ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A STUDY ON THE LIGHTING ENERGY PERFORMANCE OF AN OFFICE WITH BUILDING INTEGRATED PHOTOVOLTAIC SYSTEM

M.Sc. THESIS

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Department of Architecture

Environmental Control and Construction Technologies Programme

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

FOTOVOLTAİK SİSTEM ENTEGRE EDİLEN BİR BÜRO BİNASININ AYDINLATMA ENERJİ PERFORMANSI ÜZERİNE BİR ÇALIŞMA

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Arezou Mahmoudi, a **M.Sc.** student of ITU **Graduate School Of Science Engineering and Technology** student ID **502111501**, successfully defended the **thesis** entitled "**A STUDY ON THE LIGHTING ENERGY PERFORMANCE OF AN OFFICE WITH BUILDING INTEGRATED PHOTOVOLTAIC SYSTEM**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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FOREWORD

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April 2014

Arezou MAHMOUDI
Architect

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ABBREVIATIONS

GHG : Green House Gas
PV : Photovoltaic
DC : Direct Current
TFSC : Thin Film Solar Cell
TFPV : Thin Film Photovoltaic
a-Si : amorphous silicon
AC : Alternating Current
BIPV : Building Integrated Photovoltaic System
IEEE : Instutue of Electrical and Electronics Engineers
CIE : International Commission on Illumination
HID : High-Intensity Discharge
DSE : Display Screen Equipment
CAD : Computer-Aided Design
CCT : Correlated Color Temperature
POCS : The Predicted Occupancy Control Strategy
CFL : Compact Fluorescent Lamp
LED : Light-emitted diode
IESNA : Illumuniting Engineering Society of North America
lm : Lumen
ILPA : Interior Lighting Power Allowance
3D : Three Dimension(al)
TL : Turkish Lira
ASHREA : American Society of Heating, Refrigeration, Air-Covditioning Engineers

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A STUDY ON THE LIGHTING ENERGY PERFORMANCE OF AN OFFICE WITH BUILDING INTEGRATED PHOTOVOLTAIC SYSTEM

SUMMARY

This thesis aims to investigate building integrated photovoltaic systems, collaborated with case study building in Istanbul-Turkey, in order to evaluate their performance of energy-efficient lighting design.

Energy demand of buildings requires high electricity consumption, especially office spaces that use energy for lighting. Therefore some strategies, such as energy-efficient building design, are necessary to improve a sustainable development in the existing buildings. In this thesis, these strategies and importance of energy-efficient lighting technologies in office buildings are clarified.

In this study, firstly energy-efficient lighting approach is defined. In the next step a suitable artificial lighting system which has low electricity consumption is selected for case study building. The most common key element for reducing the electricity demand for lighting in office buildings is daylight. By using RELUX simulation it is possible to design the energy-efficient lighting system considering daylight availability by using a daylight responsive control system.

To reduce the annual fossil energy consumption, building integrated photovoltaic system is applied to the case study building. According to simulation results of PVSYST program, the actual utility ratio of photovoltaic systems' electrical generation and its effect on the lighting energy consumption are discussed. The photovoltaic system design can enhance rate of energy saving that will calculated in this case.

Additionally, the economic aspect of photovoltaic panels' energy system is evaluated according to building integrated photovoltaic systems payback time calculation that emphasises the relationship between the area of the office building and the system energy efficiency to reduce expensses.

This study emphasis the importance of energy-efficient lighting approach on office buildings. The optimum facade system supply the enhance daylight that is integrated with lighting control systems dependant to daylight and occupants who are conscious of daylight in order to save electric energy annually.

FOTOVOLTAİK SİSTEM ENTEGRE EDİLEN BİR BÜRO BİNASININ AYDINLATMA ENERJİ PERFORMANSI ÜZERİNE BİR ÇALIŞMA

ÖZET

Bu tez, enerji etkin aydınlatma sistemi tasarımında binaya entegre edilmiş fotovoltaik sistemlerin performansını, İstanbul'da ele alınan bir örnek uygulama çerçevesinde incelemeyi hedeflemektedir.

Binaların enerji gereksinimini karşılamak yüksek düzeyde bir elektrik tüketimini ortaya çıkarmaktadır; bu durum, özellikle günboyu kullanım halinde olan ofis binalarındaki aydınlatma gereksinimi için önemli bir durum teşkil eder. Bu nedenle, enerji etkin bina tasarımı stratejileri, enerji performansı ve sürdürülebilirlik açılarından önem kazanmaktadır. Bu çalışmada, enerji etkin aydınlatma sistemi stratejileri açıklanarak, ofis binalarında uygulanabilecek teknolojilerin önemi ortaya konulmaktadır.

Bu çalışmada, öncelikle enerji etkin aydınlatma tasarımı yaklaşımı tanımlanmıştır. Daha sonra, ele alınan örnek bina için, aydınlatma enerjisi gereksinimini minimize edebilecek bir tasarım öngörülmüştür. Aydınlatma amaçlı enerji gereksinimini minimize etmek amacıyla, enerji verimli lamba ve aygıtların seçimi ile birlikte, günışığı kullanımının maksimize edilmesi ve günışığına bağlı yapma aydınlatma kontrolünün sağlanması gerekmektedir. Bu amaçla, öncelikle ele alınan binanın yıl içindeki günışığı performansı RELUX programı aracılığıyla belirlenmiş ve öngörülen yapma aydınlatma sisteminin günışığına bağlı kontrolü ile enerji gereksiniminin optimize edilmesi sağlanmıştır.

Ayrıca, aydınlatma amaçlı fosil enerji gereksinimin azaltılabilmesi için binaya PV entegrasyonu öngörülmüş ve PVSYST programı kullanılarak bu sistemden elde edilebilecek yıllık enerji hesaplamaları gerçekleştirilmiştir.

Son olarak, önerilen çözümün ekonomik analizi amacıyla PV sistem entegrasyonuna ilişkin geri ödeme süresi hesaplaması gerçekleştirilmiştir.

Bu çalışma büro binalarında enerji etkin aydınlatma yaklaşımının önemini vurgulamaktadır. Uygun cephe tasarımı ile yıl boyunca mekandaki günışığı miktarı maksimize edilerek ve günışığına bağlı yapma aydınlatma kontrol sistemleri entegre edilerek aydınlatma enerji tasarrufu sağlanması mümkün olmaktadır.

1. INTRODUCTION

One of the main challenges that will be faced in the future is sustainable style of economics and energy solicitations of a growing world population. It is necessary to increase the portion of renewable energy resources for climate conservation, which is beside the advanced energy efficiency proceedings. Nowadays passive solar energy potential for photovoltaic and their multipurpose applications on building surfaces, can play a leading role towards energy sustainability.

1.1 Description of Problem

Efficient use of energy is an important aspect of sustainable design. Then for the environmental and economical efficiency, energy demand of the building should be decreased. Use of energy-efficiency products is an important aspect of a sustainable design.

Energy-efficient buildings have a large spectrum of different categories, start with ecological buildings, then modern intelligent ones that use passive and solar systems together, end up with zero energy buildings that do not have any energy need from exterior. Approximately 50% of total world energy consumption is related to buildings, and electric lighting energy demand in office spaces requires almost 70% of the total energy consumption. Use of renewable energy sources in buildings is an important point in reduction of energy consumption.

Daylight strategies and architectural designs are inseparable. Daylight not only replaces artificial lighting, but also influences both heating and cooling loads, reduces energy use. Planning for daylight therefore involves collaboration of various specialists and professionals, their perspectives and meets customer requirements. Daylight design starts with the selection of a building site and continues as long as the building is operated [1].

Obviously the sun is the most important renewable energy source in the world. Solar energy technologies include solar heating, solar photovoltaic systems, solar thermal electricity and solar architecture, which can make considerable methods to solving some of the most urgent problems that the world now faces. The use of photovoltaic systems in the building design, helps architects to build energy-efficient buildings that produce their own electricity.As the photovoltaic systems for producing the electricity are powered by the sun, they do not emit any harmful gas.

1.2 Aim of Thesis

The use of renewable energy sources in the buildings is important for both energy consumption and environmental aspects. And solar power panels are in this categories.They supply a clean, local and renewable energy generation, which features nowadays gaining importance.

This study is planned on inspecting the performance of an energy-efficient lighting design based on daylight accessibility and analysing the photovoltaic systems' contribution on energy demand in an office building as a case study in Istanbul, Turkey. Also it includes economic analyzes according to pay-back time of the photovoltaic systems to find out the feasibility of the panels, and their integration to the mentioned case study building.

1.3 Method of Thesis

The objective of this thesis is desiging an energy efficient lighting system with integrated photovoltaic panels into the case study building to evaluate it's performance in energy saving. This comes off by choosing a daylight responsive control system. To achieve this aim, thesis consists of theoretical and practical parts. The theoretical part, tries to explain renewable energies derived from natural sources. The practical part of this study tries to introduce an energy-efficient lighting design and its application principles, to minimize artificial lighting energy consumption according to standards.

The next step focuses on the photovoltaic requirements' history from a cell to system, their types, components and costs. Also new integration technologies, design principles, advantages, and usage types in buildings, with remarkable application examples all around the world, are examined.Computer-aided design and experts at software in this area improve accuracy and the speed-up in energy-based designs.

Using RELUX simulation software for lighting design and PVSYST simulation software for electricity production of PV panels, are opportunities to attain the realistic statistics about energy saving potential of the case study building. Its working schedules, lighting and photovoltaic system and performance evaluation are clarified.

2. ENERGY EFFICIENCY AND RENEWABLE ENERGIES

Energy is an issue that touches every person on the planet, especially petroleum, from the beginning of 20th century is regarded as the key factor energy uses competition between countries to benefit human’s life. Energy utilization shows a rapid increase at this period. Although enormous progresses have been made in technological innovations, environmental pollution grew too. For example the 80% of the CO_2 emission causing global warming is due to the fossil fuel [2]**.**

Researchers have suggested one approach that they call "stabilization wedges". This means reducing GHG (Green House Gases) emissions from a variety of sources with technologies available in the next few decades, rather than relying on an enormous change in a single area.

There are many possible wedges, including improvements to energy efficiency and vehicle fuel economy (so less energy has to be produced), and increases in wind and solar power, hydrogen produced from renewable sources, biofuels (produced from crops), natural gas, and nuclear power [3].

So to help reduce global warming gases, choose of energy-efficient electrical appliances is necessary. These equipments themselves must be cheap as long as their produced energy, especially in electrical light field.

An efficient energy source which provides sufficient amount of saved-energy and can be obtained more cheaply is the aim of this thesis. Solar energy is the one, which gains more importance day by day. Because it is clean, renewable and steady without any harmful effects on the environment.

There are different ways of capturing solar radiation and converting it into usable energy. The methods use either active solar energy or passive solar energy. Active solar technologies use electrical or mechanical devices to actively convert solar energy into another form of energy, most often heat or electricity. Passive solar technologies do not use any external devices. Instead, they take advantage of the local climate to heat structures during the winter, and reflect heat during the summer.

Photovoltaic is a form of active solar technology that was discovered in 1839 by French physicist Alexandre-Edmond Becquerel. Becquerel discovered that when he placed silver-chloride in an acidic solution and exposed it to sunlight, the platinum electrodes attached to it generated an electric current. This process of generating electricity directly from solar radiation is called the photovoltaic effect, or photovoltaics [4].

Photovoltaic systems are one of the most promising renewable energy sources which using around the world "Like the other systems that use alternative energy sources, photovoltaic systems have shown rapid development after energy crisis of 1970" [5].

In recent years, photovoltaic usage increases by over 300%. In term of energy efficiency, examination of photovoltaic systems, as an architecture element which can be integrated and benefiting from solar energy is important [6].

2.1 Basic Concept of Renewable Energy

Renewable energy is a socially and politically defined category of energy sources and generally defined as energy that comes from resources which are continually replenished on a human timescale [7]. In other words, this Energy is generated from natural resources. In 2008, about 18% of global final energy consumption came from renewable energies, with 13% coming from traditional biomass, such as wood burning [8].

New renewable accounted is growing very rapidly the share of renewable in electricity generation is around 19%, with 16% from hydroelectricity and 3% from new renewable energies. Since 2004, photovoltaic passed wind as the fastest growing energy source. At the end of 2011, the photovoltaic capacity worldwide was 67,000 MW. As of 2011, small solar PV systems provide electricity to a few million households, and micro-hydro configured into mini-grids serves many more [9]. With the industrial revolution, increasing energy demand of fossil fuels on the world, leads to rapid depletion of this kind of energies. Especially after the energy crisis in 1970, assessment of different energy sources has come up strongly [10]. Combustion of fossil fuels, for years, is the main source of heat and energy of the industrial world. Moreover, it is the main reason for air pollution. Human energy consumption releases harmful gases CO_2 and CO into the atmosphere. Although natural transformations such as photosynthesis and decay are obstacles to them, a steady increase of these gases is a menace for environment and human's safety. Usage of limited and non-renewable energy sources like coal, oil, natural gas and nuclear energy brings environmental degradation in many ways.

The renewable energies exist naturally and compatible with environment. They are almost cheap and at hand. Furthermore, they secure the independence of each country. For these reasons, there is an observable increase, in recent years, in the use of renewable energies in most countries. For example the usage of the renewable energy sources in electricity production is considerable, Figure 2.1 and Figure 2.2 show the changes of world electricity generation from 1971 to 2011 by fuel. In the figure the values referred as "other" includes geothermal, solar, wind, bio fuels and waste, and heat [11].

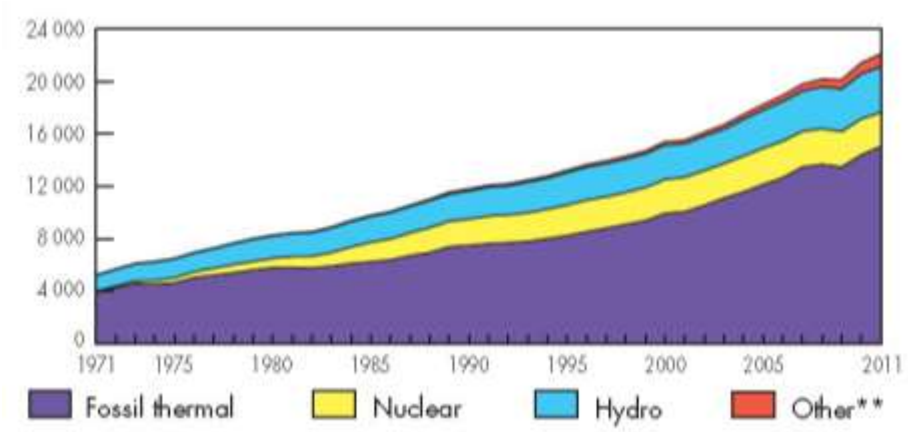


Figure 2.1 : World electricity generation from 1971 to 2011 [11].

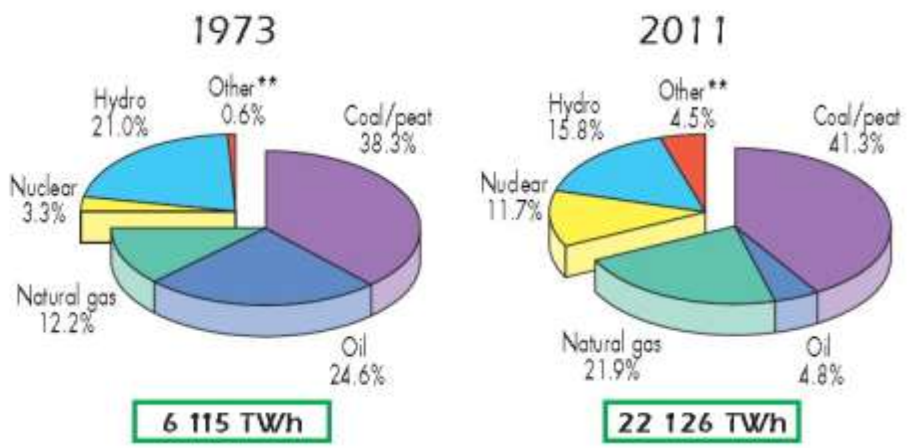


Figure 2.2 : Fuel shares of electricity generation [11].

Major amount of the energy consumption belongs to building industry. Structures can make negative impact on the environment by using natural energy sources. Methods and processes supply energy from renewable sources. New technologies of recycling of energy ensure the continual use of energy. Solar, wind, geothermal, biomass and hydrogen energy are some of these sources with various ways of use in constructions. Most renewable are derived from the sun, directly used for heating or electricity (Figure 2.3).

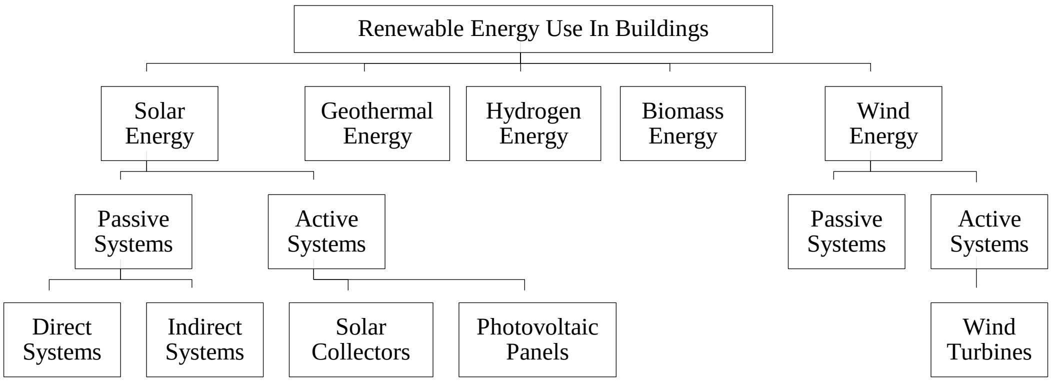


Figure 2.3 : Renewable Energy Use In Buildings [11].

2.2 Solar Energy and Importance of Solar Systems

Solar energy, the light and radiant heat from the sun influences Earth's climate and weather and sustains life. Sun, wind, wave power, hydroelectricity and biomass account for most of the available flow of renewable energies.

The Earth receives 174 petawatts[1](PW) of incoming solar radiation at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near- ultraviolet [12].

Radiation energy of sun that affects the physical creation on the earth and atmosphere system is a major source of energy. Solar radiation energy falling to earth is approximately 160 times more than specified fossil fuel chambers [13]. Solar energy is a preferred source in recent years, because of some advantages such as

1 petawatt (10^{15} watts)

renewability, inexhaustibility, locally implementation, being free and harmless to environment, and does not require complex technology, this energy may be used for two mainly purposes, first of these objectives is using solar energy to generate heat and the second one is to generate electricity. Different technologies used for these objectives and the efficiency of them increases day by day [14].

Besides it has an enormous amount of energy, approximately 170 million MW (Mega Watts) of energy comes from the sun to the world per second [15]. According to a study conducted by EIE (Electrical works survey administration) in Turkey average annual sunshine hours have been found 2640 hours in total (Table 2.1). Turkey has a high potential for solar energy, with 110 sunny days per year. If the required investments for utilization of solar energy were made in Turkey, it can produce 1100 kWh energy per square meter [16]. Unfortunately despite of Turkey's good condition in terms of solar energy potential, it doesn't attrack sufficiently the attention of industrialism. A 1 kWh Solar system in Turkey with an optimum angle of system modules provides a 1650 – 1050 kWh electrical energy annually. It is a high value when compared with European countries performance [17].

Table 2.1 : Monthly Average Solar Energy Potential of Turkey [16].

Mounts	***Mountly Solar Energy*** Kcal/cm^2		***Sunshine hours***
January	4.45	51.75	103.0 hours
February	5.44	63.27	115.0 hours
March	8.31	96.65	165.0 hours
April	10.51	122.23	197.0 hours
May	13.23	153.86	273.0 hours
June	14.51	168.75	325.0 hours
July	15.08	175.38	365.0 hours
Agust	13.63	158.40	343.0 hours
September	10.60	123.28	280.0 hours
October	7.73	89.90	214.0 hours
November	5.23	60.82	157.0 hours

December	4.03	46.87	103.0 hours
Total	112.74	1311	2640 hours
Avrage	308 cal/cm^2-Day	3.6 kWh/m^2-Day	7.2 Hour/Day

Due to limit energy reserves in the world, it hardly meets the energy demand the solar energy picked up by the earth during one hour could be enough to satisfy the worldwide consumption during one year but because of issues such as low density, disconnect ability and efficiency of the existing solar technologies it cannot call as a sufficient technology yet [18]. To eliminate this problem it is important to use available energies efficiently. Reducing of energy consumption overall, without affecting the convenience of daily life is important too.

In terms of energy efficiency, using photovoltaic systems in buildings to produce electric energy, due to directly use of sunlight and to be harmless to the environment, is preferred.

2.3 Energy Efficiency in Buildings

As mentioned, solar energy is an inexhaustible and a clean energy source. To benefit of this favor, investigation of primarily systems related to solar energy has to be done. Passive systems, active systems and mixed systems are defined to take advantage of solar energy in buildings. On an annual basis, buildings in the United States consume 39% of America's energy and 68% of its electricity. With the world's supply of fossil fuel dwindling, demand for fossil fuel rising, concerns for energy supply security increasing, and the impact of greenhouse gases on the world's climate rising, it is essential to find ways to reduce load, increase efficiency, and utilize renewable fuel resources in facilities of all types [19].

Solar technology researches still continue very hard to invent available systems (tools) to increase the energy efficiency and to reduce the costs. Germany is the leader for the solar energy issue which is produced the half amount of photovoltaic panels in the world with 750MWp power capacity of solar energy systems in 2007. It is planned that energy production from renewable resources will increase 27% of total energy production by 2020 [20].

Some cases such as population growth, urbanization and industrialization increase energy consumption rapidly and it is clear that there will be economical and environmental problems considerably in the absence of sufficient appliances of efficiency usage of energy. Nowadays buildings have a significant role in energy consumption and environmental challenge.

Efficient energy, sometimes simply called energy efficiency, is the goal of efforts to reduce the amount of energy required to provide products and services. Building's location and surroundings play a key role in regulating its temperature and illumination. The choice of what kind of heating or cooling technology to use in buildings can have a significant impact on energy use and efficiency [21]. Energy efficiency is to retain economically the amount of consumed energy without reducing the quantity and quality of production energy saving is the most important factor in energy efficiency. Generally energy saving understood as consuming less energy but it is to evaluate of energy waste and unavoidable loss of energy to minimize energy consumption [22].

In the field of architecture the most effective way of energy efficiency is to design buildings and structures as passive systems, in view of energy. If the passive design fulfils an optimal level for a building, climate control will show the optimal performance. That means, if heating and cooling systems run in the way of reinforcing task, the consumption of energy will reduce. To minimize the dependence of buildings on additional energy systems, according to the impact of climate surrounding elements, a varity of designs under the supervision of architectures, is needed to keep fair values. Site location, orientation and form of building, optical and thermo physical features of building envelope, natural ventilation and solar control are some of these variable designs [6].

The improvement of buildings with a consumption percentage about 50%, to economize on fuel, and also to resolve air pollution is in the accountability area of architects. Solar system is going to be examined from the side of using of solar radiation in two broad categories that are:

- Passive solar systems

- Active solar systems

2.3.1 Passive Solar Systems

Passive solar system's parameters are very important for energy efficiency. These systems without the use of additional mechanical equipments and any additional energy consumption are used for collating, storage, dispersing and controlling solar power through building components. In other words, Passive solar systems collect solar heat, store and deliver it, in the most elegant examples, without any hardware driven by energy - hungry machinery [23].

Passive solar systems use solar energy to heat, to cool and to lighten buildings. Passive solar building design is essential for cold weather, to maximize heat gains and reduce heat losses while it makes adequate ventilation and illumination. In this way warm weather minimizes heat gains, eschews overheating and optimizes ventilation and illumination efficiently.

This system cannot be useful all times, also the active system. The parameters of the both must be used together and supported each other if real intelligent building design is required.

Main parameters of passive solar building design are:

- Site of building:

Building location is an important design variable in term of airflow required, solar radiation and its effect on the buildings. These terms consist of some sub-variables like: the direction of the flow field, land slope, location of the land and land's cover and vegetation. Appropriate values of these variables are determined, based on climate conditions [24]. Then the geographical region of the building forms the basis for daylight avalibility and for reduction of electrical energy consumption.

- Location of building in the site and orientation:

Building direction is one of the most important design parameters that affect the total gain from solar energy according to utilization rate of façade from direct sunlight [25]. Therefore proper location, that is, south-orientated buildings is a determinant factor in increase of daylight avalibality by augmentation of sunlight transparency. Careful orientation of buildings is biotic for passive solar energy gains. The space between buildings must be adjusted to obtain the optimal solution. As a potential threat to the future of solar access, not only the effectiveness of existing buildings should be considered, but also the future development of the building that into account [25].

- Form of building:

The building forms play a very important role in the energy performance of buildings. It must be designed according to characteristics of climate, to obtain intended results and informed consent for passive solar and users of the building compact form suitable for cold weather conditions to minimize the surface area that is responsible for heat loss. In warm weather, again compact form can be selected, but less intensely than cold weather. These parameters are paid attention during energy efficient design [26].

- Building envelope:

Designers are always able to select and / or modify previous parameters such as weather, location, and site and sometimes even form, but they are more independent to form a pocket. That is to say, improvement of trasnparency by appropriate choose of glazing, number and design of windows, which allow to get the most efficient daylight avalibility.

The building envelope consists of transparent and opaque components that their thermal conductivity is significantly different from each other. Some important physical properties which effect thermal performance of building envelope are:

- Opaque and transparent components heat transfer coefficients,
- Operating loss opaque components,
- Time lag of opaque component,
- Absorption, reflection and transmission coefficients of opaque and transparent parts [26].

2.3.2 Active solar systems

An active solar system is defined as some technical equipment which is using solar energy to convert it into another useful form of energy. These technologies are divided into two main groups in terms of their method, material and technological level: Solar collectors and Photovoltaics.

2.3.2.1 Solar collectors

A solar collector is basically flat box, composed of three main parts: a transparent cover, tubes which carry a coolant and an insulated back plate the solar collector works on the green house effect principle solar radiation incident upon the transparent surface of the solar collector is transmitted through this surface.The inside of the solar collector is usually evacuated. The energy contained within the solar collect is basically trapped and thus heats the cool contained within the tubes. The tubes are usually made from copper, and the backplate is painted black to help absorb solar radiation. The solar collector is usually insulated to avoid heat losses [27][28].

2.3.2.2 Photovoltaics

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material [29].

Photovoltaic system is an active solar system that can be integrated with buildings and also it is almost new system which will be explained with details in next Chapter.

3. BUILDING INTEGRATED PHOTOVOLTAIC SYSTEMS

A portion of the energy demands of buildings can be met by PV systems. These are based on a combination of solar cells which form PV panels. These panels in turn are equipped with auxiliary elements which convert solar energy into electrical energy. Therefore in terms of energy efficiency the use of PV system is so important.

In this chapter the identification of PV systems, especially solar cells, solar cell types, types of PV systems will be informed.

3.1 Definition of Photovoltaic Systems

“PV” is the abbreviation of the word “photovoltaic”. Actually, the word photovoltaic is a compound of the words 'photo', which means light, and 'voltaic', which refers to the production of electricity solar electric modules or photovoltaic system are solid state semiconductor devices which convert solar radiation without any moving parts straight into electricity, creating almost no pollutants, and requiring no fuel over their life cycle [30].

A well-designed photovoltaic system can produce megawatts of electricity with a little amount of light, and solar cells are electronic devices which convert sunlight directly into the electricity. To convert electrical energy in an effectively way, high quality semi permeable layers are required. Sunlight is a compound of photons that strike a PV cell. And then the energy is transferred to electrons when some of them are absorbed by the semiconductor material [31].

Photovoltaic, in other words, is a converter of the sun energy into a flow of electrons photovoltaic is the technology of generating direct current (DC) electric power which measured in Watts(W). Solar cell generates electrical power, as long as light is shining on them [32].

3.1.1 Advantages and disadvantages of photovoltaic systems

Some of the advantages and disadvantages of photovoltaic systems are given in following lines and they include both technical and nontechnical issues often, these advantages and disadvantages are almost completely opposite of conventional fossil-fuel power plans [32].

Advantages of photovoltaic systems have been arranged below:

- No need to an additional fuel,
- High efficiency because of directly convert system,
- There is no need to transmission equipment,
- Long-lasting (about 25 year guaranteed),
- Do not polluted the air,
- There is no need to an extra area for montage,
- Quick installation,
- Can support the electricity grid during the peak hours,
- Do not hinder the electricity from the network,
- Excellent safety record,
- Can be integrated into new or existing building structures,
- Low operating costs [32][33][34].

Despite of these opportunities, photovoltaic have a few disadvantages too. Although, several of these disadvantages are nontechnical but relate to economics and infrastructure.

Disvantages of photovoltaic systems have been arranged below:

- High investment cost,
- Need some elements to convert generated electricity,
- Lack of economical efficient energy storage,
- Efficiency decreases with shadow effect [32].

3.2 Type of Photovoltaic Systems

Mainly, photovoltaic systems are divided into two different types:

I) Silicon-based solar cells,

II) Thin-film

I) Silicon-based solar cells:

Silicon is the most commonly used cell material. In fact, the most prevalent bulk material for solar cells is crystalline silicon (abbreviated as a group as c-Si), as well as "solar grade silicon" is known bulk silicon that has multiple categories according to crystalline and crystal size in the resulting ingot, ribbon, or wafer is separated [35].

Polycrystalline silicon (polysilicon) is a material consisting of small silicon crystal PV cells which are made from single crystal silicon (often called mono crystalline cells) today are available with efficiencies close to 20% on the market. Laboratory cells are efficiencies close to the theoretical limit of silicon, which is 29% [30].

Polysilicon is more convenient than single crystal polycrystalline silicon. The performance is only slightly lower than the performance of single-crystal cells (Figure 3.1) [30].

II) Thin-film solar cells:

A thin-film solar cell is the second type of photovoltaic systems this system also called a thin-film photovoltaic cell that obtained by depositing one or more thin layers (thin film) of photovoltaic materials. The layer thickness range is wide and varies from a few nanometers to tens of micrometers [35].

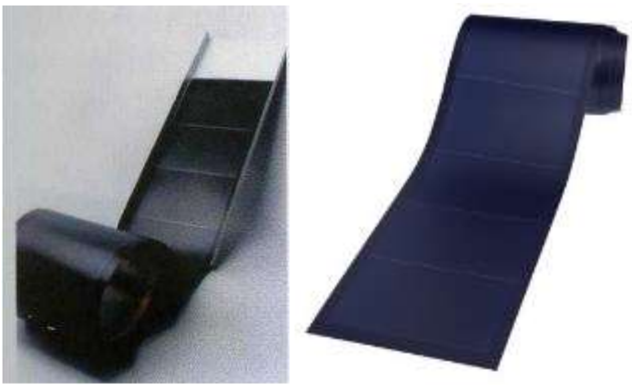


Figure 3.1 : Samples of amorphous silicon cell [30].

In order to lower the cost of PV manufacturing, thin-film solar cells with means of using less material and faster manufacturing processes are being developed. The main work on thin films has been focused on amorphous silicon (a-Si) during last 10 years. The long-term advantage of amorphous as compared to crystalline silicon is the lower need for production energy leading to shorter energy payback time [30].

3.3 Usage Type of Photovoltaic Systems

The distance between buildings and electrical network and differences between produced power of the solar systems and the amount of energy required from them, specify the type of transformation and storage of photovoltaic systems.

PV systems are generally separated into three types:

1. Grid-connected systems.

2. Stand-alone systems.

3. Direct use systems.

3.3.1 Grid-Connection systems

PV systems may be connected to the public network and this connection needs an inverter at the level of the grid voltage for the transformation of the PV-generated DC electricity to the grid AC electricity (Figure 3.2) [30].

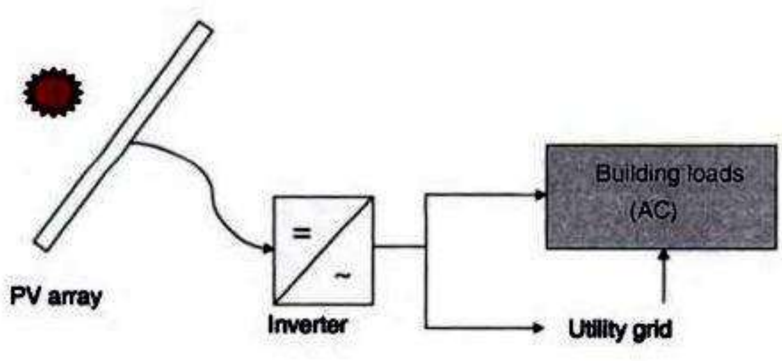


Figure 3.2 : Schematic diagram of grid-connected photovoltaic system [30].

3.3.2 Stand-Alone systems

By means of storage battery, these systems are designed for the storage of energy. Excess energy during time, with no or low loads charge the battery, while at time solar radiation discharges it. In order to ensure a long battery lifetime, charge controller supervises the charge/discharge process, like an inverter in the grid-connected systems, which transforms DC to AC electricity when required (Figure 3.3) [30].

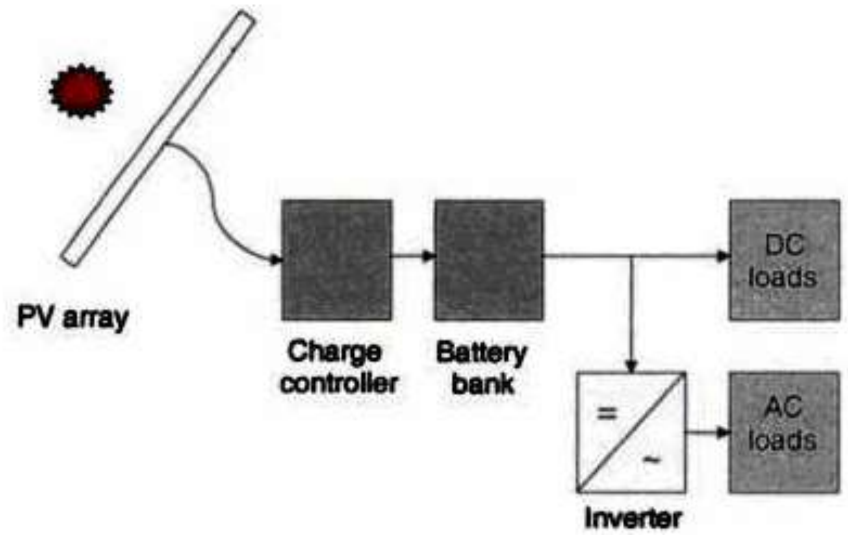


Figure 3.3 : Schematic diagram of stand-alone photovoltaic system [30].

3.3.3 Direct Use system

This kind of photovolatic systems need any electrical storage, there are applications when the load exactly matches the accessible radiation. This omits any need for electrical storage and backup. A generic example is the electricity supply for a circulation pump in a thermal collector system [30].

PV components could be integrated into the existing buildings for improvements, or into the new ones for various purposes. PV systems could be mounted on different surfaces of a building. Thus energy production function combine function combined with building façades function. By mounting PV systems on different surfaces of a building, the function of energy production combines with that of building façades. Therefore, building elements can solve the problem of electricity need.

3.4 Building Integrated Photovoltaic Systems

As said, photovoltaic systems are one of the most promising renewable technologies which are truly indeed usable by means of producing electricity on site. These solid-state devices simply make electricity from sunlight, silently, with no pollution and no depletion of materials, photovoltaic systems are also very versatile: the same technology could produce electricity, pump water out, grind grains, and facilitate communications in rural areas of developing countries, as well as the electricity and the distribution systems of buildings and industrial countries [30].

The terms component-integrated and building-integrated photovoltaic systems (BIPV) refer to the concept of integrating photovoltaic elements into the building envelope, establishing a symbiotic relationship between the architectural design, functional properties and economic regenerative energy conversion. Although this idea is not new, it is not widely harnessed due to the extensive planning and architectural challenges currently involved [36].

In principle, BIPV can be used in all parts of the building envelope. Although roof surfaces are the preferred area for installing PV elements due to their advantageous irradiation values, façades also offer enormous potential [36].

3.4.1 Benefits of building integrated photovoltaic systems

Environment, grid, building and its owners gain many profits from BIPV. Some of them are arranged below:

- Photovoltaic system in building is multifunctional element,

- It’s adequate to meet building needs,

- It is a silent system,

- It can be deployed very rapidly,

- It provides grid support, particularly in areas of summer peak loads,

- It has basic thermal benefits.

Energy produced by this system can generate surplus electricity cost, as well as energy contribution to the thermal performance of building systems. Thus, the BIPV system can be designed according to the heating, cooling and delighting loads of building.

In spite of these advantages, building integrated photovoltaic systems have a few disadvantages, too.

- The efficiencies of thin-film BIPV modules are less than normal crystalline solar panels,

- BIPV costs more than normal crystalline solar panels,

- No air space-lack sufficient ventilation for convection,

- Not much angular flexibility for the installation [37][38].

3.4.2 Type of building integrated systems

The interface between managed internal environment and variable external climate represent by the building envelope. This ought to achieve a certain level of air pressure to prevent unnecessary space heating and cooling, due to the result, in order to enable the effective operation of ventilation systems it needs weather tight cladding design to be a line of defense against water entering the compound.

Finally a façade needs to mediate the transfer of heat between the external and internal environment in order to create a comfortable indoor environment while using the minimum amount of energy [39].

Any building surface which prevents the sun is a candidate for PV integration. Many buildings incorporate semi-attached elements, such as awnings, light shelves, canopies and fences in addition to walls and roofs [40].

Based on the function, the materials which composed of their mechanical characteristics, BIPV products can be classified in five main categories:

-Standard in-roof systems,

-Semitransparent systems,

-Cladding systems,

-Solar tiles and shingles,

-Flexible laminates.

3.4.2.1 Standard in-roof systems

Standard in-roof systems are the simplest and most common approach to BIPV, just by modifying existing panel designs with the crystalline silicon PV industry and mounting systems to make them thinner, more uniform, and flush-mountable on top of existing roofing or siding.

In any case, they represent an important approach to building integration that is still going strong, this approach also makes sense from the manufacturer's perspective. Because minimal retooling and redesign is needed and these flat panels are well-suited to the crystalline silicon industry. As the products do not differ significantly from the conventional panels, they represent low risk investment, guaranteeing similar conditions to the customers [41].

3.4.2.2 Semitransparent systems

Although the glass based modules still are not completely transparent, they are integrated into where only some sunlight penetration is required, added mainly for aesthetical reasons rather than structural. They are commonly used to protect building surfaces and interiors from sun and wind the market sectors where these types of BIPV are commonly used are skylights, semi-transparent façades, curtain walls and shading structures (canopies, atrium roofing.) [41].

Figure 3.4 : Laminated glass composition and application [41].

By dimensioning and adjusting the number and spacing of cells of crystalline silicon or by modifying the manufacturing process of thin-film, the design of structures will be suited to better light. In both cases more transparent the module, the lower energy efficiency, these products are used usually for commercial and prestigious buildings, designed to provide a great deal of natural lightning by using large areas of semi-transparent window-like areas. High visibility of those projects/constructions guarantees wide opportunities for BIPV suppliers [41].

3.4.2.3 Cladding systems

Solar panels can be integrated into building walls as conventional cladding elements. The creation of a "cladding void" helps to, firstly, regulate the internal temperatures of the building by minimizing solar gain in summer and secondly, by encouraging a “thermal stack effect” which helps to draw air through the building spaces. These help to minimize the year-round energy demand of the building, to keep the PV modules operating at their highest efficiency and so to maximize the contribution of the PV to the energy requirements of building. This application therefore minimizes the overall energy demand, also reduces overheads obtaining good ventilation behind the modules. So that the PV system can work at full efficiency, if this is not possible, the performance will be reduced but the system will continue to work (approx. 10% loss of performance) [41].

Glass PV laminates, replacing conventional cladding material, are basically the same as tinted glass. They provide long-lasting weather protection and can be tailor-made to any size, shape, pattern and color.

Figure 3.5 : Conventional cladding elements [41].

3.4.2.4 Solar tiles and shingles

The current available on the market products of this category include: i) tiles, designed to interlace with conventional roofing tiles or cladding materials; ii) larger tiles that serve as entire roof or wall portions themselves; and iii) thin, flush-mounted panels that overlay conventional roofing or siding but specifically designed for that purpose. Many proprietary roof-integrated BIPV systems are available, since the design of a PV tile/shingle has to adapt to regional/local roofing methods and buildings.

Therefore the market for one particular BIPV roofing system may not be applicable to a wide range of countries. Products such as flexible PV roofing shingles and analogically rigid PV tiles enable reasonably and cost effectively allocating expenses between power production and design/architecture [41].

The main categories of applications where PV tiles and shingles are used are pitched roofs, in this type of application the most common solutions are photovoltaic roof tiles with mono or polycrystalline solar cells used together with the classical roof tiles [41].

Figure 3.6 : PV roof shingles application [41].

3.4.2.5 Flexible laminates

The c-Si PV systems gradually due to their rigidity are excluded from architecture. Flexible laminates, instead of them, are designed to construct building materials such as metal roofing. They avoid conventional framework of rigid panels because of adhesively bonding to roofing materials. This group consists of innovative materials of platforms (such as thin-film and organic PV) which can be used in a variety of different applications, mainly flat and curved roofs. Therefore it is thin film that is used within this category of products, many of the flexible modules brings along many advantages like light weight, avoidance of heavy wind loads (because they do not allow wind beneath them) and avoidance of rack mounting system since they can be directly glued to the roofing material [41].

3.4.3 Cost of building integrated photovoltaic systems

Costs are important matter next to benefits of BIPV. The BIPV system cost on current PV technology depends on the type and size of system and it is used on weather a custom product or a standardized manufactured product. BIPV applications are available for both new and renovation construction projects. BIPV façade systems' products such as laminated and patterned glass, cladding and awning systems can displace traditional construction materials, curtain wall glazing materials. Roofing system's products such as tiles, BIPV shingles, metal roofing and atrium or laminate roof systems can replace traditional construction materials or as a construction material has risen to be sold [38].

Systems can replace traditional construction materials or as a construction material promoted to be sold. So that the polished stone façade construction cost per square meter is $2400-$2800; the photovoltaic façade construction cost per square meter is $500-$1500; the stone façade construction cost per square meter is $800; the glass wall systems façade construction cost per square meter is $560-$800 and the stainless steel façade construction cost per square meter is $280-$400 [38].

So according to the cost of façade with various features, we can conclude that the implementation of the photovoltaic façade is expensive.

3.4.4 Building integrated photovoltaic systems samples in the world

Unfortunately photovoltaic applications is limited in Turkey, however some universities and private companies research into photovoltaic technology continousely. Here are some examples of the most valuable and important worldwide applications with their remarkable properties:

- Galleria Naviglio

Location:

Town, country: Faenza, Italy

Latitude, longitude, élévation: 44.313º, 11.898º, 23m

Average horizontal irradiation: 3.28 kWh/ (m^2.day)

Photovoltaic system:

Area: 285m^2

Peak power specification: 23kWp

Power output: 33.345 kWh/ Y

Individual module dimensions: 1937 x 220 x 299mm

Technology: Monocrystalline silicon

Building:

Type: office, shop and apartments

Height, storey: 11m, four

Floor area: 4000m^2

Two buildings use a reinforced-concrete structure to meet anti-seismic requirements: The infill panels on the north façade are precast- concrete panels with an external visible brick wall. The southeast and west elevations use curtain-walling system, preferred for the wider glazed surfaces. External glass louvers are used on the lightweight elevations on the south-east, north-east and south-west faces to provide some level of protection from the solar radiation. These louvers are fitted with monocrystalline silicon PV cells. The PV louvers are tilted 70º from horizontal and cover a surface of 285m^2. The array specification is 23kWp [39].

Figure 3.7 : PV louvers on the Galleria Naviglio [39].

- The Co-operative insurance tower:

Location:

Town, country: Manchester, UK

Latitude, longitude, elevation: 53.487º, -2.238º, 54m

Average horizontal irradiation: 2.53 kWh/ (m^2.day)

Photovoltaic system:

Area: 3972m^2

Peak power specification: 391kWp

Power output: 183000 kWh/ Y

Individual module dimensions: 1200 x 530 mm

Technology: polycrystalline silicon

Building:

Type: office, conference, cinema

Height, storey: 118m, 25

Floor area: 54000m^2

At first estimation, thin-film technology represents an aesthetically suitable cladding material. The modules cost lower than crystalline silicon modules. Moreover, standard thin-film modules are available in a variety of sizes.

However the planning authority rises, because of the concerns about the appearance of the thin-film modules on the building. The overall effect will be too uniform, existing identification of the floor-to-floor separation of 3.74m, a key feature in the original mosaic design, will be losed. Polycrystalline modules have a more desirable appearance, furthermore the size of standard modules available from sharp (shape) overcomes the planner's aesthetic concerns. The particular module was the 1200mm wide by 530mm high with a frame thickness of 35mm.

A "cassette" formed of seven modules could be created in which the cassette height of 3.71m corresponded to the floor-to-floor separation required by the planning authority. The cassette width of 1.20m means that the wide south façade and narrow east and west façade are incompletely covered, yet an absolutely even appearance was essential. Electrically inactive PV modules with a bespoke width of 230mm were used for the visible areas. For less prominent parts, plain blue powder-coated steel panels sufficed [39].

Figure 3.8 : Completed PV cladding of the Co-Operative [39].

- Tobias Grau GmbH Head Office:

Location:

Town, country: Rellingen, Germany

Latitude, longitude, elevation: 53.631º, 9.885º, 16m

Average horizontal irradiation: 2.73 kWh/ (m^2.day)

Photovoltaic system:

Area: 179m^2

Peak power specification: 18kWp

Power output: 10800 kWh/ Y

Individual module dimensions: 1970 x 1430 mm

Technology: polycrystalline silicon

Building:

Type: office

Height, storey: 10m, 2

Floor area: $4160m^2$

The vertical south façade of two buildings together present an overall area of $179m^2$ for PV integration. The west building has an area of $128m^2$ for 45 modules.

The modules are clear laminates with blue polycrystalline cells. The 10mm spacing of cells acts as solar shading device and causes the modules to let some natural daylight through the façade. These properties together with the high transparency of the other façades make the daylight one of the key aspects of this project. Module dimensions are 1.97 x 1.43 m.

The two PV systems have been founded by the government and have a specification of 18kWp. They generate about 11 MWh per year [39].

Figure 3.9 : PV cells letting in filtered natural daylight [39].

- Alan Gilbert building

Location:

Town, country: Melbourne, Australia

Latitude, longitude, elevation: -37.800º, 144.959º, 52m

Average horizontal irradiation: 4.12 kWh/ (m^2.day)

Photovoltaic system:

Area: 426m^2

Peak power specification: 46kWp

Power output: 40000 kWh/ Y

Individual module dimensions: 2664 x 1895 mm

Technology: polycrystalline silicon

Building:

Type: Faculty of Economics and Commerce

Height, storey: 24m estimate, 2

Floor area: 4550m^2 estimate

Glass-to-glass laminated polycrystalline cells are spaces that allow part of the incident ray of daylight to pass through the façade. The cells on particular consist of: an outer layer from low-iron heat-strengthened glass panel and an inner alyer from clear heat-strenghened glass panel, both with 6mm thick.The two panels are separated by 2mm of liquid interlayer, within which the polycrystalline cells are embedded.

Seeing that, the polycrystalline cells match the mono crystalline cells with aesthetic aspects, they are the first choice for their cheaper prices.

The PV façade is made of 148 modules with eight different sizes, each with a different number of cells and thus a different output voltage. The modules are connected together in different groups, which present different output voltage too. For this reason each group has its own inverter, which is designed to receive the specific output from the relevant group of modules.

The installation produces 47.3kWp and the generated power feeds the services of building and if the generated electricity exceeds the requirement, the power is exported to the grid network [39].

Figure 3.10 : PV in the two top storeys [39].

4. THE PRINCIPLES OF LIGHTING DESIGN IN OFFICE BUILDINGS

Lighting is responsible for the 20-70% of the consumed electric energy in office spaces. Energy-efficiency and sustainability are the applied concepts in overall design of buildings. When lighting concept of the building is assumed in the energy-efficiency frame of building design, the energy consumption is reduced and a comfortable as well as profitable life for occupants is provided. If efficient lighting, building controls and etc. are exerted to the project, office spaces use 10-30% of the energy of the country in the frame of energy-efficiency program, nearly 50% saving can be provided [42].

Daylight is a key element when the occupancy time assumed and automatic control systems reserve energy efficiency besides occupants' acquiescence. Daylight-responsive lighting is the energy efficient one, which is the key element in this approach. When you change the location of daylight-depending lighting also control shadow in daylight, this will be known as energy efficiency resources. There are two dimensions for daylight-responsive lighting: the control of daylight (quality of daylight related to the quantity of inside space) and the control of daylight depending electric lighting. The users control the daylight-responsive lighting: when daylight is not enough, saving and providing of energy requires light.

4.1 Visual Requirements in Offices

For commercial buildings including office spaces, institute of Electrical and Electronics Engineers (IEEE) has published IEEE standard 241 "The Recommended Practice for Electric Power Systems in Commercial Buildings (1990)", mentions that providing illumination without annoyance or discomfort due to luminaire or window brightness is desirable. According to this standard ranges from 100lx to 200lx illuminances are recommended for working spaces where visual tasks are only occasionally performed. If performance of visual tasks of high contrast or large size like reading printed material, typed originals, and handwriting in ink is the type of activity in the workplace, then the recommended luminaires are between 200lx-500lx [43].

