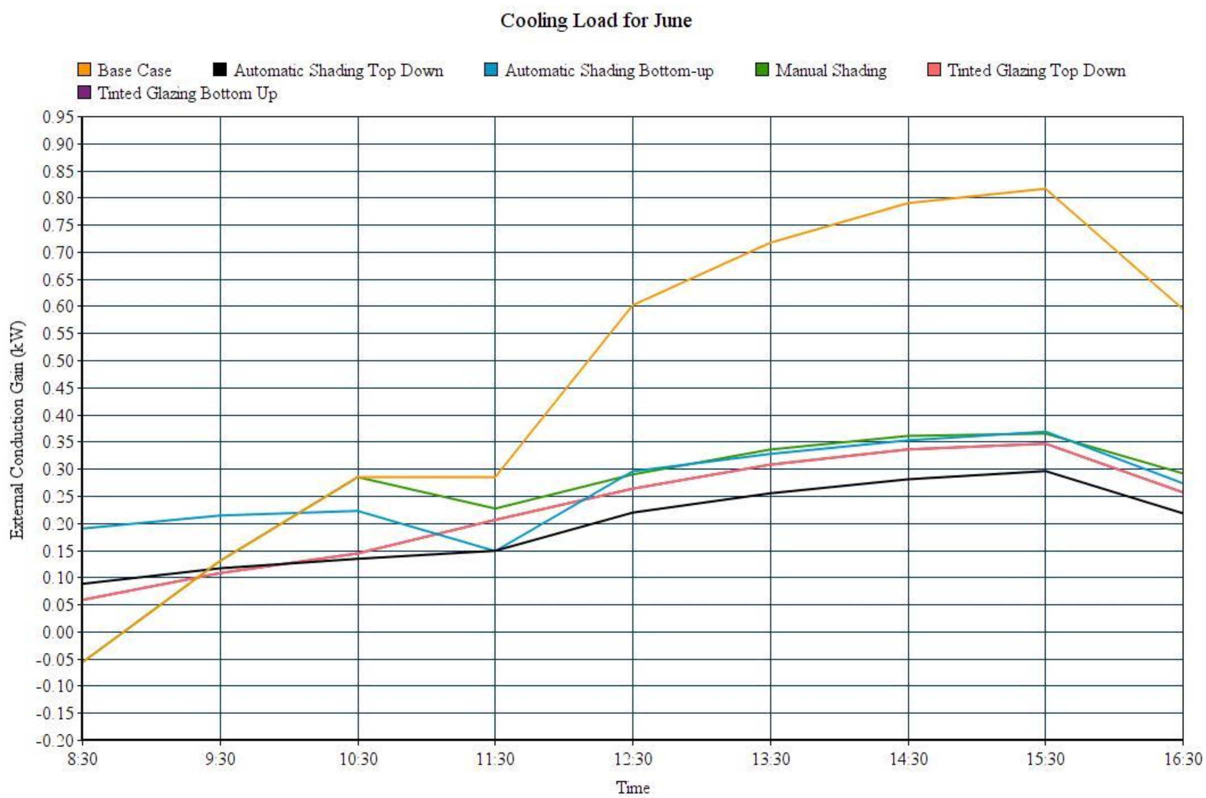


Figure 5.27: External Conduction Gain for 21st June

According to figure 5.26, all scenarios have a much lower external conduction gain when comparing them to Base Case. Putting that aside; automatic top down shading seem to have least external conduction gain in average and even peeks up very mildly at 3:30 pm.

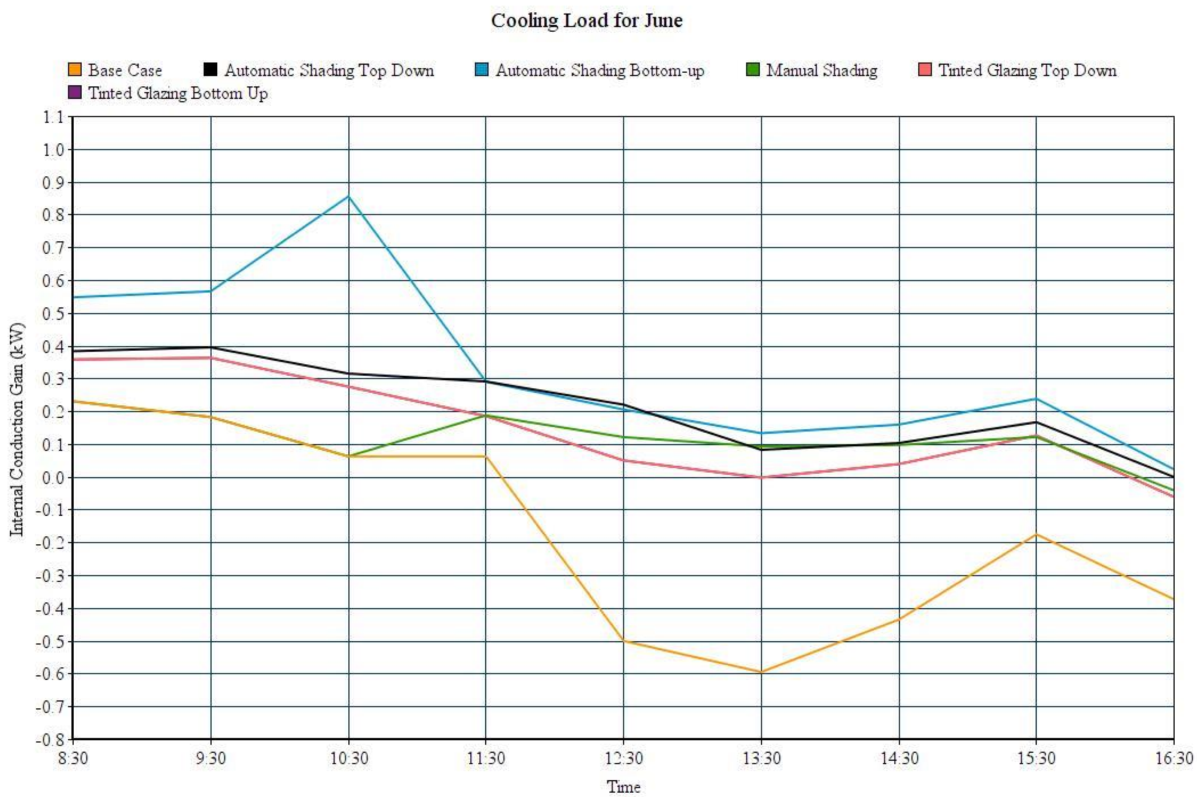


Figure 5.28: Internal Conduction Gain for 21st June

When assessing the internal conduction gain; automatic bottom-up shading seem to have the largest peak at 10:30 am and highest slope. Aside from that, all other scenarios overlap a lot of times at different working hours. They all seem to be sloping downwards uniformly.