The task area is defined as the area in which the visual task is carried out. The visual performance required for the visual task is determined by the visually relevant elements: Size of objects, background contrast, and luminance of objects, presentation time of the activity performed. The task reference surface can be horizontal, vertical or inclined.

Defining the work station area as an area in which visual tasks may be presented. For illuminances up to 500 lux, maintained illuminance needs to be observed across the work station area; for illuminances over 750 lux, it should be observed on the work surface. The surrounding area borders directly on one or more work station areas and from there extend to the walls of the room or to circulation routes [44].

In very large rooms where work stations are occasionally or regularly not managed (e.g. in a call centre), DIN EN 12464-1 allows a background area to be applied.

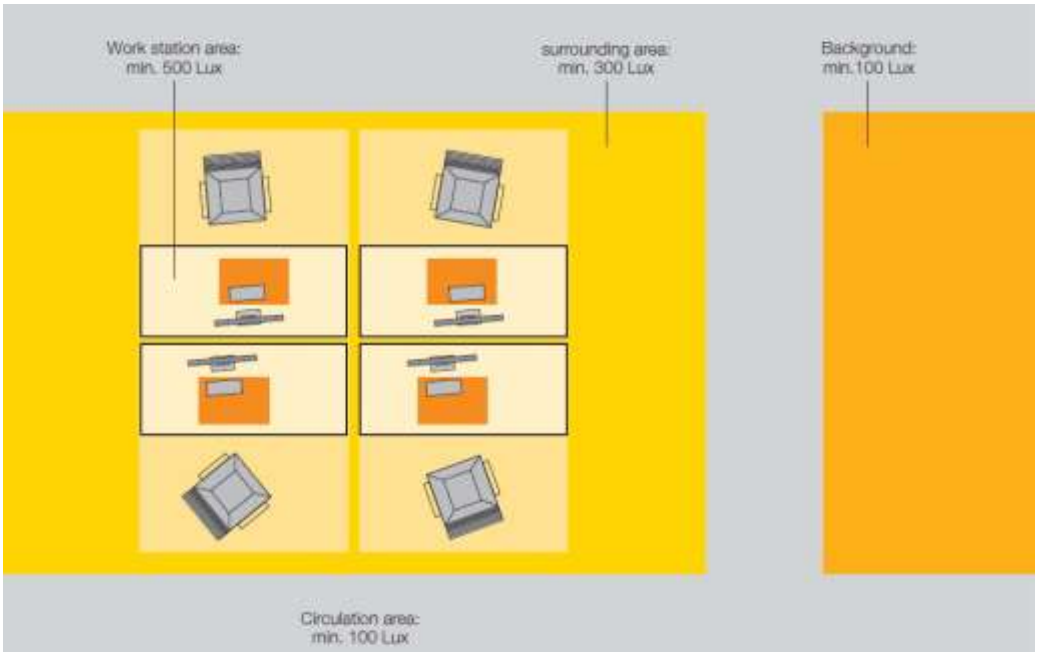


Figure 4.1: Typical plan of work station area, surrounding area, circulation zone and adjoining background area in a very large room [44].

Lighting design relates work station areas to the offices which can accommodate to one or more work stations in known or unknown arrangements in this offices which are like room with possible arrangement of work stations extending to the boundaries of the room, the precise location of the work station areas is unknown, the whole room is taken to be the work area without deduction of any marginal zones (Figure 4.1) [44].

A work station area includes desktop surface(s) and user space. The working plane is assumed to be 0.75 m above floor level.

International Commission on Illumination (CIE) and lighting of indoor work places standard (2001) declare lighting design criteria basically for office lighting like luminance distribution, illuminance and glare. The luminance distribution in the field of view controls the adaptation level of the eyes, which affects the task visibility. The luminances of all surfaces are important and will be determined by the reflectance of the surfaces 0.6-0.9 for ceiling, 0.3-0.8 for wall, 0.2-0.6 for workplace and 0.1-0.5 for floor. For office spaces where writing, typing, reading and data processing take place, 500lx is the maintained illuminance on the reference surface for the task. The maintained illuminance of the immediate surrounding areas may be lower than the task illuminance, but it shall not be less than the value of 300lx for task illuminance of 500lx [45].

4.2 Atificial Lighting System in Offices

When uniform lighting is in consideration, recessed fluorescent luminaire and access to ceiling plenum spaces for installing and servicing mechanical and electrical equipment are necessary, these permit easy relocation. Localized lighting may be required in certain cases to decrease costs and improve illumination another approach in office lighting is the task concept, and defined as the best solution which provides the optimum visual or seeing conditions in the work setting and it conserves best energy by providing high-level illumination where it is needed [46].

In modern buildings, artificial lighting as general lighting, localized or local lighting should be suited to different purposes. Localized lighting provides more intense illumination at the work stations and its units illuminate only specific work areas, like a desk. General lighting is designed for activities such as filing, and its installations provide uniform illumination over the whole workplace. Both quality and quantity of light are important. Glare will result and may affect visibility if lights are too bright. Discomfort glare does not cause direct visual interference, but it can be annoying or uncomfortable. It can be caused by direct or reflected light. Disability glare usually happens when broad-band light illuminates your workstation, like light from a window [47].

In all workplaces, the adaptation of lighting to energy codes has become a major criterion. The primary result is the pervasive use of compact fluorescent lamps.

Some products which have created by expanding development of fluorescent technology can address all of the needs of the workplaces lighting, from subtle effects to dramatic spectacular the bulk of lighting solutions are accomplished with fluorescents and high-Intensity Discharge (HID) lamps and low-voltage lighting can assist in office facilities [46].

Fluorescent lamps generate light more efficiently than incandescent lamps, through there is great variation in fluorescent lamp efficacy depending on color and wattage they also have characteristics of low brightness and diffusion, making them excellent for many lighting application where luminarie discomfort glare should be controlled [43].

- **Lighting and safety**

Too little light and shadows or dirty light sources end in insufficient lighting, which may cause the user to squint and eye strain. Fine works usually need more light but too much light can cause eye-strain. The optimum light intensity for workplaces depends on the task at hand. Optimum lighting situation depends on an optimum contrast between illumination of the workstation and its surroundings. At the workstation the light contrast between the task and its immediate background should not exceed a ratio of 10:3.

In working with colors, like paint or ink, the type of used lamp would be important. Universally lamps with high luminous efficiency render colors poorly, but fluorescent lamps give good vision and color rendering.

Three forms of signs and symptoms of visual strain which diverse and complicated are ocular, visual and systemic, ocular problems should be dealt with by an optician, visual difficulties usually result from poor lighting contrast, systemic symptoms are headache and eye-strain, which are usually not specific and are therefore overlooked [47].

Visual strain may result after long working hours if the lighting condition of the workstation is poor, it may also make the workers to adopt unsuitable postures that lead to other forms of health concerns such as neck pain. Working on display screen equipment (DSE) is visually demanding [47].

Flexible or adjustable lighting systems give better control over light sources. In addition, knowledge of the best lighting conditions brings the best of equipment it is important for both visual performance and feeling of comfort and well being that colors in the environment of objects and human skin are rendered naturally, correctly and in a way makes people look attractive and healthy [45].

To provide an objective indication of the color rendering properties of a light source, the general color rendering index R_a has been introduced. Lamps with a R_a less than 80 should not be used in interiors where people work or stay for long periods. The color appearance of a lamp refers to the apparent color of the light it emits. It is described by its Correlated Color Temperature (CCT) the color of the lamp will depend upon the atmosphere to be achieved and the need for color rendering. Where daylight makes a substantial contribution, lamps with a CCT of 4000K or above may be preferred [48].

4.3 Lighting Control Systems

A lighting control system is an intelligent network that synthesizes communication between outputs related to lighting control and various system inputs, with the use of one or more central calculating devices, it is widely used on both indoor and outdoor lighting of different spaces. These systems serve to provide the right amount of light where and when it is needed [49][50].

Manually or automatically lighting systems' control can balance electricity supply and peak demand in commercial buildings.

The lighting regulations can be done by setting a remote system with location. So that the building administrator could be able to control the brightness settings, thus the spending on maintenance could be economized. This would be possible automatically too.

A lighting control system must be accepted by the users and satisfied with its performance. Employees must have sufficient and accurate information about the purpose and operation of the given systems. The presence and daylight detectors can be added or subtracted. Adding automatic times and calendars are very easy [51].

Lighting control systems will play an important role in the reduction of energy consumption of the lighting often the largest electrical load in offices is lighting [52].

Building managers have accomplished programs to reduce lighting energy requirements by installing more efficient light sources and luminaries to perform the requirements about comfort and energy efficiency. Optimal illuminance level have to prepare by lighting energy management for the tasks being performed using the most efficient light source suitable for the application, and preparing light only when and where it is needed [52].

Artificial lighting control systems development process has begun in 1980.The past 25 years is the concept of reducing energy consumption. The electronic ballasts were produced for fluorescent lamps achieving energy saving about 25%. In 1985, dimming properties are added to electronic ballasts [53].

Lighting control is the main objective to reduce the amount of time, therefore the payment of consumes. This control depends on the daylight, occupancy and some factors of the space. When daylight changes place with electric lighting, energy saving are determined around 50%, as the time of electric consumption decreases and the costs decrease as well [54].

An artificial lighting control system is based on the regulation of luminous flux, the directional control or the color.

Daylight illumination is an important concept in the context of lighting control systems. The examinations on users' behaviors show that, without lighting controls, the artificial lighting is switched on manually when they enter the room and is not switched off during the occupancy hours, even if the illuminance that is supplied only by daylight exceeds 500lx. Although they left the room for a long time in the busy hours, the artificial light is not lit. Therefore, controlling daylight response with presence detectors can provide a lot of savings [55].

United States department of Energy has determined three different types of electric lighting control systems. The manual controls that they have defined are manual dimming, bi-level switching and the automatic controls that have been clarified as occupancy sensors, time scheduling and daylight dimming [56].

Mainly the electric lighting control can be divided into two basic categories: manual electric lighting control and automatic electric lighting control.

4.3.1 Manual lighting controls

The most widely used lighting control is the manual switch to put on or off an individual luminaires or a group of luminaires, this type of control is the first one and it is not huge enough with respect to energy efficiency as it relies solely on the behavior of the occupants which is not necessarily related to energy savings, especially in the tertiary sector buildings [52].

- **Manual dimming:**

This type of control can be wall-mounted or remote controlled and give opportunity to occupants to change the light level anytime they want [56].

- **Bi-level switching:**

Bi-level switch is the derivative of manual on/off switches. Manual on/off switch is the conventional system that is wall-mounted mostly next to the room or door and controlled manually by the occupants. Bi-level switching gives convenience to a manual on/off switch system by separating the power of multi lamps in the same fixture. So that user can switch one lamp in a three-fluorescent-lamp luminarie resulting in energy saving [56].

4.3.2 Automatic lighting controls

The operation of an automatic control system changes in accordance with the amount of daylight, timing (time intervals) and user occupancy. In this way, the lighting is managed by light and space availability and this makes the employees more comfortable with their job.

- **The Predicted Occupancy Control Strategy (POCS)**:

The predicted occupancy control strategy is used to reduce the operating hours of the lighting installation. It generates energy savings by turning lighting on and off, on a preset daily time schedule. Schedules usually vary on a daily basis according the building occupancy. Lights automatically turn off at a preset time, help system managers, building operators / installations to avoid having light in unoccupied hours, mostly at night and the holiday weekend [52].

- **The time scheduling control strategy:**

This strategy enables the switch on or off automatically at schedule time and occupancy patterns for different regions.

Twenty-four hour timer allows employees to set specific times for lighting.Timer is set to change the lighting during the occupation. Measurements have shown that the best energy efficient solutions are combining the use of a cut off system with a manual switch on system, potential gains are between 10% and 15% without daylighting [52].

- **The Daylight harvesting control strategy:**

This strategy on a surface or at a specific point uses a photocell to measure the illuminance level within a space. The system's controller reduces the lumen output of the light sources if the light level is too high. The controller increases the lumen output of the light sources if the light level is too low. Sensors are often used on large areas, each controlled by a separate group of lights in order to maintain consistent brightness levels throughout the region. The result is a system that minimizes lighting energy use while maintaining uniform illuminance levels and this system can also provide the constant illuminance strategy. Generic applications include classrooms, high-rise office buildings and retail facilities. The potential savings varies from 20% daylight-harvesting alone to more than 50% daylight harvesting plus real occupancy [52].

4.4 Energy-Efficient Lighting System

The processes of primary energies conversion to more convenient forms are develloped. The total primary energy factor for electricity is 2.5 in Europe. This value reflects an efficiency of 40%, which is the average efficiency of electricity production [57]. In addition to affecting the physical and mental well-being of occupants building's interior lighting system is both a dominant consumer of electrical energy and a major source of internal heat [58].

Determining a high quality energy-efficient lighting system that utilizes both natural and electric sources as well as lighting controls can still have a comfortable environment for the occupants of the space. Recently developed energy-efficient lighting can be used to reduce operating costs by 30% to 60%. Brightness while improving lighting quality reduces environmental impact and improves the health and productivity of labor [58].

Figure 4.2 presents the comparison of CO_2 emissions during life time of an incandescent lamp, CFL and a future LED light source, a 75W incandescent lamp with luminous efficacy of 12 lm/W, a 15W CFL with luminous efficacy of 60 lm/W and a 6W LED light source with luminous efficacy of 150 lm/W were compared to provide the same light output. The lifetime of future LED light source is assumed to be 25 000 h. The calculation was done for 25 000 lamp burning hours. During this period one LED, 3 CFLs and 21 incandescent lamps were needed [58].

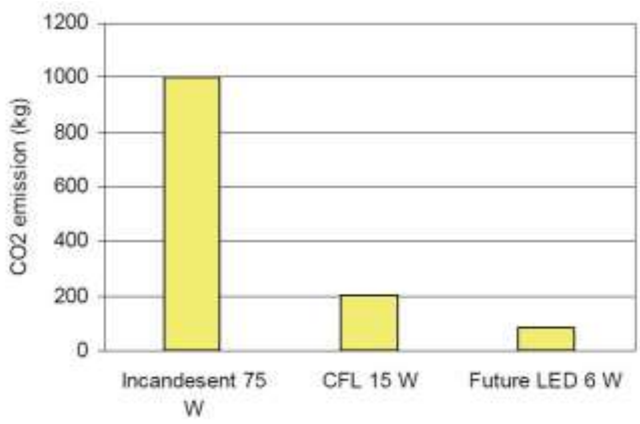


Figure 4.2: Comparison of CO_2 emmissions during life cycle of incandescent lamp (12lm/W), CLF (60lm/W) and LED (150lm/W) [58].

There are large variations in annual lighting energy consumption per unit area for different types of buildings due to the different occupancy levels of the buildings. The average electricity consumption for lighting per square meter in healthcare buildings is the highest of all types of buildings because of the long operating periods [9].

Supply occupancies with energy-efficiency automatic control systems satisfy them. By reason of, this control system saves the 20-70% of the electric energy costs in office spaces. Energy-efficiency and sustainability are concepts that can be applied to the overall design. Energy efficient lighting is a key element in this approach and it is called daylight-responsive lighting. Daylight-responsive controls have two dimensions: daylight control and electric lighting control.

Daylight and artificial lighting should be used together for more efficient lighting. Energy-efficient lighting can be achieved when the daylight-responsive is used as control system and electric costs are reduced. Energy-efficient aspects are described in three topics as below.

4.4.1 Environmental Aspect

The one of the greatest sources of atmospheric CO_2, which is caused global warming, is electricity. This is also related with CO_2 emissions when energy consumption decreases. Emissions could be reduces 1% in the time interval written in the Kyoto Protocol when cost-effective lighting is applied [59].

The use of daylight is on the worldwide increase in recent years as direct and indirect replacements for fossil fuel, motivated to some degree by environmental concerns such were expressed in the Kyoto Protocol [60].

As a result, a complete knowledge and detailed analysis about the potentiality of the site for daylight activity is of considerable interest.

4.4.2 Economic Aspect

Global solar radiation is of economic importance as a renewable energy alternative. Recently, global solar radiation due to its importance in providing energy for Earth's climate system is studied. Daylight information on solar thermal in building profit forecasts, weather forecasts, and predictions of agricultural potential evaporation from lakes and reservoirs are required. However, the best information is clear from the empirical measurement of global and local components obtained [60].

The substitution of daylight for electric lighting decreases costs. When light is controlling according to availability of shadows, it provides also economic savings. Enhancement of daylight into building can supply economic and energetic saving around 20-40% [61].

4.4.3 Energetic Aspect

There are principal worries about the future of energy, as world energy consumption doubles in every ten-year time in the entire world. Due to global sustainable decisions, the relationship between the building and the energy prevents an energy crisis.

Solar energy in the form of daylight means a free energy source for lighting services of the building. The energy sources, demand-supply relations, renewability of sources and finding new sources should all be observed for the sustainability [62].

5. PERFORMANCE EVALUTION OF CASE STUDY BUILDING: ARI TEKNOKENT 2

As mentioned before the main factor of energy demand in office spaces is lighting. This chapter is intended to evaluate the lighting energy performance of a case study building, “ARI Teknokent 2”, based on an energy efficient lighting system design with a daylight responsive control and taking the energy gain by PV’s into consideration.

5.1 Description of Case Study Building

ARI (Advanced Research and Innovation) Techno polis is a science park located in Istanbul Technical University main campus [63].

ARI TEKNOKENT 2 building which inaugurated by Hüseyin Kahvecioğlu, is built in a total area of 20.000 m^2, at June 2005 [63, 64]. It is intended for new technical knowledge activities, Research and Development (R&D)[2]. The building consists of two main blocks, A and B. Block A is oriented to south and Block B to southwest at an angle of 25°. Case study building has a glazed façade. The static solar shading elements are installed on the façade at an angle of 30. *ARI TEKNOKENT 2* is a glazed façade 30 meters high structure. An exterior view of the building is given in Figure 5.1.

[2] R&D (Research and Development), defines creative efforts and the use of knowledge in new applications, which was carried out on a systematic basis, in order to increase scientific and technical knowledge.

Figure 5.1 : An exterior view of ARI TEKNOKENT 2 [64].

The ground floor plan (1441m^2), mezzanine floor plan (1285.7m^2), type floors plan (1565.5m^2) and terrace floor plan (1174.7m^2) can be seen in Figure 5.2, Figure 5.3, Figure 5.4 and Figure 5.5.

Figure 5.2 : Ground floor plan.

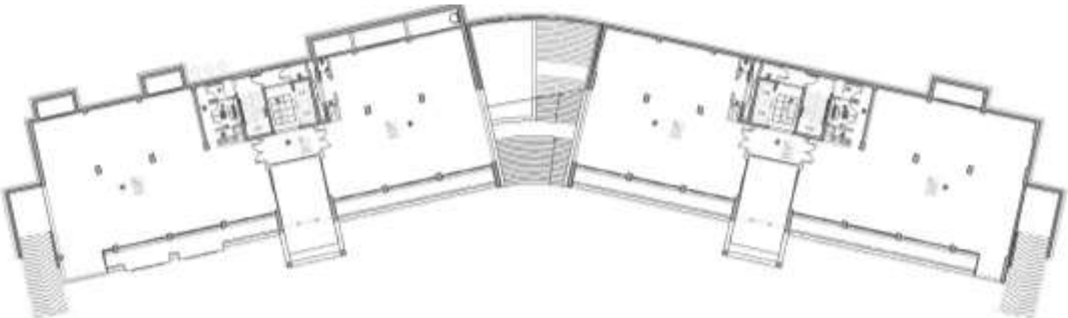


Figure 5.3 : Mezzanine floor plan.

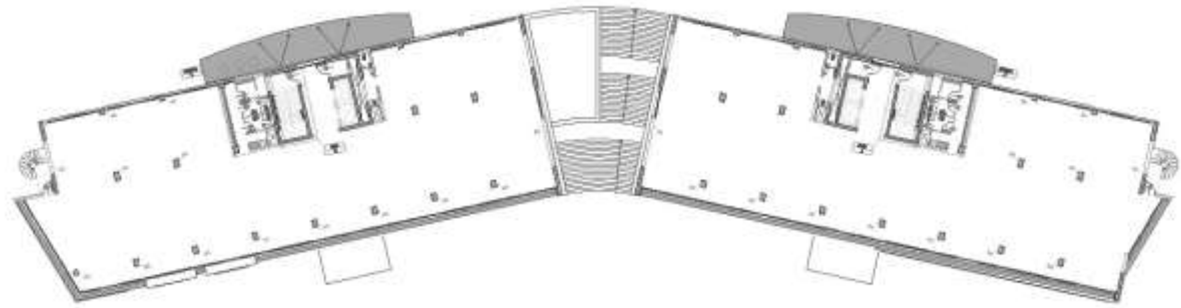


Figure 5.4 : Type floors plan.

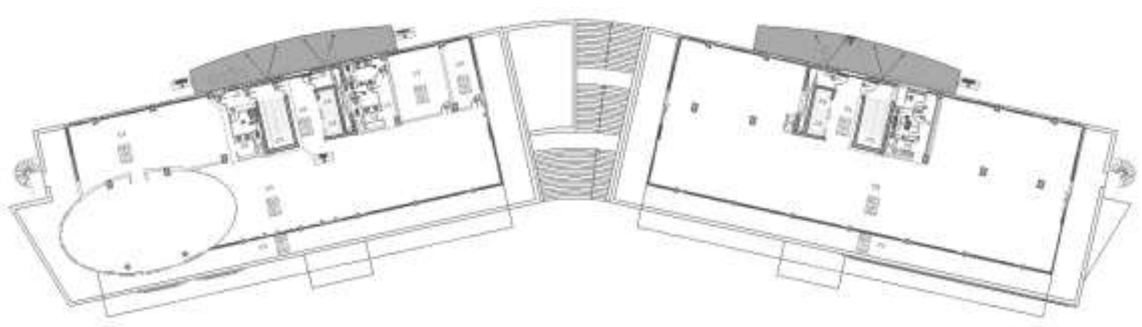


Figure 5.5 : Terrace floor plan.

5.2 Lighting System of the Case Study Building

As mentioned before, this study looks for the consumption of the amount of energy in artificial lighting systems and energy-efficient lighting in office spaces. Thus the lighting system changes have been made in accordance with energy-saving methods by integration an optimum control system.

According to the energy-efficient lighting data, high amount of energy consumption can be decreased by enhancing the daylight accessibility. This is an opportunity to reduce annual electric energy cost.

Lighting energy consumption depending on the daylight accessibility has been calculated by RELUX software. Simulations are done in two sets. The first one is based on the energy efficient artificial lighting system design which providing the visual comfort conditions. The second set has an advance artificial lighting control system (switch on/off system) that supplies the most energy saving, depending on the enhanced daylight and occupancy.

Computing the rate of saved-energy by daylight responsive control system, could help us having a clear idea of economizing electric energy consumption.

5.2.1 Simulation with RELUX software

Informatik AG develops RELUX Professional, can be used both for interior and exterior lighting design. This program uses average indirect fraction methodology for calculation [65]. RELUX is a ray tracing freeware supported by a number of luminaire, sensor and luminaire manufacturers. It is an easily usable tool, where visual design elements of a building including materials, furnishing and color can be simulated, showing their influence to real light distribution [66]. For interior lighting, simple geometries can be automatically generated, based on room dimensions. Geometries that are more complex can be created by means of blocks and surfaces or can be imported from AutoCAD through a dedicated plugin. RELUX is also a radiosity-based program (point to point method) where both artificial lighting and daylight simulations can be conducted [67].

RELUX can take luminaire definition in greater details by online or downloadable catalogue from manufacturers. RELUX also affords opportunity to modify the parameters of luminaire definition like: luminous flux output, luminaire color and dimension etc [65]. Luminaire photometry can be imported directly from manufacturers' integrated libraries or in IESNA or Eulumdat formats also luminaire dimensions can be set manually [67].

The program's 'Easy Lux' feature gives ability to calculate the number of luminaire and position with ease, moreover the ability to visualize results with graphical aids is desired for designers. RELUX also provides limited opportunity to customize material properties [65].

Simulated sky conditions are CIE overcast and clear skies [67]. RELUX lighting simulation will be carried out to obtain the illuminance distribution in the open plan offices.

5.2.2 Artificial lighting system

Besides affecting the physical and emotional well-being of the building occupants, a building interior lighting system is a dominant consumer of electrical energy. In commercial buildings its electricity budget normally accounts for more than 30% of the total electrical energy consumed [58]. EN 12464 standards for work places lighting provides the recommended illuminance values for specific activities. The illumination value, after commence of the artificial lighting system, meets the required comfort condition that is described 500lx for office spaces, according to this principle [44]. The required artificial lighting energy is calculated for a specific year of the open office spaces based on the occupancy schedules. The illumination level provided by intended artificial lighting system is 500lx. The annually electric energy consumption is calculated according to these principles.

To achieve a high quality lighting environs, suitable equipments should be selected for preparing both performance and aesthetics needs. Luminaire selection is based on efficiency color temperature, color rendering index, life and lumen maintenance, availability, switching, dimming capability and cost [58].

Lighting designers by using simulation tools, could determine approximate for electric energy consumption of artificial lighting system. They give opportunities for evaluating the energy saving possibilities by choosing most suitable system in the design process.

Energy demand of illumination is significantly higher for the existing system, which can be explained as a result of improper use of energy-efficient luminaires. In order to reduce the existing buildings energy consumption, energy-efficient design modifications have been performed. For evaluating the artificial lighting layouts' opportunities, the office spaces are simulated for different lighting systems with three different luminaires.

By considering working days, working hours, luminaires type and number, annually energy requirement is calculated by RELUX simulation tool. As seen in Figure 5.6, the simulated office spaces has north and south façades (Block A). Static solar shading elements are installed at an angle of 30° on the south façade (Blcok A) of the case study building, located in Istanbul-Turkey (41ºN, 29ºE).

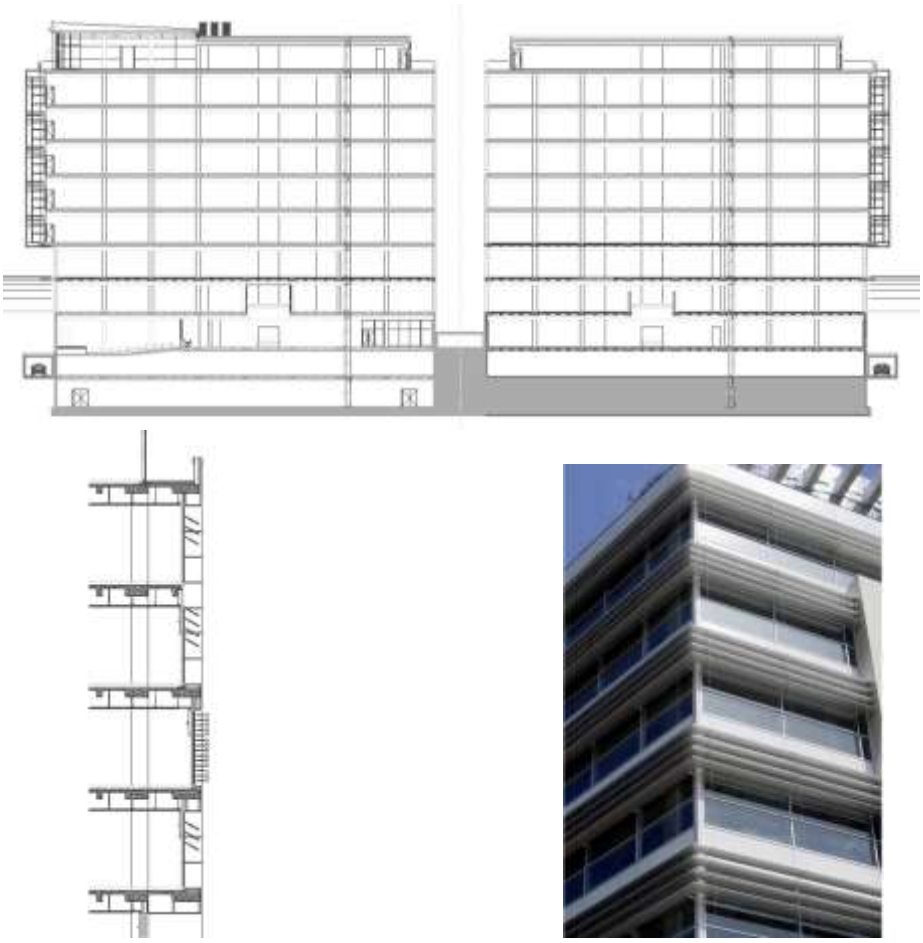
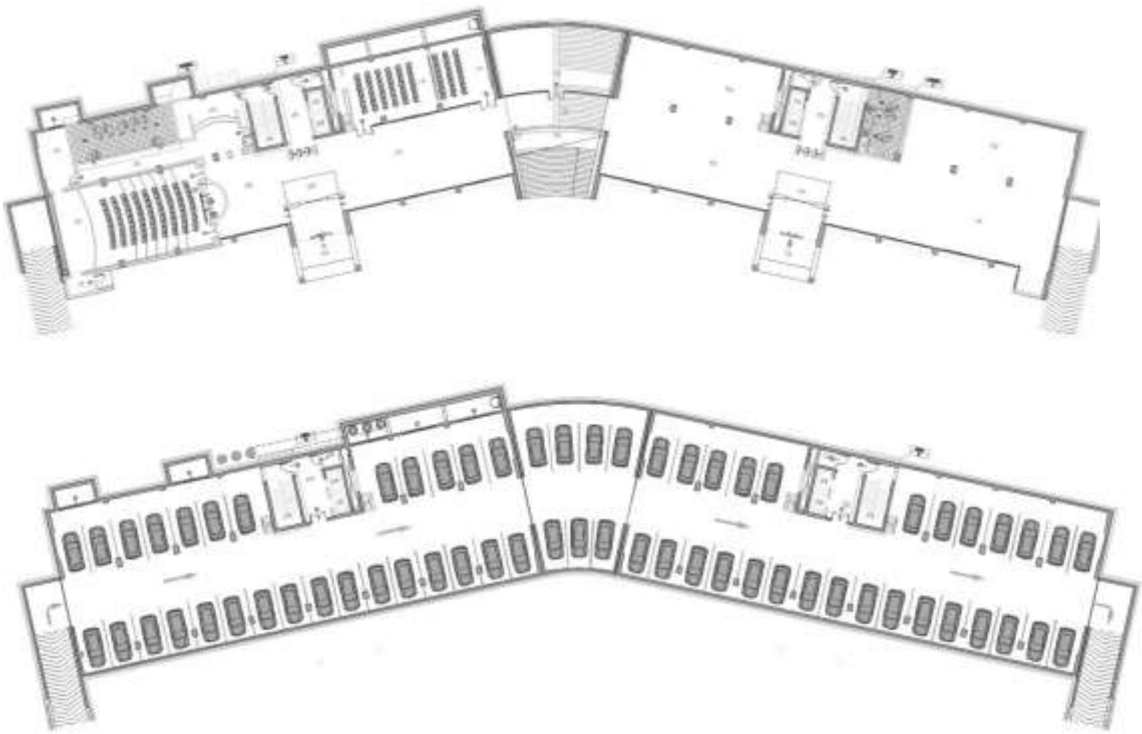


Figure 5.6: Solar shading elements of the north façade of the ARI TEKNOKENT 2.

Plan of the entrance, lobby, conference hall and basement floors shown in Figure 5.7



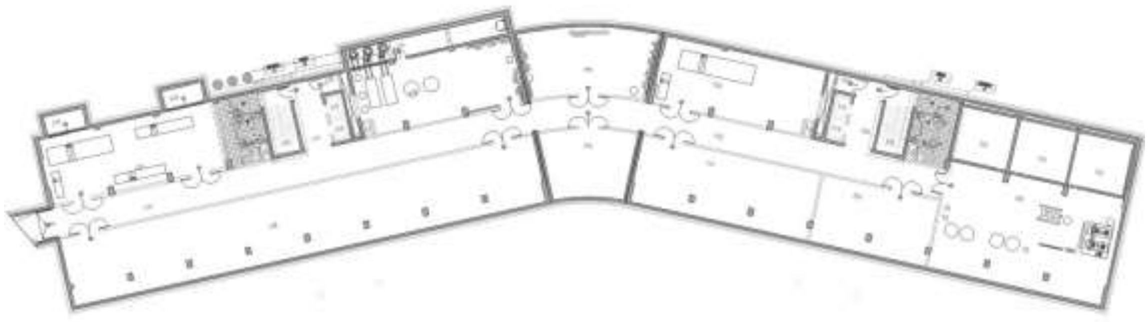


Figure 5.7 : Entrance, conference hall, car park and mechanical room of ARI TEKNOKENT 2.

Ceiling, wall and floor light reflectance are assumed 70%, 50% and 20% as default. Windows can be defined frameless, double glazing with a visual transparency of 65% which derives a transmissivity value of 70% for using in simulation program (RELUX). As mentioned before, minimum illuminance level, 500lx has been determined for simulating administration office space. Work plane is 0.8m above the floor.

Artificial lighting simulations are carried out related with the working hours of the case study building. The working calendar of 2013 is taken into account; 248.5 working days from January 1st to December 31st; 9 working hours per day between 9:^{00} and 18:^{00}. All these data are taken from case study building's regulations of the Board of Directors. Table 5.1 shows weekends and holidays of 2013 in Turkey's working calendar.

For the first simulation set all the luminaires supposed to be switched on during the working hours of the year.

Calculations were performed for three different luminaires that are suitable for office lighting. Due to different dimensions and light emission characteristics of selected devices, different arrangement types were selected through the 'Easy Lux'.

Table 5.1 : Working calendar of 2013 in Turkey [68].

	weekends	***Holidays***	***Number of Working days***
January	8 days	1. January 1st- First day of year	22 days
February	8 days	-	20 days
March	10 days	-	21 days
April	8 days	1.April 23rd- The Holiday of National Sovereignty and Children	21 days
May	8 days	1.May 1st -International Workers' Day	22 days
June	10 days	-	20 days
July	8 days	-	23 days
August	9 days	1. August 7th – Ramadan eve feast[3] 2. August 8th -August 10th – Ramadan feast 3. August 30th – Victory day	18.5 days
September	9 days	-	21 days
October	8 days	1. October 14th – Sacrifice eve feast[4] 2. October 15th - October 18th – Sacrifice feast 3. October 28th – Republic day eve[5] 4. October 29th – Republic day	17 days
November	9 days	-	21 days
December	9 days	-	22 days

[3] Ramadan eve feast is considered as half-day working. Working hours will be $9{:}^{00}$ to $13{:}^{00}$.
[4] Sacrifice eve feast is considered as half-day working. Working hours will be $9{:}^{00}$ to $13{:}^{00}$.
[5] Republic day eve is considered as half-day working. Working hours will be $9{:}^{00}$ to $13{:}^{00}$.

5.2.2.1 Lamps and luminaires

Fluorescent lamps are energy efficient, readily available, easy controllable and very affordable. In addition, they have great color rendering properties and long life. High frequency electronic ballasts are important to visual performance, because they reduce eyestrain and fatigue. These ballasts also prepare a better lamp performance, extending life and improved color characteristics. Luminaries selected by their lighting effectiveness, this includes distribution characteristics, efficiency, construction quality, aesthetics and economics.

In the list of newest energy-efficient light sources, also LED lamps are placed. While LED lamps emit visible light in a very narrow spectral band, they produce white light. This is accomplished with either a red-blue-green array or a phosphor-coated blue LED lamp.

For the purpose of this study, three different types of recessed products that are suitable for open plan office spaces, in term of color rendering index (R_a) >80 and color of the lamp (4000K°) were selected. Then the annual electricity consumption of each luminaire is calculated. According to the results, the most appropriate luminaire in term of both electric consumption and illuminance are selected. Different features of luminaires such as ballast type, luminous flux and lamp's power are clearly explained with scatter diagrams.

I) 2xTL-D36W

This luminaire equipped with two TLD fluorescent lamps (36W) that have 72-watt power, 840-color code[6] (cool white), 3350lm luminous flux and 72% efficiency factor in system [35].

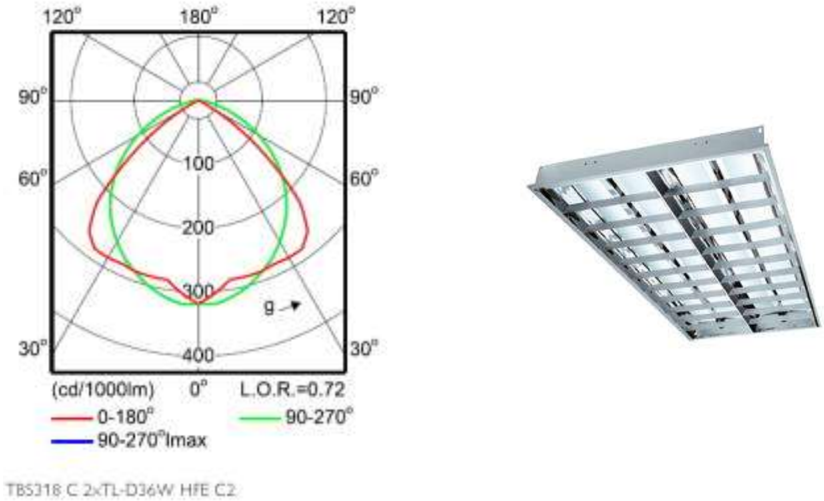


Figure 5.8 : Polar intensity diagram and luminaire appearance [69].

II) 4xTL-D18W

This luminaire equipped with 4 TLD fluorescent lamps (18W) that have 72 watt power, 840 color code (cool white), 1350lm luminous flux and 72% efficiency factor in system [70].

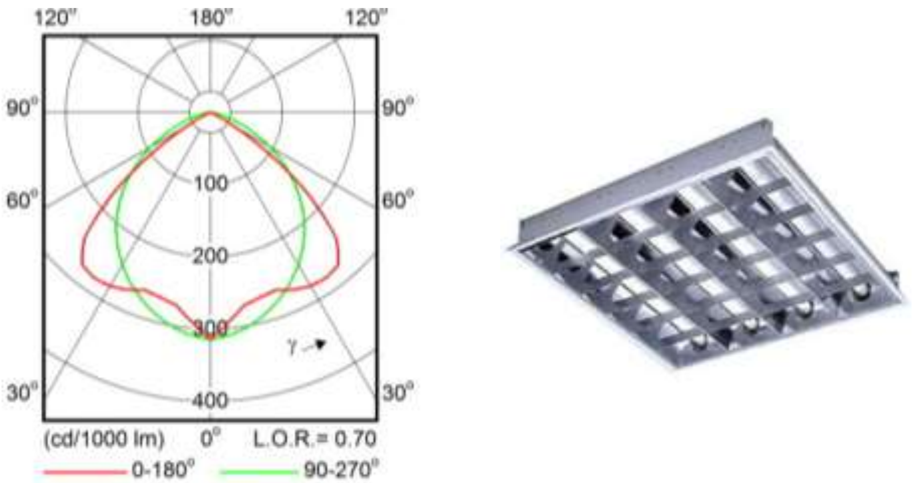


Figure 5.9 : Polar intensity diagram and luminaire appearance [69].

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[6] According to Philips catalogue of 2008-2009 the 840 color code is equal to 3000-5000K°

III) 1xLED48

This luminaire equipped with 47 watt power lamp, 840 color code (cool white), 4200lm luminous flux and 100% efficiency factor in system [70].

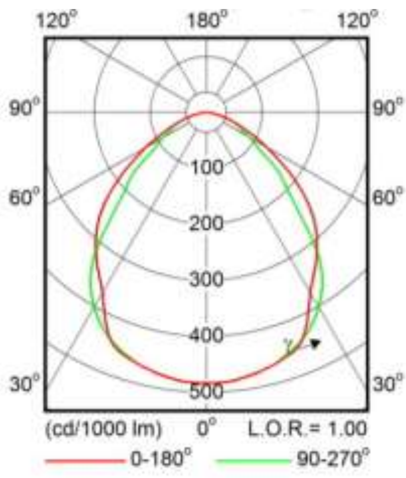

Figure 5.10 : Polar intensity diagram and luminaire appearance [69].

Calculations were done with RELUX as a lighting analysis software package for three different luminaires previously described, without concerning schedules and program. In accordance with the most appropriate luminaire, the main part of the study was designed and calculated.

5.2.2.2 RELUX simulation result

Due to different light-emitting of the devices and lamps that are proposed before, different numbers and arrangements can be seen in the same plan types. The number of lamps may have a major impact on annual electric consumption.

As shown before, the plans of the floors are different. But calculations of artificial lighting and energy consumption for selecting optimal lamp and lighting systems among the three altrnatives was done for 1st floor as a reference for whole case study building

Table 5.2 describes the result of artificial lighting simulation for the case floors.

- By using Philips 2xTL-D36 fluorescent luminaires, the average illuminance on the working plan was calculated as 538lx. Minimum and maximum illuminance was calculated 219lx and 614lx. The described power in the Table 5.2 is system power.

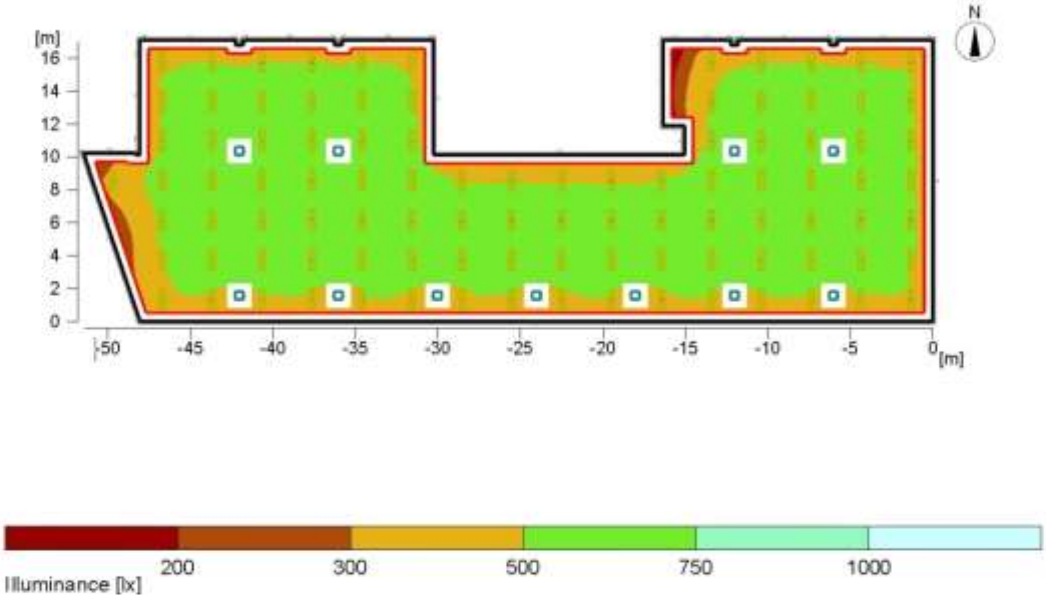

Figure 5.11: Arrangement and luminance range of first luminaire.

- By using Philips 4xTL-D18 fluorescent luminaires, the average illuminance on the working plan was calculated as 565lx. Minimum and maximum illuminance was calculated 188lx and 662lx.

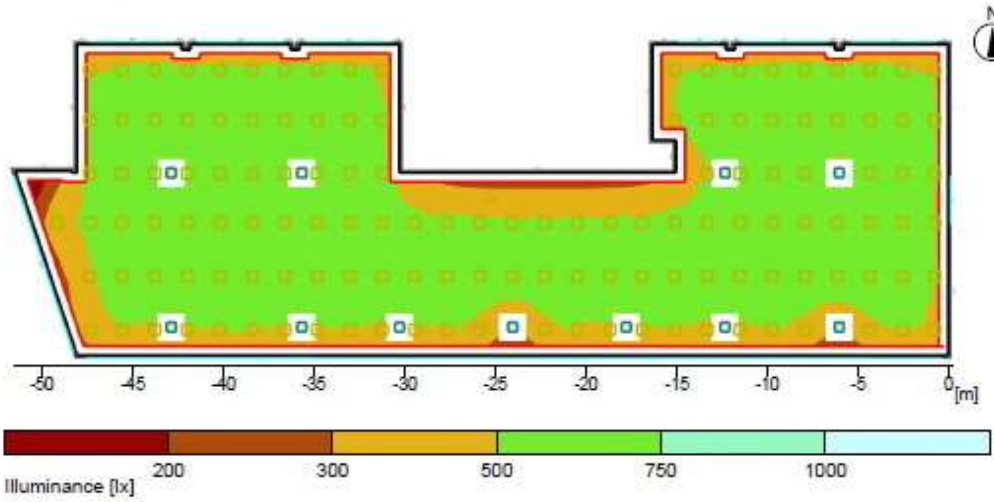

Figure 5.12 : Arrangement and luminance range of second luminaire.

v

- By using Philips 1xLED48 luminaire the average illuminance on the working plan was calculated as 546lx. Minimum and maximum illuminance was calculated 154lx and 740lx in order.

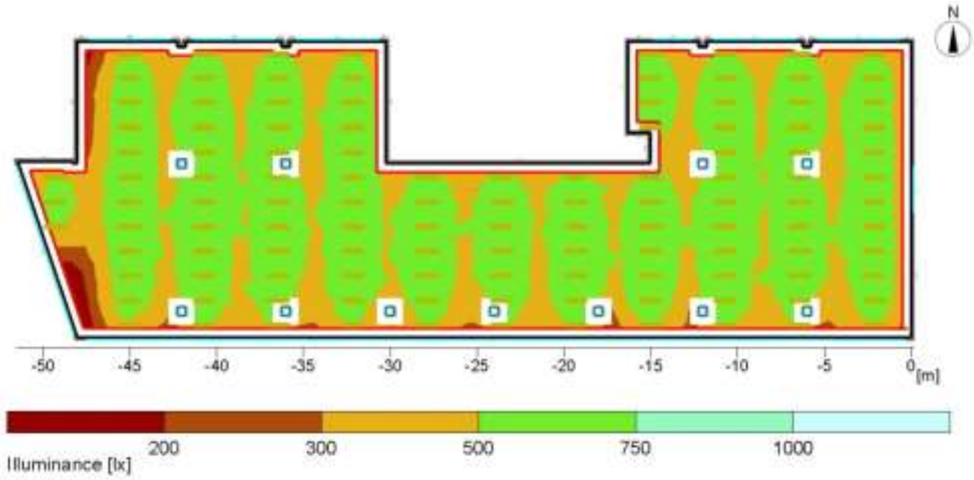

Figure 5.13 : Arrangement and luminance range of second luminaire.

According to Table 5.2, there is a major difference between fluorescent's annual consumption and the LED's. According to the results, annual electricity consumption of fluorescent lamps in the reference floors is more than LED lamps. In other words, LED luminaires decrease electric consumption by 33% in a year.

Table 5.2 : Artificial lighting simulation result of the specific floors and electric lighting energy consumption per unit area.

	Area(m^2)	*Number of luminaire*	*Power of luminaire(W)*	*Luminous flux(lm)*	*Consumption per hour(W)*	*LPD (W/m^2)*
2xTLD	1466.22	196	72	2x3350	14112	9.62
4xTLD	1466.22	270	72	4x1350	19440	13.25
LED	1466.22	238	47	4200	11186	7.62

5.2.2.3 Electricity consumption of lighting system

RELUX software is used to perform the space lighting analysis. For interior lighting, simple geometries- based on room dimensions- can be automatically generated. More complex geometries can be created by means of blocks and surfaces, or can be imported from AutoCAD through a dedicated plug in [67]. The simulation of the case study is done in order to predict the artificial lighting energy consumption. Required electric lighting hours for the open plan office space are set according to data given in Table 5.1. Total annual hours of occupancy are 2238 hours. Lighting system is programmed to provide a required illumination level 500lx. The case study building includes two basement floors with mechanical and electrical rooms, parking area, the entrance lobby, corridors, toilets and etc. Office floors include also corridor, restrooms, elevator lobbies and electrical room. Mentioned spaces' lighting energy requirements are calculated by using a particular method, fully explained in the ASHRAE standard.

The prescriptive lighting requirements are one of the most important features of the ASHRAE standard. For specific projects designers it is a main reference to design more efficient lighting systems. There are two ways to determine the interior lighting power: allowance the Building Area Method and the Space-By-Space method [71].

- The Building Area Method is the easiest one and is appropriate for an entire building or an entire occupancy in a multi-occupancy building.
- The Space-By-Space method accounts for specific lighting applications and can distinguish, for instance, between seating areas of various space types. For example, garages and parking areas are treated as interior space and are included as part of the interior lighting power allowance.

The Space-By-Space method is the second of two methods for determining the interior lighting power allowance (ILPA). This approach offers greater flexibility. It is applicable to all building types and generally results in more Watts. Although the lighting power allowance has been determined separately for each space within the building. Even though the designer must develop lighting working in each space, it may be simpler for code compliance purposes to use the Building Area Method.

The Space-By-Space allowances are included in Figure 5.14. The allowance for some space types can vary considerably. For instance, there is a big variation for dining areas, active storages, auditoriums and lobbies. These differences take into account the varying lighting conditions. The typical lighting equipment is used in different space types and other cases [71].

Building Type	Space Type	LPD (W/ft²)	Area (ft²)	LPD (m²)	Area (m²)	Allowance (W)
Office	Offices, enclosed	1.11	4,100	11.9	381	4,551
	Offices, open	0.98	12,000	10.5	1,115	11,760
	Meeting rooms	1.23	800	13.2	74.3	984
	Lobby	0.90	800	9.68	74.3	720
	Dining area (family)	0.89	200	9.58	18.6	178
	Food preparation	0.99	100	10.7	9.29	99.0
	Restrooms	0.98	300	10.5	27.9	294
	Corridors	0.66	1,000	7.10	92.9	660
	Active storage	0.63	400	6.78	37.2	252
	Inactive storage	0.63	200	6.78	18.6	126
	Electrical/mechanical	0.95	100	10.2	9.29	95.0
	Total/Weighted Average	0.99	20,000	10.6	1,859	19,719

Figure 5.14: Lighting power allowance for some space types [71].

For the first simulation set, all the luminaires supposed to be switched on during the working hours of the year. Table 5.3 describes the annual electric lighting energy use per unit area and total annual electric lighting energy for case study building. As a result, the total annual lighting energy use is 229580.02kWh, during all working hours (passive user).

Table 5.3 : Annual electric lighting energy use per unit area .

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Basement Floor	Space -by-space	Storage	407.3	6.78	2.76	0.9	0.27	617.63	-
		Mech. and Elec. Room	778.8	10.2	7.94	0.9	0.79	1776.71	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.20	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.10	-
		Corridor	284.5	7.10	2.02	0.0	2.02	4519.18	-
		Space-by-space result	-	-	-	-	-	7932.85KW	-
		Total result	**1545.4m²**	-	**13.37kW**	-	**3.546kW**	**7932.85kW**	**7932.85kW**

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Car park	Space -by-space	Park Area	1698.5	2.0	3.39	0.8	0.67	1519536.83	-
		Mech. and Elec. Room	5.7	10.2	0.058	0.9	0.005	13139.88	-
		Elevator Lobby	38.5	6.9	266.13	0.0	0.26	595206.45	-
		Space-by-space result	-	-	-	-	-	2127.88kW	-
		Total result	**1742.8m²**	-	**3722.01kW**	-	**951.43kW**	**2127.88kW**	**2127.88kW**

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Ground Floor	Space -by-space	Enclosed Office	187.6	11.9	2.23	0.0	2.23	4993.38	-
		Break Room	53.8	9.6	0.51	0.5	0.25	577.79	-
		Elevator Lobby	38.5	6.9	0.266	0.0	0.26	595.2	-
		Restroom	60.02	10.5	0.63	0.5	0.31	704.73	-
		Corridor	336.06	7.10	2.38	0.0	2.38	5336.4	-
		Elec.Room	2.8	10.2	0.02	0.9	0.002	6.56	-
		Total result	-	-	-	-	**5.46**	**12214.09kW**	**12214.09kW**

Ground Floor	Lighting design	Space name	Area(m^2)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Conference Hall	136.1	35	25	F_a=0.5	0.43	978.46	-
		Office	625.8	94	47	4.41		9880.85	-
		Total result	**1441.01m²**	-	-	**10.31**		**23073.41**	**23073.41kW**

Mezzanine Floor		Space name	Area(m^2)	LPD(W/m^2)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
	Space -by-space	Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	54.7	7.10	0.388	0.0	0.38	868.98	-
		Total Result	-	--	-	-	0.85	1901.44KW	**1901.44kW**
	Lighting design	Space name	Area(m^2)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Office	1150.5	186	47	8.74		19551.48	-
		Total result	**1285.7m²**	-	-	**9.59**		**21452.92**	**21452.92kW**

Ground 2 Floor		Space name	Area(m^2)	LPD(W/m^2)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
	Space -by-space	Elec. Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.4	10.5	0.38	0.5	0.19	427.39	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total Result	-	-	-	-	0.59	1335.85	**1335.85kW**
	Lighting design	Space name	Area(m^2)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Office	1432.02	232	47	10.9		24386.79	-
		Total result	**1531.6m²**	-	-	**11.5**		**25722.65**	**25722.65kW**

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
First Floor	Space -by-space	Elec. Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total Result	-	-	-	-	0.59	1332.56	**1332.56kW**
	Lighting design	Space name	Area(m²)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Office	1466.2	238	47	11.18		25017.48	-
		Total Result	**1565.5 m²**	-	-	**11.78**		**26350.05**	**26350.05kW**

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Second Floor	Space -by-space	Elec. Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total Result	-	-	-	-	0.59	1332.56	**1332.56kW**
	Lighting design	Space name	Area(m²)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Office	1466.2	238	47	11.18		25017.48	-
		Total Result	**1565.5 m²**	-	-	**11.78**		**26350.05**	**26350.05kW**

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Third Floor	Space -by-space	Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total Result	-	-	-	-	0.59	1332.56	**1332.56kW**
	Lighting design	Space name	Area(m²)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Office	1466.2	238	47	11.18		25017.48	-
		Total Result	**1565.5m²**	-	-	**11.78**		**26350.05**	**26350.05kW**

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Forth Floor	Space -by-space	Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total Result	-	-	-	-	0.59	1332.56	**1332.56kW**
	Lighting design	Space name	Area(m²)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Office	1466.2	238	47	11.18		25017.48	-
		Total Result	**1565.5m²**	-	-	**11.78**		**26350.05**	**26350.05kW**

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Fifth Floor	Space -by-space	Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total Result	-	-	-	-	0.59	1332.56	**1332.56kW**
	Lighting design	Space name	Area(m²)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Office	1466.2	238	47	11.18		25017.48	-
		Total Result	**1565.5m²**	-	-	**11.78**		**26350.05**	**26350.05kW**

		Space name	Area(m²)	LPD(W/m²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Terrace Floor	Space -by-space	Elec. Room	5.7	10.2	0.058	0.9	0.00	13.13	-
		Elevator Lobby	38.5	6.9	0.266	0.0	0.26	595.2	-
		Restroom	50.2	10.5	0.52	0.5	0.26	590.31	-
		Corridor	22.7	7.10	0.16	0.0	0.16	361.76	-
		Storage	57.4	6.78	0.38	0.9	0.03	87.12	
		Total Result	-	-	-	-	0.73	1647.55	**1647.55 kW**
	Lighting design	Space name	Area(m²)	Number of luminaires	Power of luminaire	Hourly consumption (kW)		Annually consumption(kW)	Total consumption(kW)
		Office/canteen	999.9	151	47	7.09		15872.44	-
		Total Result	**1174.7m²**	-	-	**7.83**		**17519.99**	**17519.99 kW**

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Table 5.4 : Annually lighting energy consumption of ARI TEKNOKENT 2.

Areas	*Space-by-space (kWh)*	*Lighting Design (kWh)*	*Total annually consumption (kWh)*
Basement Floor	7932.85	-	7932.85
Car park	2127.88	-	2127.88
Ground Floor	12214.09	10859.32	23073.41
Mezzanine Floor	1901.44	11747.62	21452.92
Ground 2 Floor	1335.85	14635.28	25722.65
First Floor	1332.56	13956.5	26350.05
Second Floor	1332.56	13956.5	26350.05
Third Floor	1332.56	13956.5	26350.05
Forth Floor	1332.56	13956.5	26350.05
Fifth Floor	1332.56	13956.5	26350.05
Terrace Floor	1647.55	6904.57	17519.99
Annual lighting energy consumption of case study building with a switch on/off system			229580.02kWh

As seen, when electric consumption is only depended on the amount of occupancy, without interference of any daylight responsive control system, electrical energy consumption is high. Integration of daylight with artificial lighting during the occupation time will result in reduction of energy consumption. This strategy covers the prediction of the daylight availability of the case study building and the prediction of the lighting energy requirement with a daylight responsive control system.

5.2.3 Daylight responsive control system

Lighting energy consumption is the base part of the overall energy consumption in buildings. The daylight availability is an important criterion for the electric energy consumption. The buildings, which are occupied throughout the day, have a considerable daylight potential. A well-integrated daylight and artificial lighting design have a positive effect for sustainability in office buildings. In order to reduce the electric energy demand of artificial lighting while providing the visual comfort conditions, integration of daylight system and a proper control system is needed. In this part of the study, the lighting energy requirement based on the daylight availability for the case study building is investigated. For reducing lighting energy consumption, special attention should be paid to the light switches. Electric light switches must be turned off (either manually or automatically) when sufficient daylight is available.

Supplies like occupancy sensors and time clocks make an energy-efficient and high-quality integrated lighting system. They limit the time of energy usage only to the occupied hours, when the light is needed [72]. Artificial lighting system in a space can be controlled in two different ways: manually and automatically.

In this part of the study, the lighting energy requirement based on the daylight availability for the case study building is investigated. For reducing lighting energy consumption, special attention should be paid to the light switches. Electric light switches must be turned off (either manually or automatically) when sufficient daylight is available.

5.2.3.1 RELUX simulations and schedules

With the help of RELUX simulation tool, daylight analyses are carried out. The first step in this process of performing daylight analysis is the creation of a 3D model in a Graphic Editor program such as AutoCAD.

Daylight illumination levels under clear and overcast sky conditions are calculated for specific times of the year. In this study, daylight calculation is divided into two categories: summer and winter periods. Six months of the year, from April 1^{st} to September 30^{th} is regarded as summer time; and the remaining six months from October 1^{st} through March 31^{st} is regarded as wintertime. 21^{st} June has been considered as the reference day for 6 months of summer and 21^{st} December for six months of winter. CIE Clear Sky Model is used for summer simulations and CIE Overcast Sky Model for winter simulations. Reference hours throughout the working day are determined as 9:^{00} am, 12:^{00} pm and 3:^{00} pm for winter period; and 9:^{00} am, 12:^{00} pm, 3:^{00} pm and 5:^{00} pm for summer period. These calculations have been done for all floors with importing influence of shading elements during 70 simulations, and evaluated the effect of the daylight amount in each unit areas. The daylight simulations of first floor of Block A (*as sample*) in RELUX for December 21^{st} are given in Figure 5.15, for 9:^{00} am, 12:^{00} pm, 3:^{00} pm respectively. The results of June 21^{st} are in Figure 5.16, for 9:^{00} am, 12:^{00} pm, 3:^{00} pm, and 5:^{00} pm respectively.

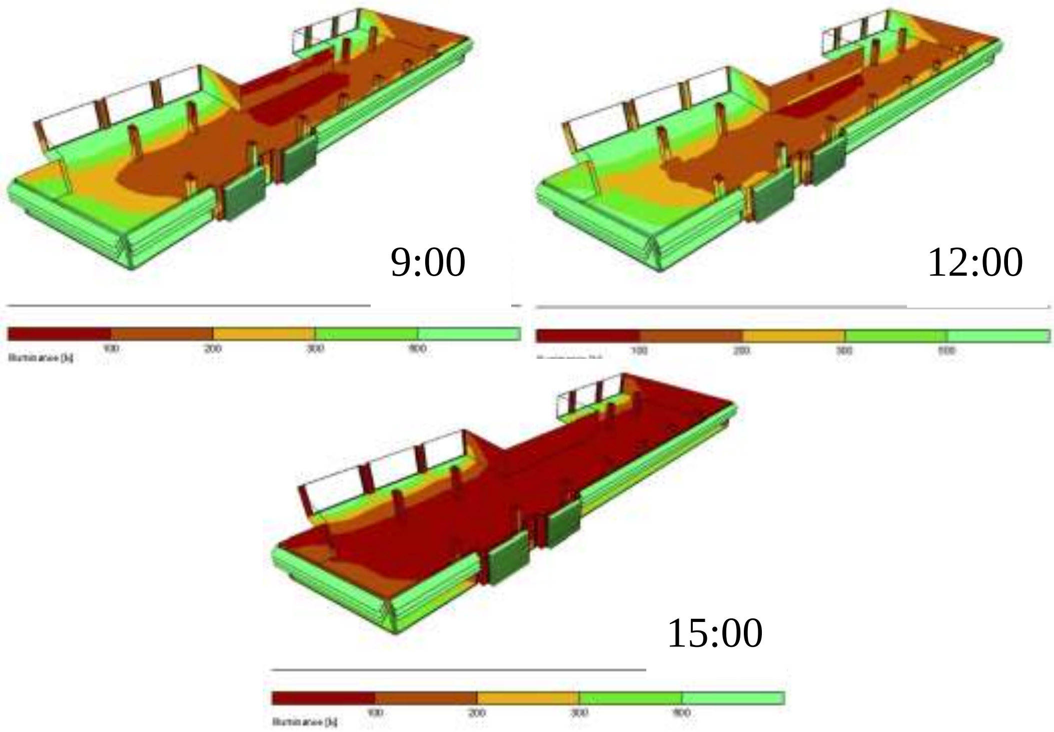

Figure 5.15: Daylight analyses of 1st floor, block A for December 21st.

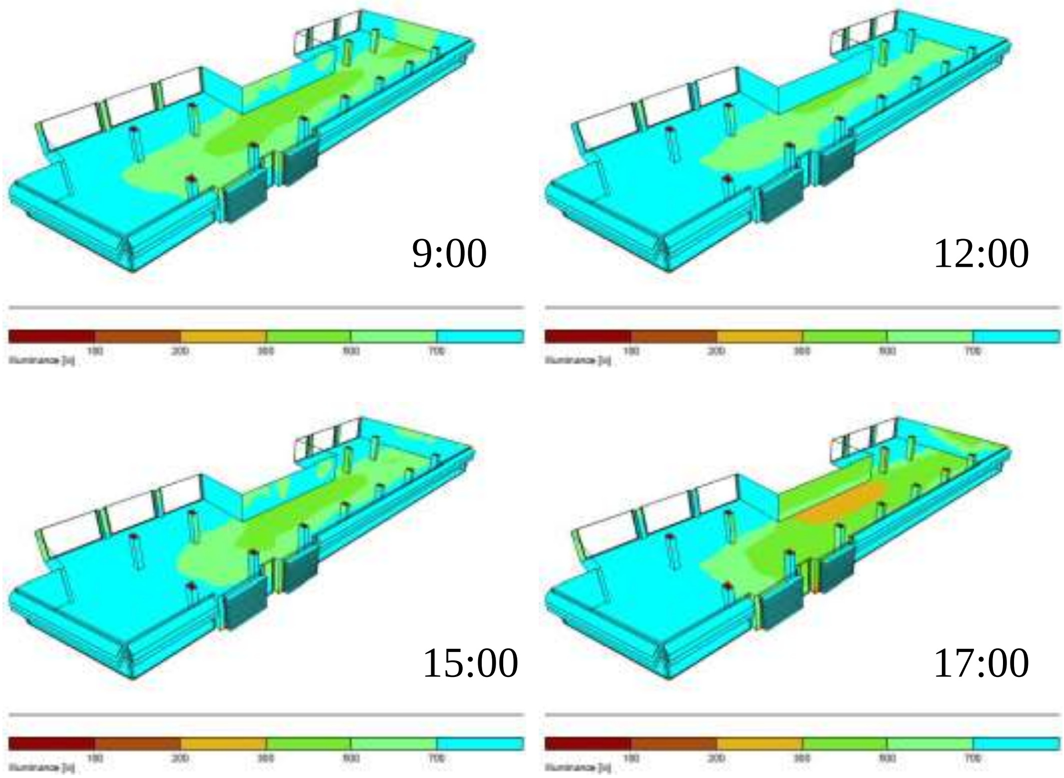

Figure 5.16 : Daylight analyses of 1st floor, block A for June 21st.

The sunlight penetration is from the South oriented windows on the work plane at 09:^{00}, 12:^{00} and 15:^{00}. The contour lines of the software in Figure 5.17 shows the daylight illuminance for integration with artificial light. According to the current daylight system, the numbers of luminaries that can be switched off are set.

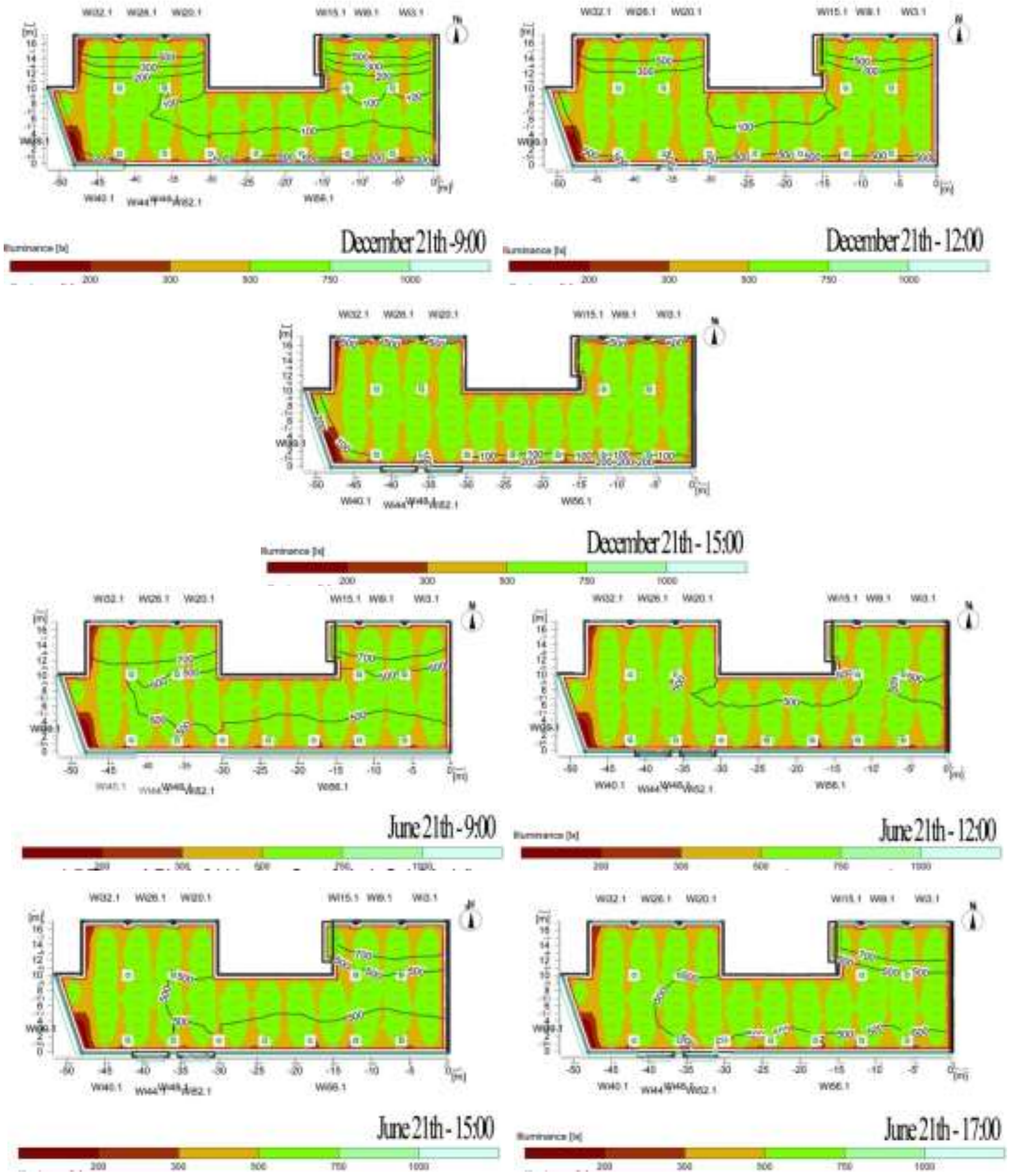

Figure 5.17: Daylight integration with artificial lighting design of 1st floor, block A.

5.2.3.2 Lighting energy requirement with a daylight responsive control system

The control system of the office space is divided into 10 zones. According to the amount of natural light of each zone the control system switches the luminaires on and off. Daylight saving time is taken into consideration.

For evaluation of daylight integration substitution with the artificial lighting system, each unit of each floor was calculated separately for three specific time of winter and four specific time of summer that each of them includes separate meshes. This segmentation specified numbers of luminaries which can be off at different hours of the day. the calculations for the 1^{st} floor are fully explained below. Calculations of the 1^{st} floor were performed in 2 Steps. The first step indicated the summer time. The mesh and areas which are off, during the summer time are shown in Figure 5.18.

It should be noted, choose of reference hours is due to small differences between the hours of daylight infiltration to the unit area. Thus, for the 6 months of winter, calculation for $9{:}^{00}$ apply to $10{:}^{00}$, calculation for $12{:}^{00}$ apply to $11{:}^{00}$ and $13{:}^{00}$ and calculation for $15{:}^{00}$ apply to $14{:}^{00}$, $16{:}^{00}$, $17{:}^{00}$ and $18{:}^{00}$.

Similarly, for the 6 months of summer, the calculation for $9{:}^{00}$ apply to $10{:}^{00}$, calculation for $12{:}^{00}$ apply to $11{:}^{00}$ and $13{:}^{00}$, calculation for $15{:}^{00}$ apply to $14{:}^{00}$ and $16{:}^{00}$ and calculation for $17{:}^{00}$ apply to $18{:}^{00}$ too.

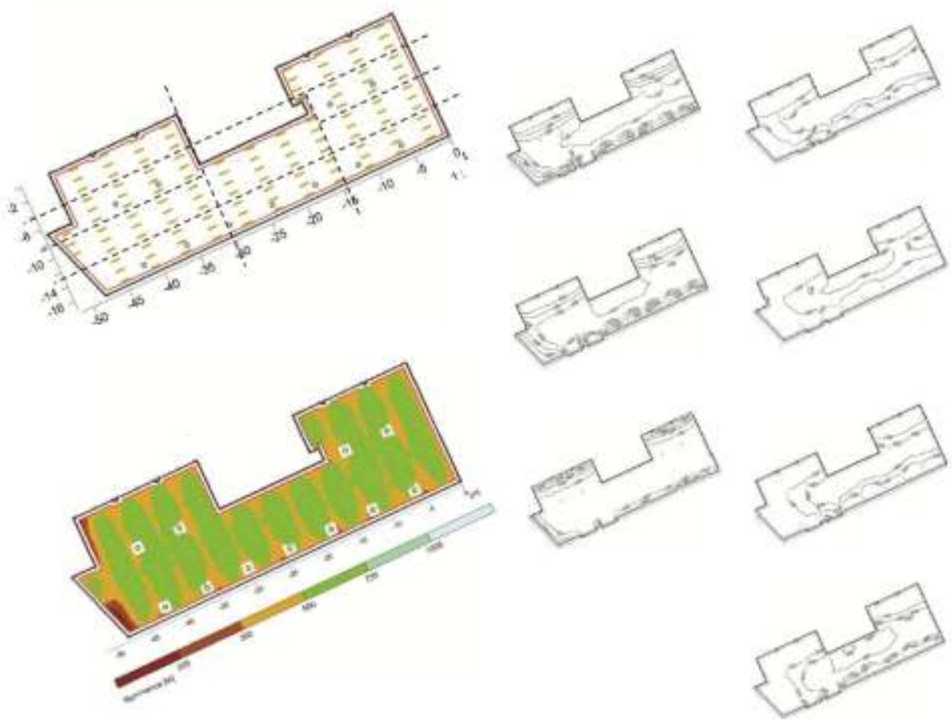

Figure 5.18 : Special lattices for 1^{st} floor artificial lighting system.

According to the daylight simulations, the maximum saving is reached on 21^{st} June at $12.^{00}$ pm, in comparison with the minimum daylight availability on 21^{st} December at $3.^{00}$ pm, with no lamps off. As a result, lighting energy saving in summer is 4476.96kWh and 693.72kWh in winter conditions.

To understand the issue more precisely, all calculations in detail for 1^{st} floor of Block A are described below with graphics. Figure 5.19 shows the integration of daylight with artificial lighting system for the unit area at 9:^{00} on December 21st. meshes of this unit is configured according to the arrangement of artificial lighting design. As shown in the picture, zones 1 and 7 can be off from 9:^{00} to 10:^{00} at the 6-month winter time in case study building.

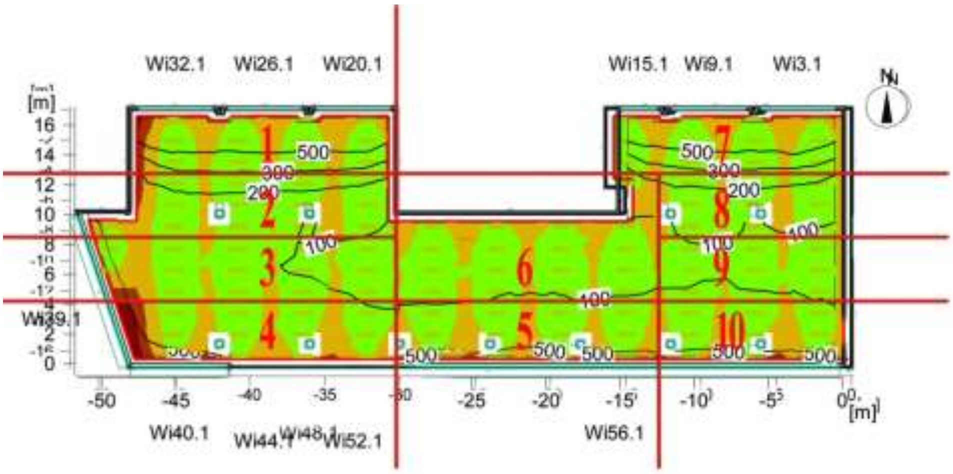

Figure 5.19: Meshes of 1st floor, block A -December 21st-9:^{00}-Overcast sky model.

Due to the amount of daylight penetration at 11:^{00} to 14:^{00} in six month of winter like previous time period, zones 1 and 7 can be off.

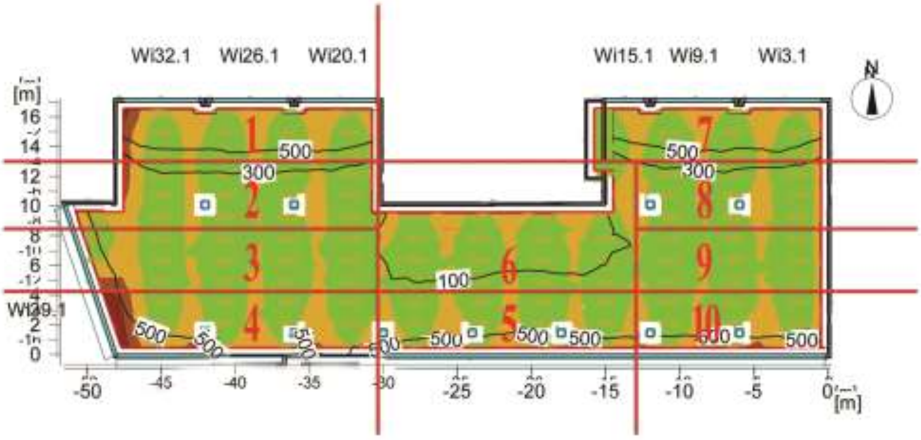

Figure 5.20 : Meshes of 1st floor, block A -December 21st-12:^{00}-Overcast sky model.

As seen in Figure 5.21, due to short days of the winter time, the amount of natural light was less than 500lx and all luminaries should be on from 14:^{00} until the end of the working hours.

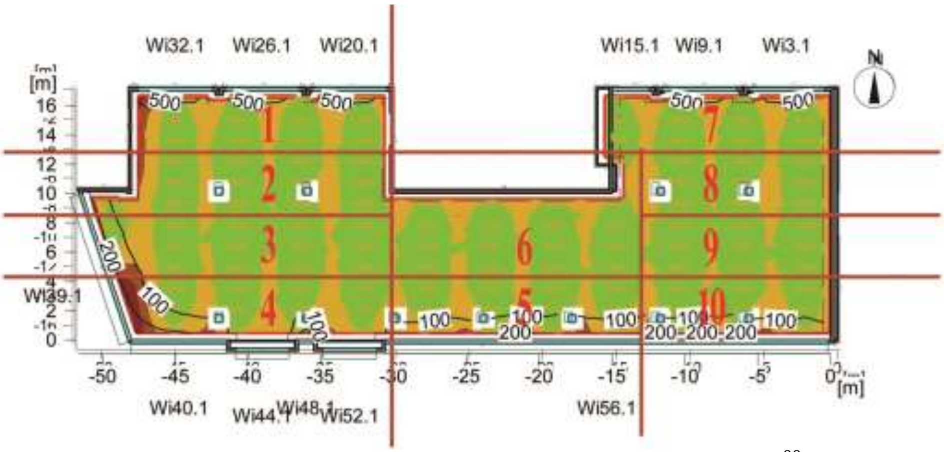

Figure 5.21 : Meshes of 1st floor, block A -December 21st-15:00-Overcast sky model.

Figure 5.22 shows the integration of daylight and artificial lighting system at 9:00 on June 21st. Through the existence light and supply of required illumination of 500lx for mentioned floor, zones 1, 2, 4, 5, 7, 10 can be turned off from 9:00 to 10:00.

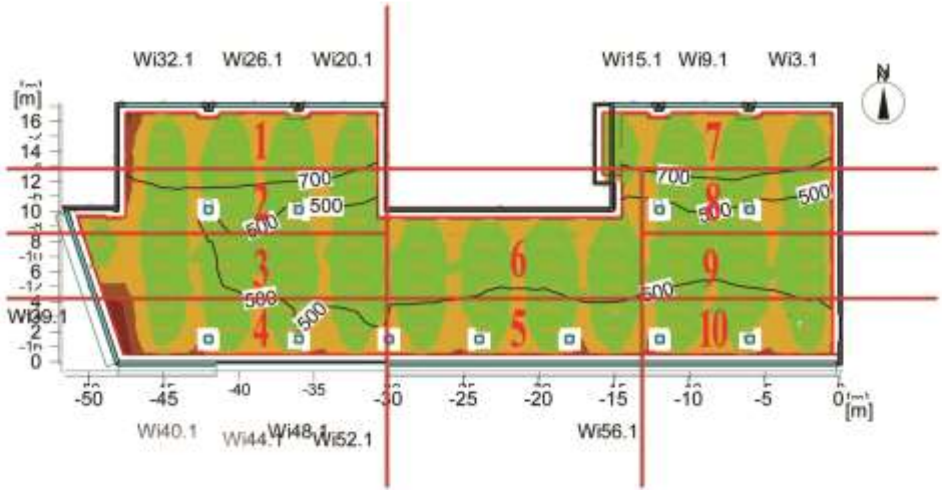

Figure 5.22 : Meshes of 1st floor, block A -June 21st-9:00-Clear sky model.

Daylight peak of summer time belongs to hours between 12:00 and 15:00. According to daylight amount, to provide the desired illuminance for an office place in all zones except zone 6 can be turned off between 11:00 to 13:00 at this time of day at 6 months of summer.

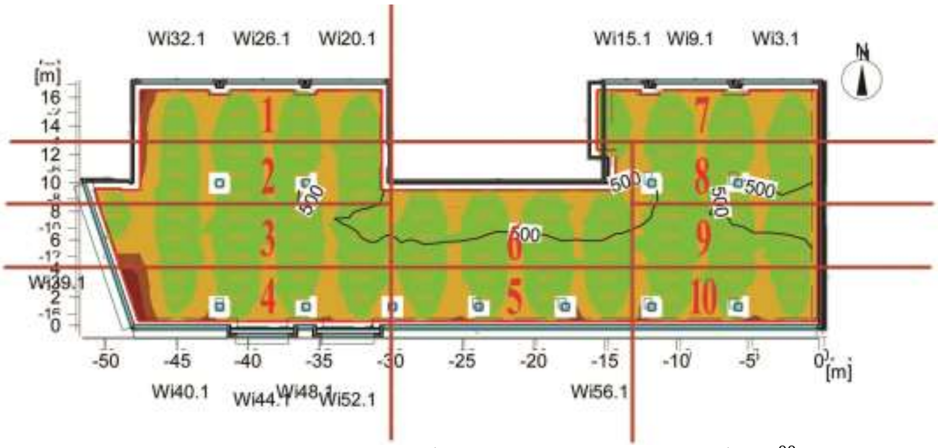

Figure 5.23 : Meshes of 1st floor, block A -June 21st-12:00-Clear sky model.

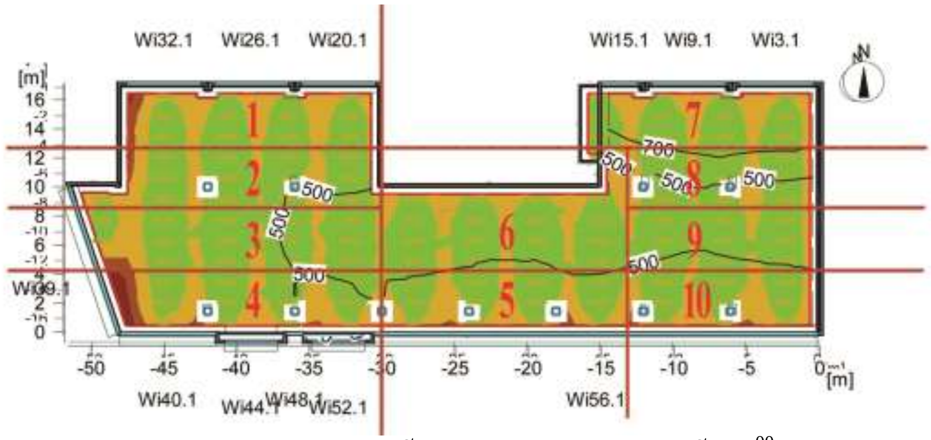

Figure 5.24 : Meshes of 1st floor, block A -June 21st-15:00-Clear sky model.

Because of the long summer days, 17:00 to 18:00 is the end of working hours in this case study. Daylight penetration can be clearly seen that led to the switch off of 5 zones.

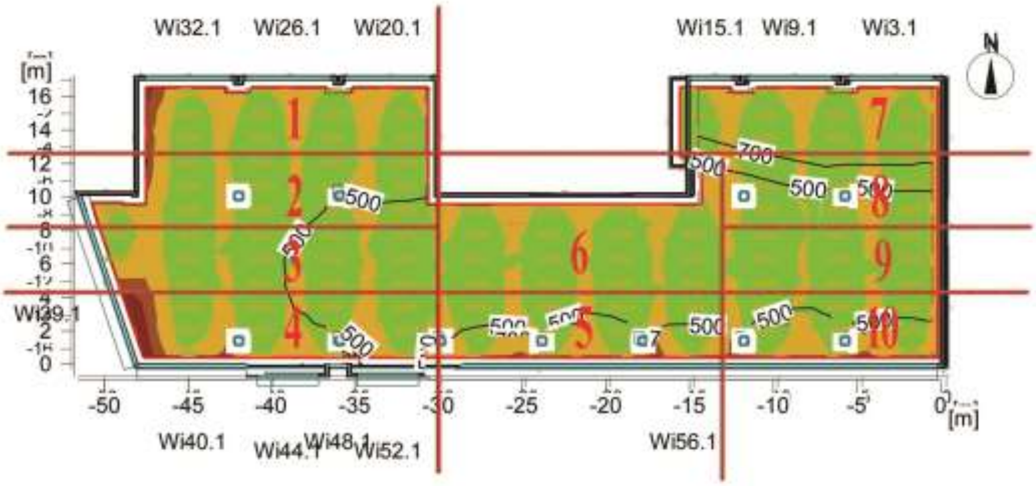

Figure 5.25 : Meshes of 1st floor, block A -June 21st-17:00-Clear sky model.

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Summary of the calculations are listed in Table 5.5. As can be deduced from the table, winter and summer saved-energy on the 1st floor of block A, which is oriented to the south is approximately 5170.68kWh per year. It should be noted that this meshes is repeated for the 1st to 5th floors of the block, which plans are type.

Table 5.5 Saved-energy rate of first floor, block "A".

First floor/ block A	***Winter time(21 December)***		***Summer Time(21 June)***	
	Off luminaries num.	Saving (kWh)	Off luminaries num.	Saving(kWh)
$9:^{00}$	24	1.128	70	3.290
$10:^{00}$	24	1.128	70	3.290
$11:^{00}$	24	1.128	103	4.841
$12:^{00}$	24	1.128	103	4.841
$13:^{00}$	24	1128	103	4.841
$14:^{00}$	0	-	84	3.948
$15:^{00}$	0	-	84	3.948
$16:^{00}$	0	-	84	3.948
$17:^{00}$	0	-	58	2.726
$18:^{00}$	0	-	58	2.726
Daily result	-	5.046kWh	-	35.673kWh
Total result		693.72kWh	-	4476.96kWh

The outputs which show the daylight layers of floors for winter and summer conditions in detail the template of manual switched-off artificial lighting system, also the integration plan of daylight and artificial lighting system for the particular hours in the sample day can be seen in the Appendixes A, B and C as RELUX images.

To figure out the amount of saved-energy in winter and summer, these results should be multiplied by the number of working days in the first and second half a year(summer and winter). The number of working days is available from Table 5.1, which is intended 125.5 days for 6 months of summer and 123 days for 6 months of winter.

The integration of daylight accessibilities into the electric lighting calculation indicates the amount of saved energy. In this calculation set, the result of a car park and basement are stable because of any natural light receiving.

Table 5.6 shows the total amount of saved-energy during summer and winter time, and annually decrease of electric consumption per unit area of case study building.

Table 5.6 : Annual electric lighting energy depends on saved-energy rates per unit area.

		Space name	Area(m^2)	LPD(W/m^2)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Basement Floor	Space -by-space	Storage	407.3	6.78	2.76	0.9	0.27	617.63	-
		Mech. and Elec. Room	778.8	10.2	7.94	0.9	0.79	1776.71	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.20	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.10	-
		Corridor	284.5	7.10	2.02	0.0	2.02	4519.18	-
		Space-by-space result	-	-	-	-	-	7932.85KW	-
		Total result	**1545.4m²**	-	**13.37kW**	-	**3.546kW**	**7932.85kW**	**7932.85kW**

		Space name	Area(m^2)	LPD(W/m^2)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Car park	Space -by-space	Park Area	1698.5	2.0	3.39	0.8	0.67	1519536.83	-
		Mech. and Elec. Room	5.7	10.2	0.058	0.9	0.005	13139.88	-
		Elevator Lobby	38.5	6.9	266.13	0.0	0.26	595206.45	-
		Space-by-space result	-	-	-	-	-	2127.88kW	-
		Total result	**1742.8m²**	-	**3722.01kW**	-	**951.43kW**	**2127.88kW**	**2127.88kW**

		Space name	Area(m^2)	LPD(W/m^2)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Ground Floor	Space -by-space	Enclosed Office	187.6	11.9	2.23	0.0	2.23	4993.38	-
		Break Room	53.8	9.6	0.51	0.5	0.25	577.79	-
		Elevator Lobby	38.5	6.9	0.266	0.0	0.26	595.2	-
		Restroom	60.02	10.5	0.63	0.5	0.31	704.73	-
		Corridor	336.06	7.10	2.38	0.0	2.38	5336.4	-
		Elec.Room	2.8	10.2	0.02	0.9	0.002	6.56	-
		Total result	-	-	-	-	**5.46**	**12214.09kW**	**12214.09kW**

Floor	Method	Space name	Area(m)	Number of luminaires	Luminaires power	Hourly Consumption (kW)		Annually consumption (kW)	Summer saving rate(kW)	winter saving rate(kW)	Total saving rate(kW)	Total consumption with saving (kW)
Ground Floor	Lighting design	Conference Hall	136.1	35	25	F_a=0.5	0.4375	978.4	-	-	-	-
		Office	625.8	94	47	4.4		9880.8	2589.4	722.6	3312.06	6568.7
		Lighting design result	-	129	-	4.8		10859.3	-	-	-	**10859.3kW**
		Total result	**1441.01m²**	-	-	**10.3**		**23073.4**	-	-	**3312.06**	**19761.3kW**

Floor	Method	Space name	Area(m²)	LPD(W/M²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Mezzanine Floor	Space-by-space	Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	54.7	7.10	0.38	0.0	0.38	868.98	-
		Total result	-	-	-	-	0.85	1901.44kW	**1901.440kW**

Floor	Method	Space name	Area(M²)	Number of luminaires	luminaires power(W)	Hourly consumption (kW)	Annually consumption (kW)	Summer saving rate(kW)	Winter saving rate(kW)	Total saving(kW)	Total consumption with saving(KW)
Mezzanine Floor	Lighting design	Office	1150.5	186	47	8.742	19551.48	6069.55	1734.3	7803.85	11747.62
		Lighting design	-	-	-	-	-	-	-	-	11747.62
		Total result	**1285.72m²**	-	-	**9.59**	**21452.92**	-	-	**7803.85**	**13649.06kW**

Floor	Method	Space name	Area(m²)	LPD(W/M²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Ground 2 Floor	Space-by-space	Elec. Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.20	-
		Restroom	36.4	10.5	0.38	0.5	0.19	427.39	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total result	-	-	-	-	0.59	1335.85	**1335.85kW**

Floor	Method	Space name	Area(M²)	Number of luminaires	luminaires power(W)	Hourly consumption (kW)	Annually consumption (kW)	Summer saving rate(kW)	Winter saving rate(kW)	Total saving(kW)	Total consumption with saving(kW)
Ground 2 Floor	Lighting design	Office	1432.02	232	47	10.904	24386.796	8364.073	1387.44	9751.513	14635.28
		Lighting design	-	-	-	-	-	-	-	-	14635.28
		Total result	**1531.6 m²**	-	-	**11.50**	**25722.65**	-	-	**9751.51**	**15971.14kW**

<table>
<tr><td rowspan="14">First Floor</td><td rowspan="7">Space-by-space</td><td>Space name</td><td>Area(m^2)</td><td>LPD(W/M^2)</td><td>consumption rate(kW)</td><td>F_a</td><td colspan="2">Hourly consumption (kW)</td><td>Annually consumption(kW)</td><td colspan="2">Total consumption(kW)</td></tr>
<tr><td>Elec.Room</td><td>5.7</td><td>10.2</td><td>0.05</td><td>0.9</td><td colspan="2">0.005</td><td>13.13</td><td colspan="2">-</td></tr>
<tr><td>Elevator Lobby</td><td>38.5</td><td>6.9</td><td>0.26</td><td>0.0</td><td colspan="2">0.26</td><td>595.2</td><td colspan="2">-</td></tr>
<tr><td>Restroom</td><td>36.1</td><td>10.5</td><td>0.37</td><td>0.5</td><td colspan="2">0.18</td><td>424.1</td><td colspan="2">-</td></tr>
<tr><td>Corridor</td><td>18.9</td><td>7.10</td><td>0.13</td><td>0.0</td><td colspan="2">0.13</td><td>300.11</td><td colspan="2">-</td></tr>
<tr><td>Total result</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="2">0.59</td><td>1332.56</td><td colspan="2">1332.56kW</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td rowspan="7">Lighting design</td><td>Space name</td><td>Area(M^2)</td><td>Number of luminaires</td><td>luminaires power(W)</td><td>Hourly consumption (kW)</td><td>Annually consumption (kW)</td><td>Summer saving rate(kW)</td><td>Winter saving rate(kW)</td><td>Total saving(kW)</td><td>Total consumption with saving(kW)</td></tr>
<tr><td>Office</td><td>1466.2</td><td>238</td><td>47</td><td>11.18</td><td>25017.489</td><td>9673.54</td><td>1387.44</td><td>11060.98</td><td>13956.5</td></tr>
<tr><td>Lighting design</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>13956.5</td></tr>
<tr><td>Total result</td><td>1565.5</td><td>-</td><td>-</td><td>11.78</td><td>26350.05</td><td>-</td><td>-</td><td>11060.98</td><td>15289.07kW</td></tr>
</table>

<table>
<tr><td rowspan="11">Second Floor</td><td rowspan="6">Space-by-space</td><td>Space name</td><td>Area(m^2)</td><td>LPD(W/M^2)</td><td>consumption rate(kW)</td><td>F_a</td><td colspan="2">Hourly consumption (kW)</td><td>Annually consumption(kW)</td><td colspan="2">Total consumption(kW)</td></tr>
<tr><td>Elec.Room</td><td>5.7</td><td>10.2</td><td>0.05</td><td>0.9</td><td colspan="2">0.005</td><td>13.13</td><td colspan="2">-</td></tr>
<tr><td>Elevator Lobby</td><td>38.5</td><td>6.9</td><td>0.26</td><td>0.0</td><td colspan="2">0.26</td><td>595.2</td><td colspan="2">-</td></tr>
<tr><td>Restroom</td><td>36.1</td><td>10.5</td><td>0.37</td><td>0.5</td><td colspan="2">0.18</td><td>424.1</td><td colspan="2">-</td></tr>
<tr><td>Corridor</td><td>18.9</td><td>7.10</td><td>0.13</td><td>0.0</td><td colspan="2">0.13</td><td>300.11</td><td colspan="2">-</td></tr>
<tr><td>Total result</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="2">0.595</td><td>1332.56</td><td colspan="2">1332.56KW</td></tr>
<tr><td rowspan="5">Lighting design</td><td>Space name</td><td>Area(M^2)</td><td>Number of luminaires</td><td>luminaires power(W)</td><td>Hourly consumption (kW)</td><td>Annually consumption (kW)</td><td>Summer saving rate(kW)</td><td>Winter saving rate(kW)</td><td>Total saving(kW)</td><td>Total consumption with saving(kW)</td></tr>
<tr><td>Office</td><td>1466.2</td><td>238</td><td>47</td><td>11.186</td><td>25017.489</td><td>9390.41</td><td>1387.44</td><td>10777.85</td><td>14239.63</td></tr>
<tr><td>Lighting design</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>14239.63</td></tr>
<tr><td>Total result</td><td>1565.5m²</td><td>-</td><td>-</td><td>11.78</td><td>26350.05</td><td>-</td><td>-</td><td>10777.85</td><td>15572.2kW</td></tr>
</table>

Third Floor		Space name	Area(m²)	LPD(W/M²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
	Space-by-space	Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total result	-	-	-	-	0.59	1332.56	**1332.56kW**

Third Floor		Space name	Area(M²)	Number of luminaires	luminaires power(W)	Hourly consumption (kW)	Annually consumption (kW)	Summer saving rate(kW)	Winter saving rate(kW)	Total saving(kW)	Total consumption with saving(kW)
	Lighting design	Office	1466.2	238	47	11.18	25017.489	9673.54	1387.44	11060.98	13956.5
		Lighting design	-	-	-	-	-	-	-	-	13956.5
		Total result	**1565.5**	-	-	**11.78**	**26350.05**	-	-	**11060.98**	**15289.07kW**

Forth Floor		Space name	Area(m²)	LPD(W/M²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
	Space-by-space	Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
		Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
		Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
		Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
		Total result	-	-	-	-	0.59	1332.56	**1332.56kW**

Forth Floor		Space name	Area(M²)	Number of luminaires	luminaires power(W)	Hourly consumption (kW)	Annually consumption (kW)	Summer saving rate(kW)	Winter saving rate(kW)	Total saving(kW)	Total consumption with saving(kW)
	Lighting design	Office	1466.2	238	47	11.18	25017.489	9673.54	1387.44	11060.98	13956.5
		Lighting design	-	-	-	-	-	-	-	-	13956.5
		Total result	**1565.5**	-	-	**11.78**	**26350.05**	-	-	**11060.98**	**15289.07kW**

Fifth Floor

Space-by-space

Space name	Area(m²)	LPD(W/M²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
Restroom	36.1	10.5	0.37	0.5	0.18	424.1	-
Corridor	18.9	7.10	0.13	0.0	0.13	300.11	-
Total result	-	-	-	-	0.59	1332.56	**1332.56kW**

Lighting design

Space name	Area(M²)	Number of luminaires	luminaires power(W)	Hourly consumption (kW)	Annually consumption (kW)	Summer saving rate(kW)	Winter saving rate(kW)	Total saving(kW)	Total consumption with saving(kW)
Office	1466.2	238	47	11.18	25017.489	9673.54	1387.44	11060.98	13956.5
Lighting design	-	-	-	-	-	-	-	-	13956.5
Total result	**1565.5**	-	-	**11.78**	**26350.05**	-	-	**11060.98**	**15289.07kW**

Terrace Floor

Space-by-space

Space name	Area(m²)	LPD(W/M²)	consumption rate(kW)	F_a	Hourly consumption (kW)	Annually consumption(kW)	Total consumption(kW)
Elec.Room	5.7	10.2	0.05	0.9	0.005	13.13	-
Elevator Lobby	38.5	6.9	0.26	0.0	0.26	595.2	-
Restroom	50.2	10.5	0.52	0.5	0.26	590.31	-
Corridor	22.7	7.10	0.16	0.0	0.16	361.76	-
Storage	57.4	6.78	0.38	0.9	0.03	87.12	
Total result	-	-	-	-	0.73	1647.55	**1647.55kW**

Lighting design

Space name	Area(M²)	Number of luminaires	luminaires power(W)	Hourly consumption (kW)	Annually consumption (kW)	Summer saving rate(kW)	Winter saving rate(kW)	Total saving(kW)	Total consumption with saving(kW)
Office/canteen	999.9	151	47	7.097	15872.4405	7927.584	1040.58	8967.864	6904.5765
Lighting design	-	-	-	-	-	-	-	-	6904.5765
Total result	**1174.7m²**	-	-	**7.83**	**17519.99**	-	-	**8967.86**	**8552.12kW**

The annual lighting energy requirement with a daylight responsive control decreases from 229580.02 kWh to 144722.94 kWh. The values are given in Table 5.7 for each floor. Final result shows that the consumption in proposed system is approximately 145000 kWh, there is an increase about 36% in annually consumption of case study building that have been achieved by manual switch on/off of an active users' effect.