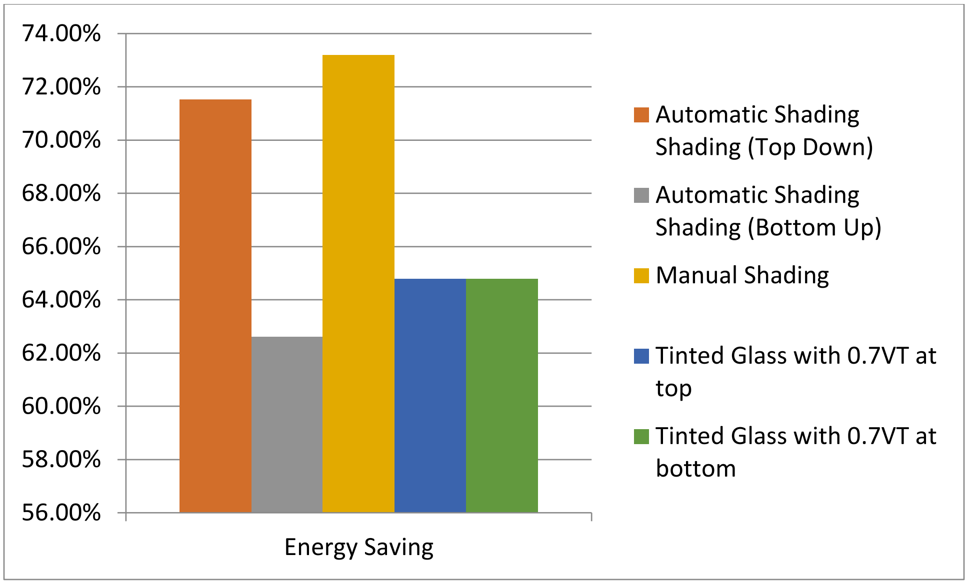


Figure 5.29: Energy saving for 21st June comparing all scenarios

The figure 5.28 compares the plant sensible loads to each other according to each scenario and how much energy it saved throughout the day. As observed, manual shading saved up most of the energy followed by automatic top down shading. Following them are tinted glazing and the least energy conserving in this area is the automatic bottom-up shading.

Cooling Loads for 21st September

The tables below show that automatic top down shading saved 49.95% and automatic bottom-up shading saved less and that is 44.2%. Manual shading saved up 57.66% and tinted glazing only 34.51%.

Table 5.40: Cooling Loads for Automatic Shading for 21st of September

Cooling Loads (kW) for Automatic Shading in September						
Time	Base Case		Automatic Shading (Top Down)		Automatic Shading (Bottom Up)	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
8:30 am	-0.0877	0.7203	0.1427	0.7490	0.1271	0.7397
9:30 am	0.0762	0.2473	0.1427	0.6187	0.1422	0.6259
10:30 am	0.1526	-0.5842	0.1268	0.2422	0.1266	0.2714
11:30 am	0.2521	-1.3782	0.1463	-0.0479	0.1446	-0.0219
12:30 pm	0.3708	-1.9523	0.1481	0.0380	0.1466	0.0476
1:30 pm	0.4713	-1.9972	0.1735	-0.0013	0.1722	0.0023
2:30 pm	0.5266	-1.4459	0.2403	-0.1563	0.2371	-0.1243
3:30 pm	0.5611	-0.6378	0.2632	0.0903	0.2594	0.1343
4:30 pm	0.2160	-0.6482	0.2160	-0.6482	0.1225	-0.0627
Average	0.2821	-0.8529	0.1777	0.0983	0.1643	0.1791
Plant sensible load	4.265		2.1345		2.3800	
% of energy saving in regard to Base Case	0%		49.95%		44.20%	

Table 5.41: Cooling Loads for Manual Shading for 21st of September

Cooling Loads (kW) for Manual Shading in September				
Time	Base Case		Manual Shading	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
8:30 am	-0.0877	0.7203	-0.0877	0.7203
9:30 am	0.0762	0.2473	0.0762	0.2473
10:30 am	0.1526	-0.5842	0.1526	-0.5842
11:30 am	0.2521	-1.3782	0.2316	0.0607
12:30 pm	0.3708	-1.9523	0.2866	-0.0203
1:30 pm	0.4713	-1.9972	0.3289	-0.0418
2:30 pm	0.5266	-1.4459	0.3515	-0.0011
3:30 pm	0.5611	-0.6378	0.3542	0.0834
4:30 pm	0.2160	-0.6482	0.2452	-0.1291
Average	0.2821	-0.8529	0.2155	0.0372
Plant Sensible Load	4.265		1.806	
% of energy saving in regard to Base Case	0%		57.66%	

Table 5.42: Cooling Loads for Tinted Glazing for 21st of September

Cooling Loads (kW) for Tinted Glass in September 21st						
Time	Base Case		VT from top 0.7		VT from bottom 0.7	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
8:30 am	-0.0568	0.2300	0.0834	0.7557	0.0834	0.7557
9:30 am	0.1300	0.1819	0.1274	0.5815	0.1274	0.5815
10:30 am	0.2844	0.0621	0.1354	0.1301	0.1354	0.1301
11:30 am	0.2844	0.0621	0.1703	-0.2464	0.1703	-0.2464
12:30 pm	0.6014	-0.5008	0.2167	-0.5091	0.2167	-0.5091
1:30 pm	0.7166	-0.5954	0.2566	-0.5578	0.2566	-0.5578
2:30 pm	0.7896	-0.4356	0.2809	-0.3576	0.2809	-0.3576
3:30 pm	0.8161	-0.1757	0.2968	-0.0125	0.2968	-0.0125
4:30 pm	0.5938	-0.3739	0.1418	-0.1959	0.1418	-0.1959
Average	0.4622	-0.1717	0.1899	-0.0458	0.1899	-0.0458
Plant Sensible Load	4.265		2.793		2.793	
% of energy saving in regard to Base Case	0%		34.51%		34.51%	

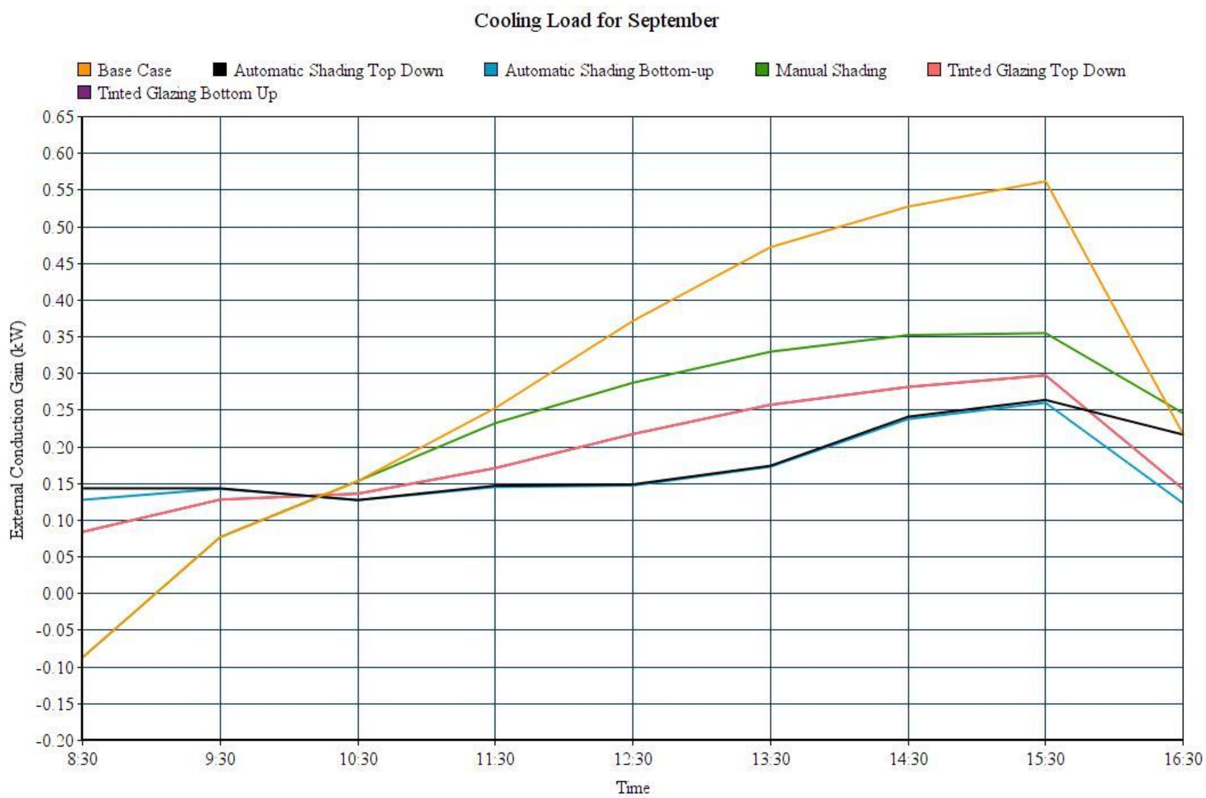


Figure 5.30: External Conduction Gain for 21st September

When assessing the external conduction gain throughout the day, the scenarios all overlap before reaching 10:30 am. After that they all peak at 3:30 pm and slope downwards until 4:30 pm. Base Case has the greatest external conduction gain at 3:30 pm while automatic bottom-up shading at that hour only has the least external conduction gain. Throughout the time, however, automatic top down shading seem to be having the least external conduction gain.

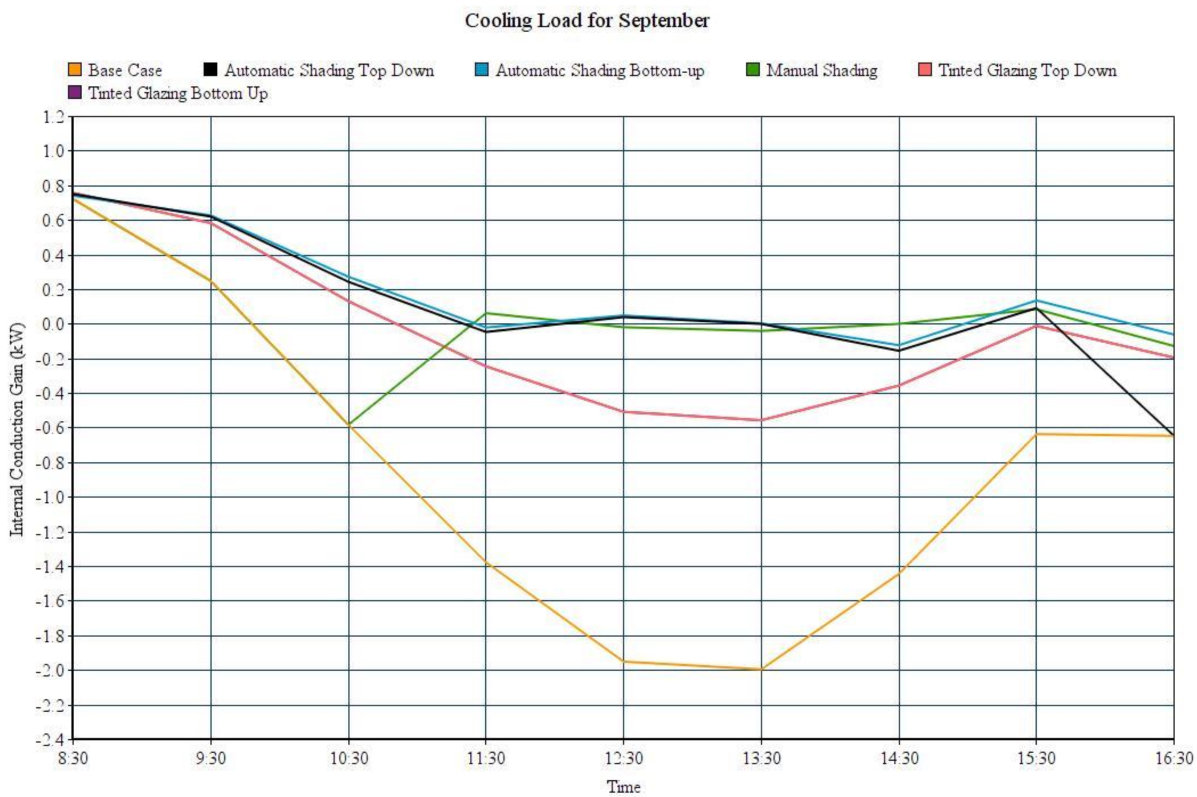


Figure 5.31: Internal Conduction Gain for 21st September

In the case of internal conduction gain, tinted glazing seems to have the lowest internal conduction gain. Manual shading, automatic top down shading, and automatic bottom-up shading, meet up most of the time through the day and all peak at 3:30 pm before sloping downwards at 4:30 pm.