Table 5.7 : Annual lighting energy consumption and saved-energy rate with a daylight responsive control system ARI TEKNOKENT 2.

Areas	annually consumption (kWh)	Summer saving rate(kWh)	Winter saving rate(kWh)	Total saving rate(kWh)	Annually consumption with saving rates(kWh)
Basement Floor	7932.85	-	-	-	7932.85
Car park	2127.88	-	-	-	2127.88
Ground Floor	23073.41	2589.44	722.62	3312.06	19761.35
Mezzanine Floor	21452.92	6069.55	1734.3	7803.85	13649.06
Ground 2 Floor	25722.65	8364.07	1387.44	9751.51	15971.14
First Floor	26350.05	9673.54	1387.44	11060.98	15289.07
Second Floor[7]	26350.05	9390.41	1387.44	10777.85	15572.20
Third Floor	26350.05	9673.54	1387.44	11060.98	15289.07
Forth Floor	26350.05	9673.54	1387.44	11060.98	15289.07
Fifth Floor	26350.05	9673.54	1387.44	11060.98	15289.07
Terrace Floor	17519.99	7927.58	1040.58	8967.86	8552.12
Annual lighting energy consumption and saved-energy rate with a daylight responsive control system				84857.07	144722.94

Figure 5.26 : Second Floor, different shading elements of Block B [64].

[7] There is a little disparity on 2nd floor's saved-energy rates in comparison with the type floors. because of the different type of the shading elements of the floor (Figure 5.26)

5.3 Application of Building Integrated Photovoltaic Systems to the Case Study Building

To optimize the integration of BIPV (building integrated photovoltaic), power modules must be placed in a way that the system provides more power. Therefore it is necessary to determine the optimal plane tilt angles on different orientations, by using the PVSYST program [73]. In the case study office building, photovoltaic panels are integrated into static solar shading elements mounted at an angle of 30° at the South (Block A) and Southwest (Block B) façades of the building on the typical floors. The eaves are on the terrace floor.

In summer, façade is partly shaded due to the 0.72m length horizontal shading devices, mounted at south façade. The photo of ARI building with shading devices can be seen in Figure 5.27. Existing eaves on the terrace floor have been changed to take more advantages of solar energy through the agency of simulation programs, by applying a 180 degree rotation (to the slope of the eaves). The changes are visible in Figure 5.28.

Figure 5.27 : Horizontal shading elements and eaves of the case study building.

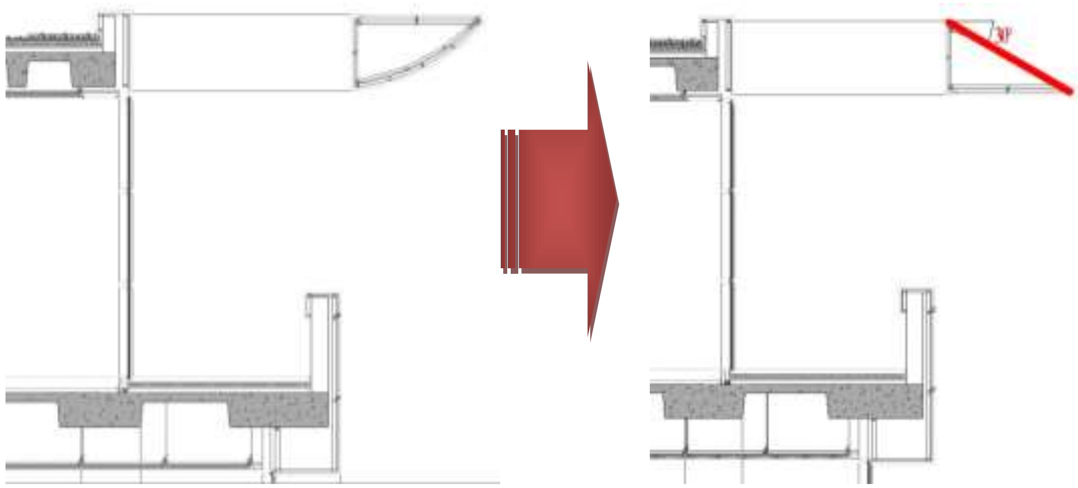

Figure 5.28 : Applied changes on existing eaves of the case study building.

5.3.1 Integration of photovoltaic panels to the case study building

The photovoltaic modules, which have been integrated into shading elements along typical floors on south and southwestern façade, produce 90W peak power. The ones that have been integrated into eaves on the both blocks of case study building, produce 250W peak power. Systems are chosen according to dimensions of eaves and shading elements. These systems are the most efficient photovoltaic systems, which are used in Turkey in recent years. Systems' type is defined as grid-connected for eaves and shading devices on both Blocks.

The photovoltaic modules have been put on the existing shading device on the typical floor, terrace floor, upper ground floor and 2nd floor of block B (because of different elevation module). Plans are shown in Figure 5.29. The modules on the eaves of terrace floor with an orientation angle of 30º are shown in Figure 5.30.

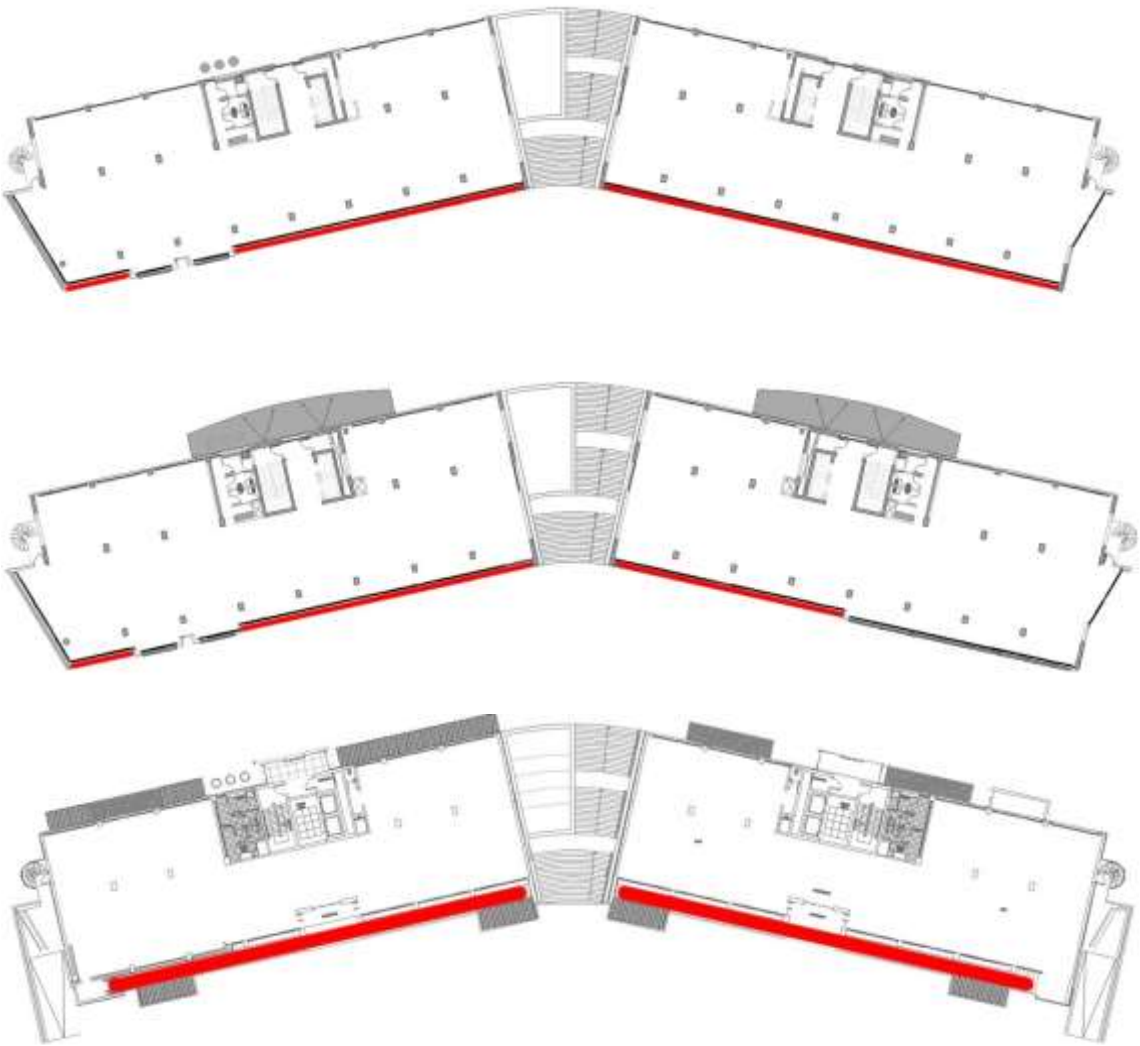

Figure 5.29 : The places of photovoltaic modules on different floors.

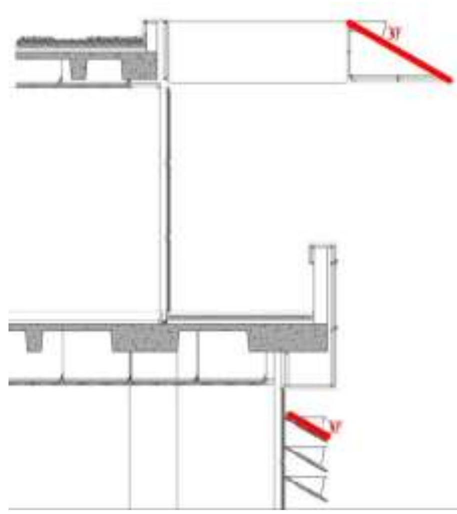

Figure 5.30 : Orientation Angle of Photovoltaic Module.

The total photovoltaic panel area of the eaves is 140m² and that of shading elements is 350m^2, which are divided between two block of the case study building and discussed below.

- **Block A consists of:**
  1- 42 modules on eaves of terrace floor-3 inverters that manage 3 parallel and 14 series strings.
  2- 36 modules in upper ground floor-1 inventers that manage 2 parallel and 18 series strings.
  3- 180 modules in typical floors-5 inverters that manage 10 parallel and 90 series strings.
- **Block B consists of:**
  1- 42 modules in eaves of terrace floor-3 inverters that manage 3 parallel and 14 series strings.
  2- 38 modules in upper ground floor-1 inventers that manage 2 parallel and 19 series strings.
  3- 152 modules in typical floors (except 2nd floor), 4 inverters that manage 8 parallel and 76 series strings.
  4- 36 modules in 2nd floor- 1 inverters that manage 2 parallel and 18 series strings.

PVSYST simulation program have been used to calculate the actual utility of the photovoltaic panels.

5.3.2 Energy performance of the case study building with building integrated photovoltaic systems

Electricity production of *ARI TEKNOKENT 2* building has been motivated by using "PVSYST 5" a version of PVSYST, developed from University of Geneva by CUEPE (Collaboration of Group for Energy). This program with Enercad Software and Meteonorm Software are suitable for grid-connected, stand-alone pumping and DC-grid (public transport) systems. The PVSYST program defines PV system, which processes the informations of orientation, location and place of the panels. Types and sizes of the photovoltaic systems as well as the inverters can be chosen from own library of

PVSYST. A synthetic weather data was generated for *Istanbul* for the dynamic simulation.

Electricity production of the case study will be simulated in four parts:

I) Production of Block A's eaves PV panels

The eaves are composed of 42 photovoltaic modules and 3 inverters. Polycrystalline photovoltaic cells produce 250-Watt power. The 3.3kW inverters are planned to apply to the case study building simulated in the PVSYST program. <u>Photovoltaic panel area of the eaves is 70 m² and the array's power is 13726kWp per year.</u> The most important input files of the software have been shown in Figure 5.31.

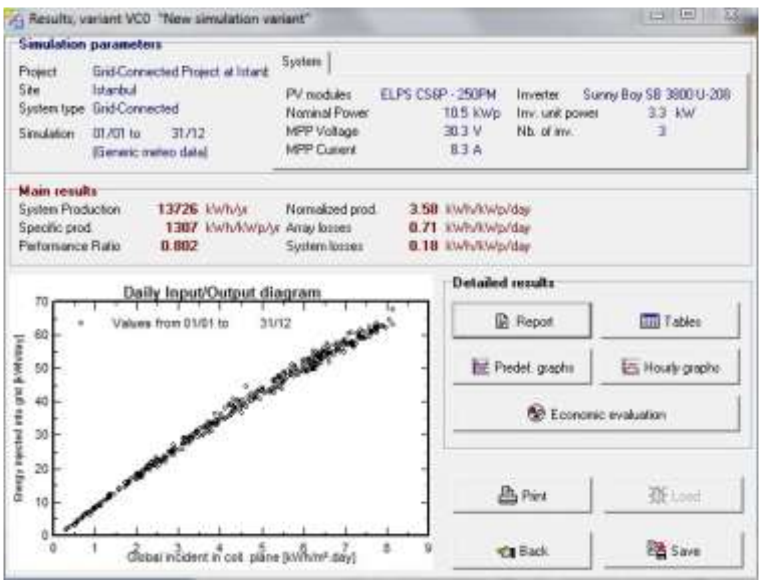

Figure 5.31 : Most important input files of the PVSYST about block A's eaves.

II) Production of Block A's shading elements PV panels

Shading elements are composed of 216 modules, lying along to upper ground floor and typical floors. 3.0kW inverter has been chosen and a 90kW polycrystalline photovoltaic module. <u>Photovoltaic panel area is 150m² and the array's power is 24384kWp for the shading elements.</u>

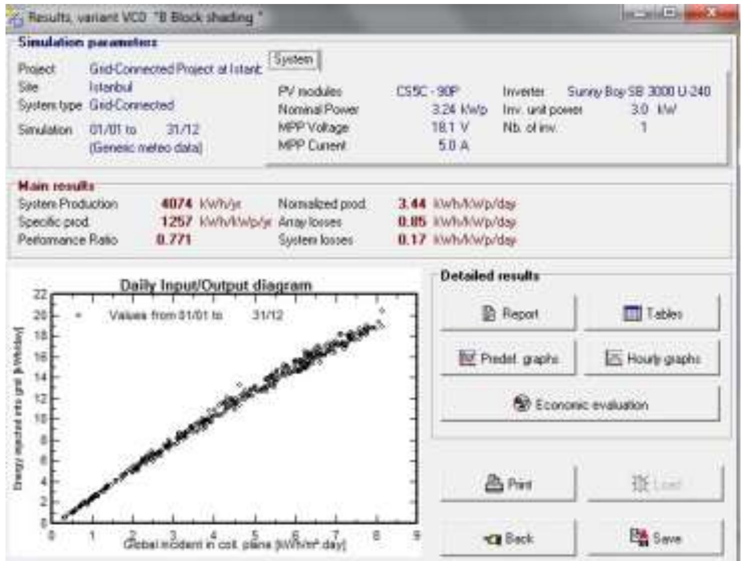

Figure 5.32 : Most important input files of the PVSYST about block A's shading elements.

Table 5.8 : Annual electricity production value of block A.

Block A	eaves	Shading element						Total result
	Terrace floor	Ground Floor	First Floor	Second Floor	Third Floor	Forth Floor	Fifth Floor	
Area of panels(m^2)	70	25	25	25	25	25	25	220
Electricity production (kWh/yr)	13726	4074	4074	4074	4074	4074	4074	38170

Therefore, the total electricity production of integrated photovoltaic systems of block A is 38170kWp per year.

III) Production of Block B's eaves PV panels

The eaves of block B are composed of the same number of modules and inverters because of the eaves' area. Like block A calculations, photovoltaic panel area of the eaves is 70 m² and the array's power is 13519kWp for them.

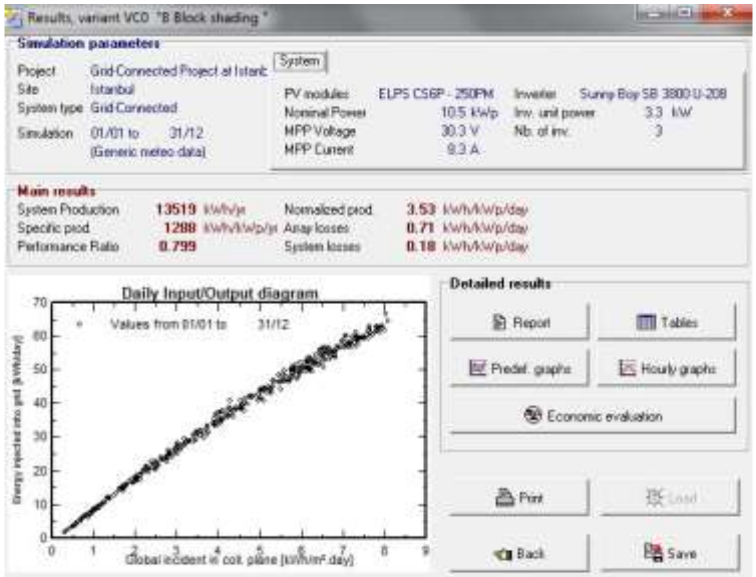

Figure 5.33: Most important input files of the PVSYST about block B's eaves.

IV) Production of Block B's shading elements shading elements' PV panels

Shading elements are composed of 226 modules lying along the upper ground floor and typical floors. Also calculation for second floor has been done in separate simulation settings. There are 226 modules for block B's shading elements. <u>Photovoltaic panel area is 270m² and the array's power is 39079kWp for the shading elements.</u>

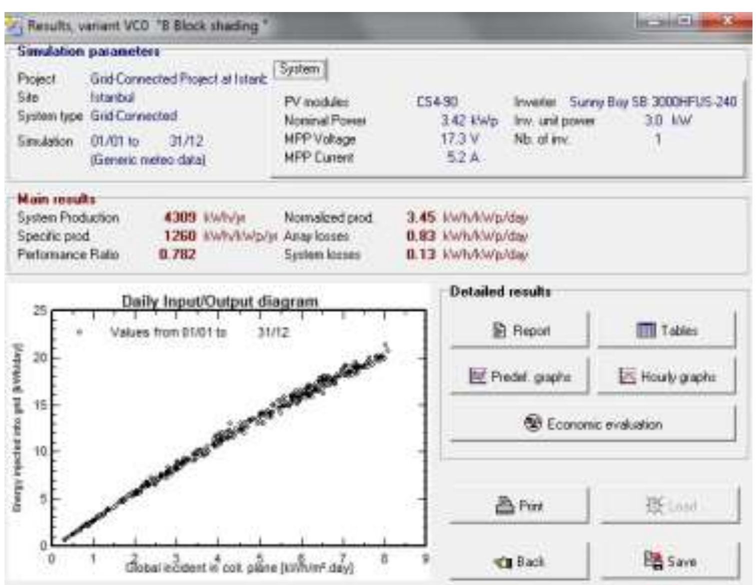

Figure 5.34: Most important input files of the PVSYST about block B's shading elements.

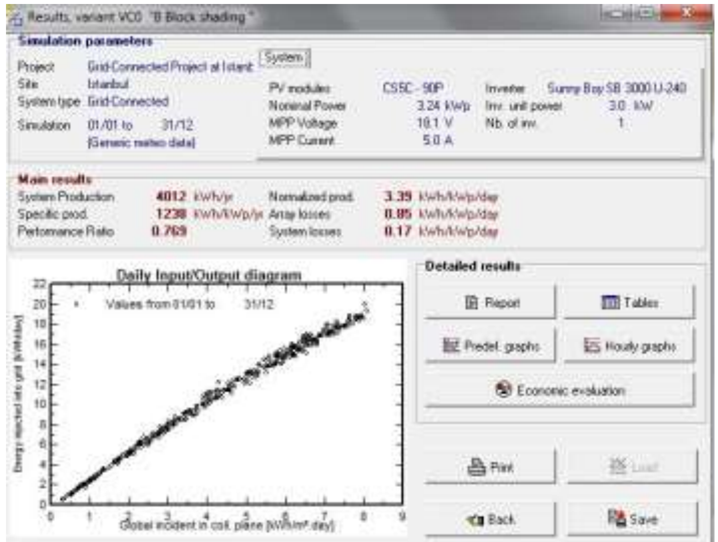

Figure 5.35 : Most important input files of the PVSYST about block B's shading elements of 2nd floor.

Table 5.9 : Annual electricity production value of block B.

Block B	eaves	Shading element						Total result
	Terrace floor	Ground Floor	First Floor	Second Floor	Third Floor	Forth Floor	Fifth Floor	
Area of panels(m^2)	70	35	35	25	35	35	35	270
Electricity production (kWh/yr)	13519	4309	4309	4012	4309	4309	4309	39076

As seen in Table 5.10, total electricity production of case study building's PV system is 77246kWp in a year. Block A's eaves produce 13726kWp; its production of shading element is 24444kWp. Block B's eaves produce 13519kWp and its production of shading element is 25557kWp.

Table 5.10 : Photovoltaic System's Annual Electricity Production.

ARI TEKNOKENT 2	Block A	Block B	Total
Electricity production (kWh/yr)	38170	39076	77246

By the result of PVSYST software based on annual electrical energy production of photovoltaic system of case study building, it can be concluded, that 490m^2 of photovoltaic panels are capable of producing approximately 77000kWp electrical power in a year. According to the results photovoltaic system integration covers the 53% of the energy need in the case of daylight responsive control of building. The difference is depended on the lighting system design and control strategies. Furthermore, energy generation by photovoltaic systems can be maximized if the decisions are taken at the earlier stages of the building design.

Then purchase of photovoltaic systems is a significant investment in order to benefit time and energy over its lifetime [74]. Within the scope of this thesis, financial analysis will be done on the basis of energy production values.

5.4 Financial Analysis of Photovoltaic System

To determine the profit of photovoltaic system installation, the main worth of it, that is, the measured rates of return should be evaluated. It is very important to demonstrate the amount of primary enterprise for the financial analysis and calculation of pay-back time.

The investment costs of the photovoltaic system of case study building were collected by a local solar company. According to information obtained from the financial analysis of this company based on 2013 prices. All analyzes of this project made into Euro terms and Euro rates have been considered to be 2.70 TL [75].

- Calculation of payback time

Payback period intuitively measures how long something takes to "pay for itself." All else being equal, shorter payback periods are preferable to longer ones. The term is used widely also in other types of investment areas, often with respect to energy efficiency technologies, maintenance, upgrades, or other changes [76]. Payback period is usually expressed per year.

Knowing how to calculate potential return from solar panels on investment makes purchasing decision easier. In pay-back time calculation, first of all the total cost of system installation is being determined. Installed factors such as PV panels included their permits and installation costs, and other incentives as well as rebates, solar tax credits offered by manufacturers or federal state and local governments. In scope of this study, the total rates of installation was determined as 1500€ per total nominal power of systems. This value is sizeable in the computational results, which are graphically shown above. All these information about rates have been getting from local company.

Initial cost of the PV system that integrated to *ARI TEKNOKENT 2* can be calculated in two stages. At first the total number of modules used in every part of the building is calculated, and then it is multiplied by the power modules per Watt power. The second stage is to calculate the initial cost of the system installation that means the result of multiplying nominal power by1500€. (Panels cost, inverter, assembly and workmanship are included)

Block A: [(42 modules x 250Wp) + (216 modules x 90Wp)] X 1500€ = 29940€,

Block B: [(42 modules x 250Wp) + (226 modules x 90Wp)] X 1500€ = 30840€,

As a result initial cost of PV system integration is 60`760 Euro. These rates can be said 164`106 TL by today's exchange cost of Euro.

Next step is the determination of annually cost of electricity consumption of lighting system of case study, and the amount of electricity generated by selected solar panels, which have been calculated by PVSYST software. According to Table 5.7 the annually generation amount of case study building's photovoltaic system is 77246kWp. Annually cost of electricity consumption has been calculated by;

$$f = A.\ (0.30\ TL/kW), \qquad (1)$$

In this formula 'A' is the annually electricity consumption of lighting and the average cost of electricity in Turkey which is 0.30TL/kWh for the calculation time (2013). So the annually cost of electricity consumption of lighting system is 23173.8 TL.

Finally, pay-back time is calculated from dividing the initial cost of the project (the nominal power multiply by in 1500€) by annual cash inflow. In fact "annual cash inflow" is the cost of consumption of that electrical energy, which is produced by photovoltaic systems. Assuming that the system is geared directly AC power, the annually consumption of lighting would have cost 0.30 TL per each ”kWh”. Calculations are done with f = A. (0.30 TL/kW) formula.

Pay-back time = cost of project / annual cash inflow, (2)

Pay-back time for *ARI TEKNOKENT 2* = 164106TL/ 23173.8TL = 7.08 years

According to this formula, the pay-back time was calculated approximately 7 years for the photovoltaic system of *ARI TEKNOKENT 2* building.

From the calculation results and pay-back estimated time, it can be concluded that the profit of installed system on case study is approximately 14% in first year.

A new legislation in Turkey allows the injection of generated energy by the PV system, into the grid. The bought back of consumed energy from public utility would be at a lower price than that of the sold PV energy [74].

6. CONCLUSION

Energy is an issue that touches every person on the planet, especially petroleum, from the beginning of 20th century is regarded as the key factor energy uses competition between countries to benefit human’s life. Energy utilization shows a rapid increase at this period. Although enormous progresses have been made in technological innovations, environmental pollution grew too.

To help reduce global warming gases, choose of energy-efficient electrical appliances is necessary. An efficient energy source, which provides sufficient amount of saved-energy and can be obtained more cheaply in order to use at public places such as offices, schools and even at homes, is our aim. Solar energy is the one, for it is clean, renewable and steady, without any harmful effects on the environment. There are different ways of capturing solar radiation and converting it into usable energy. The use methods are active or passive. Active solar technologies use electrical or mechanical devices to convert actively solar energy into another form of energy, most often heat or electricity.

Architects and designers have advantages nowadays to achieve the energy-efficient design approach. By means of different simulation tools in a building design, they are able to imitate daylight and solar radiation inside the space. Both daylight and artificial lighting systems, and their integrations, should be designed according to the energy-efficient principles. Simulation results give opportunities and useful ideas to user for evaluating the energy saving possibilities of lighting control systems and energy production of solar systems in buildings.

Daylight-responsive lighting is the energy-efficient one, which is the key element in this approach. There are two dimensions for daylight-responsive lighting: the control of daylight (quality of daylight related to the quantity of inside space) and the control of daylight depending electric lighting.

Simulation results give opportunities and useful ideas to user for evaluating the energy saving possibilities of lighting control systems and energy production of solar systems in buildings. By the result of PVSYST software based on annual electrical energy production of PV system of case study building, it can be cocluded that: 490m^2 of photovoltaic panels are capable of producing approximately 77000kWp electrical power for a year. This rate of production produces about 53 % of electrical energy for lighting.

The integration of available daylight into electric lighting calculation indicates the amount of saved energy. An active user affects this amount by controlling the number of luminaries which are switched on or off during the day.As calculated if the occupants are passive user they would have consumed 229580.02 kWh electric lighting energy annually.

The annual electric lighting energy of the case study building decreases from 229580.02kWh to 144722.94kWh by using a daylight responsive control system. Final result shows that the consumption in proposed system is reduced approximately 37 %.

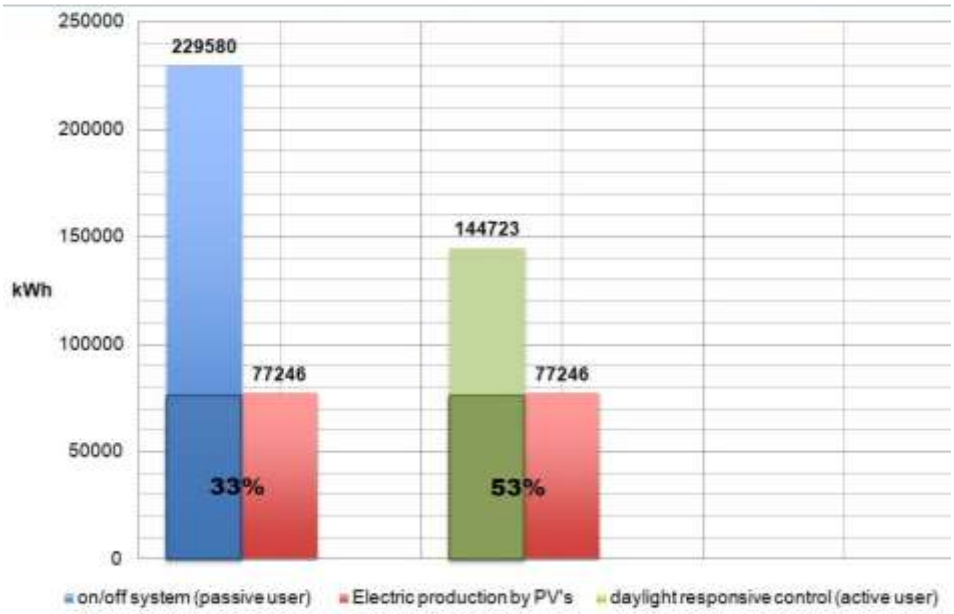

Figure 6.1 : Lighting energy requirement of the case study building.

The graph in Figure 6.1 expresses lighting energy requirement in both cases and the electric energy production by photovoltaic system integration. According to the results, in first case (passive user with an on/off switch) photovoltaic system integration covers the <u>33%</u> of the energy need. Comparatively, in second case (active user with daylight responsive control) photovoltaic system integration covers the <u>53%</u> of the energy need. The difference is depended on the lighting system design and control strategies. Furthermore, energy generation by photovoltaic systems can be maximized if the decisions are taken at the earlier stages of the building design. Buildings have a capacity to play pivotal role at solving energy problem due to consuming of almost 50% of energy demand in the world.Strategies for efficient use of energy and integrating renewable energy sources to the buildings covers all design decisions starting with the initial phase.

Additionally as a result of pay-back time calculation, PV generators inquire into the economy, with decomposing the current prices and the new feed in tariffs. The evaluation of pay-back time proves the beneficial effect of this investment both on energy use and its cost.

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APPENDICES

APPENDIX A: Graphical User Interface (GUI) of RELUX Simulation Tool for Aritifical Lighting Design
APPENDIX B: Graphical User Interface (GUI) of RELUX Simulation Tool for Daylight Simulations
APPENDIX C: Graphical User Interface (GUI) of RELUX Simulation Tool for Zones With the Enough Amount of Natural Light

APPENDIX A

This appendix gives graphical user interface (GUI) of RELUX simulation for aritifical lighting design of LEDs in open office spaces, consisted of two blocks(A&B) and eight floors.

Considering the EN12464 standard the appropriate luminance of artificial lighting design of LED lamps in open office spaces is 500 lux. Due to color bar shown in figures of appendix A, this result is got in this research.

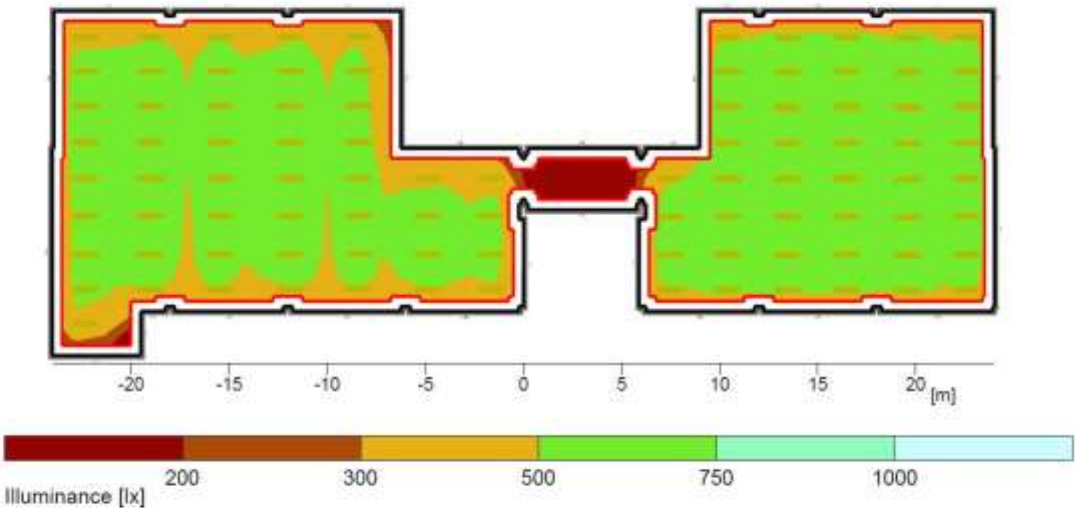


Figure A.1: The GUI of artificial lighting design of Block A mezzanine floor by LEDs.

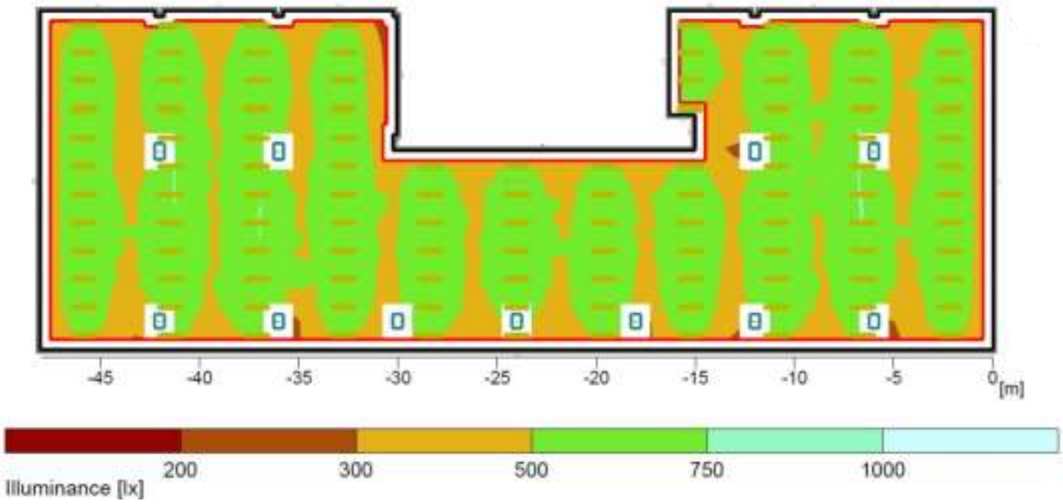


Figure A.2: The GUI of artificial lighting design of Block A Ground 2 floor by LEDs.

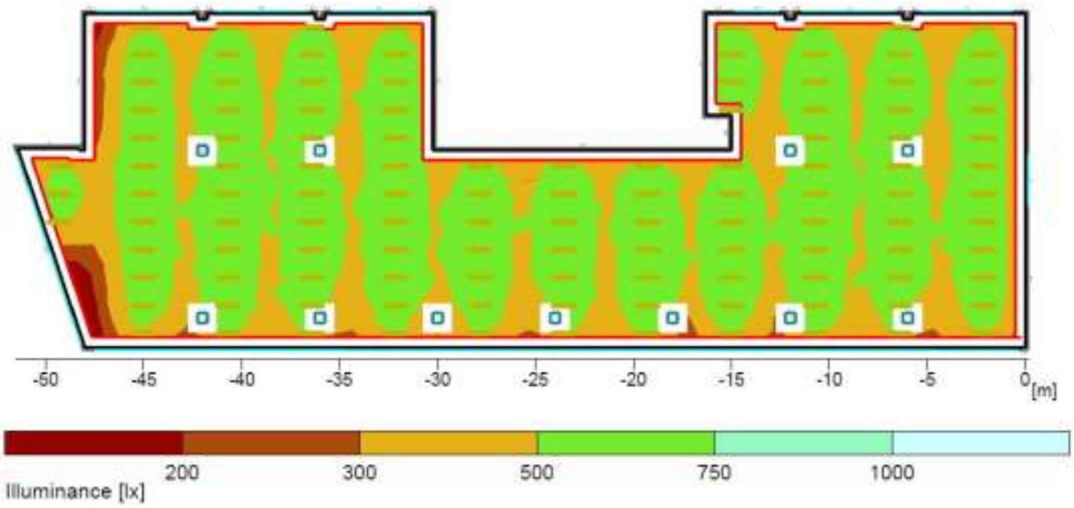


Figure A.3: The GUI of artificial lighting design of Block A type floors by LEDs.

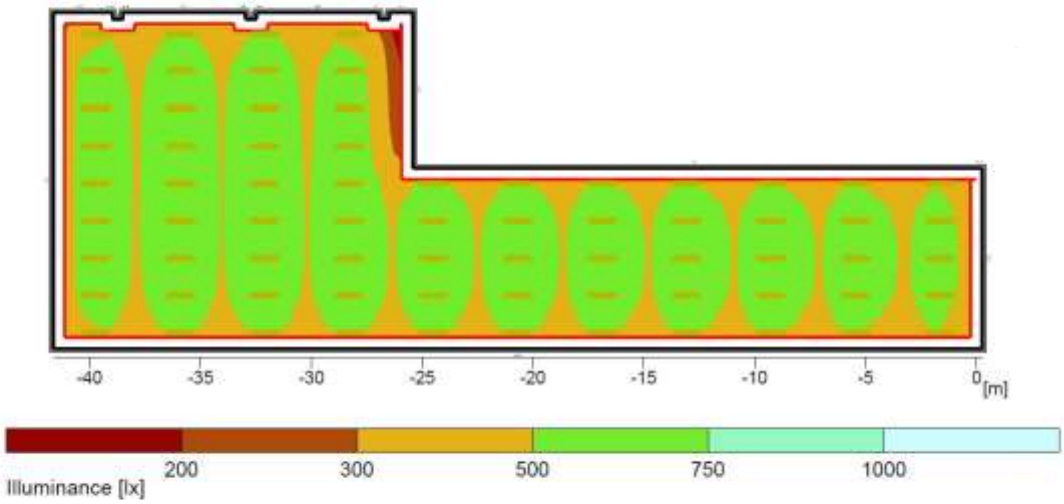


Figure A.4: The GUI of artificial lighting design of Block A Terrace floor by LEDs.

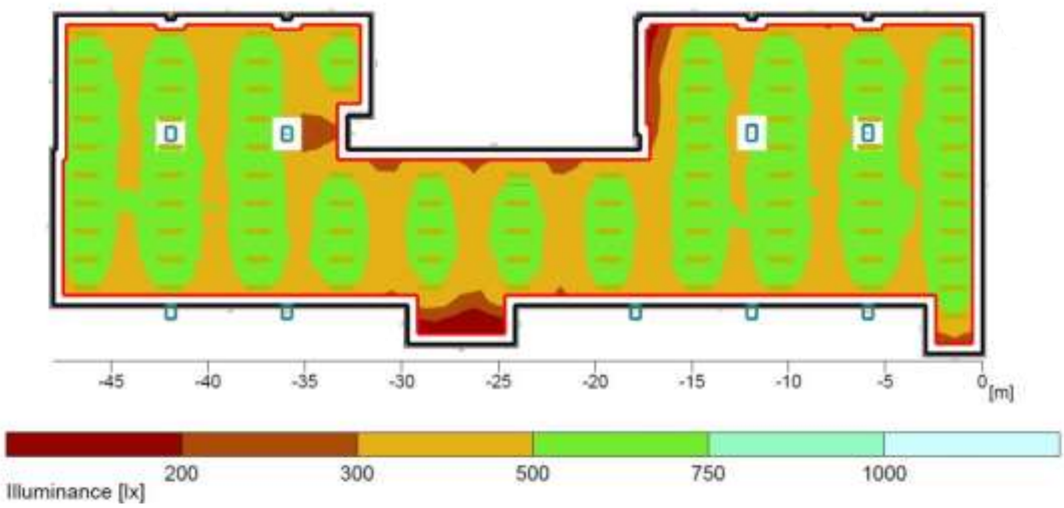


Figure A.5: The GUI of artificial lighting design of Block B ground floor by LEDs.

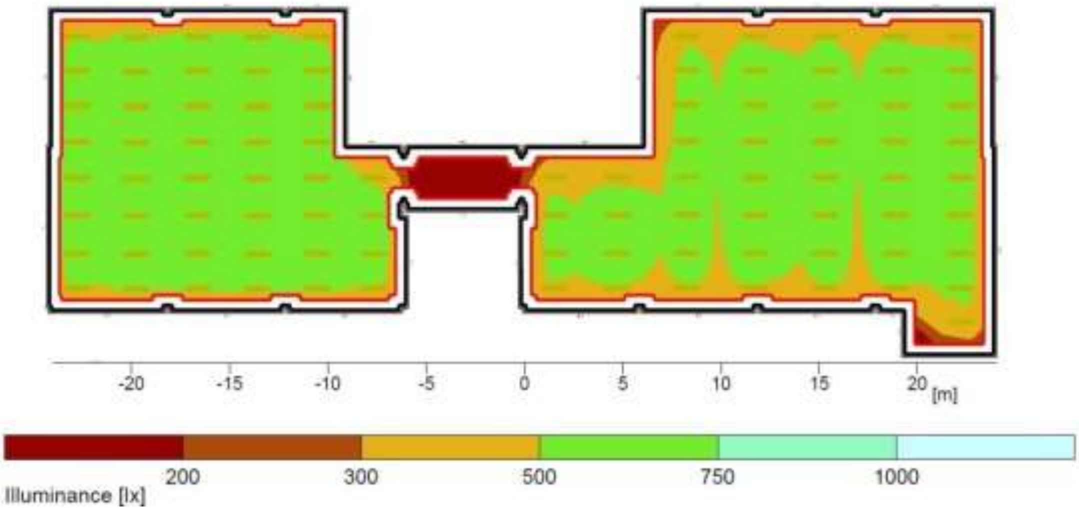


Figure A.6: The GUI of artificial lighting design of Block B mezzenine floor by LEDs.

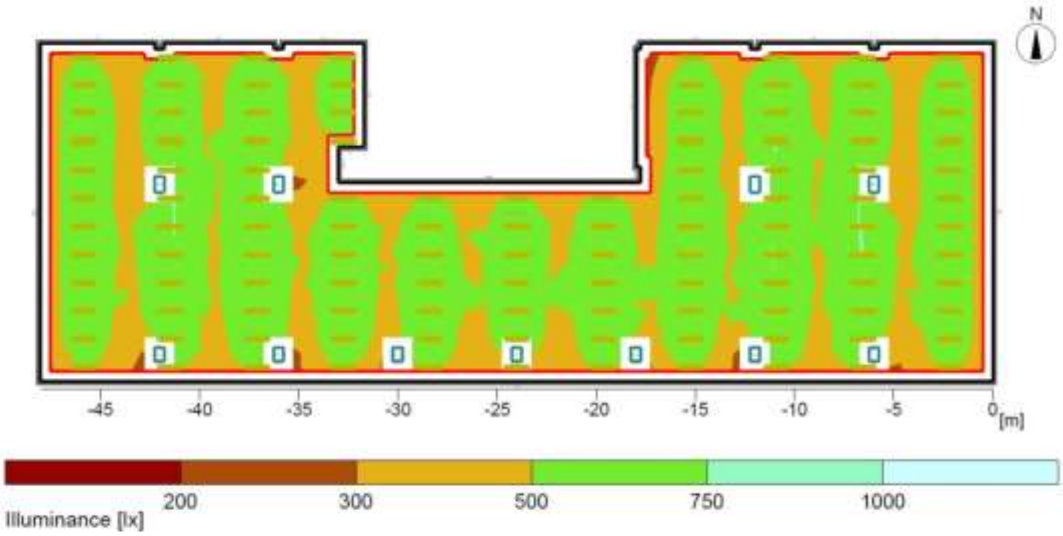


Figure A.7: The GUI of artificial lighting design of Block B ground 2 floor by LEDs.

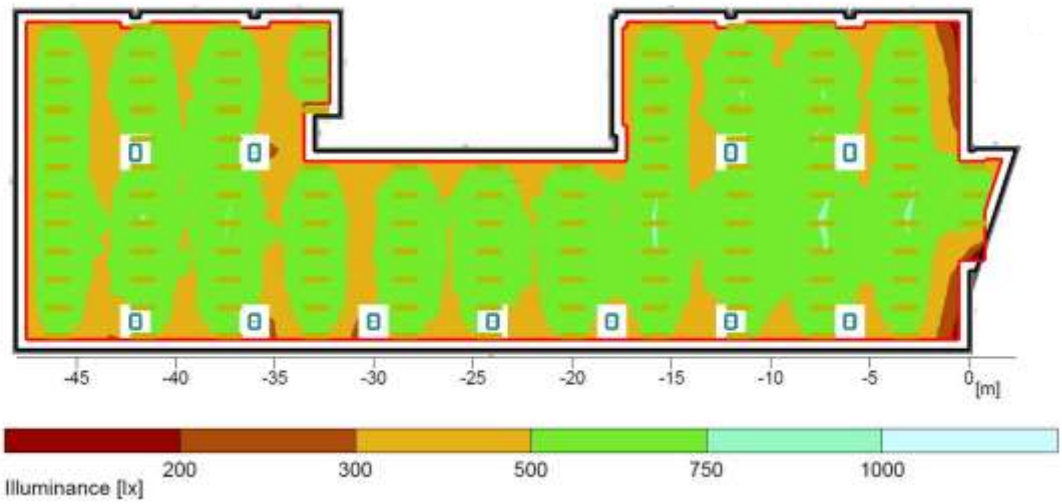


Figure A.8: The GUI of artificial lighting design of Block B Type floors by LEDs.

APPENDIX B

This appendix gives graphical user interface (GUI) of RELUX simulation for daylight simulations, consisted of two blocks(A&B) and eight floors.

Daylight calculation is divided into two categories: summer and winter periods. Six months of the year, from April 1^{st} to September 30^{th} is regarded as summer time and the remaining six months from October 1^{st} through March 31^{st} is regarded as wintertime. 21^{st} June has been considered as the reference day for 6 months of summer and 21^{st} December for six months of winter. CIE Clear Sky Model is used for summer simulations and CIE Overcast Sky Model for winter simulations. Reference hours throughout the working day are determined as $9{:}^{00}$ am, $12{:}^{00}$ pm and $3{:}^{00}$ pm for winter period and $9{:}^{00}$ am, $12{:}^{00}$ pm, $3{:}^{00}$ pm and $5{:}^{00}$ pm for summer period.

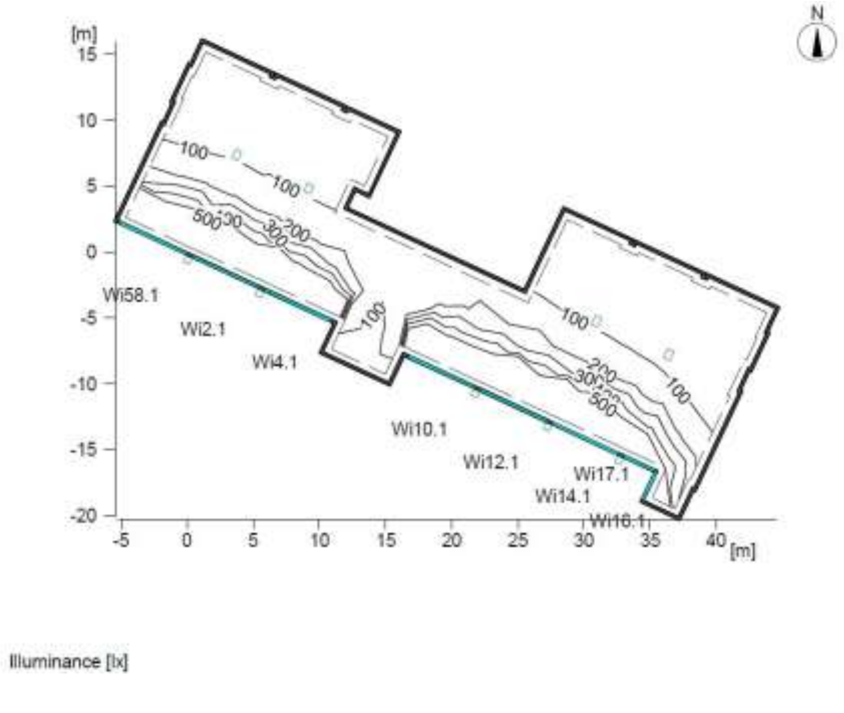


Figure B.1 : The GUI of daylight simulation of Block B ground floor December 21^{st} - $9{:}^{00}$ – Overcast sky model.