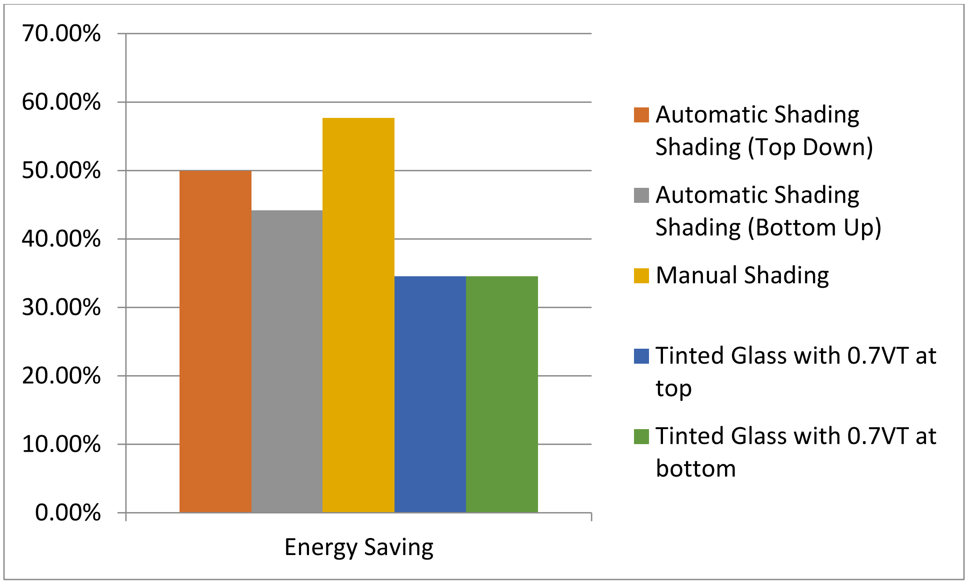


Figure 5.32: Energy saving for 21st September comparing all scenarios

Figure 5.31 represents the savings of the plant sensible load in comparison to Base Case. Once again manual shading saves most of the energy followed by automatic top down shading and automatic bottom-up shading is next. The least energy conserving are tinted glazing.

5.5 Heating Loads

The external and internal conduction gains is represented as an average throughout the working hours. The % of energy saved is calculated as a ratio comparing the energy saving scenarios in comparison to the base case in two categories internal conduction gain and external conduction gain.

It is essential to add that the heating system is set to start automatically when the interior office temperature reaches 17°C. Again when looking at the heating loads, one can see that negative values exist. A negative heat gain is when the exterior temperature is less than the interior temperature. A positive heat gain occurs when the exterior temperature is greater than the interior air temperature.

<u>Heating Loads for December</u>

For the case of external conduction gain, automatic top down shading saved up 67.38%. Automatic bottom up shading saved up 65.73%. Manual shading saved 63.43%, and tinted glazing saved 62.43%.

For the case of internal conduction gain; automatic top down shading saved up 19.22%, same goes for automatic bottom-up shading. Manual shading and tinted glazing saved up 13.18%.

Table 5.43: Heating Loads for Automatic Shading for 21st of December

Heating Loads (kW) for Automatic Shading in December						
Time	Base Case		Automatic Shading (Top Down)		Automatic Shading (Bottom Up)	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
Entire Day	-1.4332	0.0827	-0.4675	-0.0159	-0.4912	-0.0159
% of energy saving in regard to Base Case	0%	0%	67.38%	19.22%	65.73%	19.22%

Table 5.44: Heating Loads for Manual Shading for 21st of December

Heating Loads (kW) for Manual Shading in December				
Time	Base Case		Manual Shading	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
Entire Day	-1.4332	0.0827	-0.5384	-0.0109
% of energy saving in regard to Base Case	0%	0%	62.43%	13.18%

Table 5.45: Heating Loads for Tinted Glazing for 21st of December

Heating Loads (kW) for Tinted Glass in December						
Time	Base Case		VT from top 0.7		VT from bottom 0.7	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
Entire Day	-1.4332	0.0827	-0.5384	-0.0109	-0.5384	-0.0109
% of energy saving in regard to Base Case	0%	0%	62.43%	13.18%	62.43%	13.18%

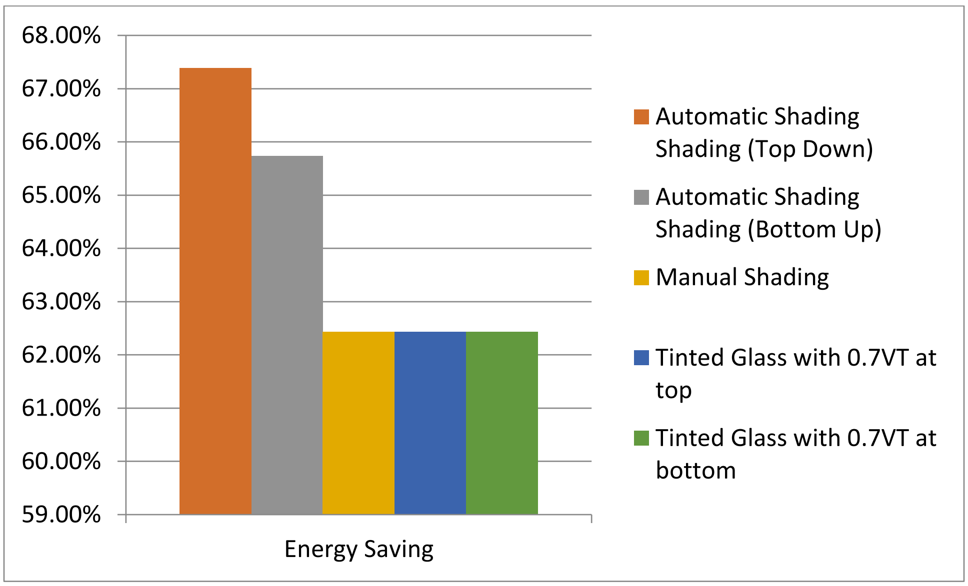


Figure 5.33: Energy saving for 21st December comparing all scenarios for external conduction gain

The figure 5.32 identifies the external conduction gain as a saving percentage. For instance, automatic top down shading saves up the most, followed by automatic bottom-up shading, followed by manual and tinted glazing which all seem to have the same value.

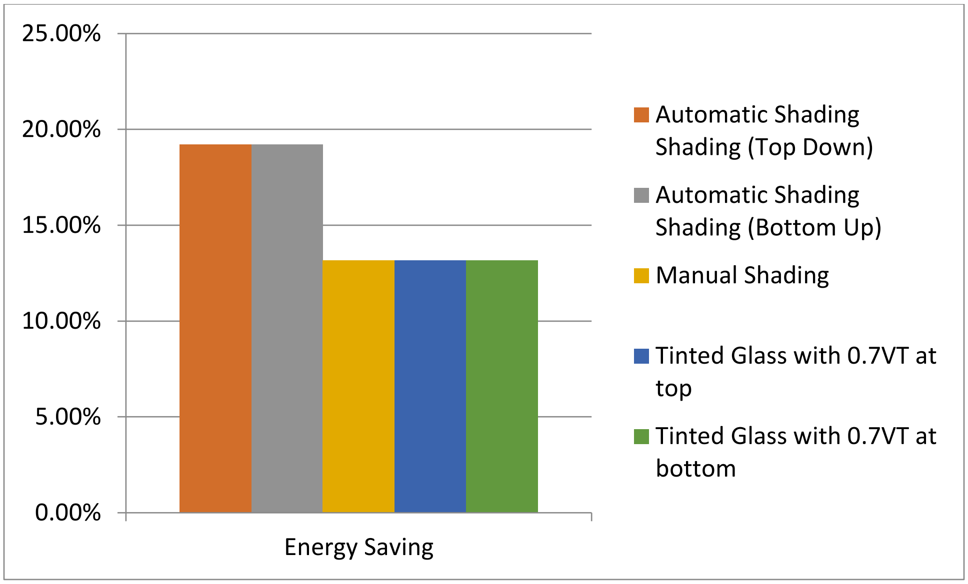


Figure 5.34: Energy saving for 21st December comparing all scenarios for internal conduction gain

As observed, for the case of internal conduction gain. Both automatic top down shading and bottom up shading are on the same level and save up the most of the energy. Following them are manual shading and tinted glazing which also happen to be on the same level.

Note that for the month of December, Figure 5.32 illustrates that automatic top down shading saves more energy in the case of heating load. That is because the internal shading practically never closes down completely (4.8 m) during the entire working day. An example of this can be seen on table 5.1. This means that there is always daylight inside the office. In the case of manual shading, note that there is a time when the shades close down completely (see table 5.2), so it saves up less energy in regard to heating load for the month of December.

<u>Heating Loads for March</u>

In the case of external conduction gain; automatic top down shading saves 75.35%, automatic bottom-up shading saves slightly more and that is 75.52%. Manual shading saves 83.73% while tinted glazing saves 69.16%.

For internal conduction gain; automatic top down shading saves 98.27%, while automatic bottom-up shading saves 97.27%. Manual shading saves 90.07% and tinted glazing save 71.22%.

Table 5.46: Heating Loads for Automatic Shading for 21st of March

Heating Loads (kW) for Automatic Shading in March						
Time	Base Case		Automatic Shading (Top Down)		Automatic Shading (Bottom Up)	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
Entire Day	-0.4799	-0.1098	-0.1183	-0.0019	-0.1175	0.0030
% of energy saving in regard to Base Case	0%	0%	75.35%	98.27%	75.52%	97.27%

Table 5.47: Heating Loads for Manual Shading for 21st of March

Heating Loads (kW) for Manual Shading in March				
Time	Base Case		Manual Shading	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
Entire Day	-0.4799	-0.1098	-0.0781	-0.0109
% of energy saving in regard to Base Case	0%	0%	83.73%	90.07%

Table 5.48: Heating Loads for Tinted Glazing for 21st of March

Heating Loads (kW) for Tinted Glass in December						
Time	Base Case		VT from top 0.7		VT from bottom 0.7	
	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain	External Conduction Gain	Internal Conduction Gain
Entire Day	-0.4799	-0.1098	-0.1480	-0.0316	-0.1480	-0.0316
% of energy saving in regard to Base Case	0%	0%	69.16%	71.22%	69.16%	71.22%

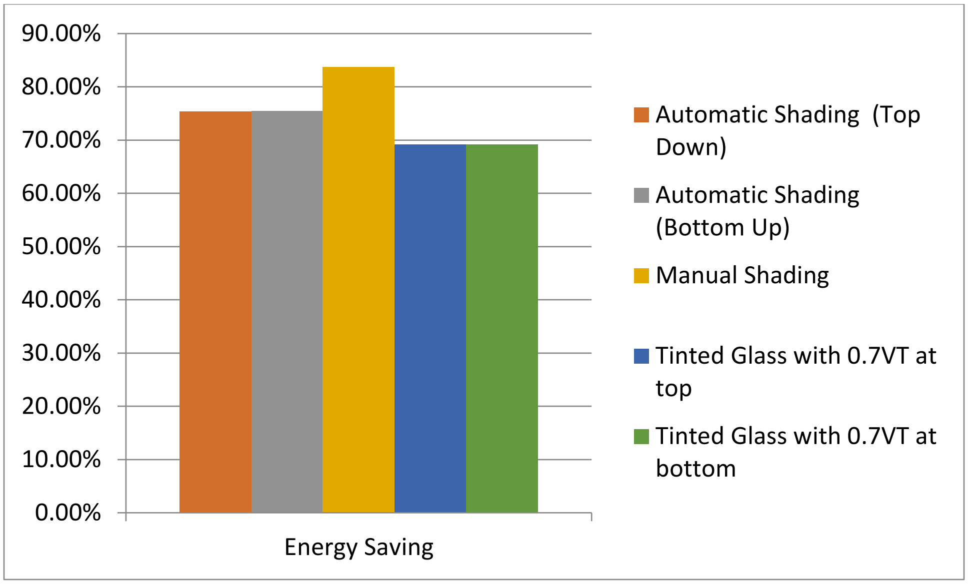


Figure 5.35: Energy saving for 21st March comparing all scenarios for external conduction gain.