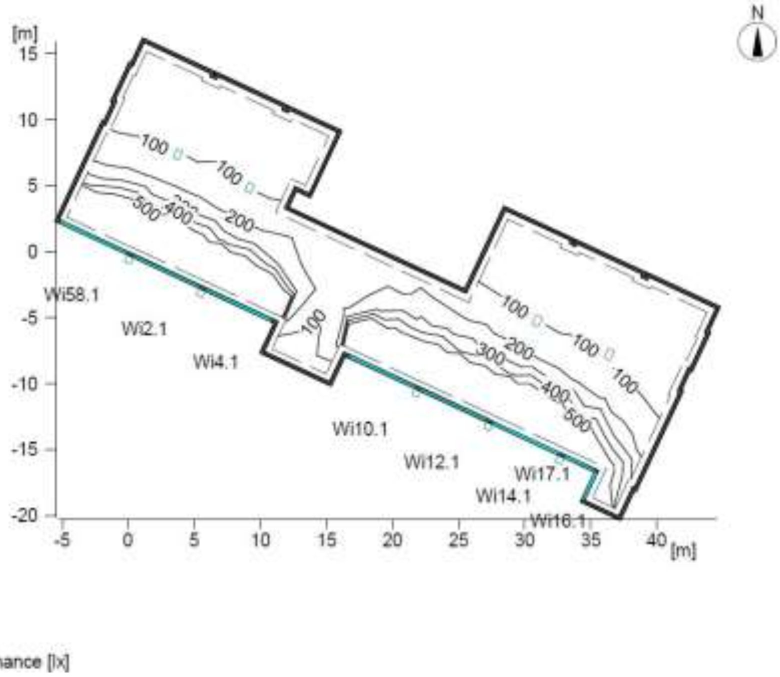


Figure B.2 : The GUI of daylight simulation of Block B ground floor December 21^{st} - $12{:}^{00}$ – Overcast sky model.

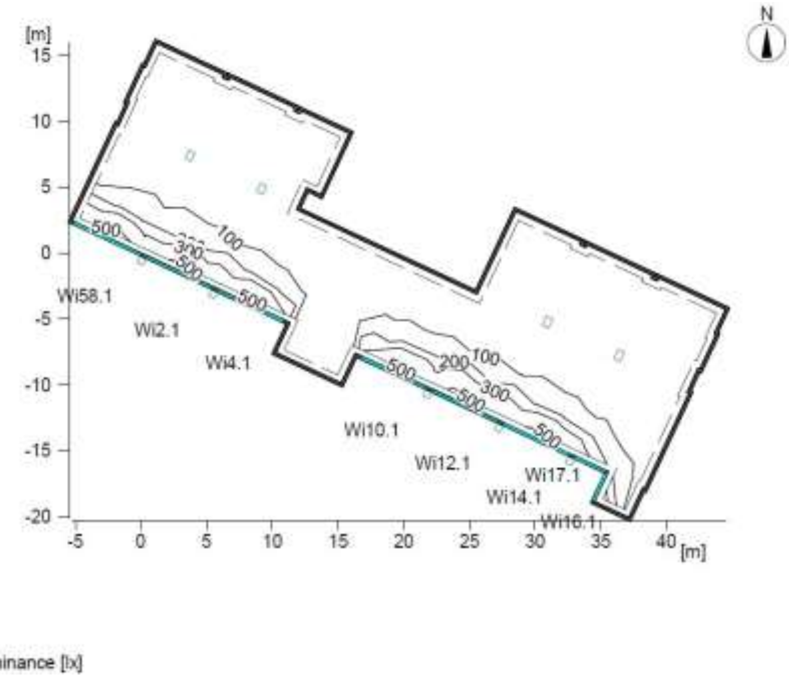


Figure B.3 : The GUI of daylight simulation of Block B ground floor December 21^{st} - $15{:}^{00}$ – Overcast sky model.

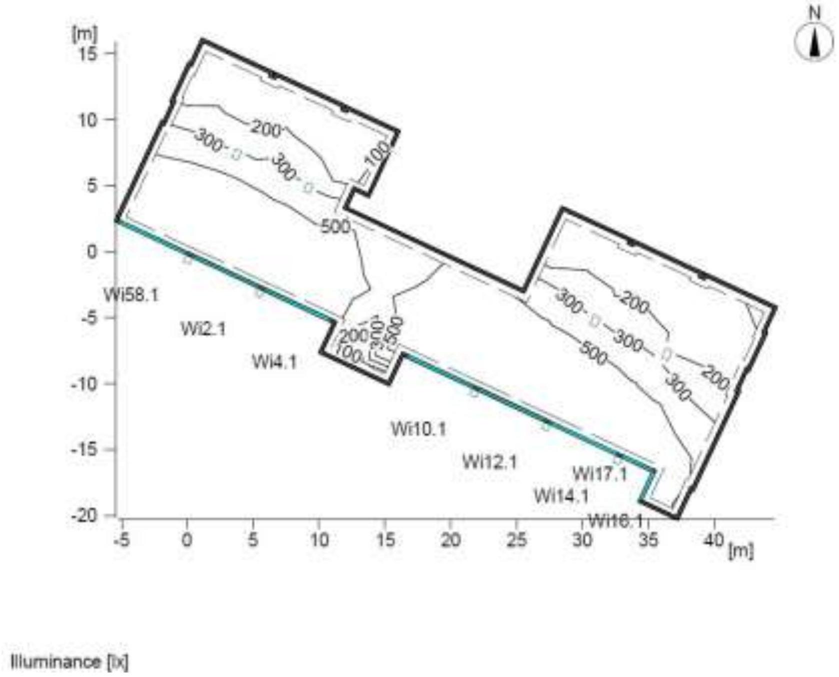


Figure B.4 : The GUI of daylight simulation of Block B ground floor June 21st - 9:00 – Clear sky model.

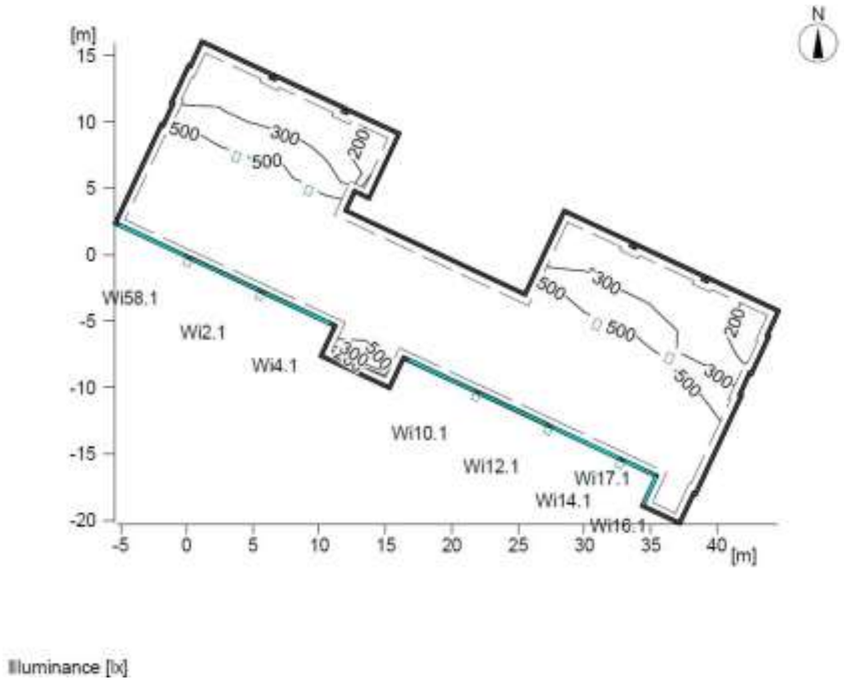


Figure B.5 : The GUI of daylight simulation of Block B ground floor June 21st - 12:00 – Clear sky model.

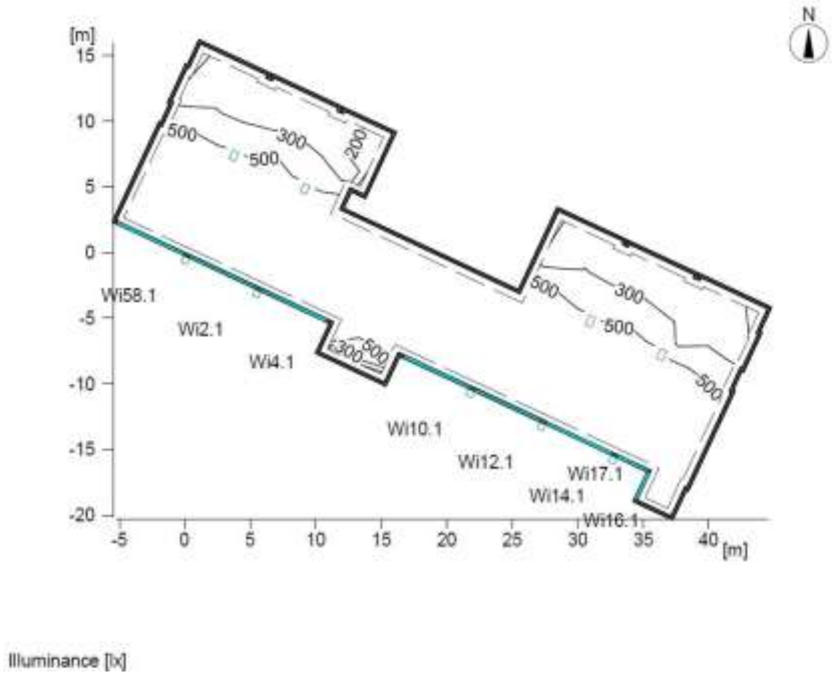


Figure B.6 : The GUI of daylight simulation of Block B ground floor June 21^{st} - $15:^{00}$ – Clear sky model.

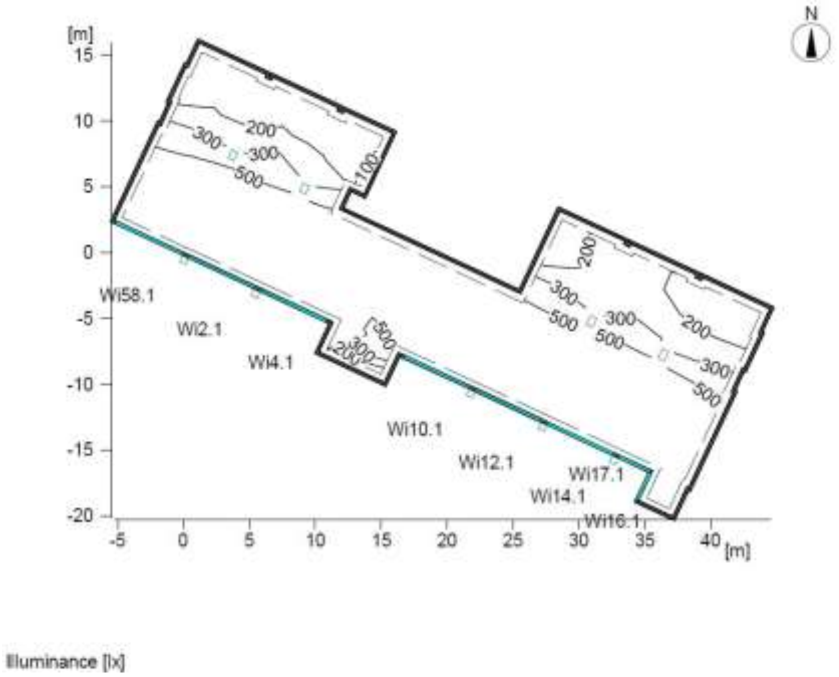


Figure B.7 : The GUI of daylight simulation of Block B ground floor June 21^{st} - $17:^{00}$ – Clear sky model.

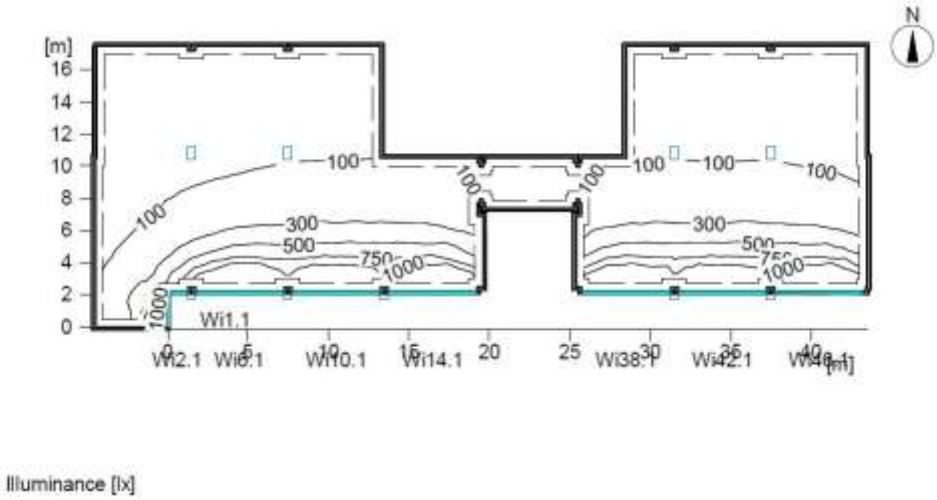


Figure B.8 : The GUI of daylight simulation of Block A mezzenine floor December 21st - 9:00 – Overcast sky model.

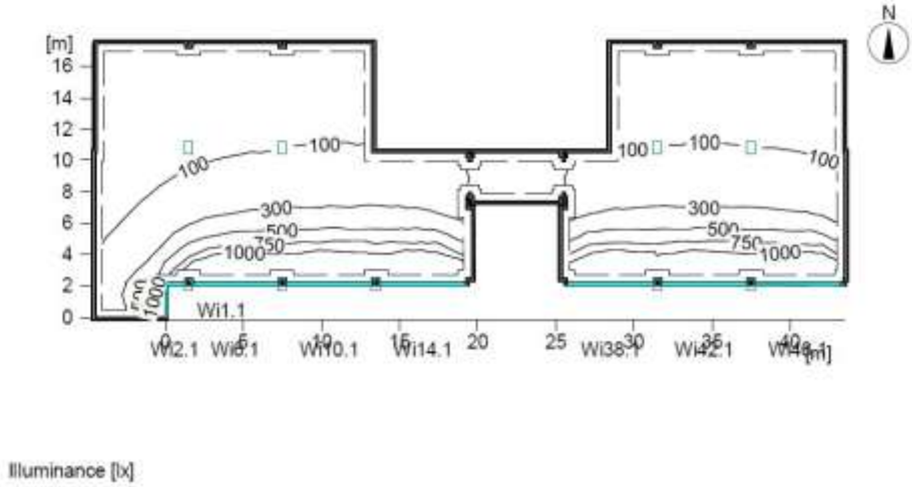


Figure B.9 : The GUI of daylight simulation of Block A mezzenine floor December 21st - 12:00 – Overcast sky model.

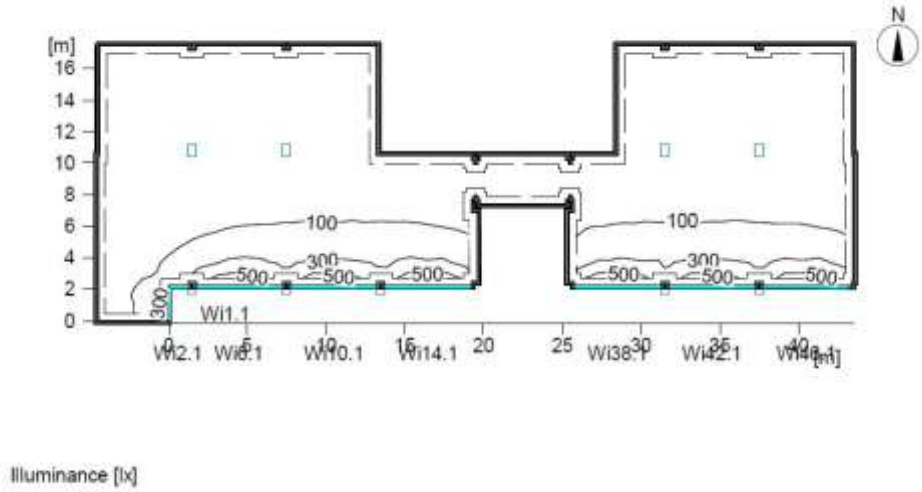
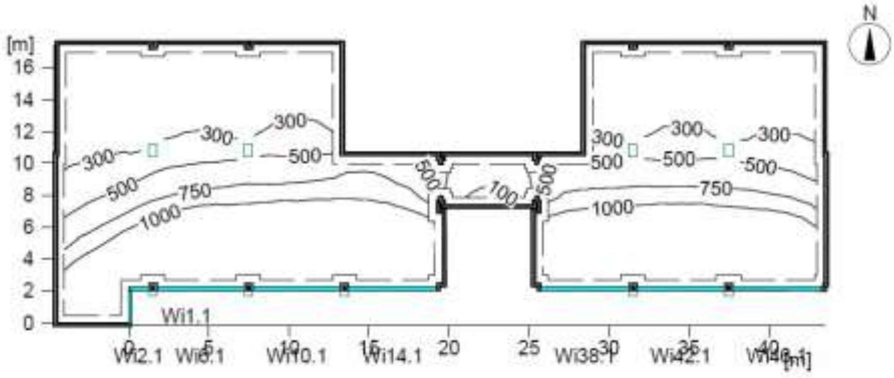
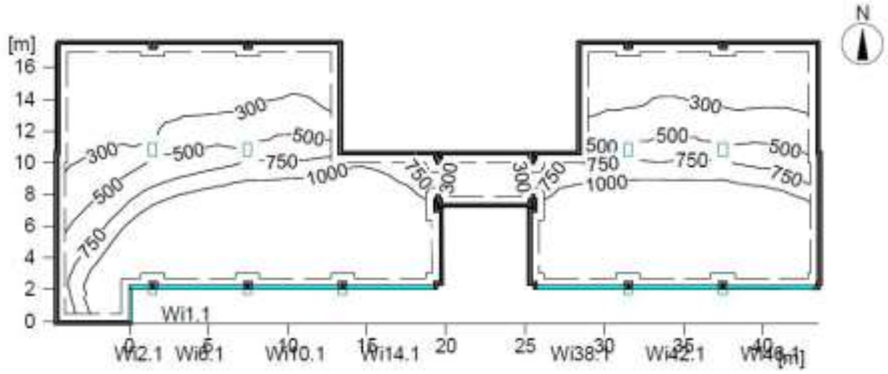


Figure B.10 : The GUI of daylight simulation of Block A mezzenine floor December 21st - 15:00 – Overcast sky model.



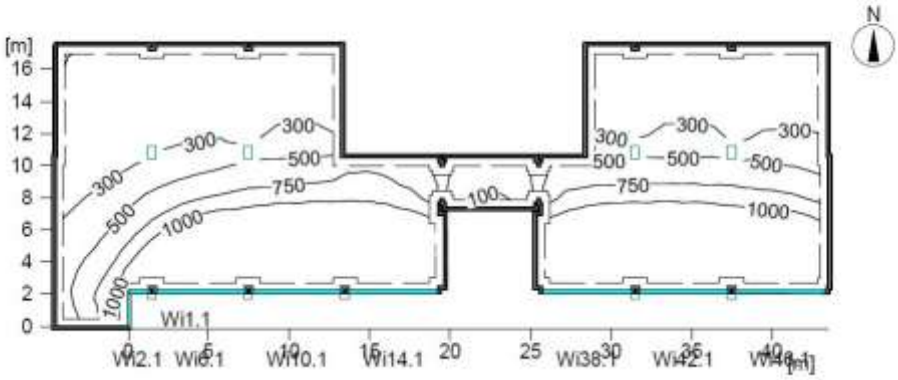
Illuminance [lx]

Figure B.11 : The GUI of daylight simulation of Block A mezzenine floor June 21st - 9:00 – Clear sky model.



Illuminance [lx]

Figure B.12 : The GUI of daylight simulation of Block A mezzenine floor June 21st - 12:00 – Clear sky model.



Illuminance [lx]

Figure B.13 : The GUI of daylight simulation of Block A mezzenine floor June 21st - 15:00 – Clear sky model.

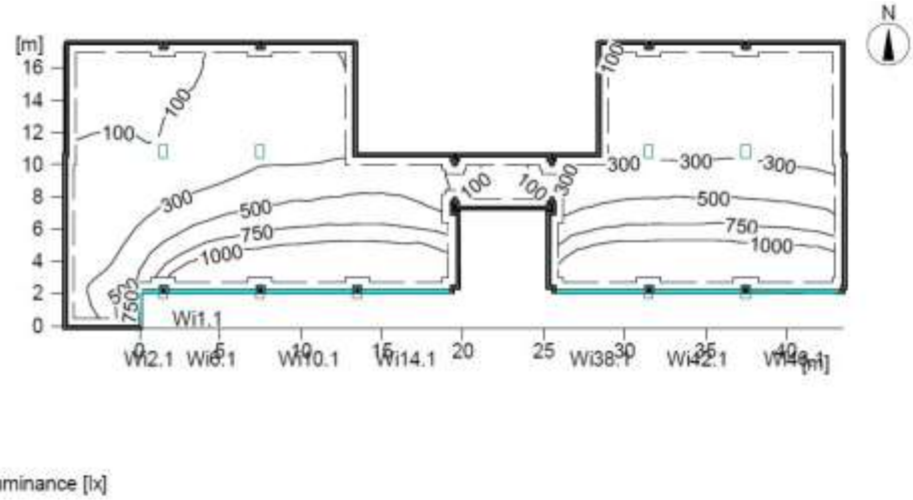


Figure B.14 : The GUI of daylight simulation of Block A mezzenine floor June 21st - 17:00 – Clear sky model.

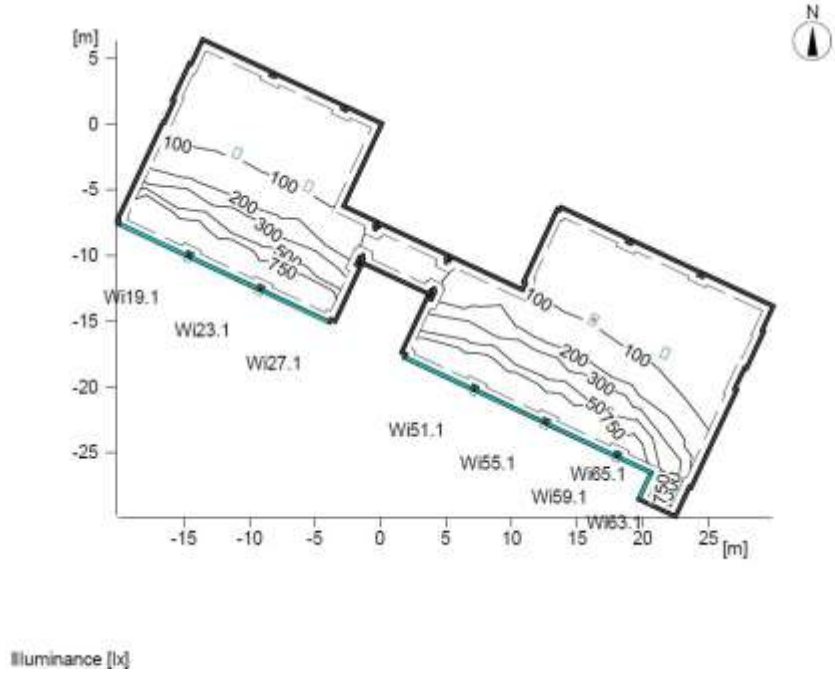


Figure B.15 : The GUI of daylight simulation of Block B mezzenine floor December 21st - 9:00 – Overcast sky model.

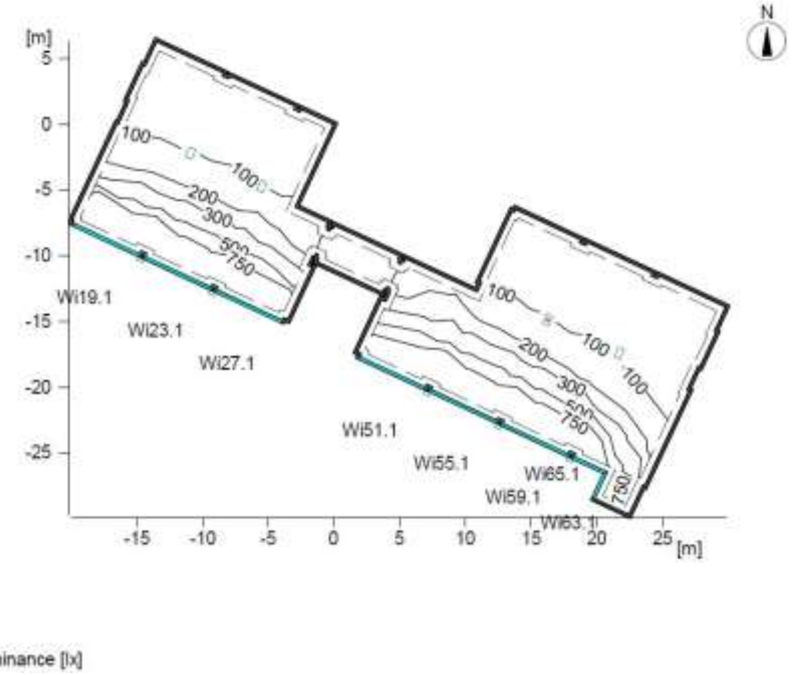


Figure B.16 : The GUI of daylight simulation of Block B mezzenine floor December 21st - 12:^{00} – Overcast sky model.

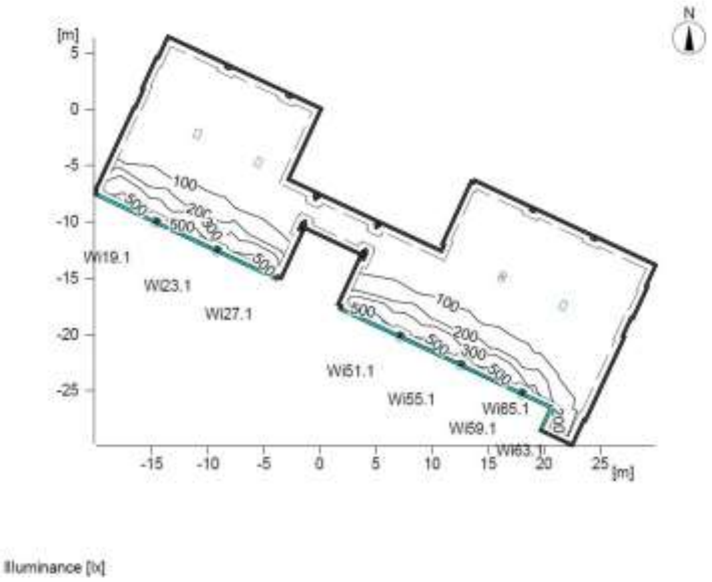


Figure B.17 : The GUI of daylight simulation of Block B mezzenine floor December 21st - 15:^{00} – Overcast sky model.

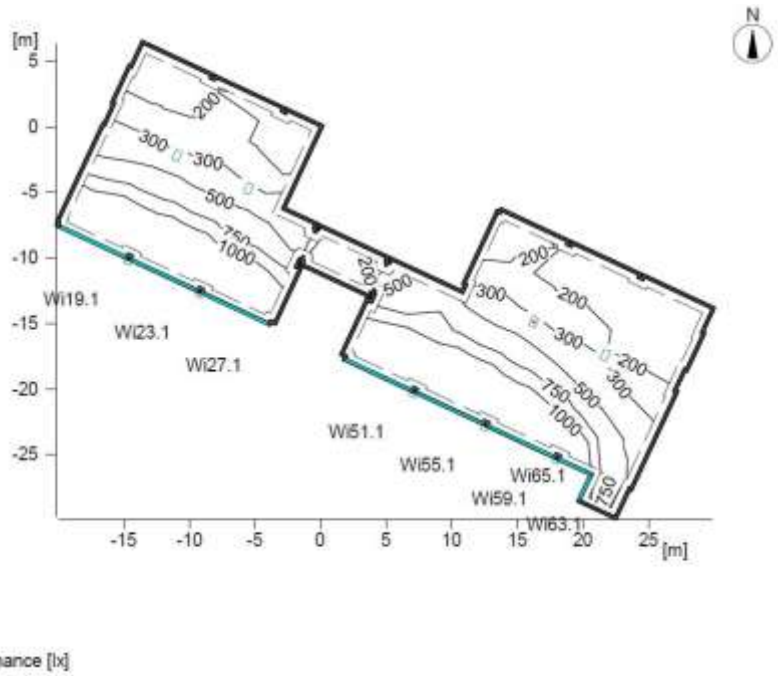


Figure B.18 : The GUI of daylight simulation of Block B mezzenine floor
June 21st - 9:00 – Clear sky model.

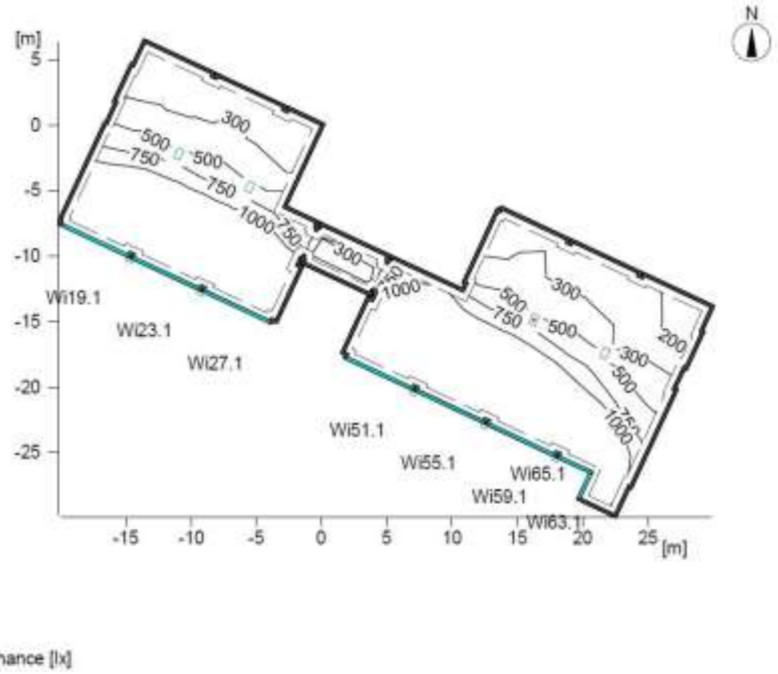


Figure B.19 : The GUI of daylight simulation of Block B mezzenine floor
June 21st - 12:00 – Clear sky model.

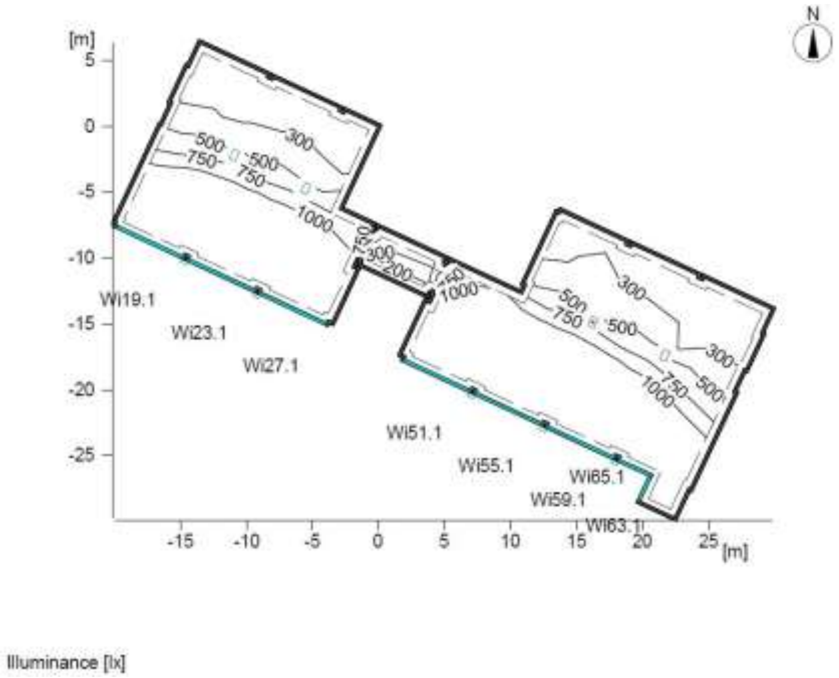


Figure B.20 : The GUI of daylight simulation of Block B mezzenine floor June 21st - 15:00 – Clear sky model.

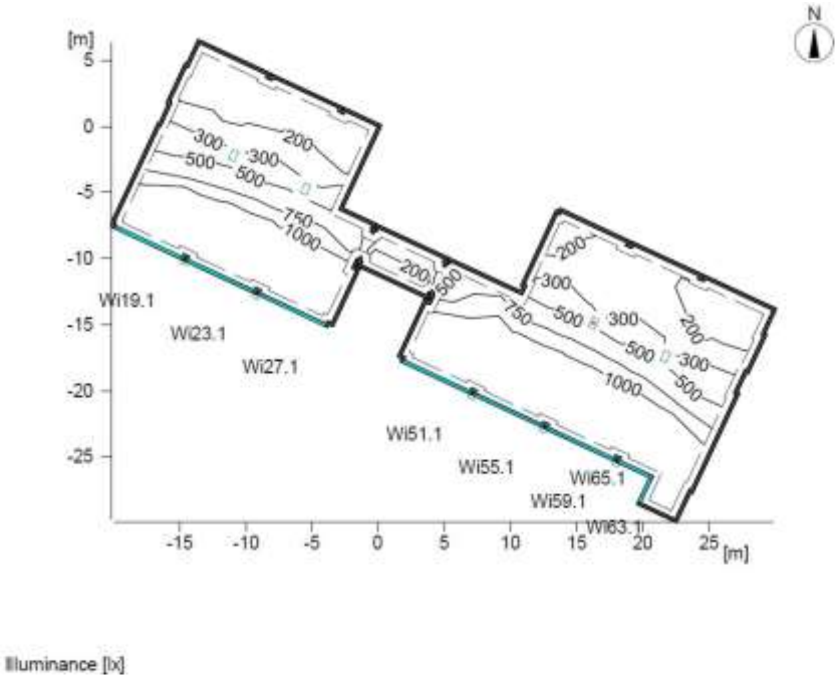


Figure B.21 : The GUI of daylight simulation of Block B mezzenine floor June 21st - 17:00 – Clear sky model.

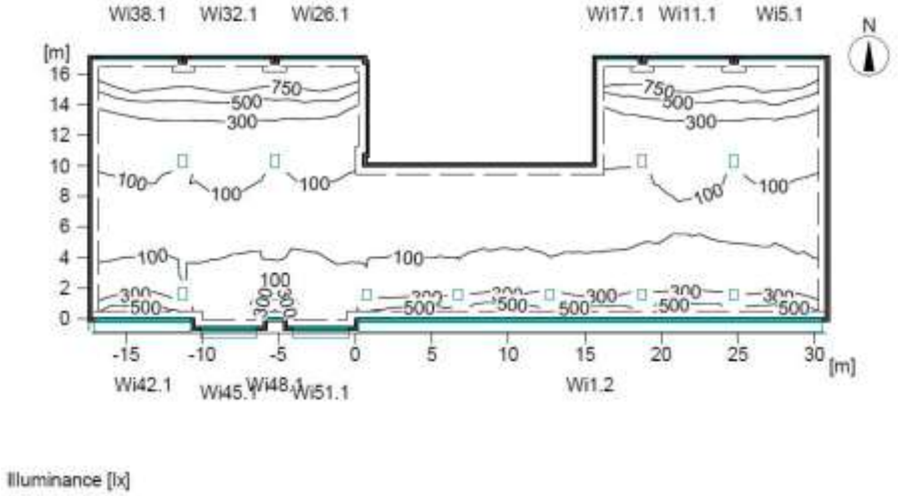


Figure B.22 : The GUI of daylight simulation of Block A ground 2 floor December 21st - 9:^{00} – Overcast sky model.

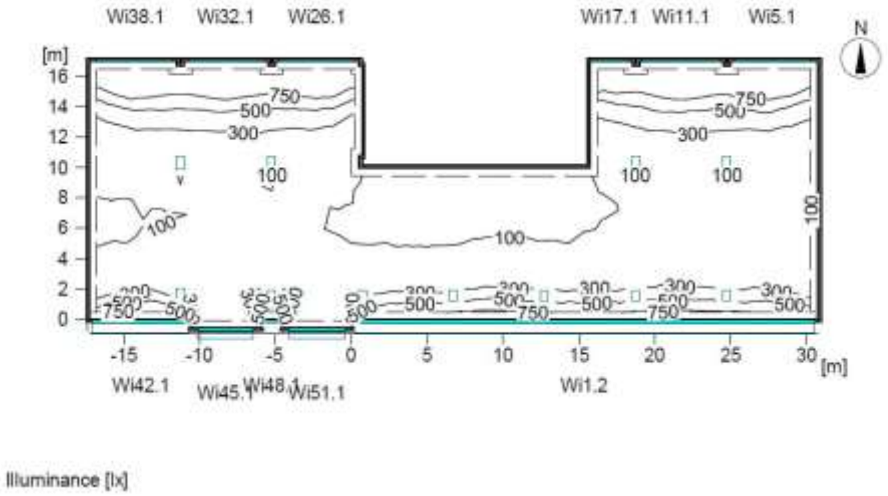


Figure B.23 : The GUI of daylight simulation of Block A ground 2 floor December 21st - 12:^{00} – Overcast sky model.

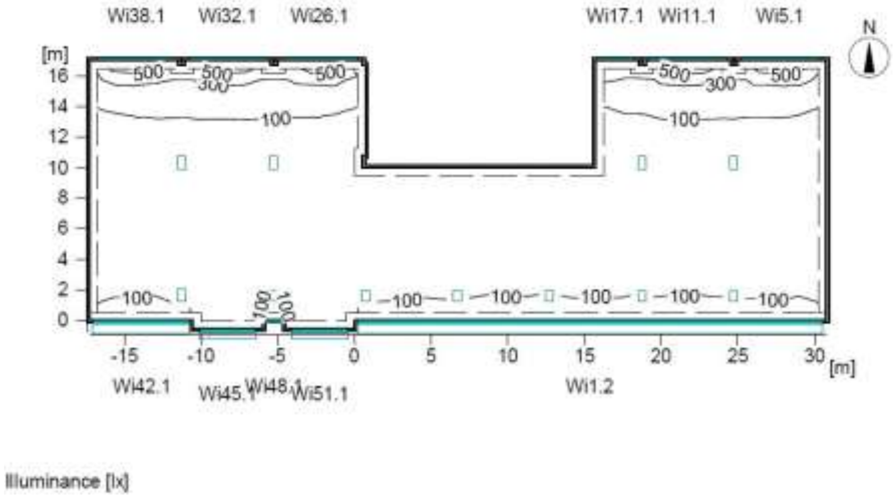
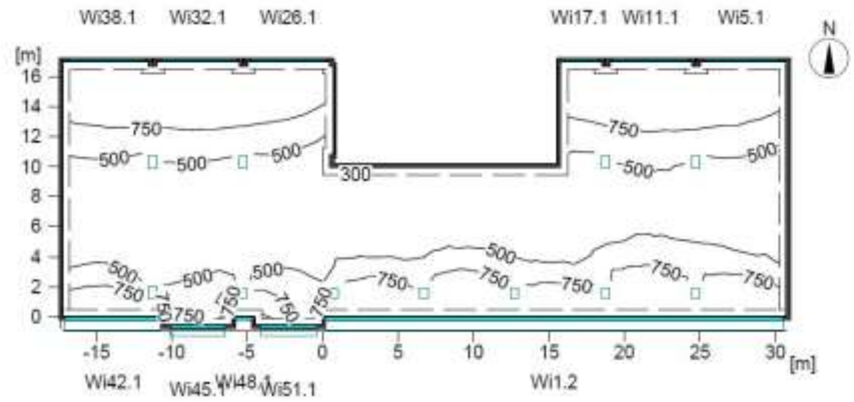
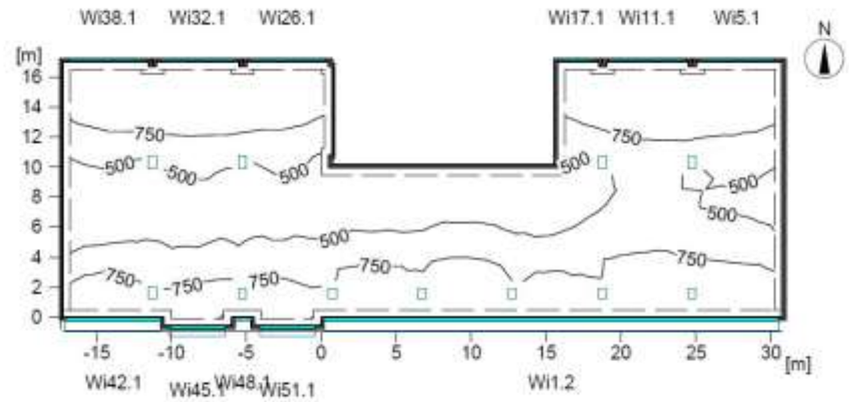


Figure B.24 : The GUI of daylight simulation of Block A ground 2 floor December 21st - 15:^{00} – Overcast sky model.



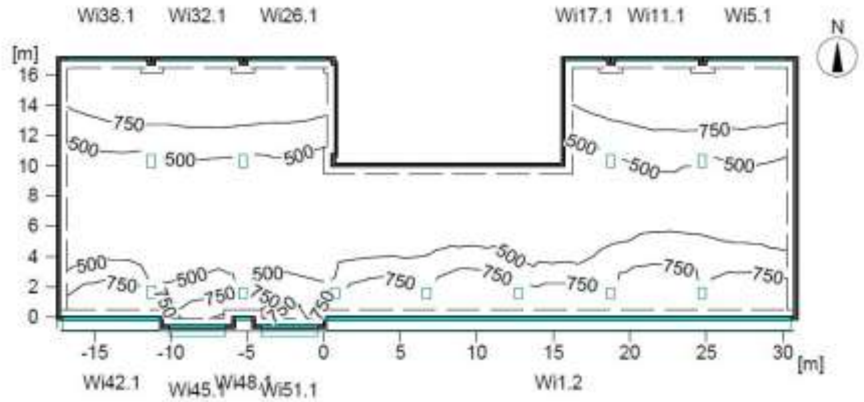
5 Illuminance [lx]

Figure B.25 : The GUI of daylight simulation of Block A ground 2 floor June 21st - 9:00 – Clear sky model.



Illuminance [lx]

Figure B.26 : The GUI of daylight simulation of Block A ground 2 floor June 21st - 12:00 – Clear sky model.



Illuminance [lx]

Figure B.27 : The GUI of daylight simulation of Block A ground 2 floor June 21st - 15:00 – Clear sky model.

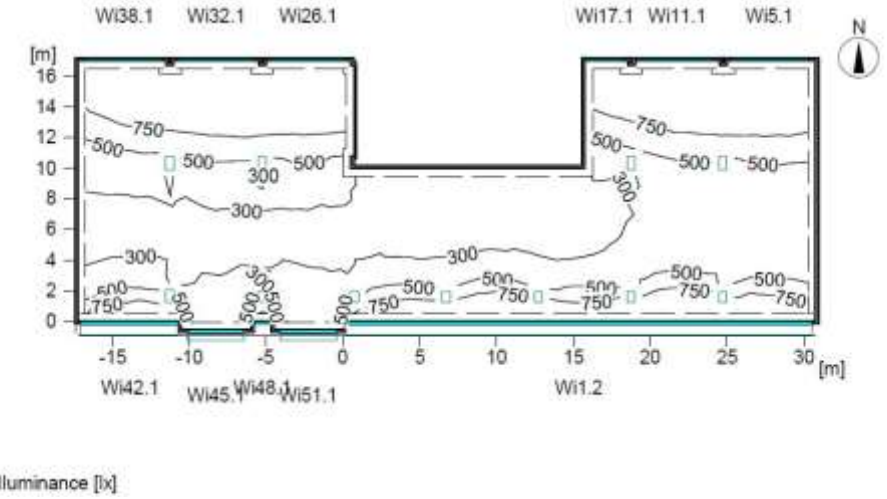


Figure B.28 : The GUI of daylight simulation of Block A ground 2 floor June 21st– 17:00 – Clear sky model.

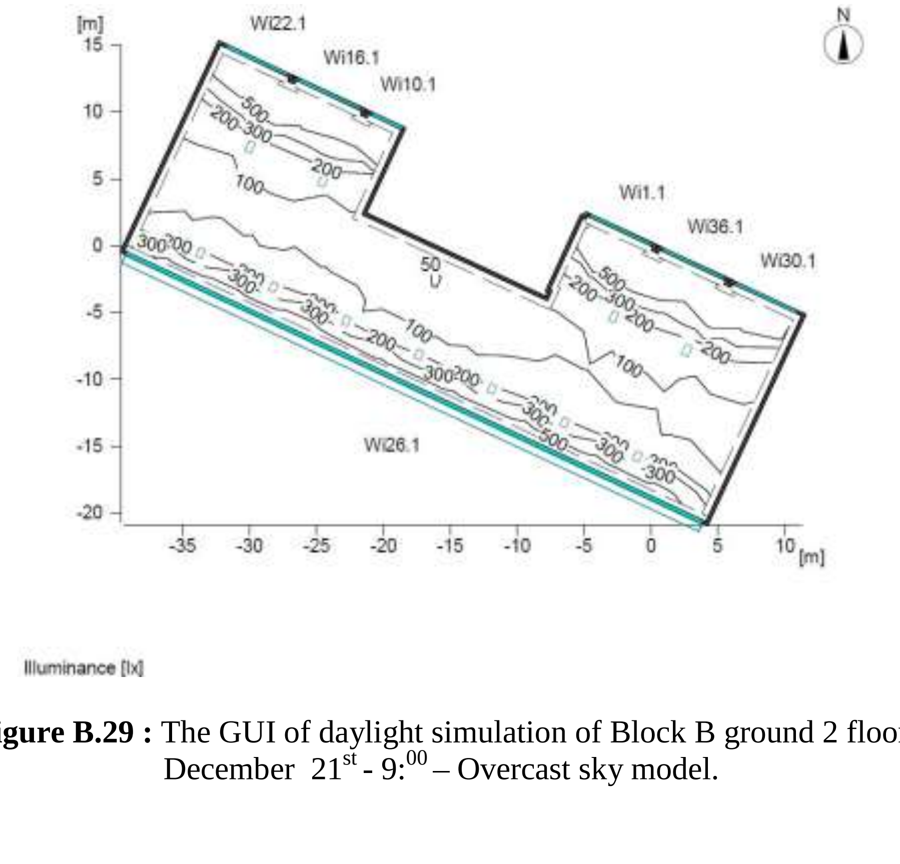


Figure B.29 : The GUI of daylight simulation of Block B ground 2 floor December 21st - 9:00 – Overcast sky model.

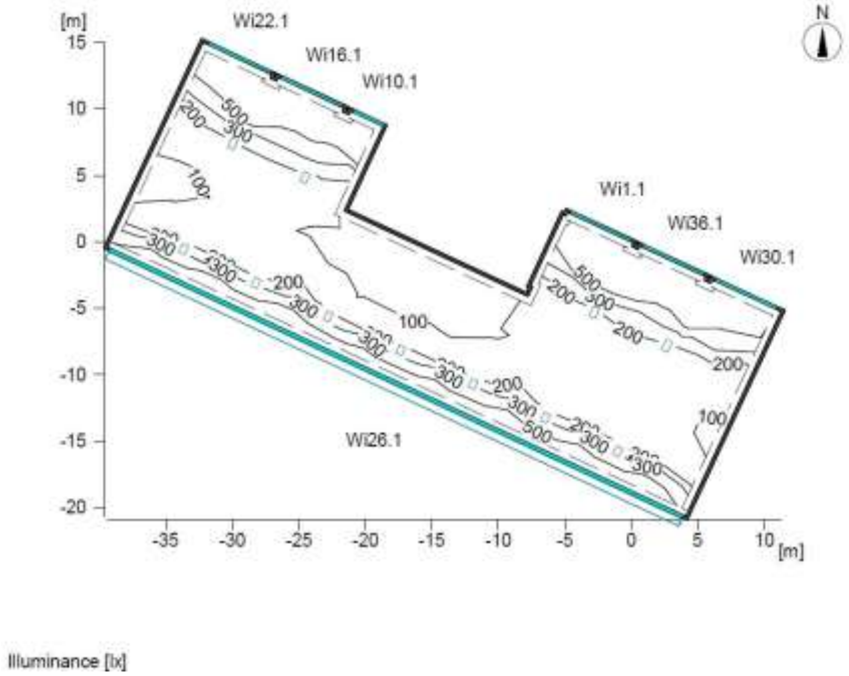


Figure B.30 : The GUI of daylight simulation of Block B ground 2 floor December 21st - 12:00 – Overcast sky model.

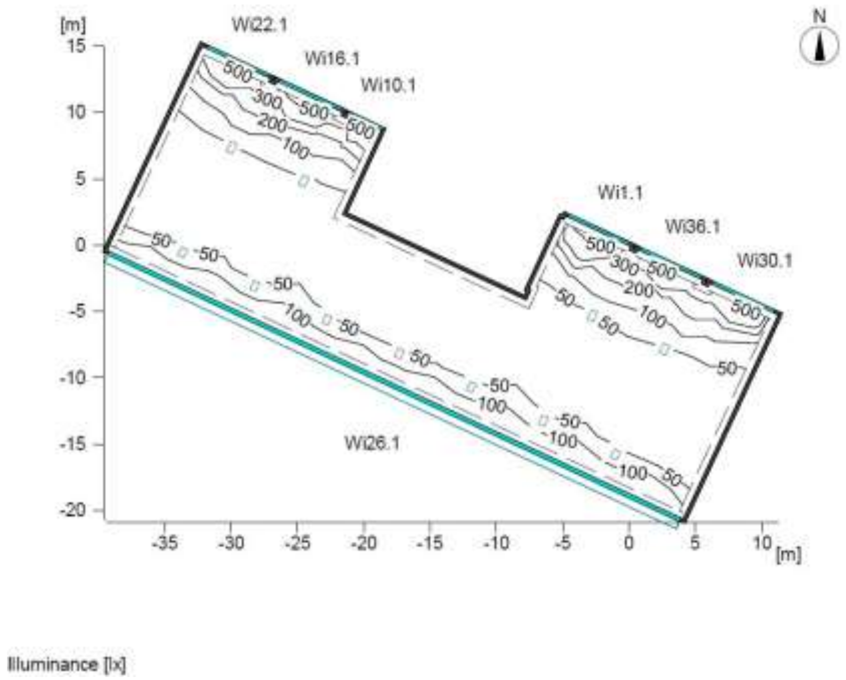


Figure B.31 : The GUI of daylight simulation of Block B ground 2 floor December 21st - 15:00 – Overcast sky model.