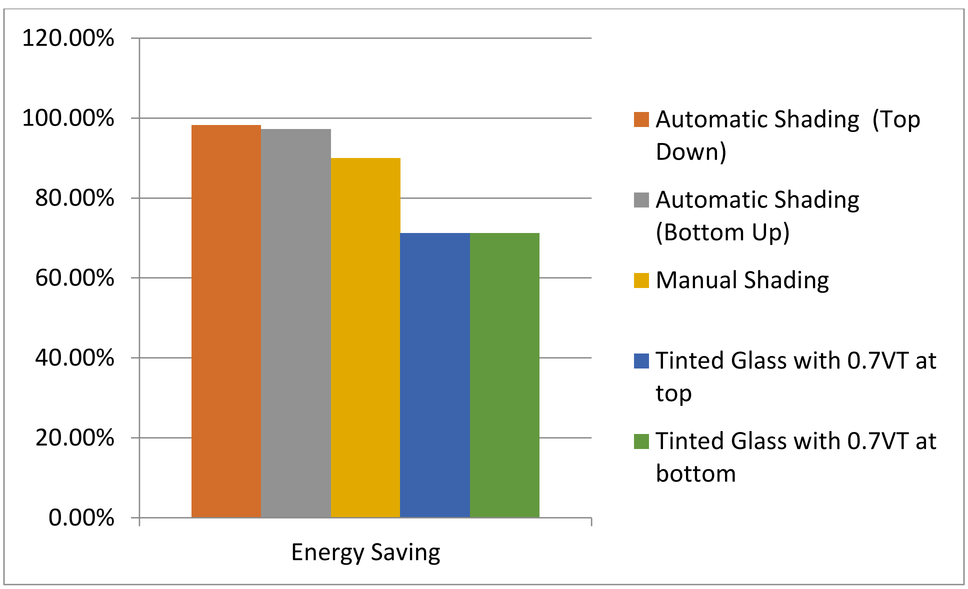


Figure 5.36: Energy saving for 21st March comparing all scenarios for internal conduction gain

Figures 5.34illustrates the conduction gain energy savings. For instance, manual shading seems to save the largest amount of energy, followed by both tops down and bottom up the automatic shading. Following them are tinted glazing in both configurations.

Figure 5.35 illustrates the energy saving in regard to internal conduction gain. Top Down automatic shading seems to save the largest amount of energy; slightly below it is automatic bottom-up shading. Following them is the manual shading and finally, the least energy saving is the tinted glazing in both configurations.

5.6 Comparing All Scenarios in Average

To summarize the results that are discussed earlier; one must review which parameter saves the greatest amount of energy per category by finding its average through the four chosen days.

For the case of lighting level as shown on figure 5.36; manual shading seems to be the greatest contributor to energy saving. One must take into account that regardless of this, a lot of times the lighting in the office reaches below 500 lux keeping it dark most of the time and forcing the luminaires to turn on. Leaving this aside, tinted glazing with 0.7 VT situated at the bottom seems to be the second largest contributor to energy saving regarding illumination. The lest energy saver in the case of illumination is Top Down Automatic Shading.

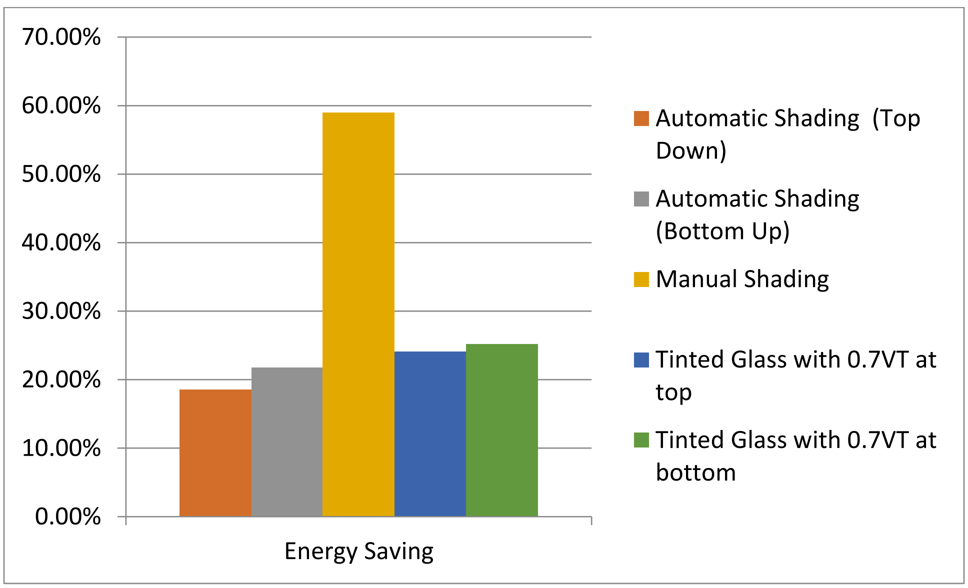


Figure 5.37: Illustrating in average the energy saving potential regarding illumination

In the case of Solar Heat Gain as shown in figure 5.37, Bottom up Automatic Shading seems to be the greatest energy saver in comparison to all other scenarios. Automatic Top Down Shading comes slightly below it leaving it in second place. The least energy savers are tinted glazing.

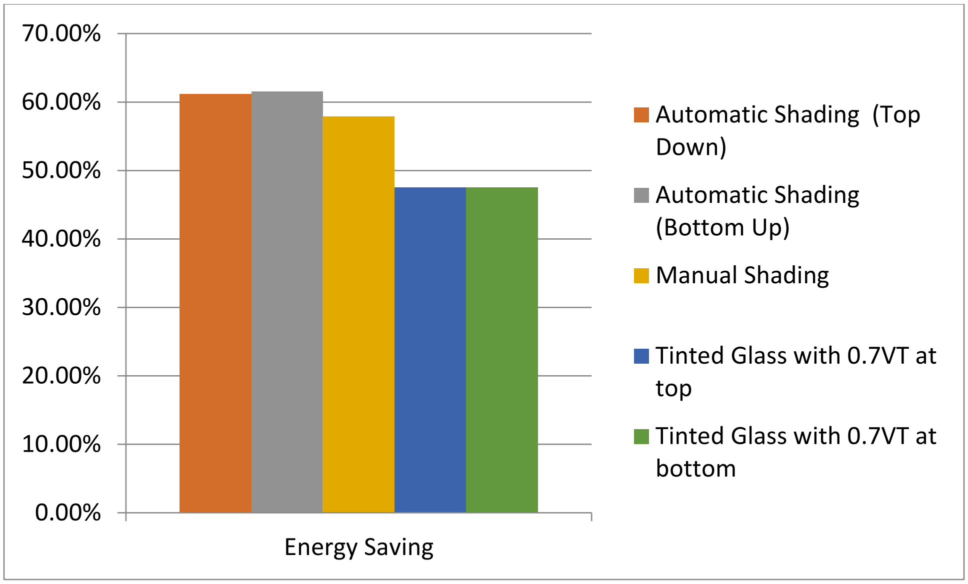


Figure 5.38: Illustrating in average the energy saving regarding Solar Heat Gain

Regarding electricity consumption as shown in figure 5.38; manual shading with sensor seems to be saving the greatest amount of energy regarding electricity load. Slightly below it is manual shading without sensors. All the other categories save up more or less the same amount of energy.