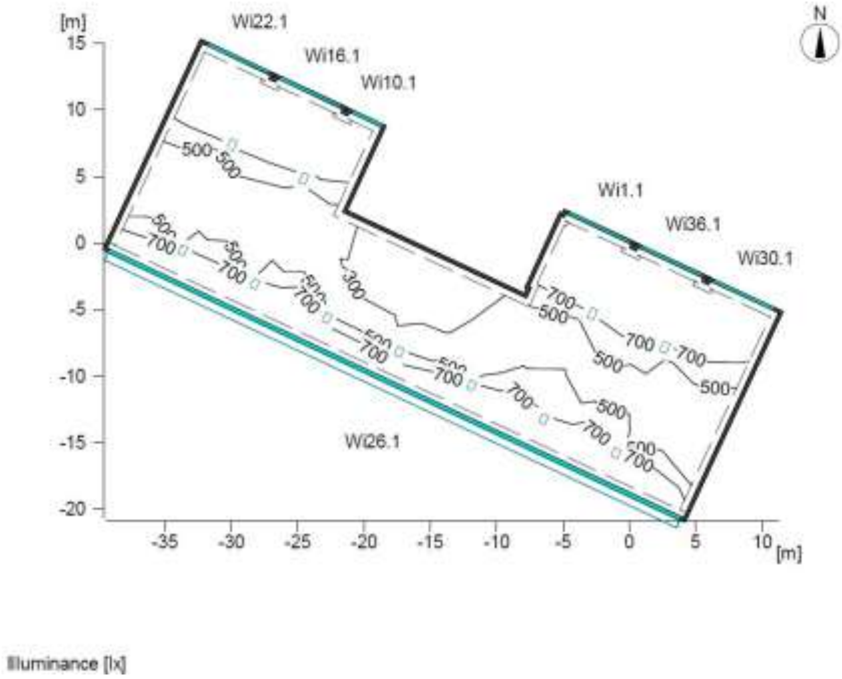


Figure B.32 : The GUI of daylight simulation of Block B ground 2 floor June 21^{st} - $9:^{00}$ – Clear sky model.

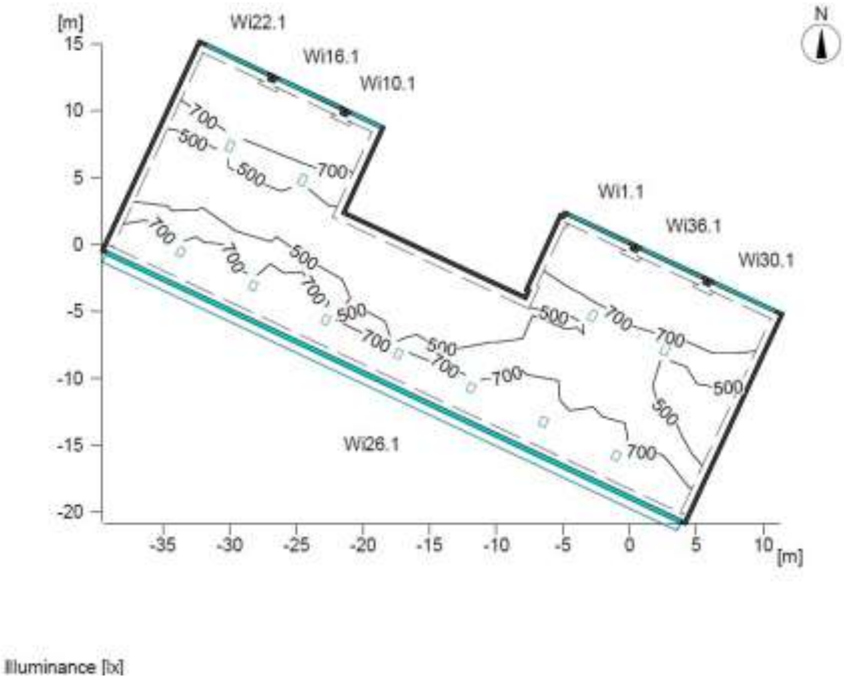


Figure B.33 : The GUI of daylight simulation of Block B ground 2 floor June 21^{st} - $12:^{00}$ – Clear sky model.

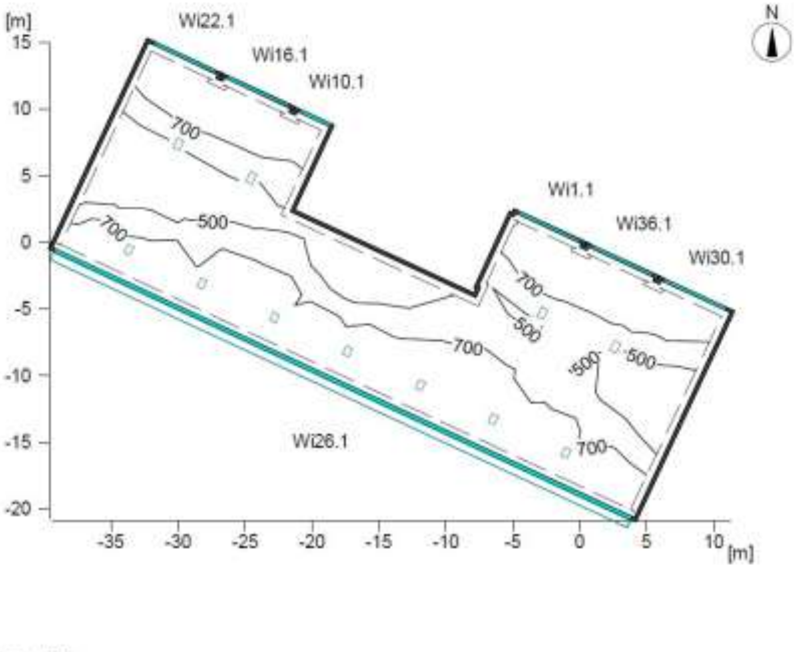


Figure B.34 : The GUI of daylight simulation of Block B ground 2 floor June 21^{st} - $15:^{00}$ – Clear sky model.

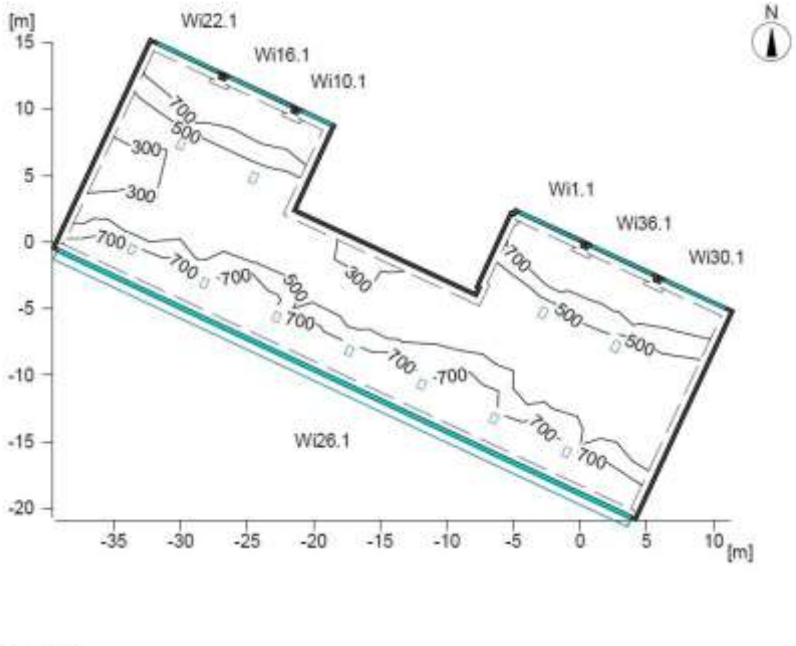


Figure B.35 : The GUI of daylight simulation of Block B ground 2 floor June 21^{st} - $17:^{00}$ – Clear sky model.

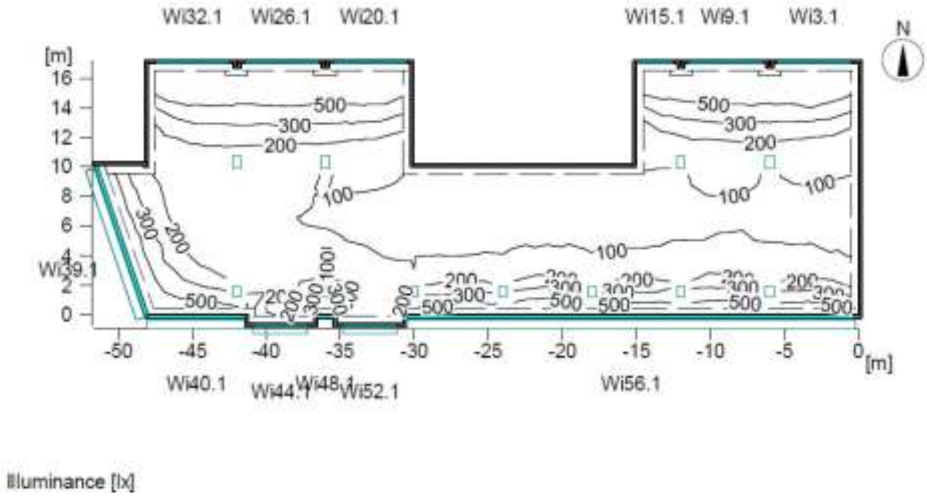


Figure B.36 : The GUI of daylight simulation of Block A Type floors December 21st - 9:00 – Overcast sky model.

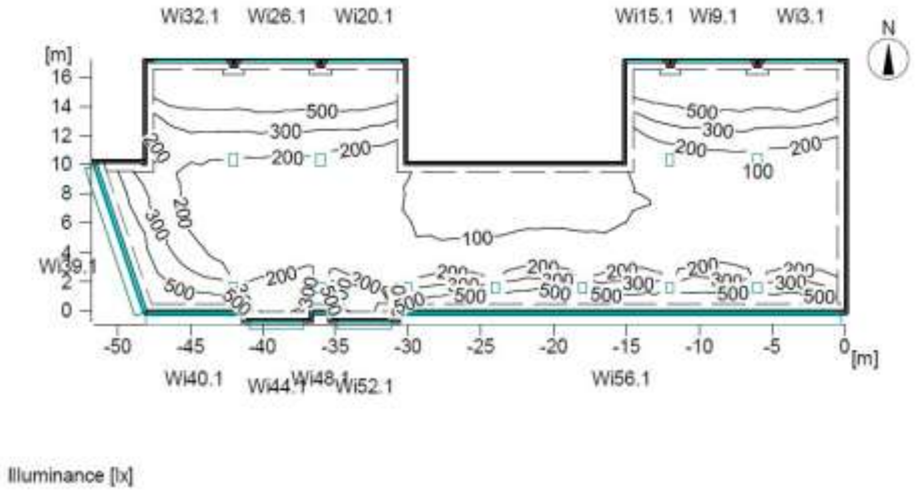


Figure B.37 : The GUI of daylight simulation of Block A Type floors December 21st - 12:00 – Overcast sky model.

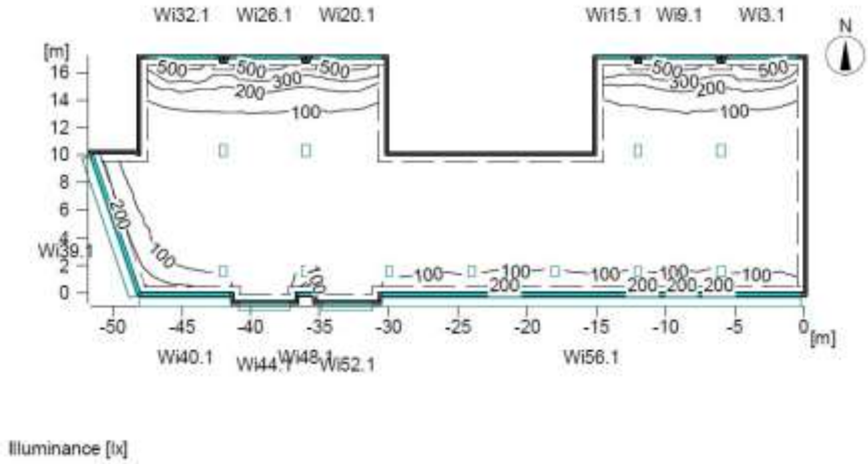
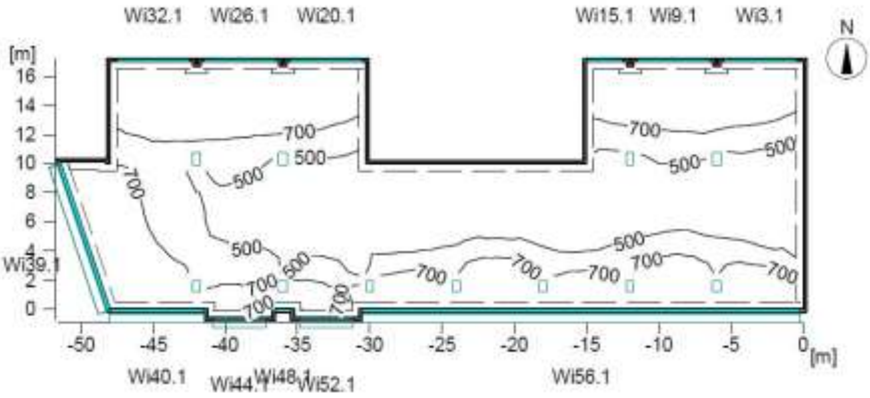
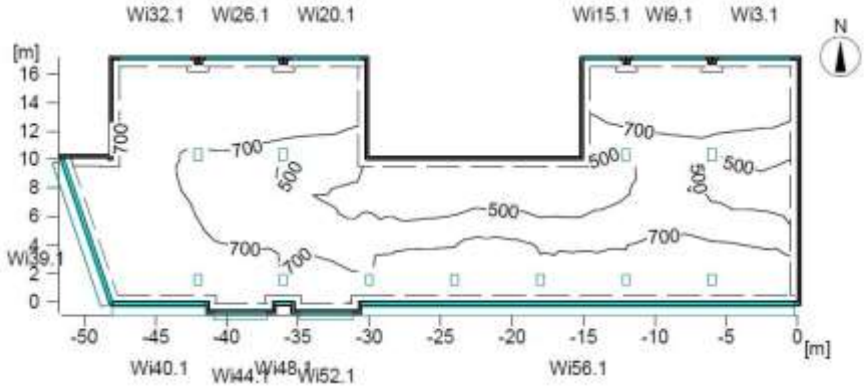


Figure B.38 : The GUI of daylight simulation of Block A Type floors December 21st - 15:00 – Overcast sky model.



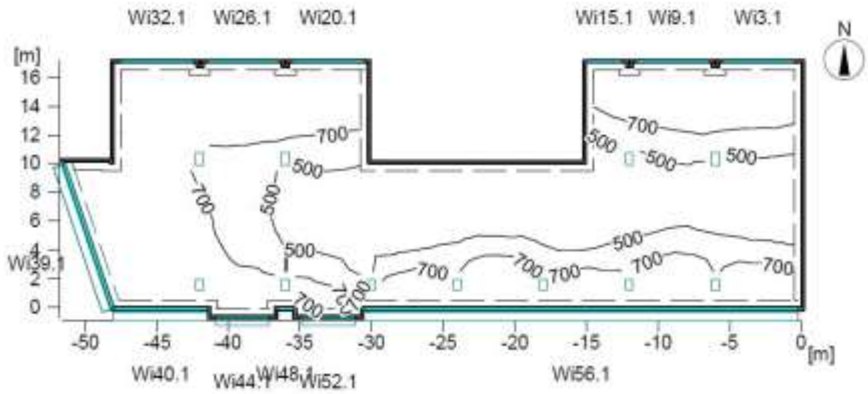
Illuminance [lx]

Figure B.39 : The GUI of daylight simulation of Block A Type floors June 21^{st} – $9{:}^{00}$ – Clear sky model.



Illuminance [lx]

Figure B.40 : The GUI of daylight simulation of Block A Type floors June 21^{st} – $12{:}^{00}$ – Clear sky model.



Illuminance [lx]

Figure B.41 : The GUI of daylight simulation of Block A Type floors June 21^{st} – $15{:}^{00}$ – Clear sky model.

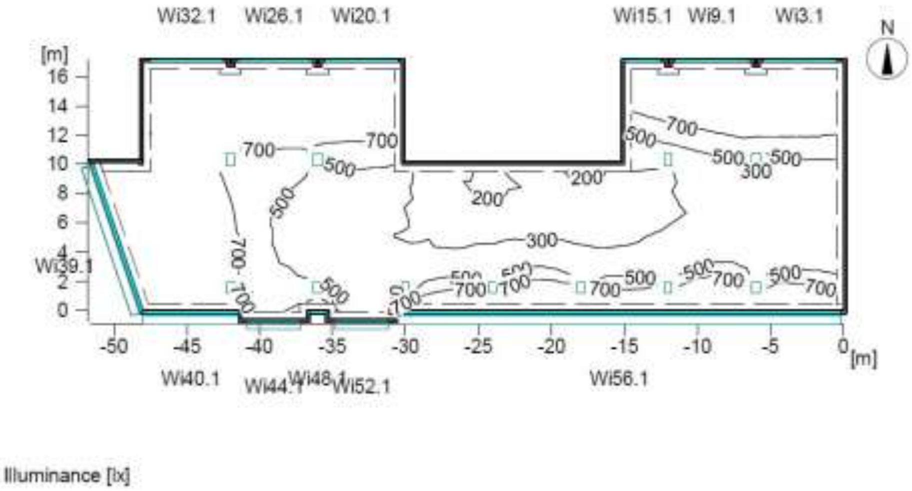


Figure B.42 : The GUI of daylight simulation of Block A Type floors June 21^{st} – $17:^{00}$ – Clear sky model.

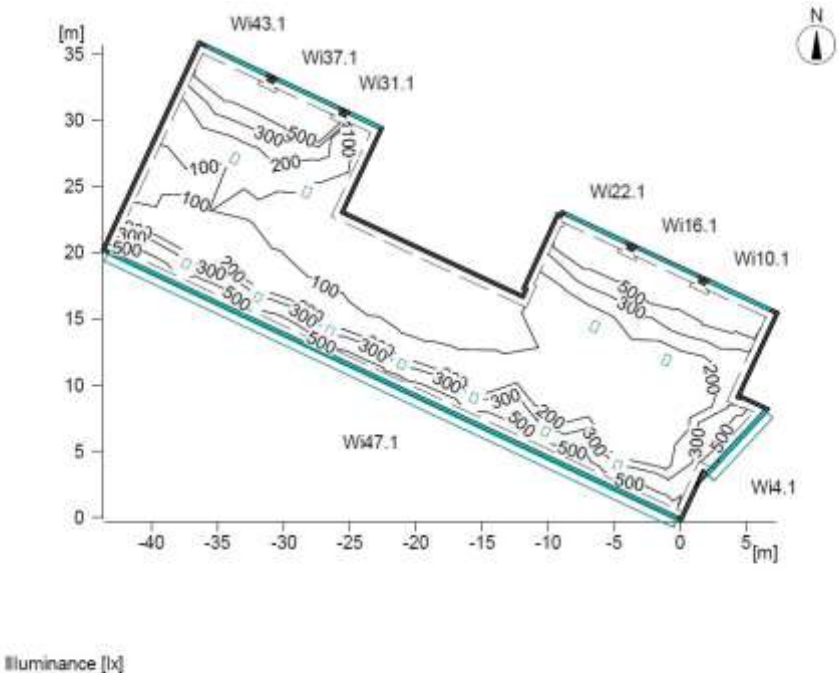


Figure B.43 : The GUI of daylight simulation of Block B Type floors December 21^{st} – $9:^{00}$ – Oovercast sky model.

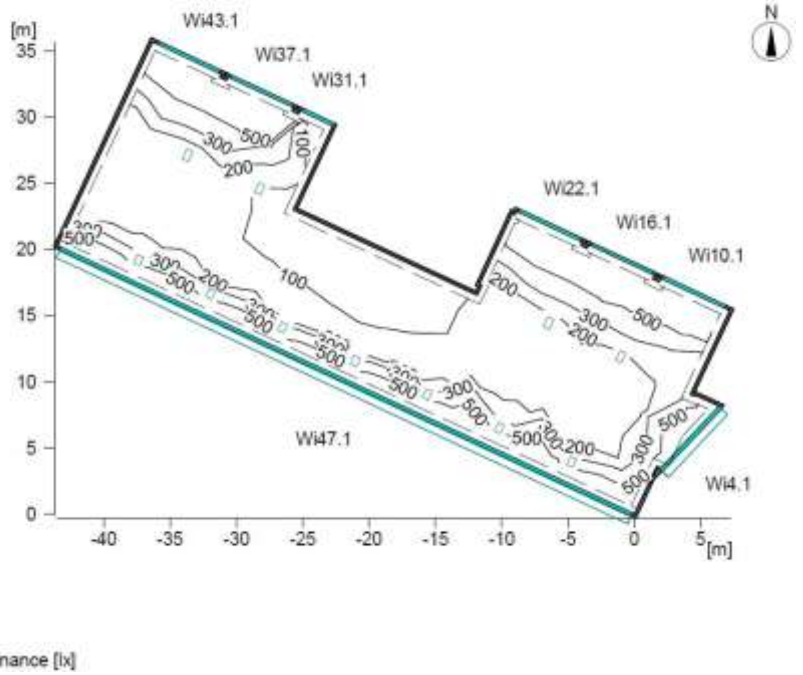


Figure B.44 : The GUI of daylight simulation of Block B Type floors December 21st – 12:00 – Oovercast sky model.

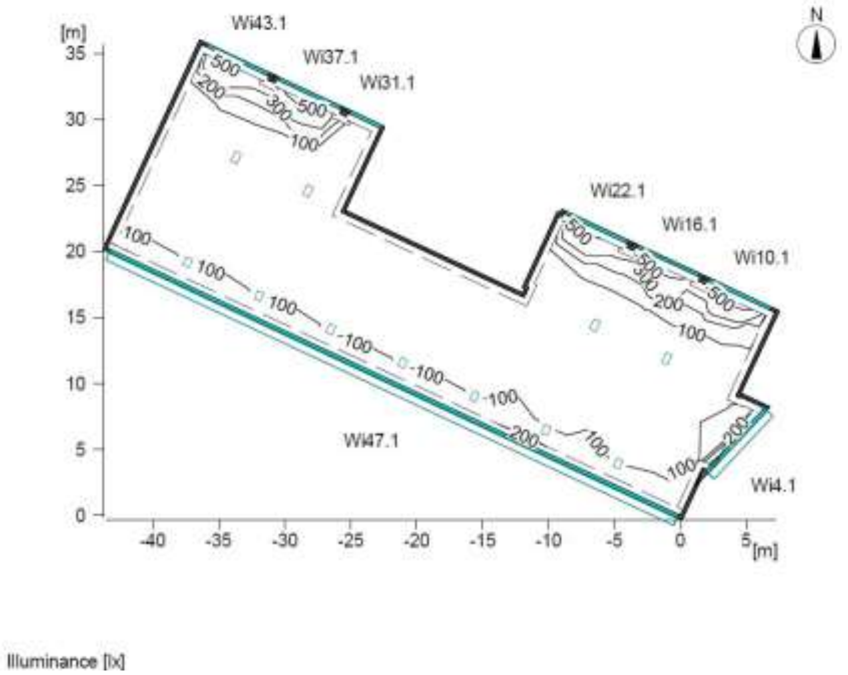


Figure B.45 : The GUI of daylight simulation of Block B Type floors December 21st – 15:00 – Overcast sky model.

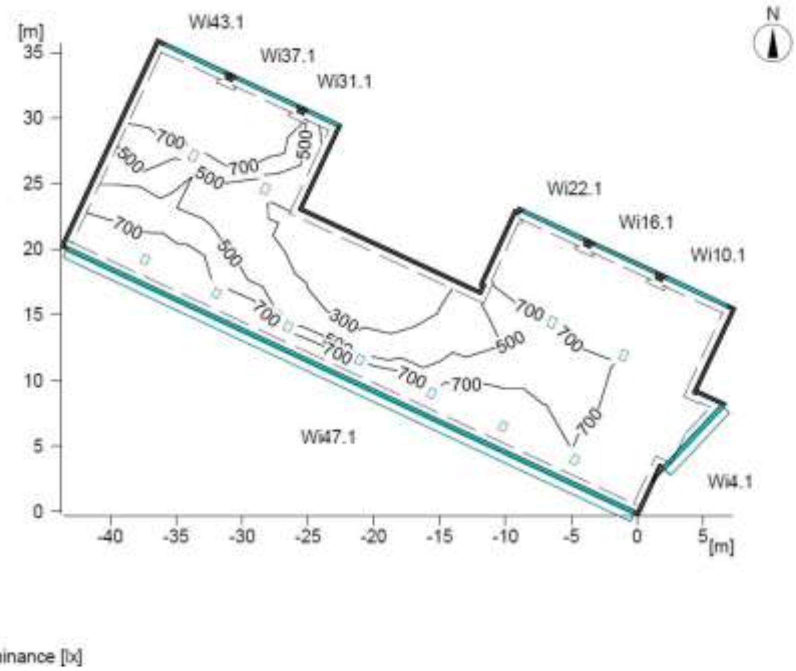


Figure B.46 : The GUI of daylight simulation of Block B Type floors June 21st – 9:^{00} – Clear sky model.

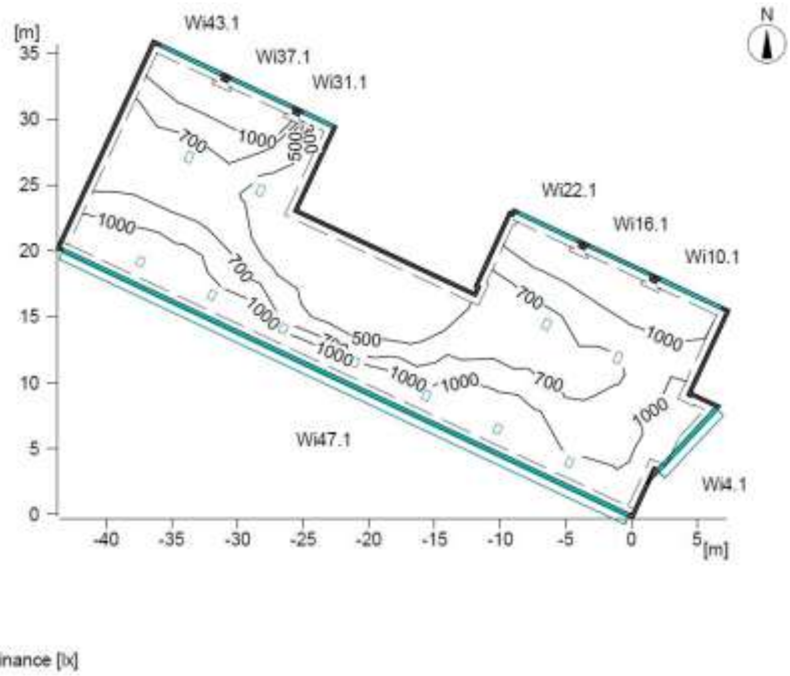


Figure B.47 : The GUI of daylight simulation of Block B Type floors June 21st – 12:^{00} – Clear sky model.

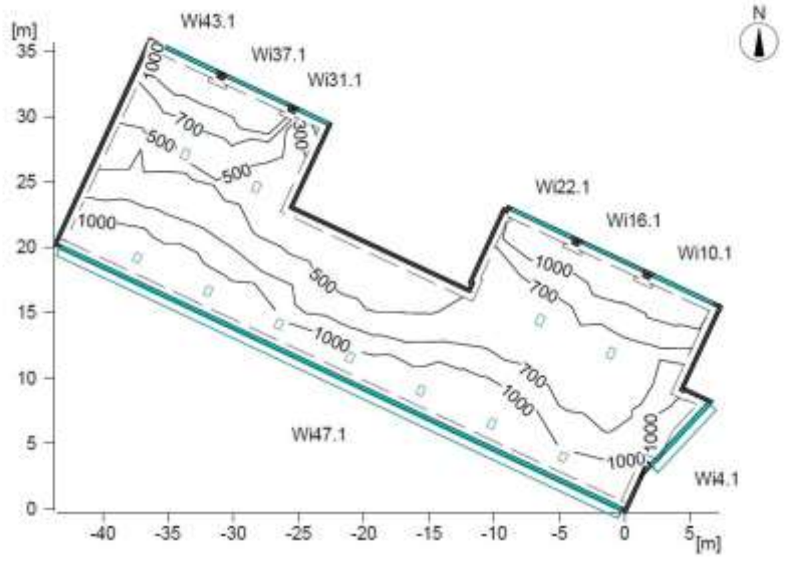


Figure B.48 : The GUI of daylight simulation of Block B Type floors June 21^{st} – $15:^{00}$ – Clear sky model.

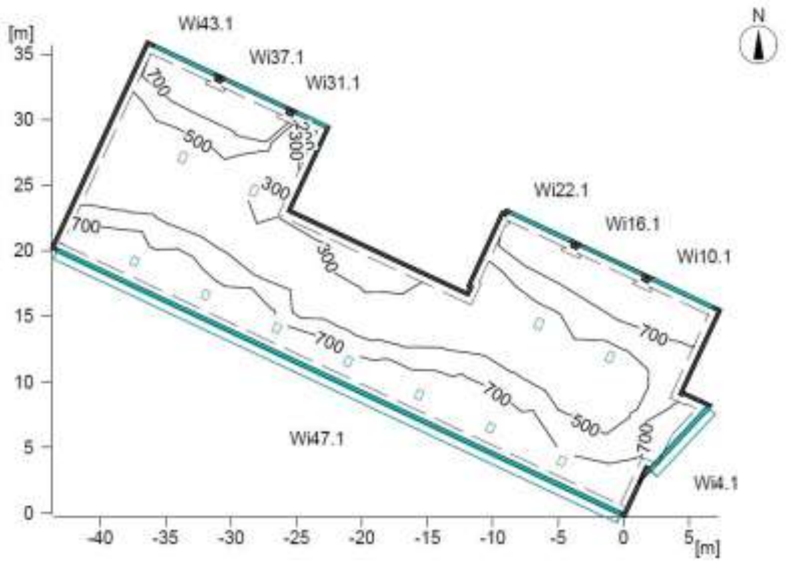


Figure B.49 : The GUI of daylight simulation of Block B Type floors June 21^{st} – $17:^{00}$ – Clear sky model.

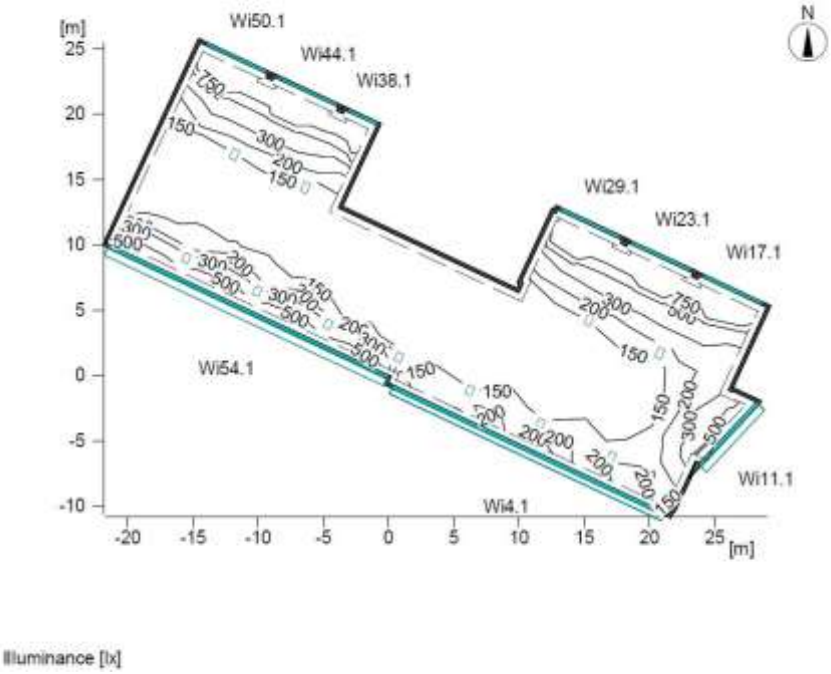


Figure B.50 : The GUI of daylight simulation of Block B second floor December 21st – 9:00 – Overcast sky model.

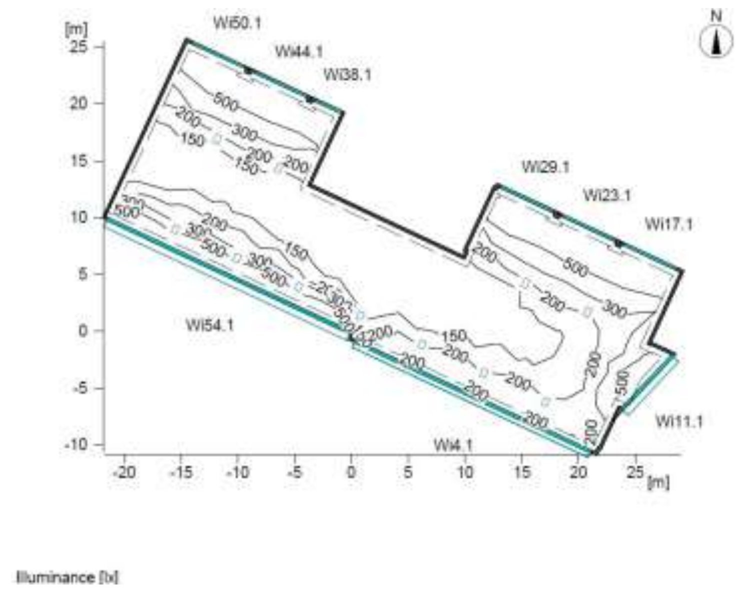


Figure B.51 : The GUI of daylight simulation of Block B second floor December 21st – 12:00 – Overcast sky model.

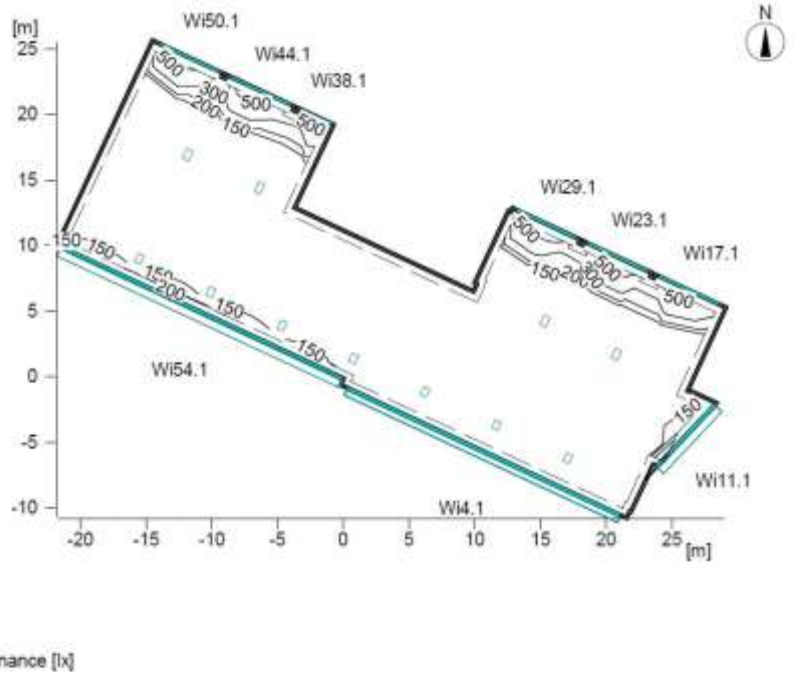


Figure B.52 : The GUI of daylight simulation of Block B second floor December 21^{st} – $15{:}^{00}$ – Overcast sky model.

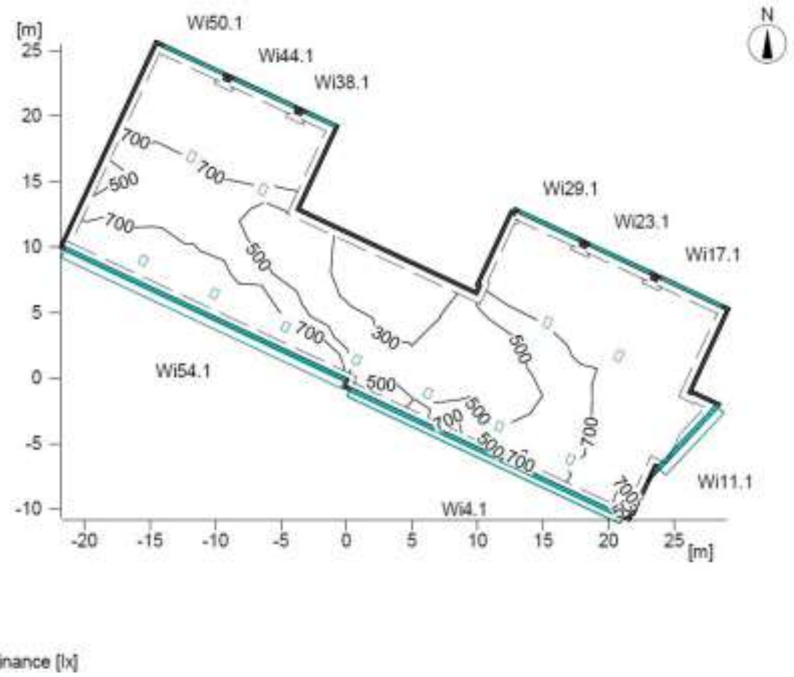


Figure B.53 : The GUI of daylight simulation of Block B second floor June 21^{st} – $9{:}^{00}$ – Clear sky model.

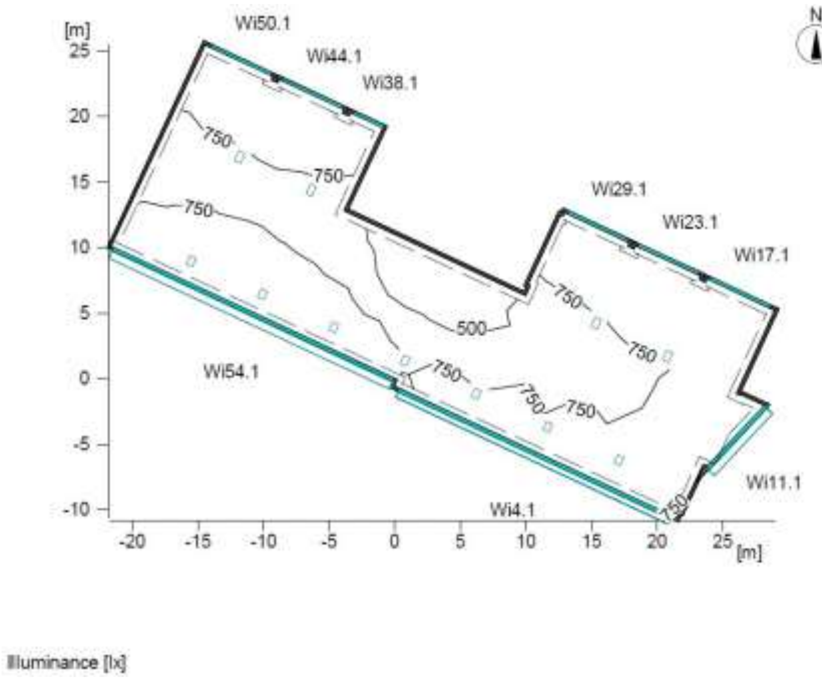


Figure B.54 : The GUI of daylight simulation of Block B second floor June 21^{st} – $12:^{00}$ – Clear sky model.

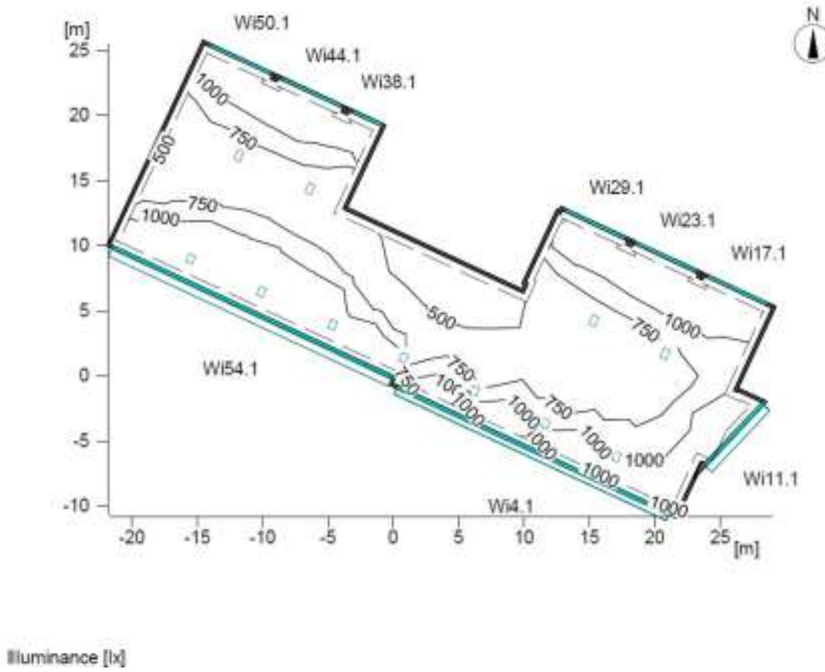


Figure B.55 : The GUI of daylight simulation of Block B second floor June 21^{st} – $15:^{00}$ – Clear sky model.

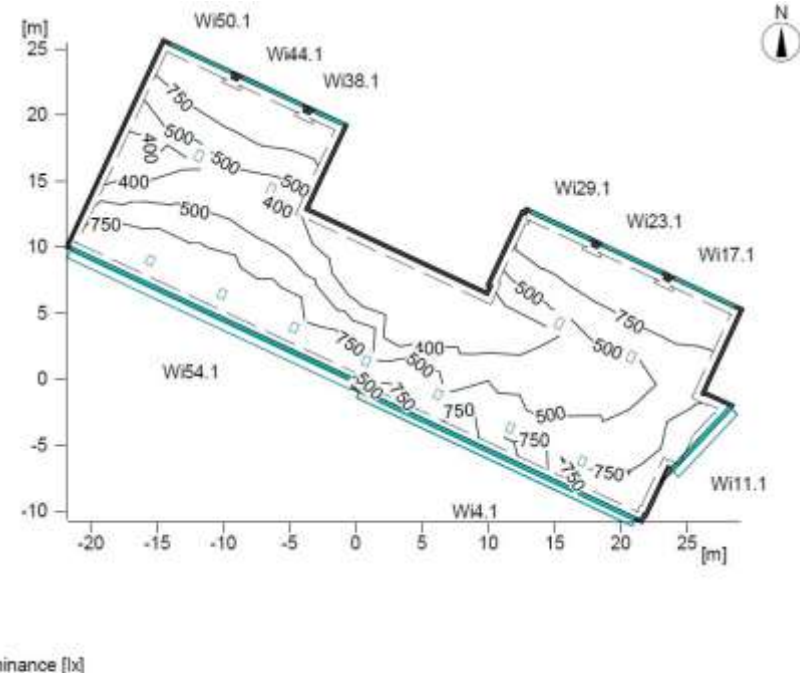


Figure B.56 : The GUI of daylight simulation of Block B second floor June 21^{st} – $17:^{00}$ – Clear sky model.

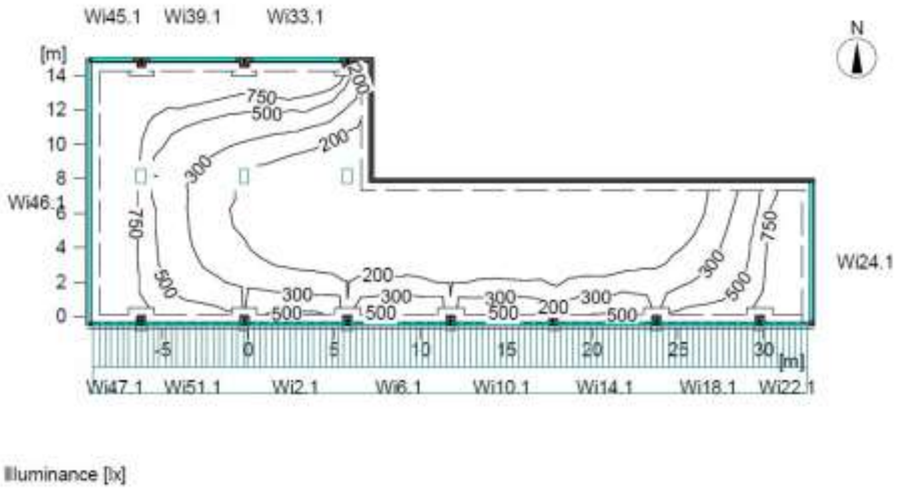
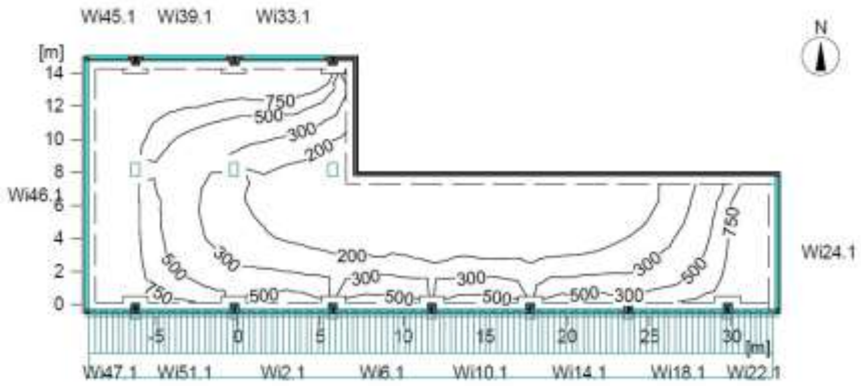
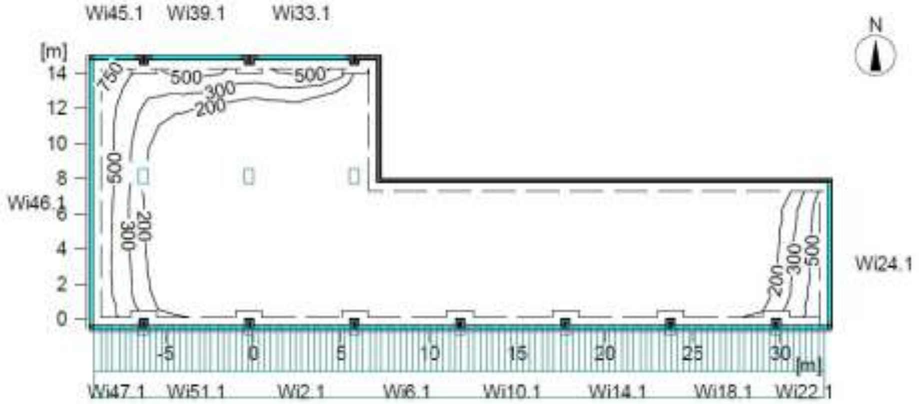


Figure B.57 : The GUI of daylight simulation of Block A Terrace floor December 21^{st} – $9:^{00}$ – Overcast sky model.



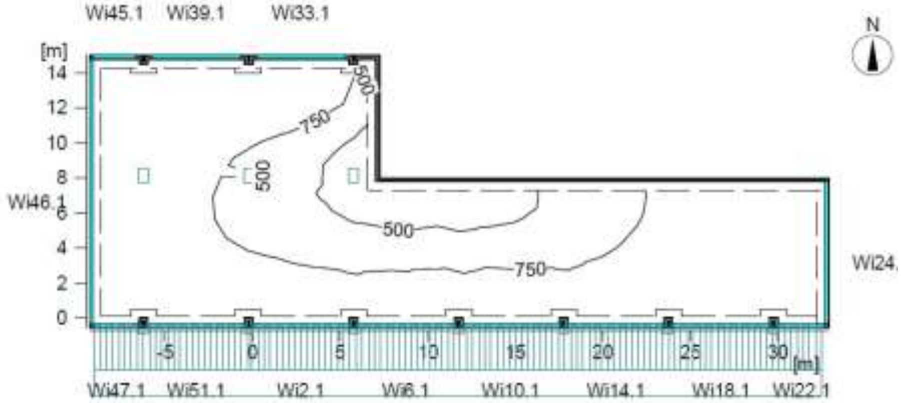
Illuminance [lx]

Figure B.58 : The GUI of daylight simulation of Block A Terrace floor December 21st – 12:00 – Overcast sky model.



Illuminance [lx]

Figure B.59 : The GUI of daylight simulation of Block A Terrace floor December 21st – 15:00 – Overcast sky model.



Illuminance [lx]

Figure B.60 : The GUI of daylight simulation of Block A Terrace floor June 21st – 9:00 – Clear sky model.

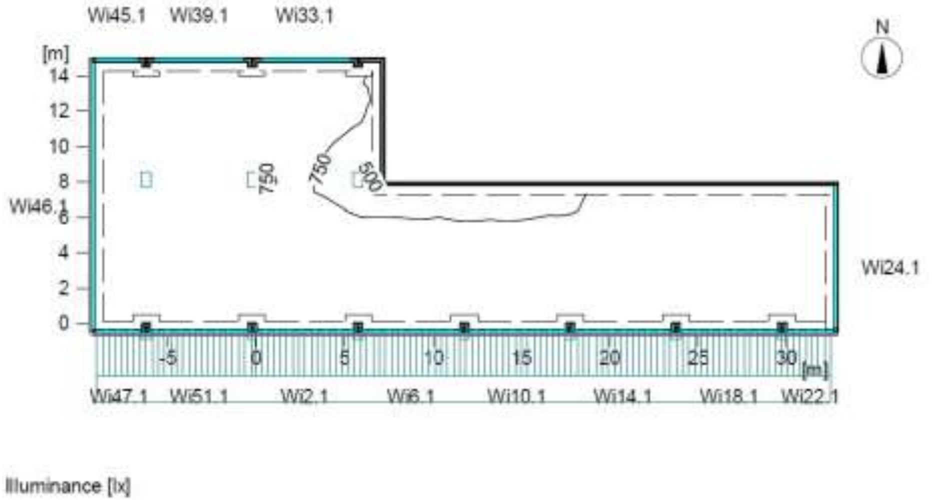


Figure B.61 : The GUI of daylight simulation of Block A Terrace floor June 21^{st} – $12{:}^{00}$ – Clear sky model.

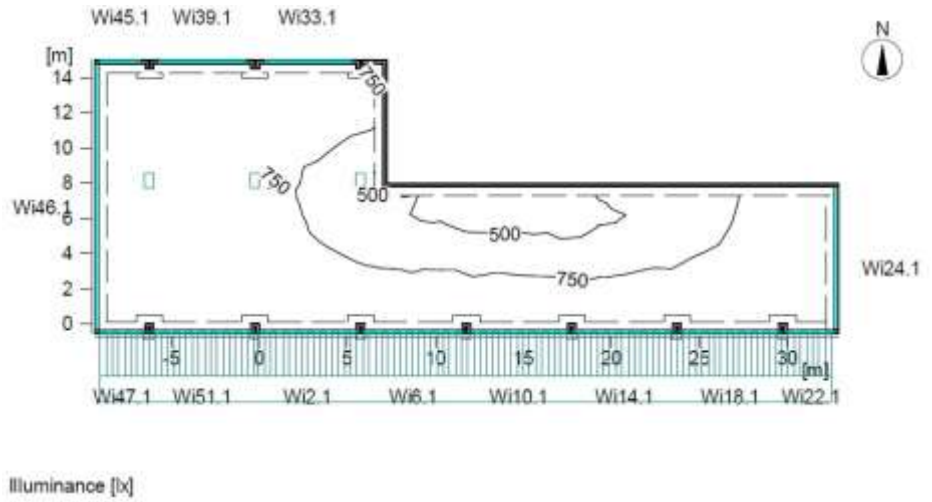


Figure B.62 : The GUI of daylight simulation of Block A Terrace floor June 21^{st} – $15{:}^{00}$ – Clear sky model.

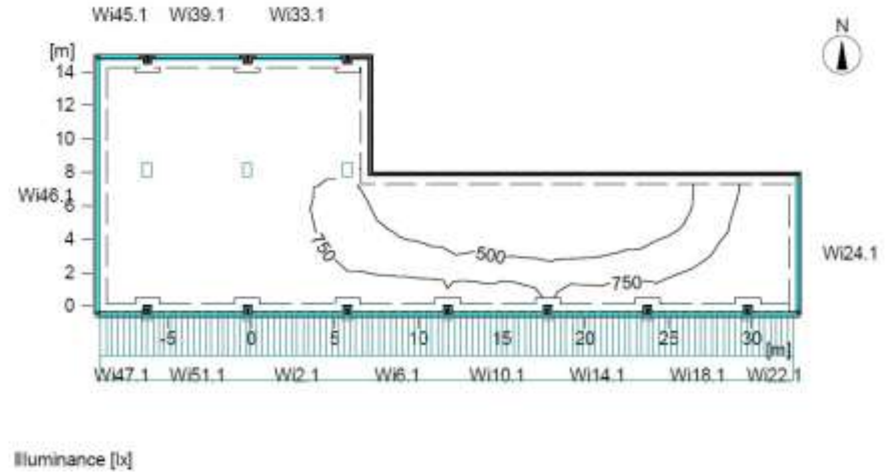


Figure B.63 : The GUI of daylight simulation of Block A Terrace floor June 21^{st} – $17{:}^{00}$ – Clear sky model.

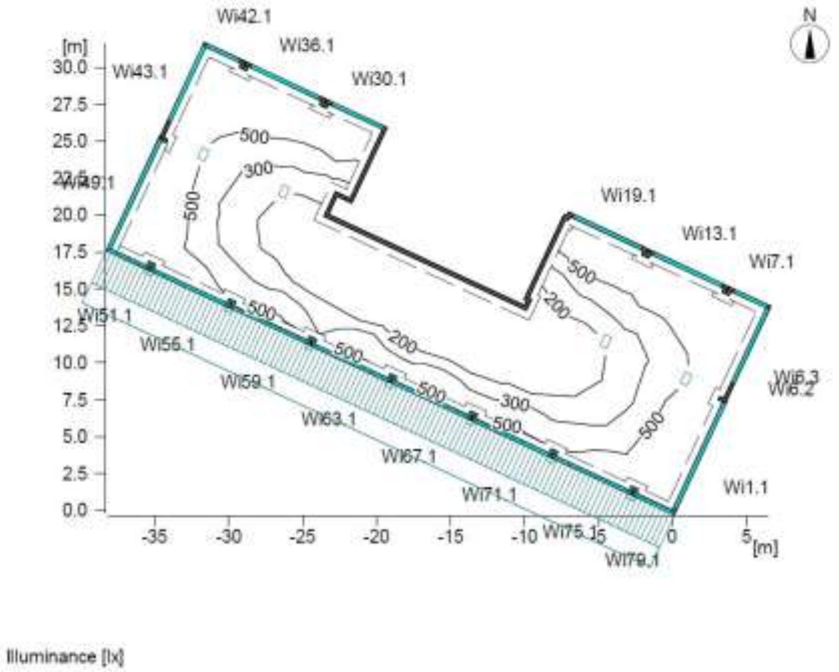


Figure B.64 : The GUI of daylight simulation of Block B Terrace floor December 21st – 9:00 – Overcast sky model.

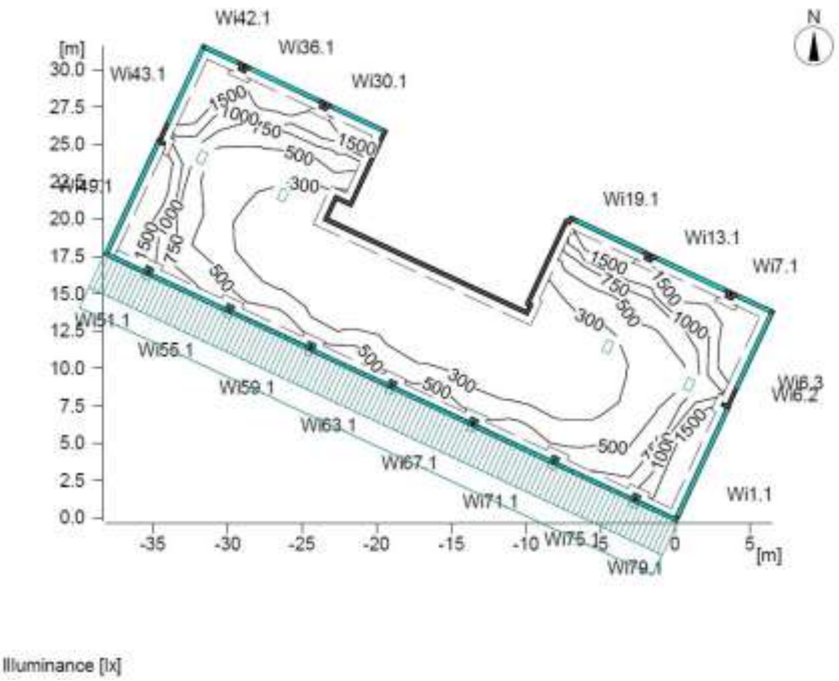


Figure B.65 : The GUI of daylight simulation of Block B Terrace floor December 21st – 12:00 – Overcast sky model.

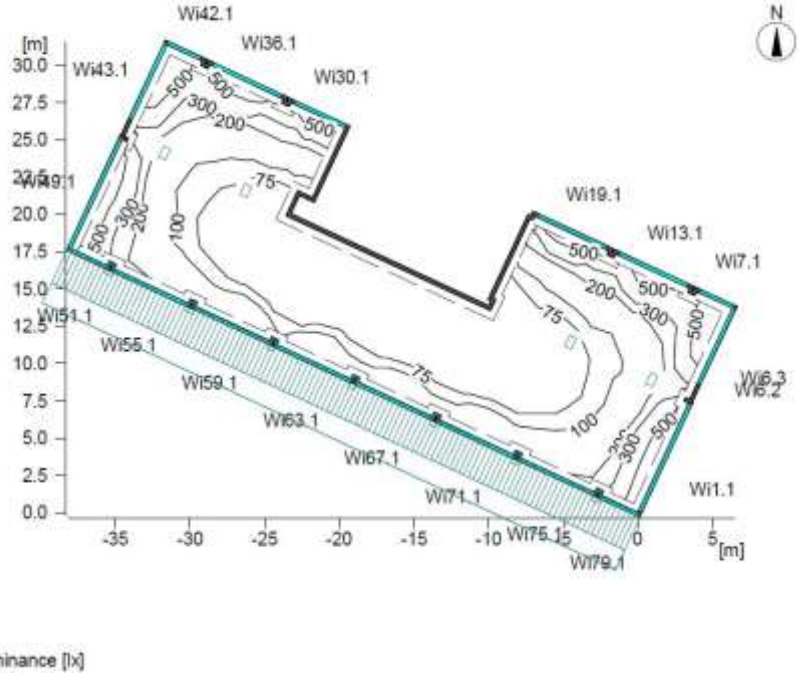


Figure B.66 : The GUI of daylight simulation of Block B Terrace floor
December 21^{st} – $15:^{00}$ – Overcast sky model.

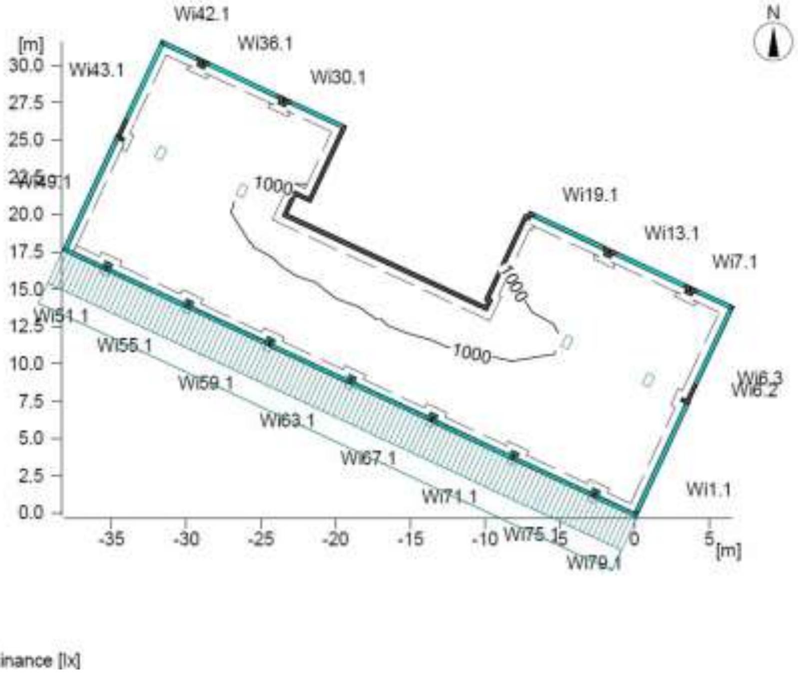


Figure B.67 : The GUI of daylight simulation of Block B Terrace floor
June 21^{st} – $9:^{00}$ – Clear sky model.

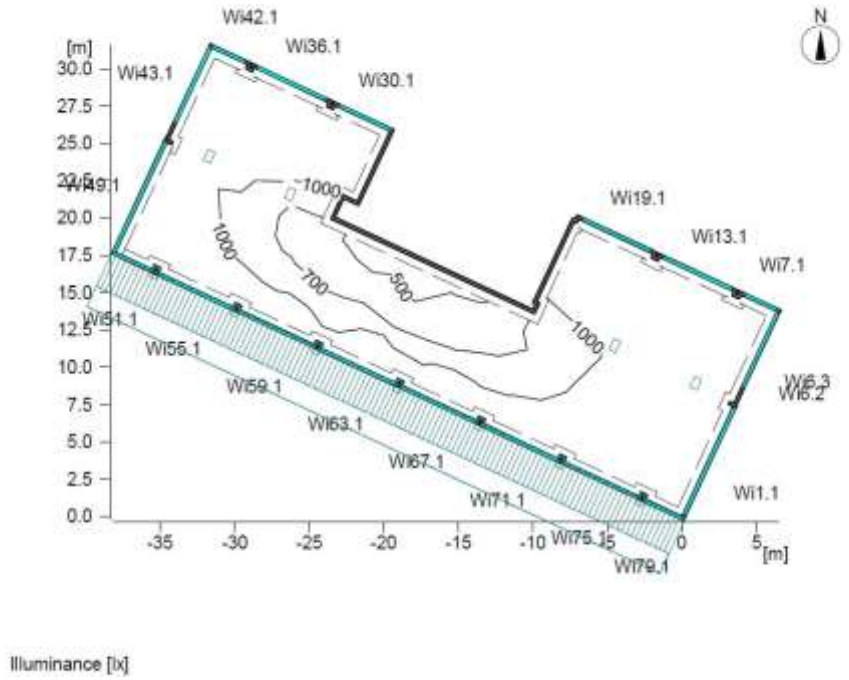


Figure B.68 : The GUI of daylight simulation of Block B Terrace floor June 21^{st} – $12{:}^{00}$ – Clear sky model.

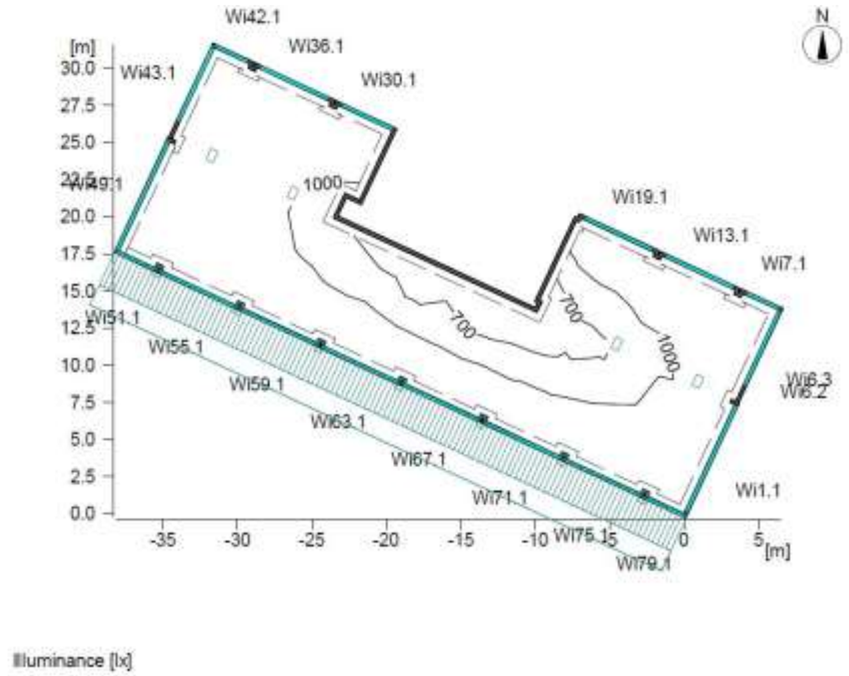


Figure B.69 : The GUI of daylight simulation of Block B Terrace floor June 21^{st} – $15{:}^{00}$ – Clear sky model.

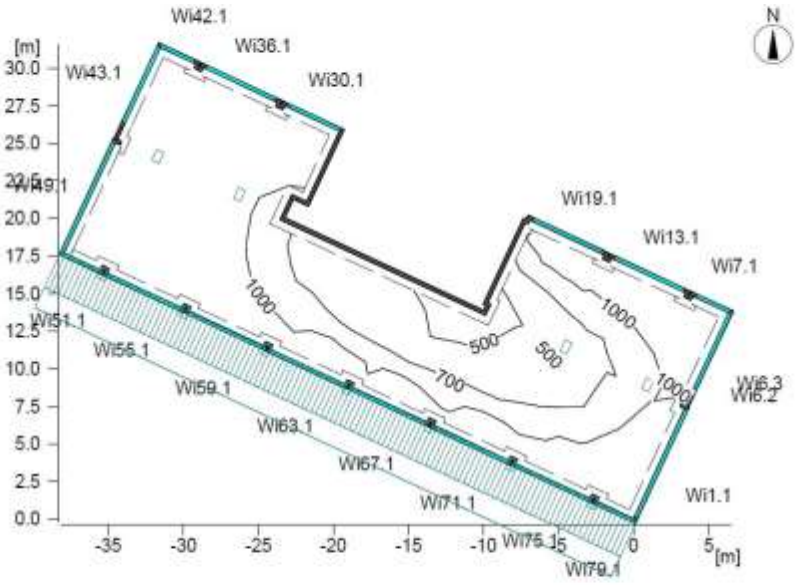


Figure B.70 : The GUI of daylight simulation of Block B Terrace floor June 21^{st} – $17:^{00}$ – Clear sky model.

APPENDIX C

Appendix C expresses the control system of artificial lighting design in each unit of floors is executed by (these) lattices. Due to the availability of natural light of each unit, this system in accordance with summer and winter saving time and their specified hours- as described earlier- can be applied to the artificial lighting of units.

These meshes help to determine zones with the enough amount of natural light, about 500lx. Artificial lighting system in these areas should be controlled by switching off or dims of the luminaries.

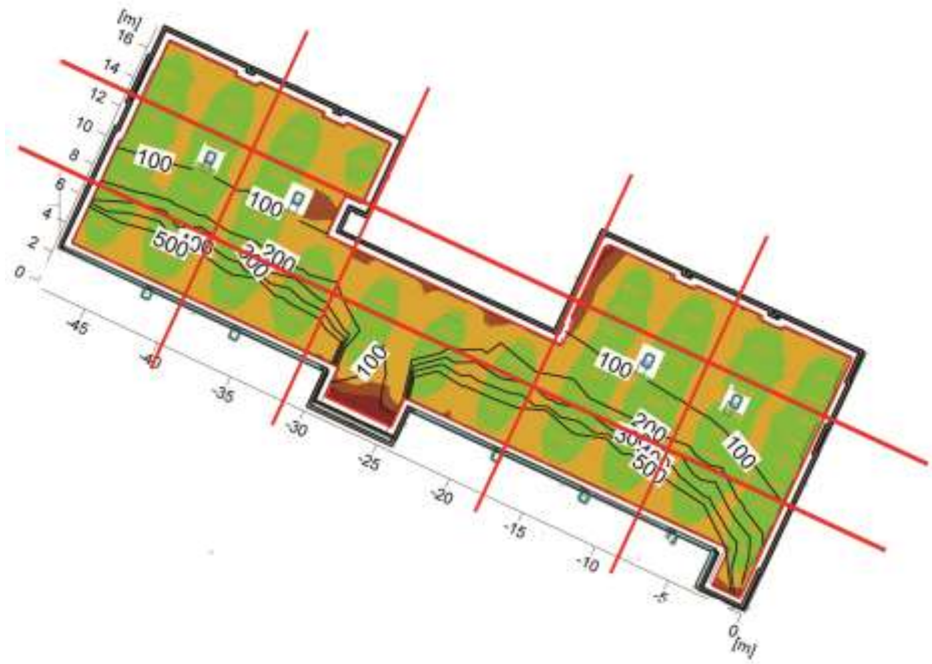


Figure C.1 : Meshes of ground floor, Block B-December 21st-9:00-Overcast sky model.

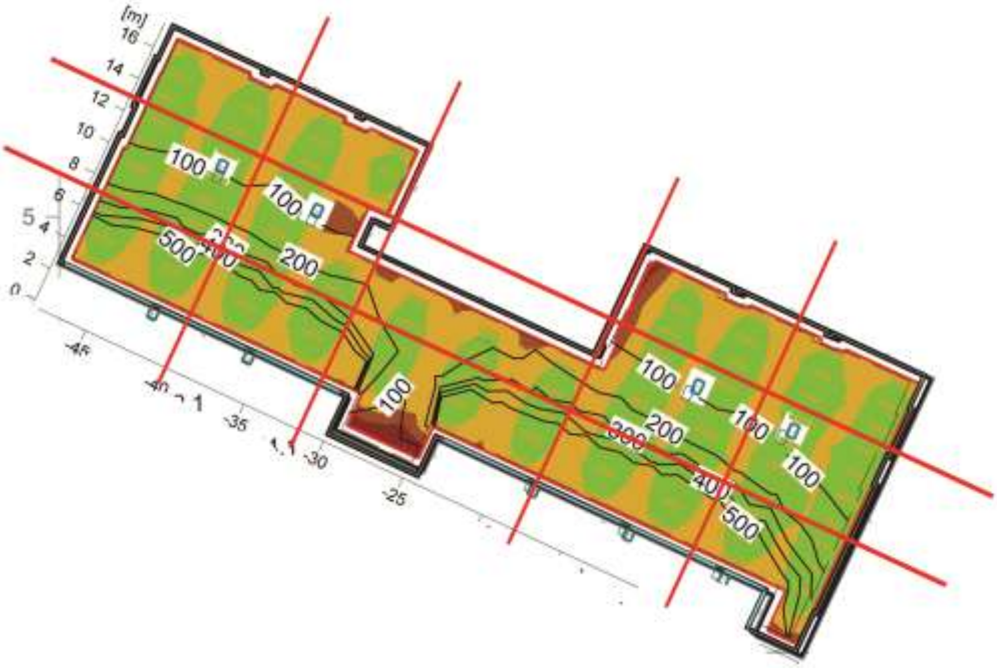


Figure C.2 : Meshes of ground floor, Block B-December 21st-12:00-Overcast sky model.

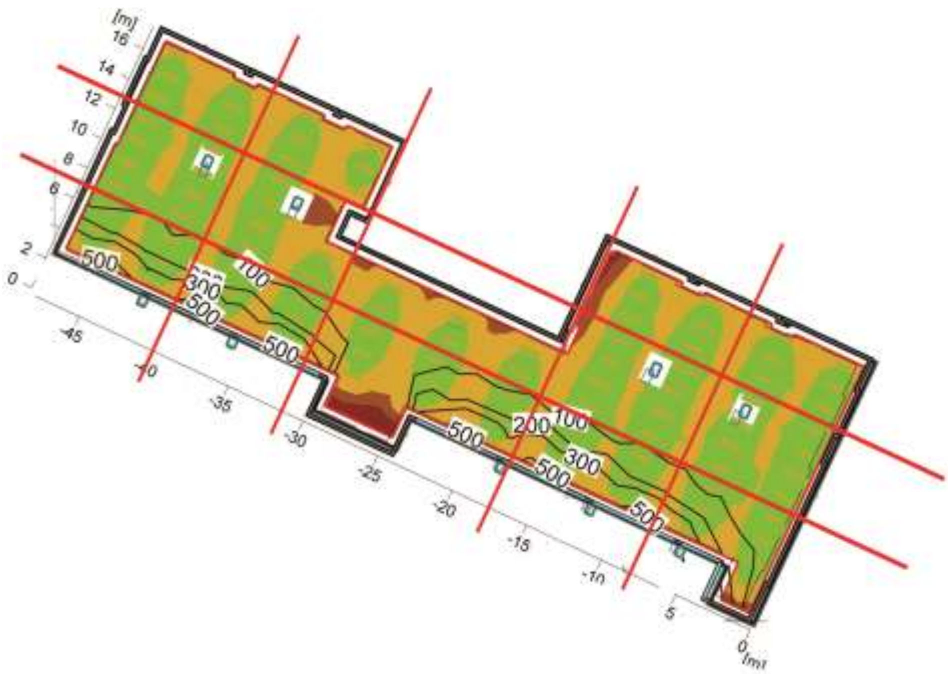


Figure C.3 : Meshes of ground floor, Block B-December 21st-15:00-Overcast sky model.

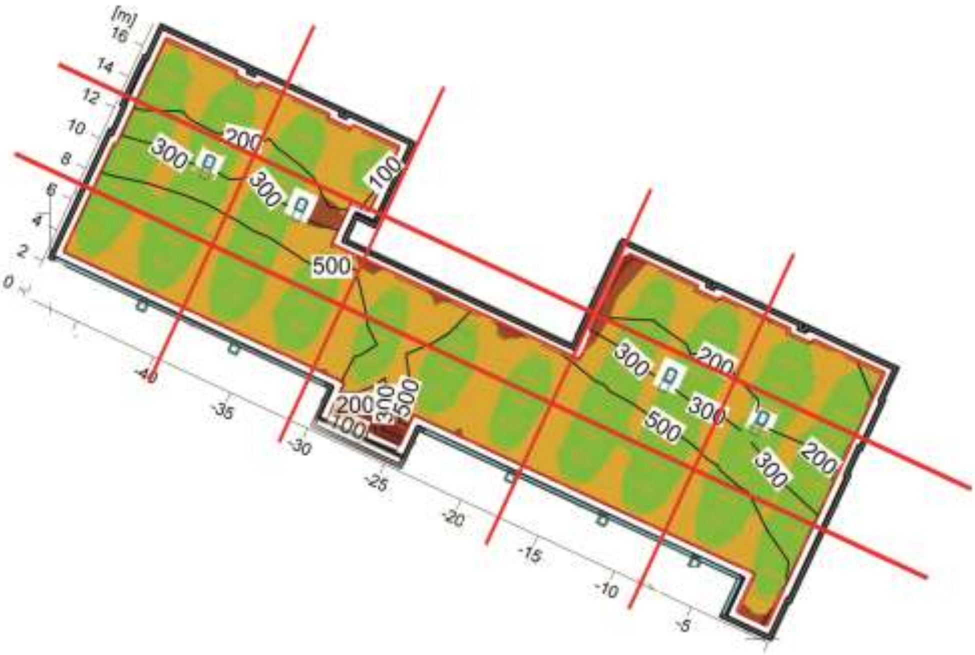


Figure C.4 : Meshes of ground floor, Block B- June 21st-9:00-Clear sky model.

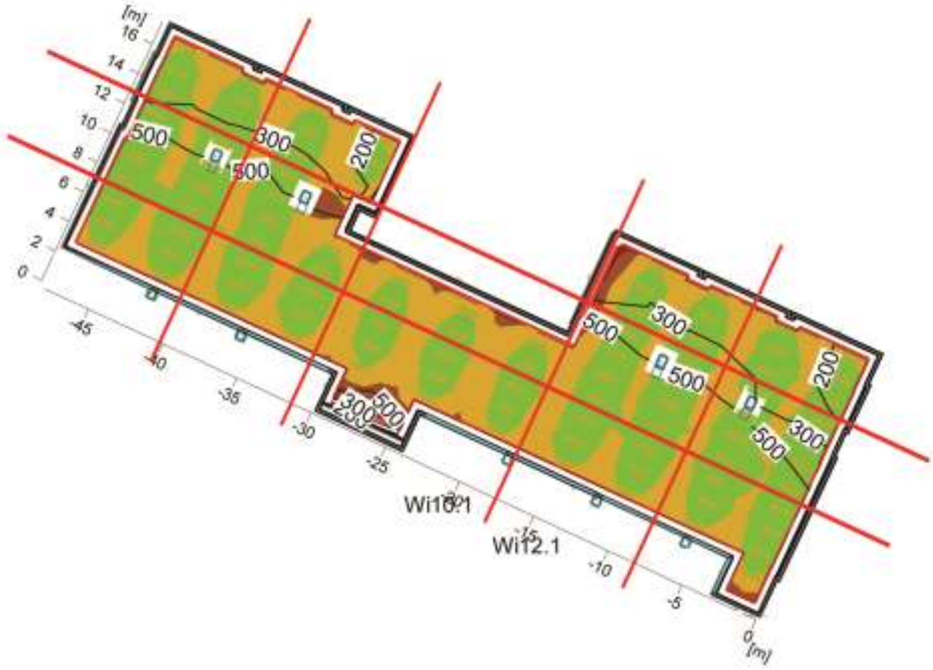


Figure C.5 : Meshes of ground floor, Block B-June 21st-12:00-Clear sky model.

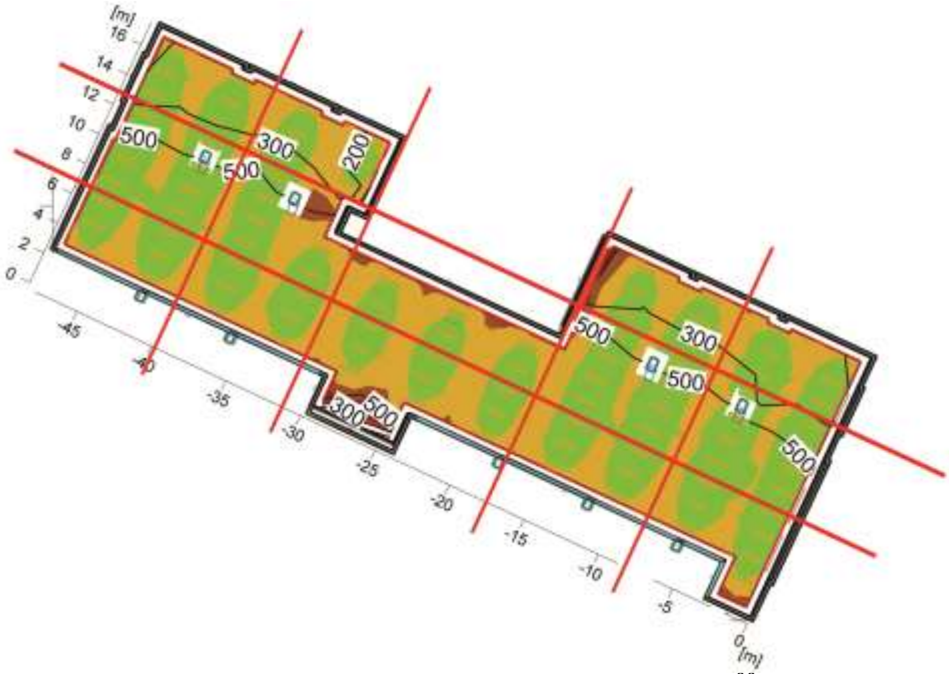


Figure C.6 : Meshes of ground floor, Block B-June 21st-15:00-Clear sky model.

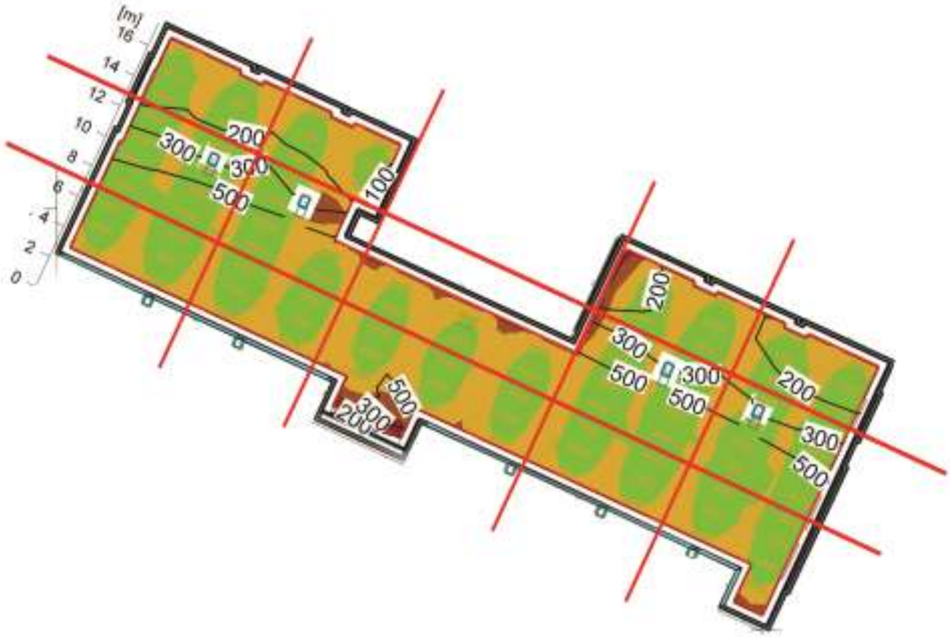


Figure C.7 : Meshes of ground floor, Block B- June 21st-17:00-Clear sky model.

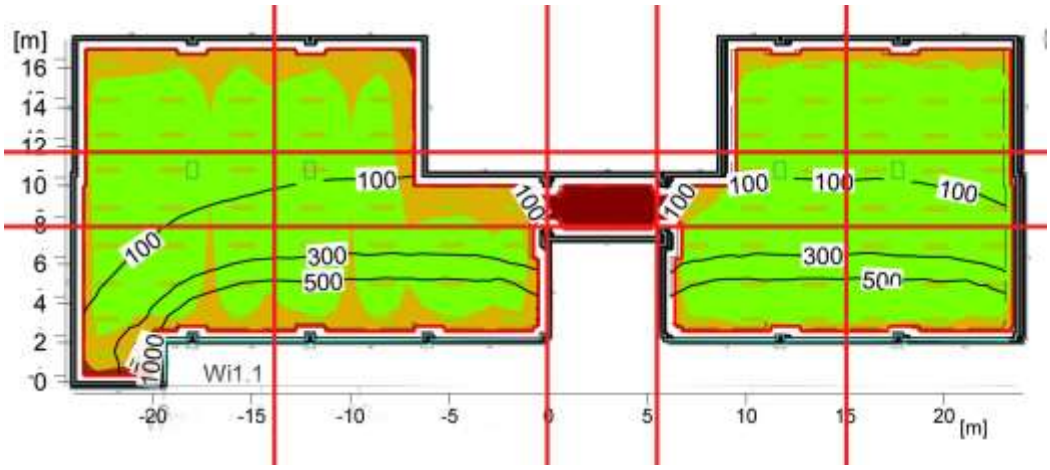


Figure C.8 : Meshes of mezzenine floor, Block A-December 21st-9:00-Overcast sky model.

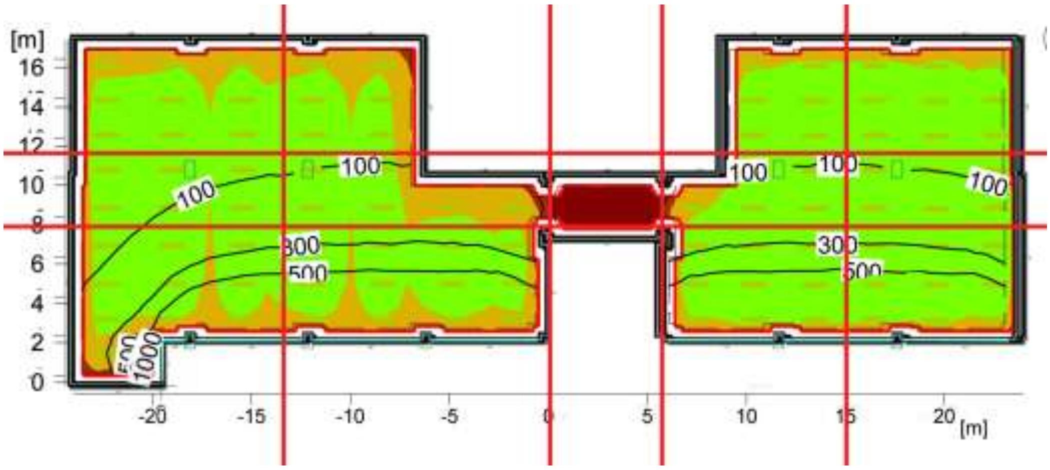


Figure C.9 : Meshes of mezzenine floor, Block A-December 21st-12:00-Overcast sky model.

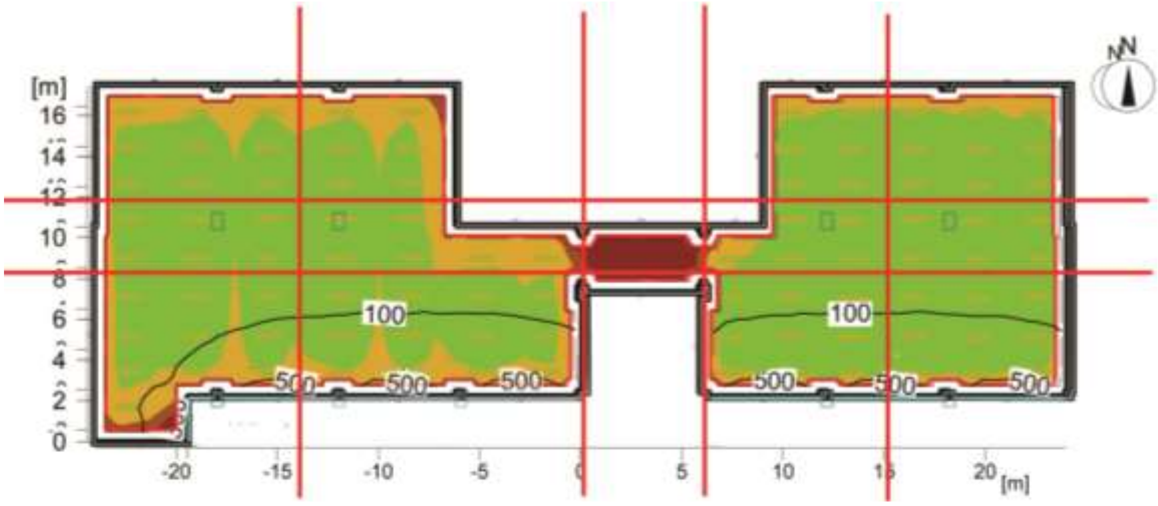


Figure C.10 : Meshes of mezzenine floor, Block A-December 21st-15:00-Overcast sky model.

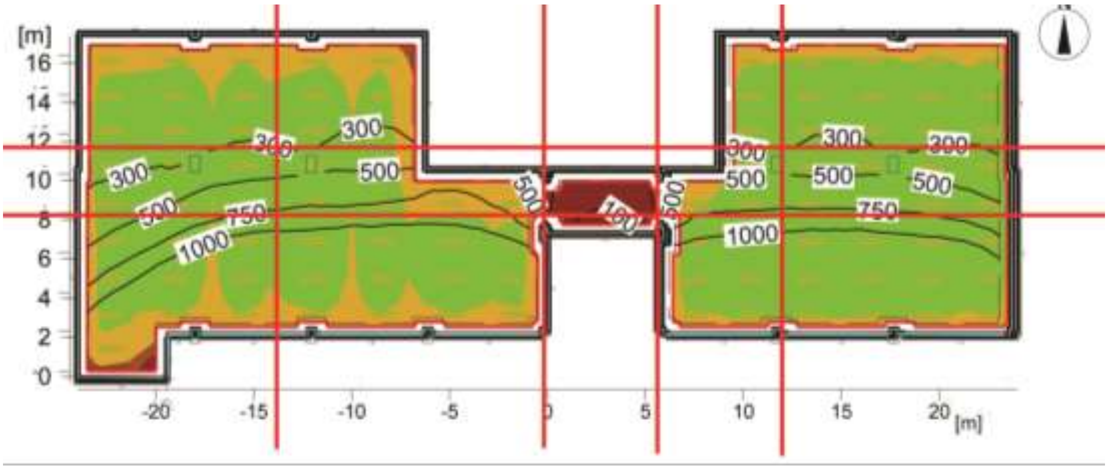


Figure C.11 : Meshes of mezzenine floor, Block A-June 21st-9:00-Clear sky model.

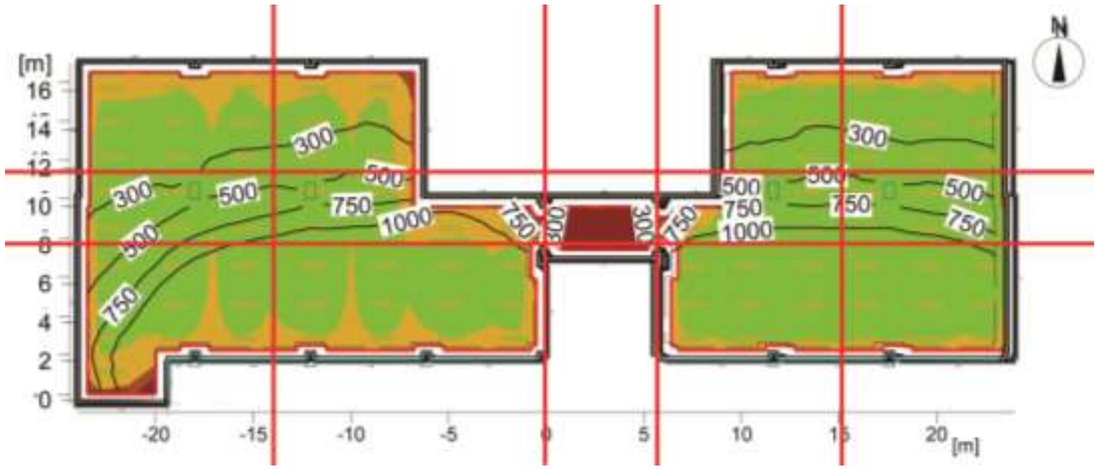


Figure C.12 : Meshes of mezzenine floor, Block A-June 21st-12:00-Clear sky model.

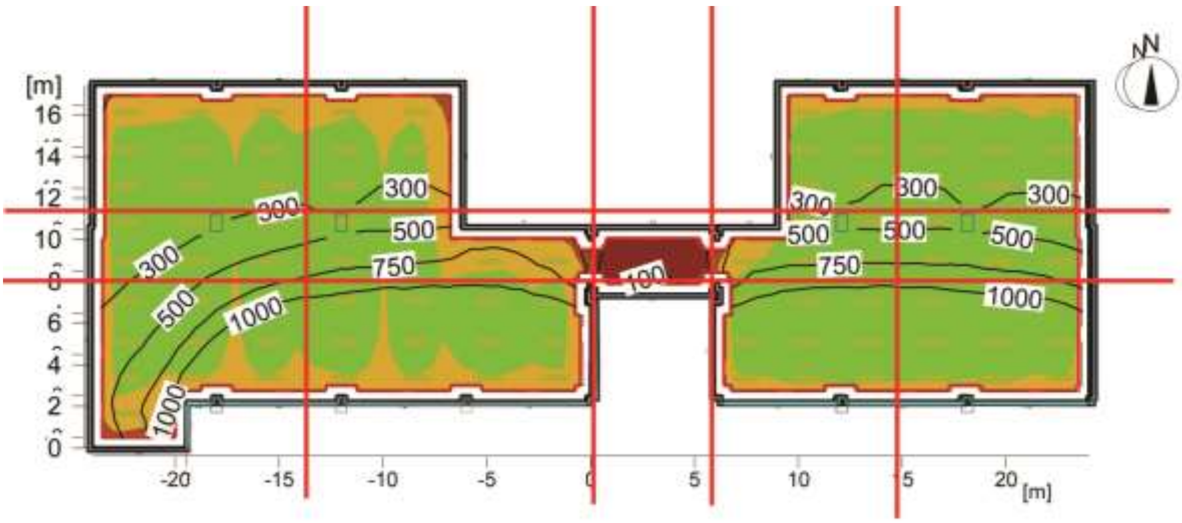


Figure C.13 : Meshes of mezzenine floor, Block A-June 21st-15:00-Clear sky model.

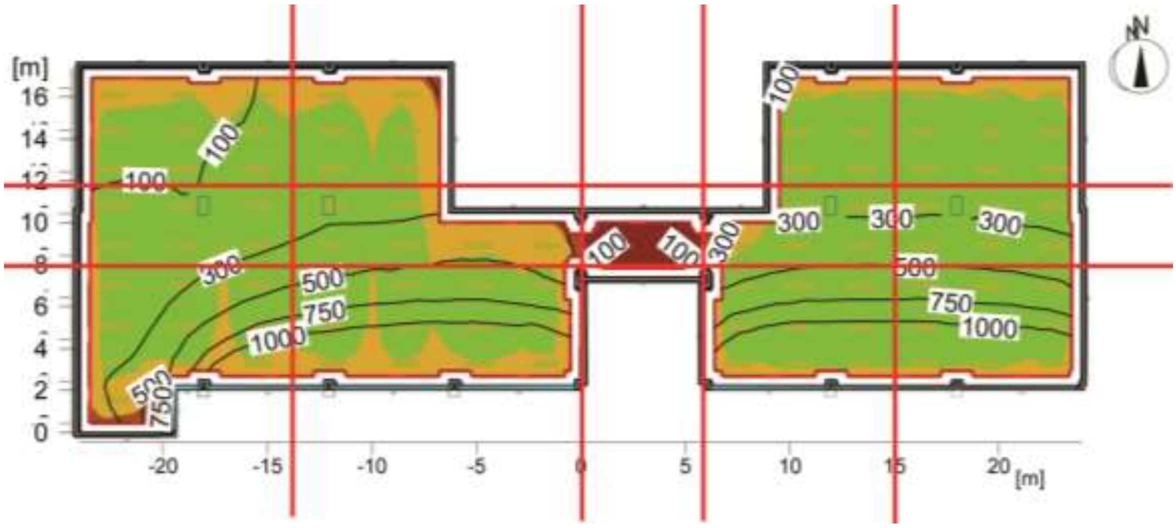


Figure C.14 : Meshes of mezzenine floor, Block A-June 21st-17:00-Clear sky model.

Figure C.15 : Meshes of mezzenine floor, Block B-December 21st-9:00-Overcast sky model.

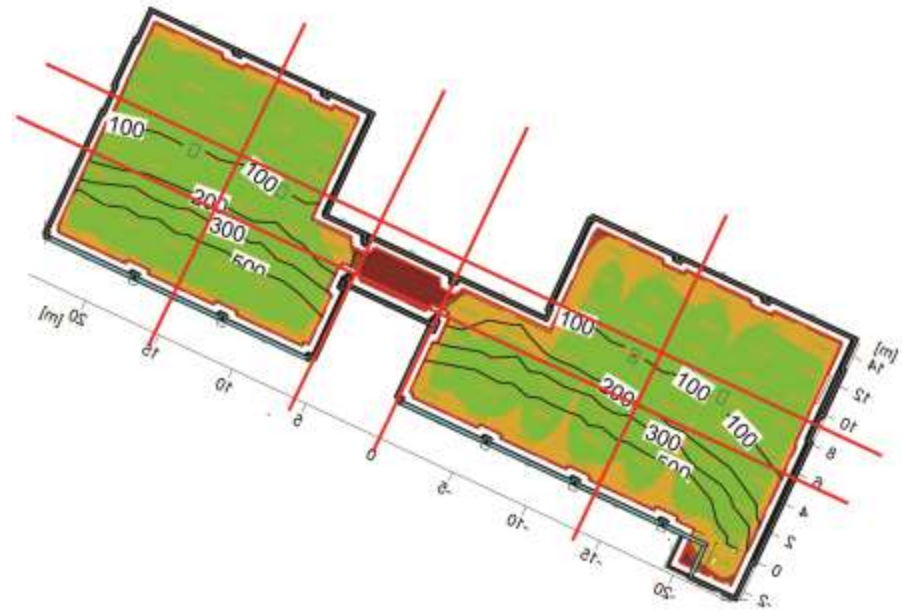


Figure C.16 : Meshes of mezzenine floor, Block B-December 21st-12:00-Overcast sky model.

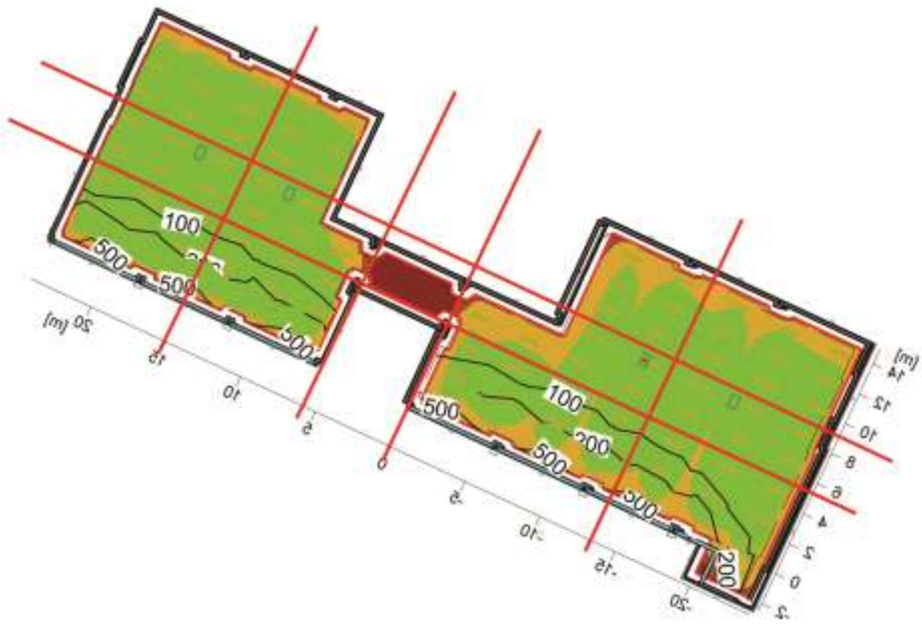


Figure C.17 : Meshes of mezzenine floor, Block B-December 21st-15:00-Overcast sky model.