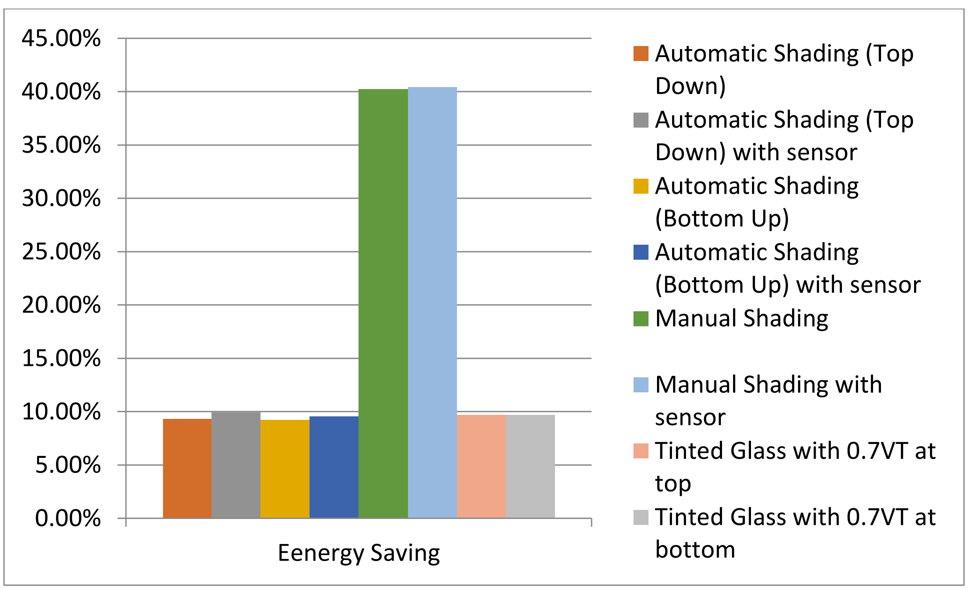


Figure 5.39: Illustrating Energy Saving regarding Electricity Consumption

For the case of cooling load as shown in figure 5.39; again manual shading seems to be saving the greatest amount of energy followed by top down automatic shading. The least energy savers is tinted glazing.

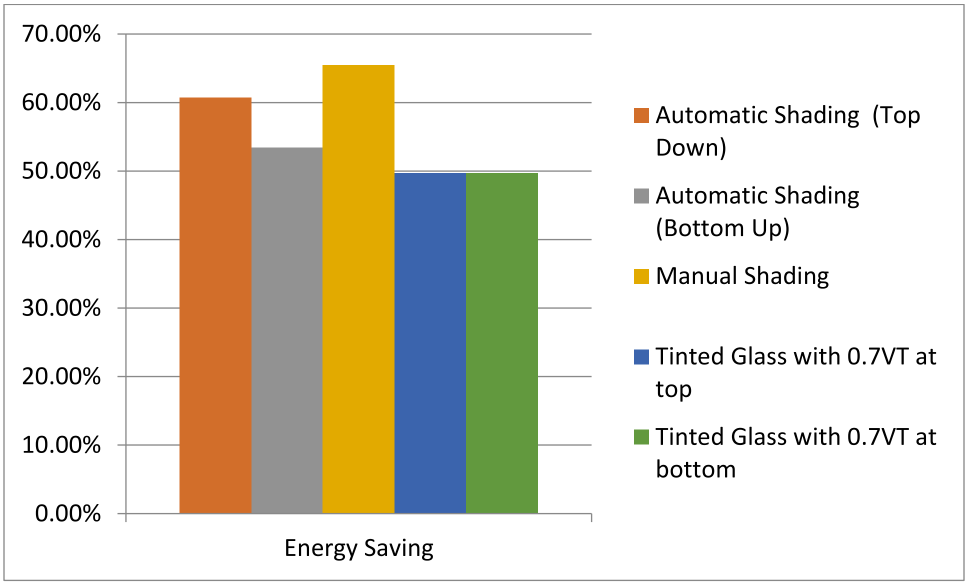


Figure 5.40: Illustrating Energy Saving regarding Cooling Load

For heating loads as observed on figure 5.40; automatic top down shading saves up followed by automatic bottom up shading and slightly below it is the manual shading.

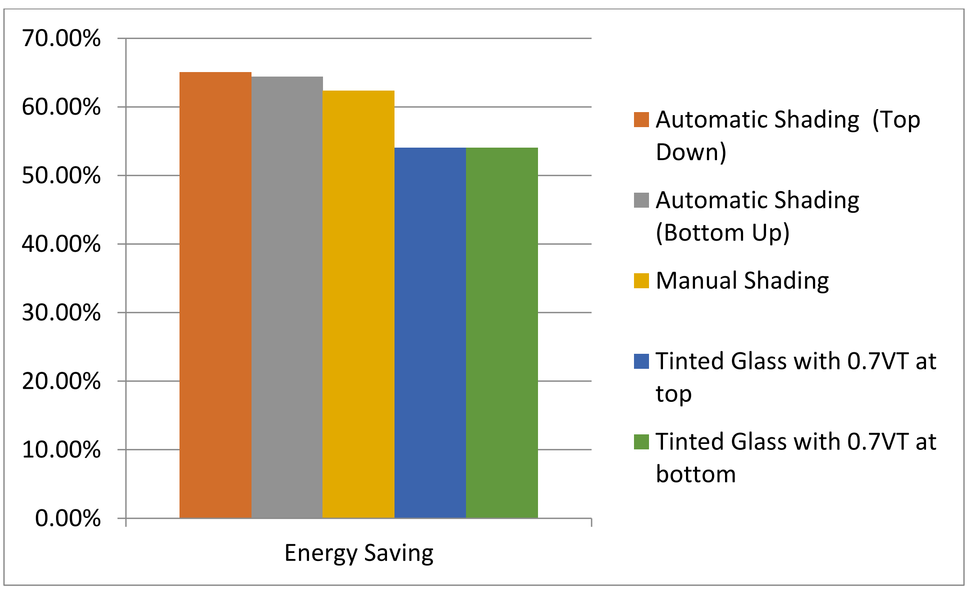


Figure 5.41: Illustrating Energy Saving regarding Heating Load

CHAPTER 6 **: ECONOMICAL ANALYSIS**

6.1 Introduction

This chapter is essential in order to compare the costs of the systems and see which one is more economical. The Base Case, automatic shading, manual shading, and tinted shading are all evaluated in terms of costs. Again it is assumed that the shades are installed in the 3 m X 4.7 m office mentioned earlier in the simulation facing the South.

According to Kasprowicz and Schulz (2015), the general formula to calculate the energy payback period is:

Payback period= t = $\frac{Initial\ invest\ cost}{annual\ net\ saving}$

6.2 Capital Cost Estimation

Due to the unavailability to obtain precise information concerning the systems mentioned earlier, a rough estimation is carried out to calculate their direct and indirect costs. The latter is created in order to just provide a rough idea about what the payback period would be. Table 6.1 summarizes the capital costs of each of the systems used for the eight glazing units (1.5 m X 1.2 m) installed already in the building. The currency is in JDs however it is changed to AED since it is more convenient for the reader.

Table 6.1: Capital Cost Estimation

	Base Case	Automatic Shading	Manual Shading	Tinted Shading
Components of light dimmers (AED)	0	1775	1775	1775
Motorization (AED)	0	1200	0	0
Roller shade fabric (AED)	1314.23	1314.23	1314.23	0
Installation (AED)	615.23	1469.2	615.23	2288.28
Total	1929.46	5758.43	3704.46	4063.28
7% maintenance	2064.5	6161.52	3963.78	4347.71
Sub Total	3993.96	11919.95	7668.24	8410.99

6.3 Annual Energy Consumption

Here the weekly energy consumption of each scenario is compared to the Base Case, yet over the entire year. In order to do that the energy consumption per week is multiplied by the annual energy consumption yet of the Base Case. At nighttime, holidays, and weekends it is assumed that all systems, equipment, and lights are turned off. In Jordan, the rate of electricity tariff for Banking is 285 fils/kWh (Nepco.com.jo, 2017). Changing the rate to AED becomes 1.48/KWh.

Table 6.2: Energy consumption per day and per week

	Base Case	Automatic Shading	Manual Shading	Tinted Shading
Equipment and system energy consumption of 1 weekday (daytime) (kWh)	2.37	1.04	0.87	1.21
Equipment and system energy consumption of 1 weekday (nighttime, holidays, and weekends) (kWh)	0	0	0	0
Average equipment and system energy consumption in a working week (kWh)	11.85	5.20	4.35	6.05
Lighting energy consumption of 1 weekday (daytime) (kWh)	4.93	4.44	2.89	4.69
Lighting energy consumption of 1 weekday (nighttime, holidays, and weekends) (kWh)	0	0	0	0

Average lighting Energy consumption in a working week (kWh)	24.65	22.2	14.45	23.45

Table 6.3: Energy consumption per year

	Base Case	Automatic Shading	Manual Shading	Tinted Shading
Annual system and equipment energy consumption (kWh)	616.2	270.4	226.2	314.6
Annual lighting energy consumption (kWh)	1281.8	1154.4	751.4	1219.4
Total energy consumption (kWh)	1897.3	1424.4	977.6	1534
Cost of the energy consumption per year (AED)	2808.00	2108.11	1446.85	2270.32
Cost Saving in Comparison to Base Case (AED)	0	700	1361	538

6.4 Annual Payback period

In order to calculate the annual payback period, one must apply the formula:

Payback period= t = $\frac{Initial\ invest\ cost}{annual\ net\ saving}$

The initial investment is the capital cost that is calculated per system above. The annual net saving is the energy savings per year for each system. The results are summarized in table 6.4.

Table 6.4: Annual payback period

	Automatic Shading	Manual Shading	Tinted Shading
Payback period (years)	17.0	5.6	15.6

As observed in table 6.4, manual shading seems to the most economic among the other systems because it has the shortest payback period. Tinted shading has payback period of 15.6 years and the least economic of them all is the automatic shading having 17 years as a payback period.

CHAPTER 7 : CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The Bank of Housing was chosen as mentioned above because it is the first building to introduce automatic internal shading devices. When talking about total energy savings; the introductory of automatic shading in general aids in energy saving, yet apparently not in this building in particular; yet perhaps in others. In average the greatest scenario in energy saving point fingers at manual shading by 57.01% in total energy saving in comparison to Base Case. If at 11:30 am the curtains are shut down completely without the introduction of any human interaction, then this saves up the greatest amount of energy. Thus manual shading tops automatic shading in energy saving by around 13.93 % . One must consider however that the manual shading shuts out the view to the outside completely which might affect the mood of some employees.

Dimming is always beneficial, manual shading with the application of dimming technology saves up by 0.18% only in comparison with manual shading when no dimming is applied.

Automatic shading in average saves up 43.08% of total energy in comparison to Base Case. When comparing automatic shading to each other; one can observe that in the case of illumination and solar heat gain, bottom up saves more energy than top down. For the case of electrical consumption, cooling load, and heating load, automatic top down shading with sensor saves more energy than the bottom up. This sum up the fact that automatic top down shading saves a total energy of only 0.95% when comparing it to automatic bottom up shading. The difference is negligible.

Automatic top down shading with dimming saves up 0.6% of energy more than when no dimming is applied. For automatic bottom up shading with dimming; a saving of 0.36% occurs when comparing it to a basic automatic bottom up shading with no dimming control.

Tinted glazing saves up the least amount of energy and that is around 37% of total energy saving in comparison to Base Case. On the other hand, tinted glazing with 0.7 VT at the bottom saves total energy by only 0.2% more than tinted glazing with 0.7 VT at the top. Again the difference is negligible.

In case of the economic analysis, manual shading proves to be the most economic with the shortest payback period of 5 years. Tinted glazing falls in between and automatic shading has the longest payback period of 17 years.

7.2 Recommendations for Future Studies

This research focuses on finding other substitutions of automatic shading which contribute to energy saving. The latter is performed when taking into account certain features and manipulating the parameters. In addition to that; more research can be performed in the future to experiment even further; for example:

-Since it is proven that manual shading outcomes automatic in this simulation, one can carry on the research by studying the performance and mood of the employees when each scenario is applied.

-This research focused on zone 7 from the building construction plan that is situated on the southern façade. One can choose a different zone with either the same or a different orientation to see if the results are still matching or not.

-A study can be performed on all the orientations of the zone including North, East, and West.

-Glare can be another factor to study through the proposed scenarios.

-One light sensor is used in the simulation. The use of multiple light sensors at different positions in the office space can give more accurate results for the research.

-Another study can focus on the integration of photovoltaic cells on the already installed automatic shading to save up more energy in comparison with manual shading.

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