Figure C.18 : Meshes of mezzenine floor, Block B-June 21^{st}-$9{:}^{00}$-Clear sky model.

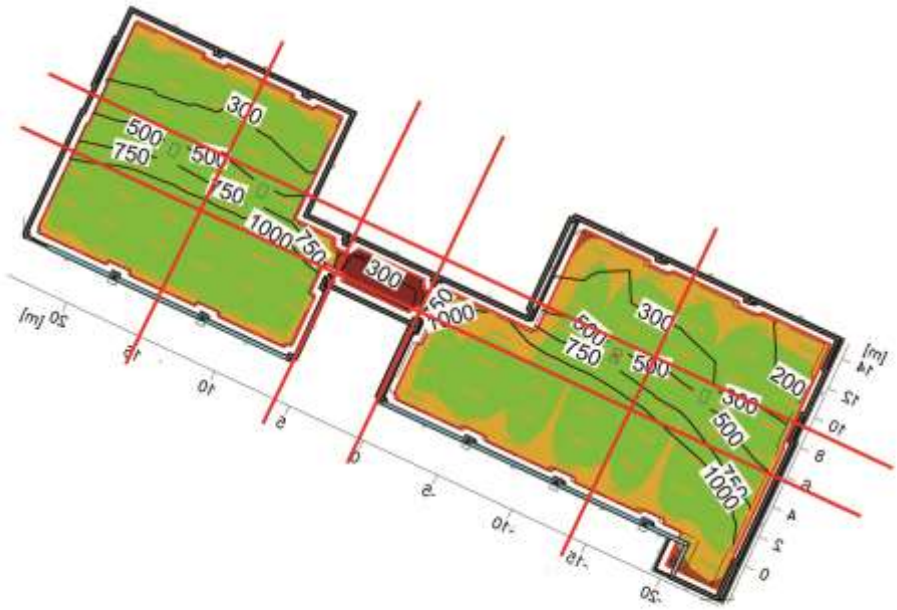


Figure C.19 : Meshes of mezzenine floor, Block B-June 21^{st}-$12{:}^{00}$-Clear sky model.

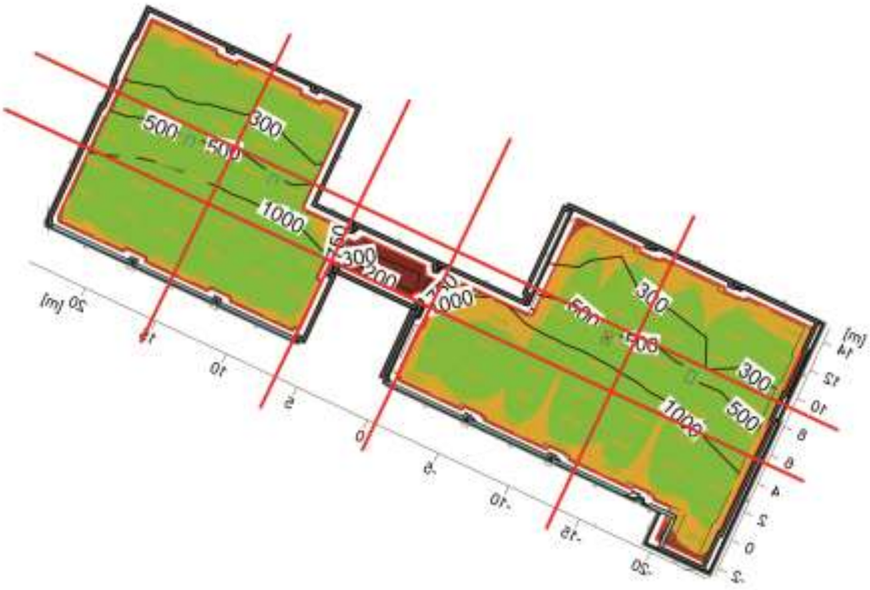


Figure C.20 : Meshes of mezzenine floor, Block B-June 21st-15:00-Clear sky model.

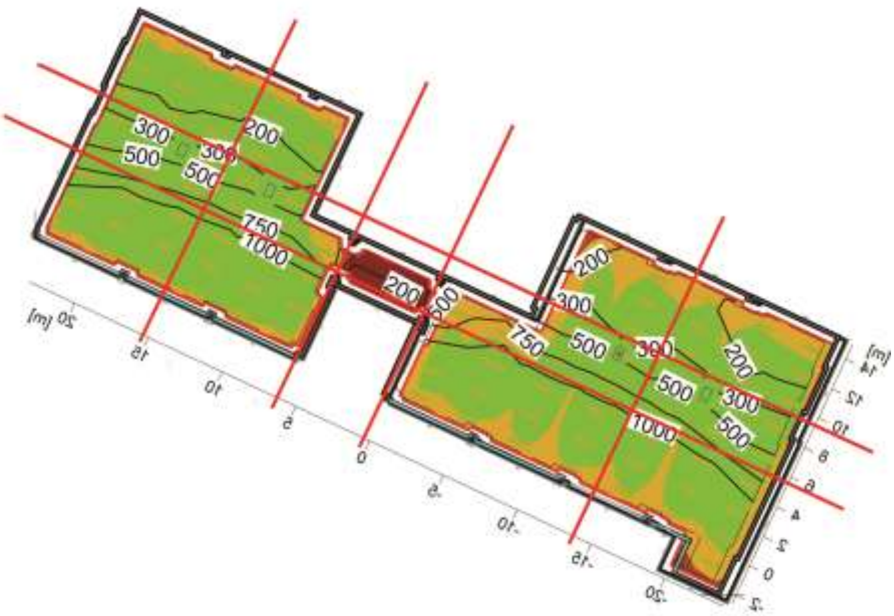


Figure C.21 : Meshes of mezzenine floor, Block B-June 21st-17:00-Clear sky model.

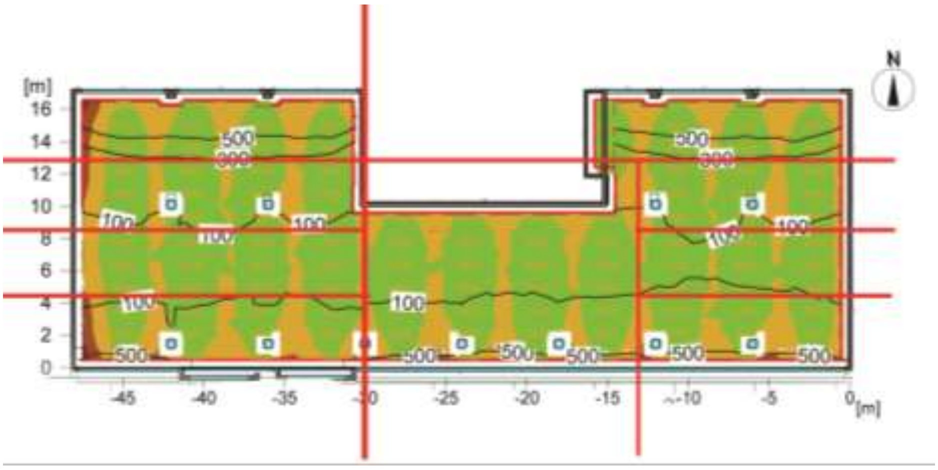


Figure C.22 : Meshes of Ground 2 floor, Block A-December 21st-9:00-Overcast sky model.

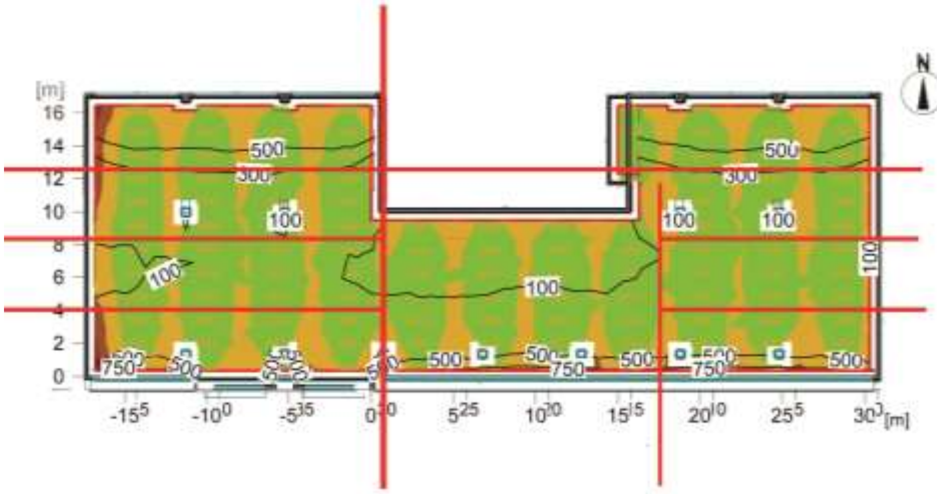


Figure C.23 : Meshes of Ground 2 floor, Block A-December 21st-12:00-Overcast sky model.

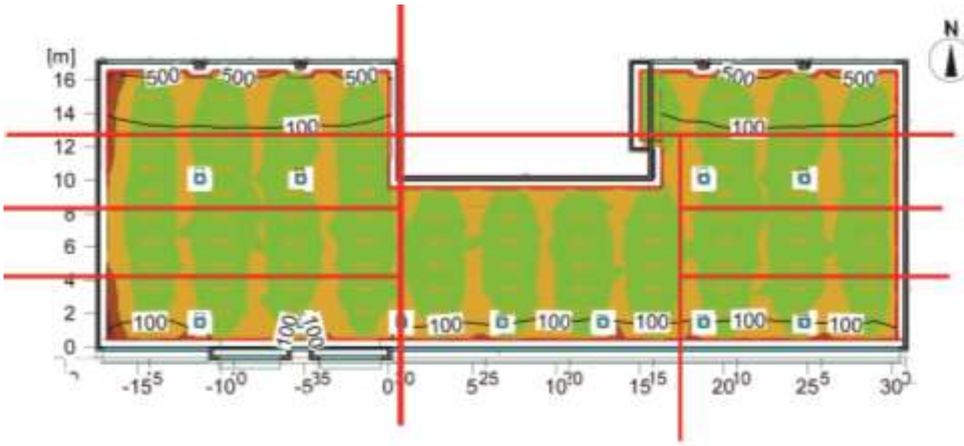


Figure C.24 : Meshes of Ground 2 floor, Block A-December 21st-15:00-Overcast sky model.

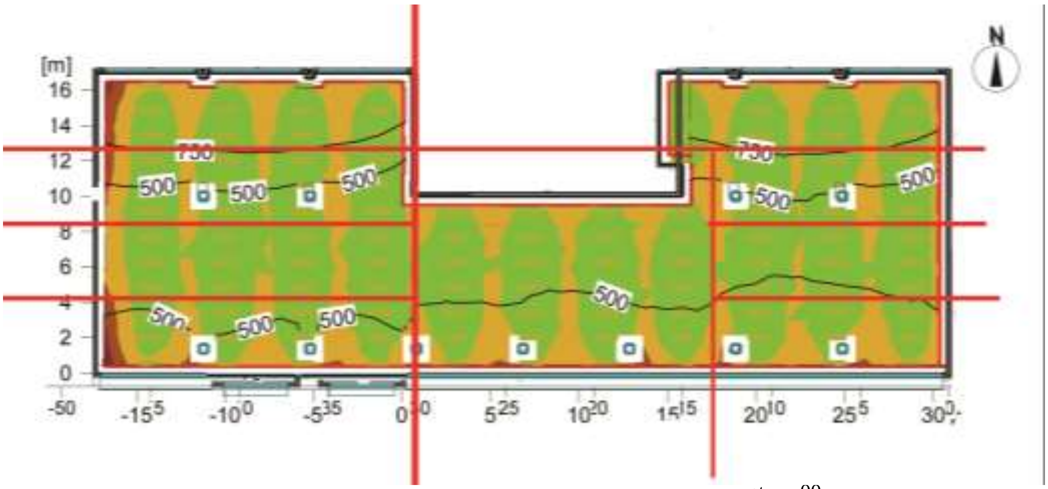


Figure C.25 : Meshes of Ground 2 floor, Block A-June 21st-9:^{00}-Clear sky model.

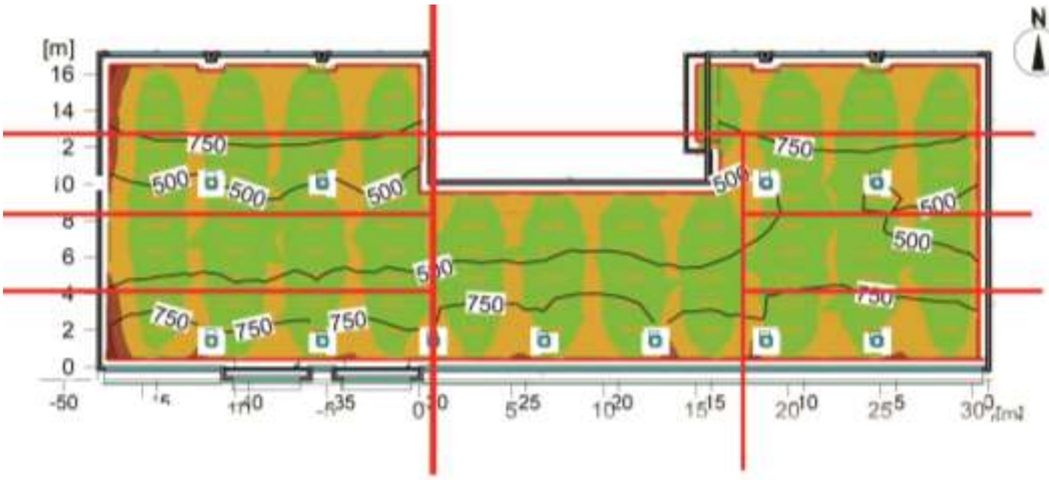


Figure C.26 : Meshes of Ground 2 floor, Block A-June 21st-12:^{00}-Clear sky model.

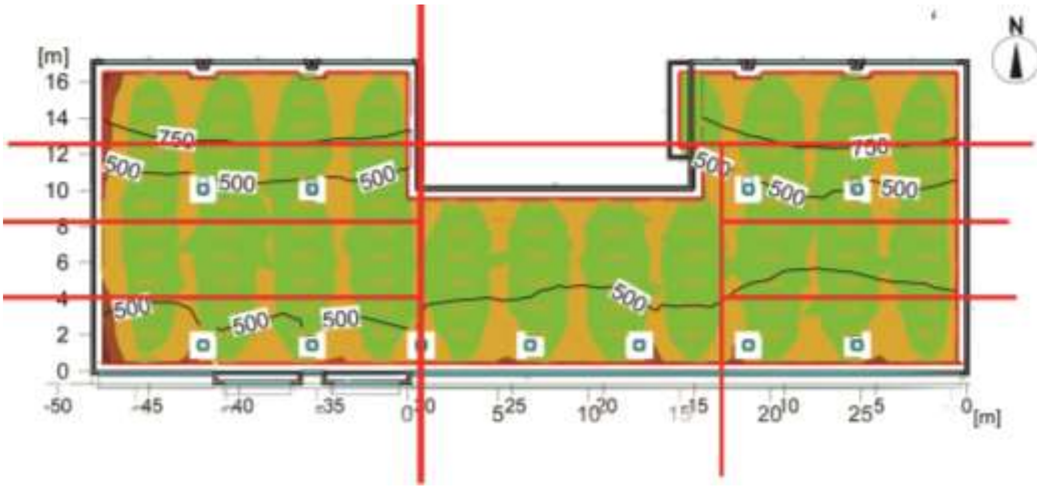


Figure C.27 : Meshes of Ground 2 floor, Block A-June 21st-15:^{00}-Clear sky model.

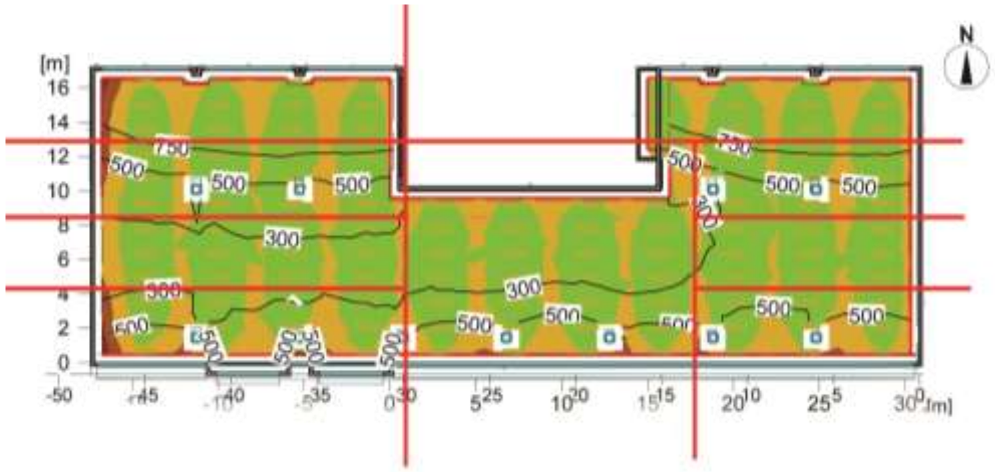


Figure C.28 : Meshes of Ground 2 floor, Block A-June 21st-17:00-Clear sky model.

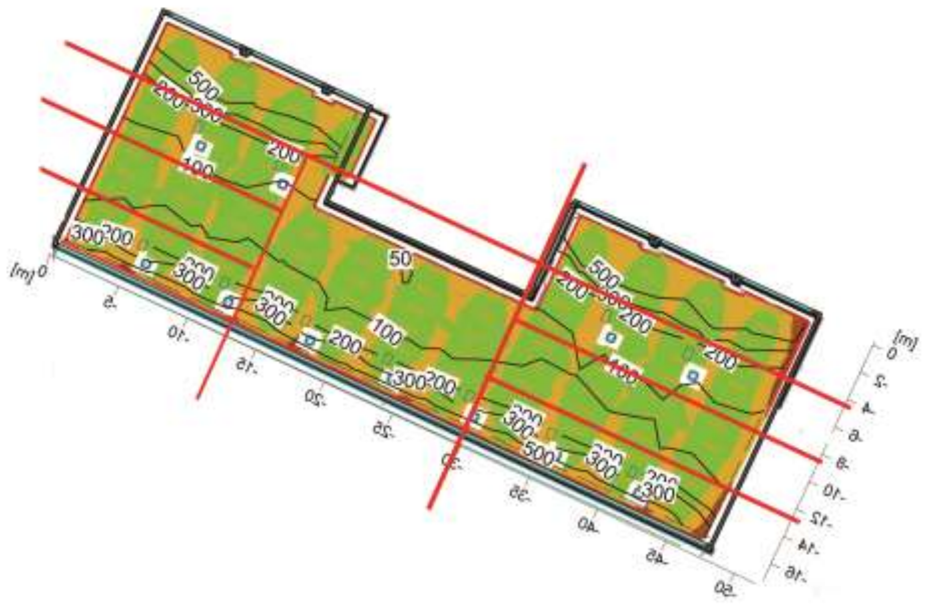


Figure C.29 : Meshes of Ground 2 floor, Block B-December 21st-9:00-Overcast sky model.

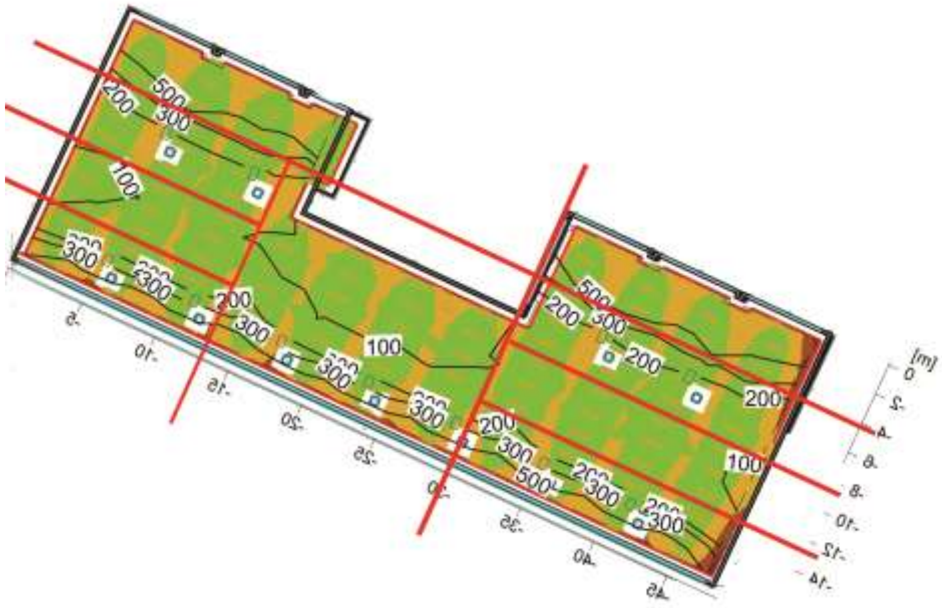


Figure C.30 : Meshes of Ground 2 floor, Block B-December 21st-12:00-Overcast sky model.

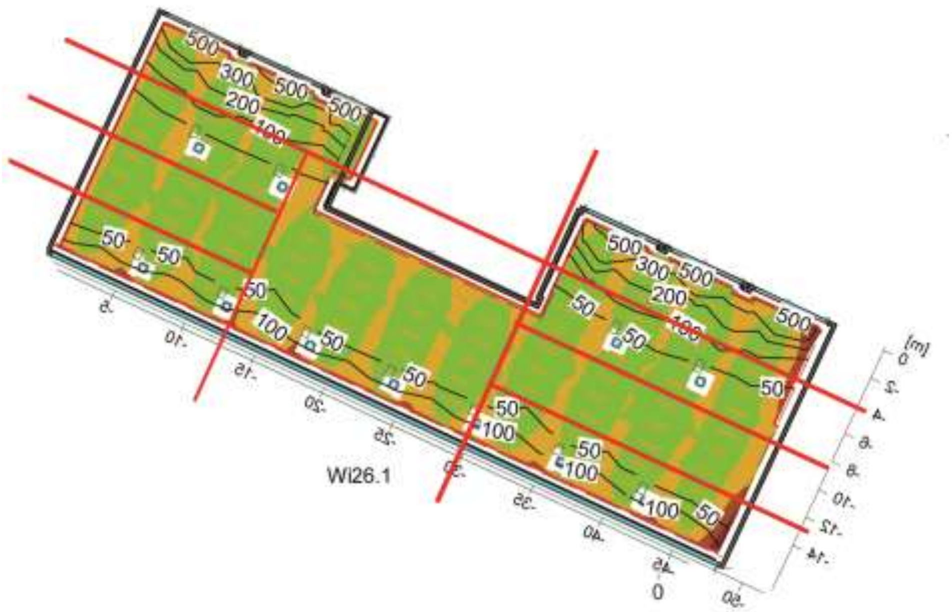


Figure C.31 : Meshes of Ground 2 floor, Block B-December 21st-15:00-Overcast sky model.

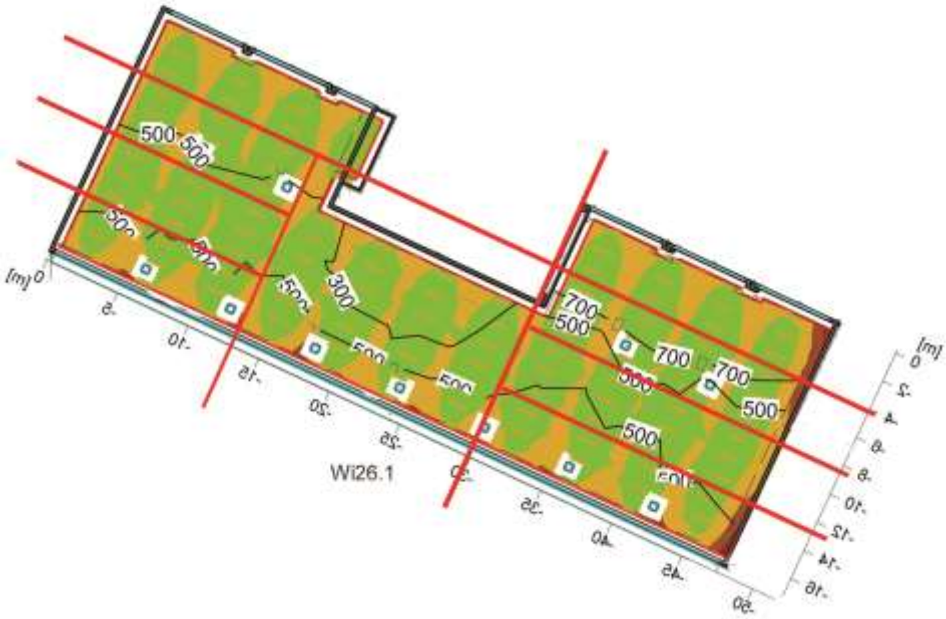


Figure C.32 : Meshes of Ground 2 floor, Block B-June 21st-9:^{00}-Clear sky model.

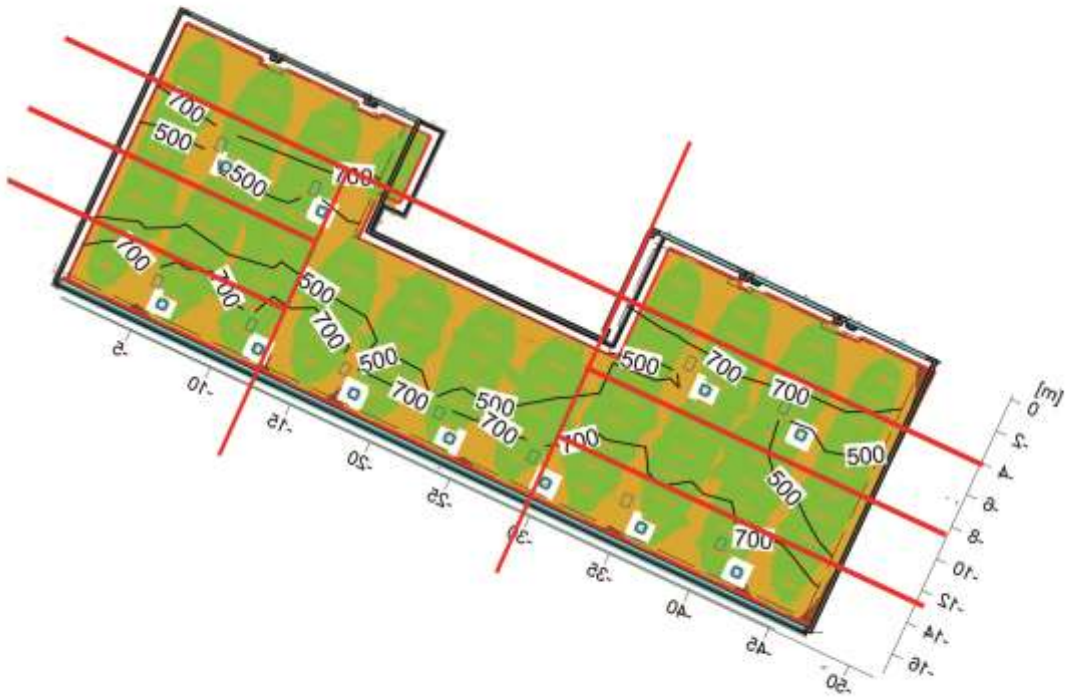


Figure C.33 : Meshes of Ground 2 floor, Block B-June 21st-12:^{00}-Clear sky model.

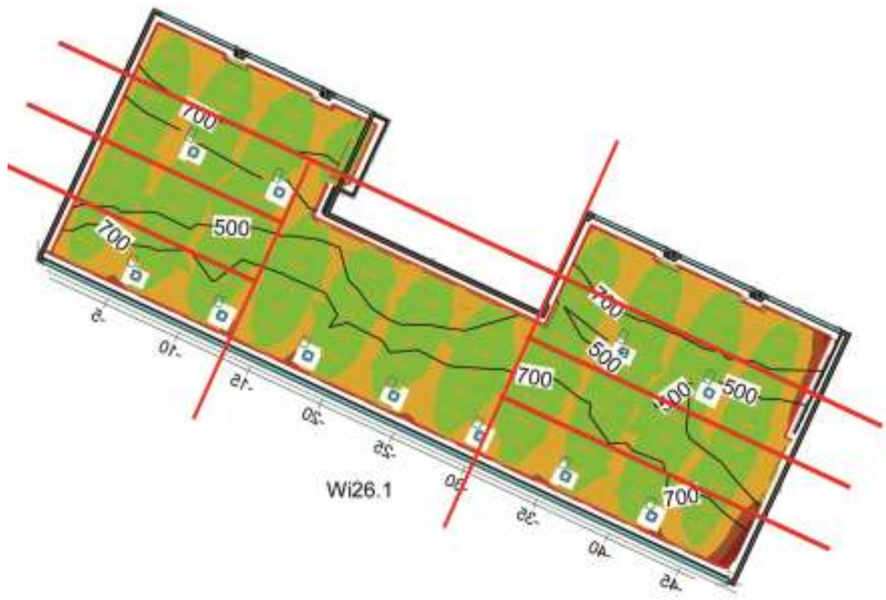


Figure C.34 : Meshes of Ground 2 floor, Block B-June 21st-15:^{00}-Clear sky model.

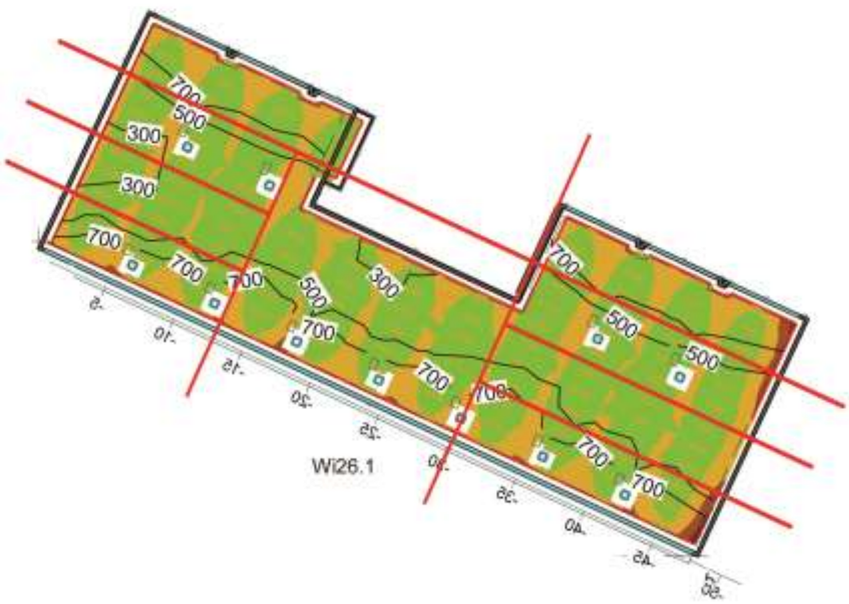


Figure C.35 : Meshes of Ground 2 floor, Block B-June 21st-17:^{00}-Clear sky model.

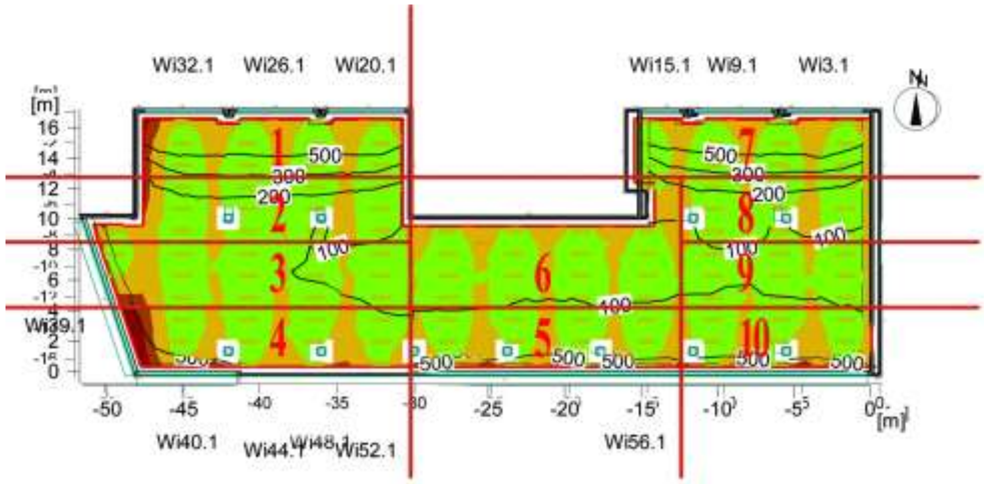


Figure C.36 : Meshes of Type floors, Block A-December 21st-9:00-Overcast sky model.

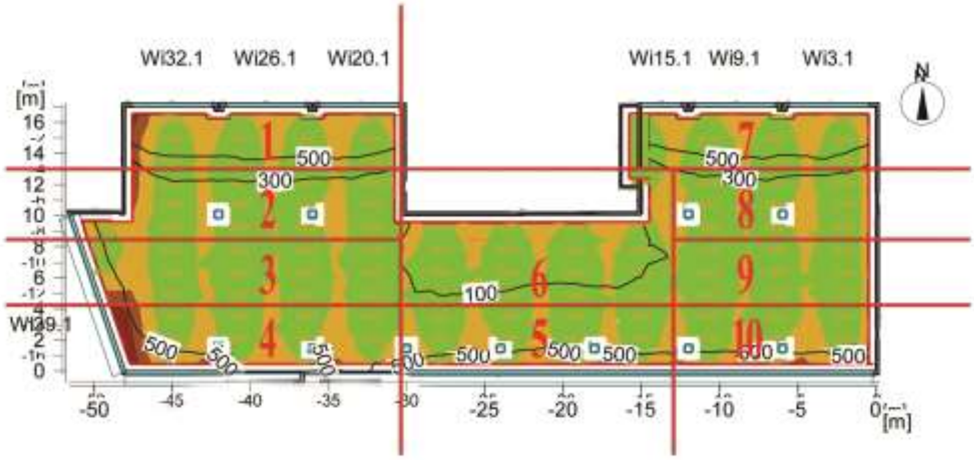


Figure C.37 : Meshes of Type floors, Block A-December 21st-12:00-Overcast sky model.

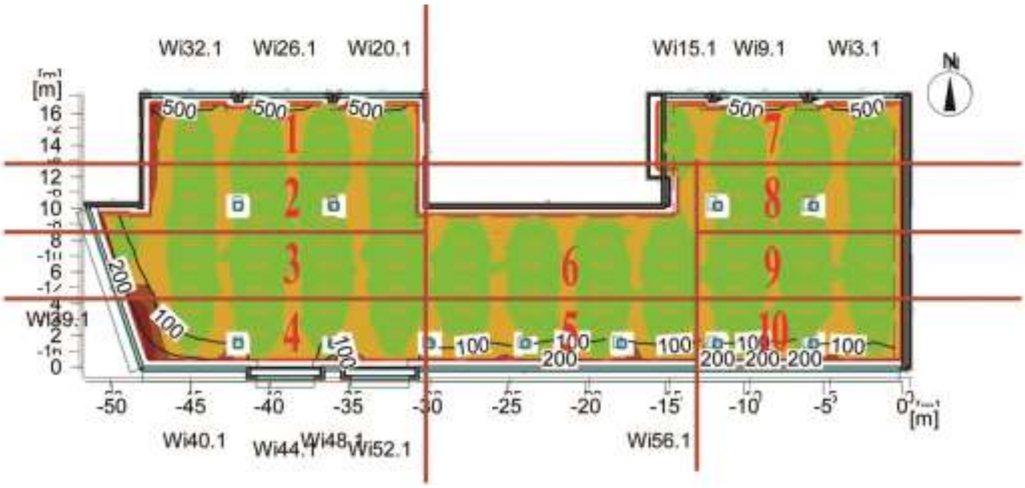


Figure C.38 : Meshes of Type floors, Block A-December 21st-15:00-Overcast sky model.

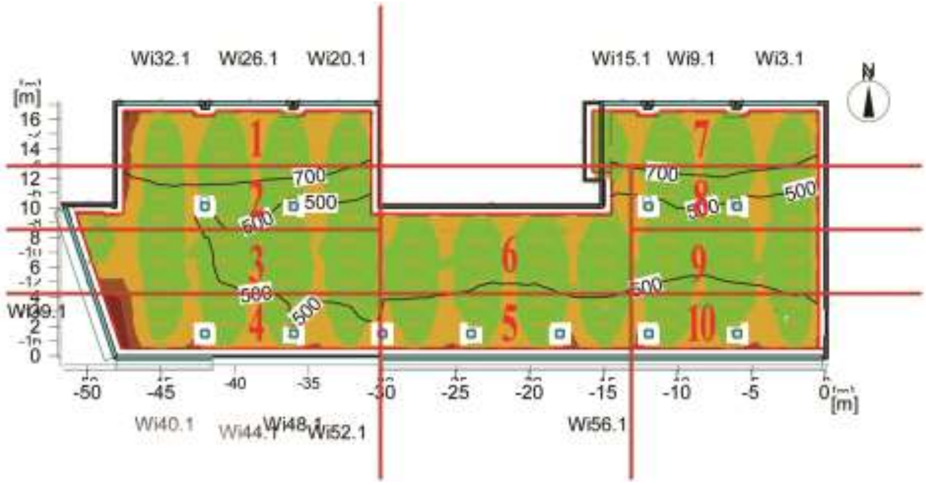


Figure C.39 : Meshes of Type floors, Block A-June 21st-9:^{00}-Clear sky model.

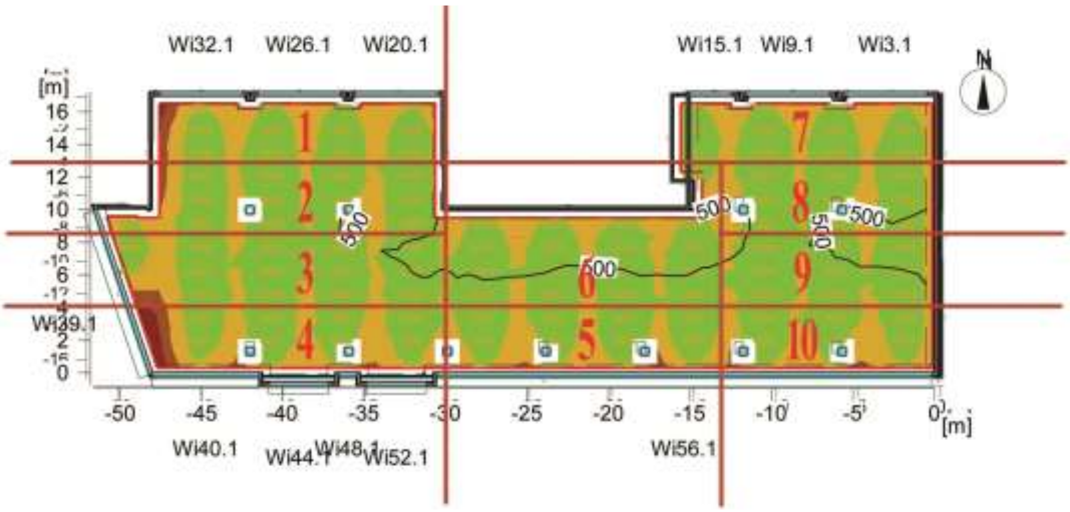


Figure C.40 : Meshes of Type floors, Block A-June 21st-12:^{00}-Clear sky model.

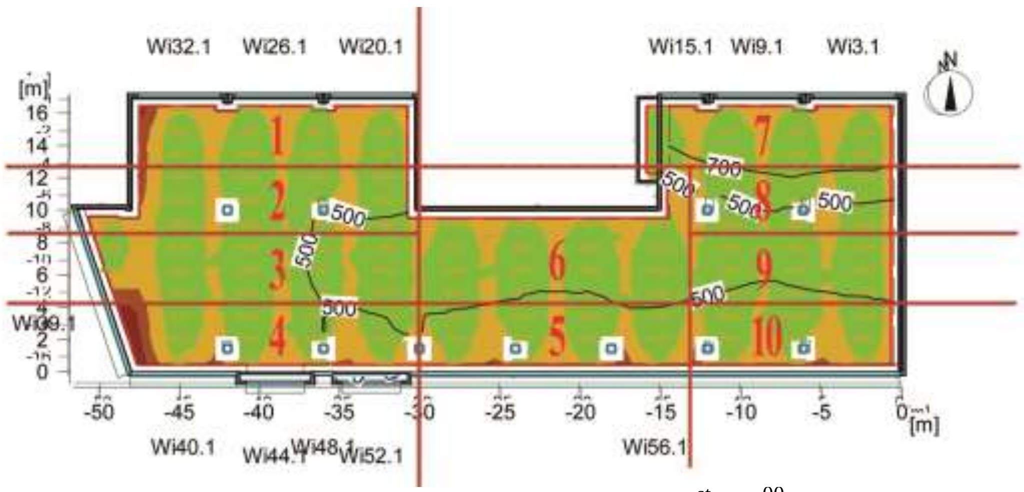


Figure C.41 : Meshes of Type floors, Block A-June 21st-15:^{00}-Clear sky model.

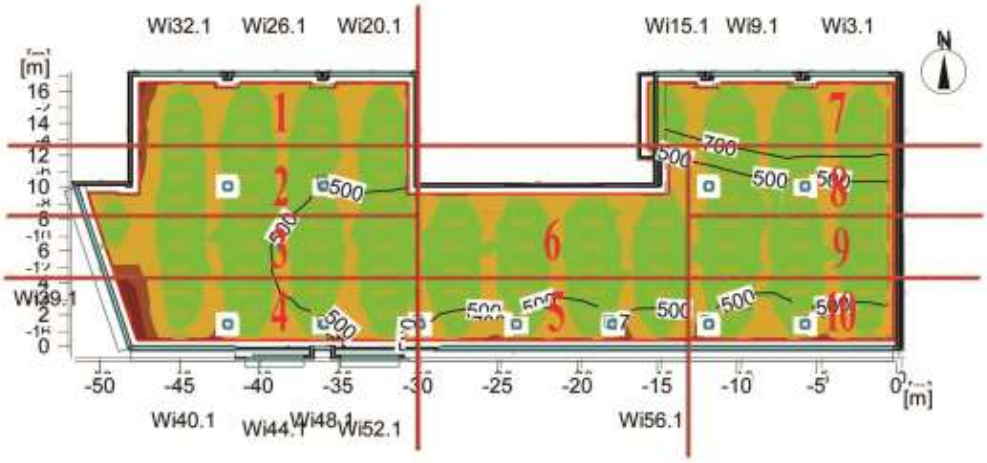


Figure C.42 : Meshes of Type floors, Block A-June 21st-17:00-Clear sky model.

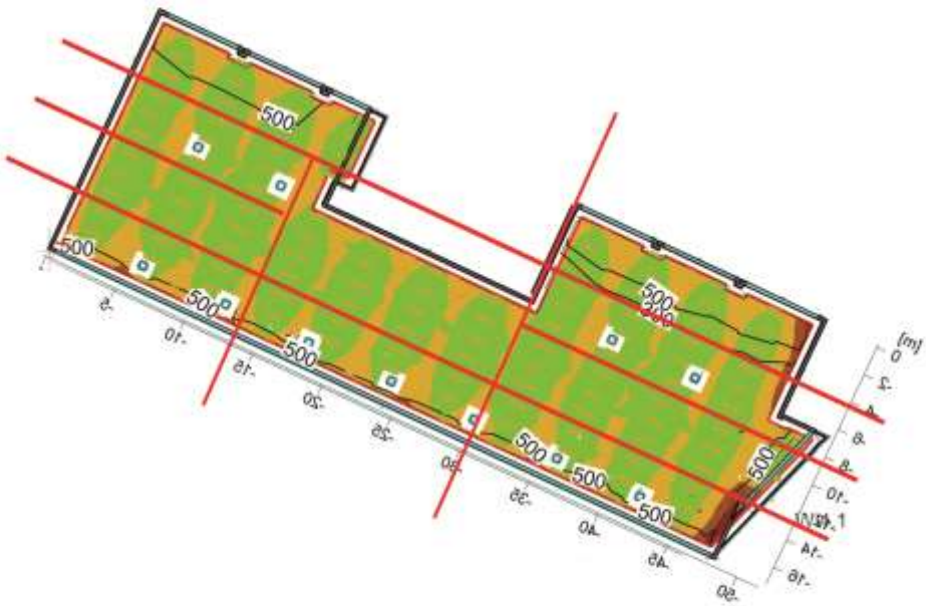


Figure C.43 : Meshes of Type floors, Block B-December 21st-9:00-Overcast sky model.

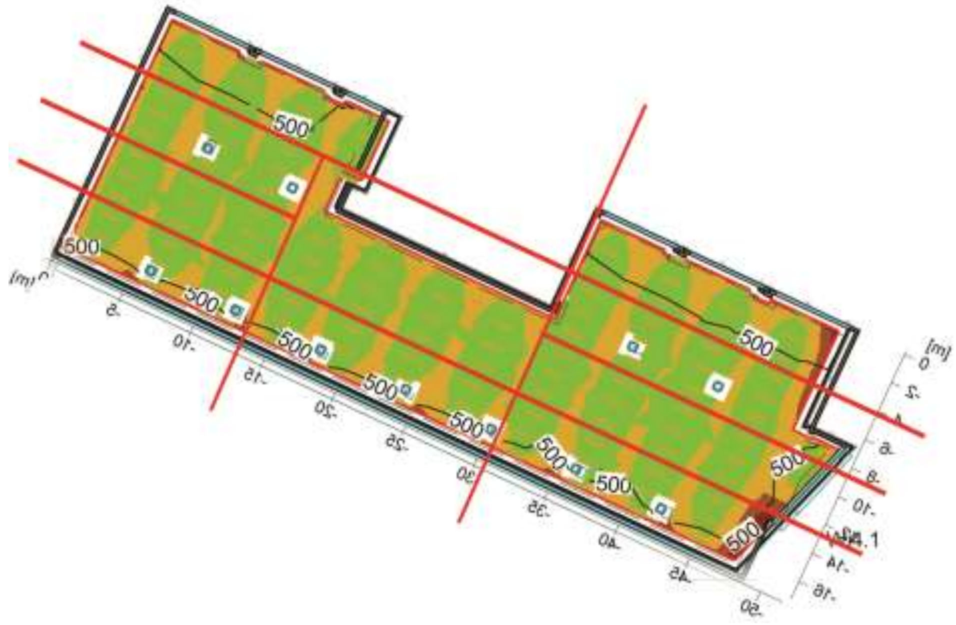


Figure C.44 : Meshes of Type floors, Block B-December 21st-12:^{00}-Overcast sky model.

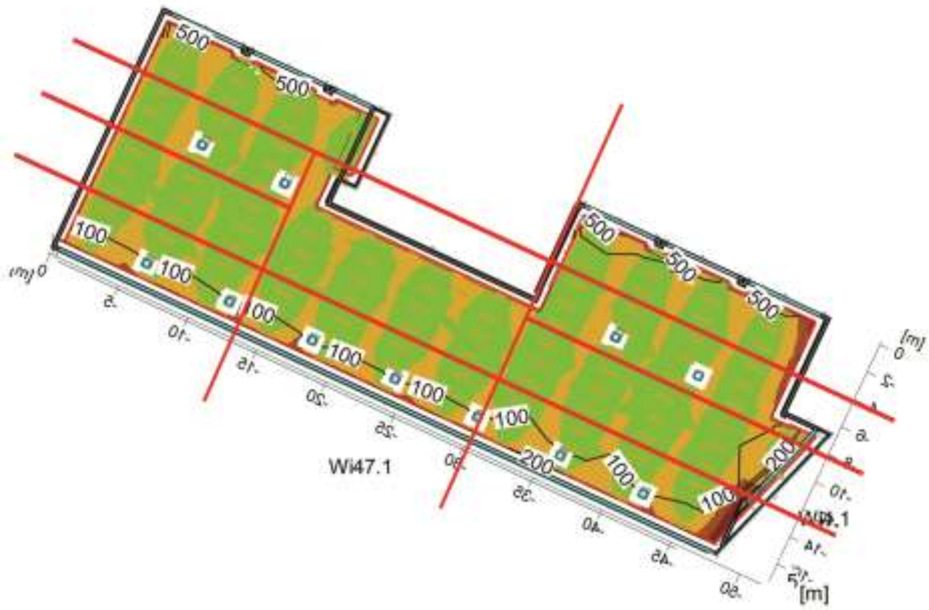


Figure C.45 : Meshes of Type floors, Block B-December 21st-15:^{00}-Overcast sky model.

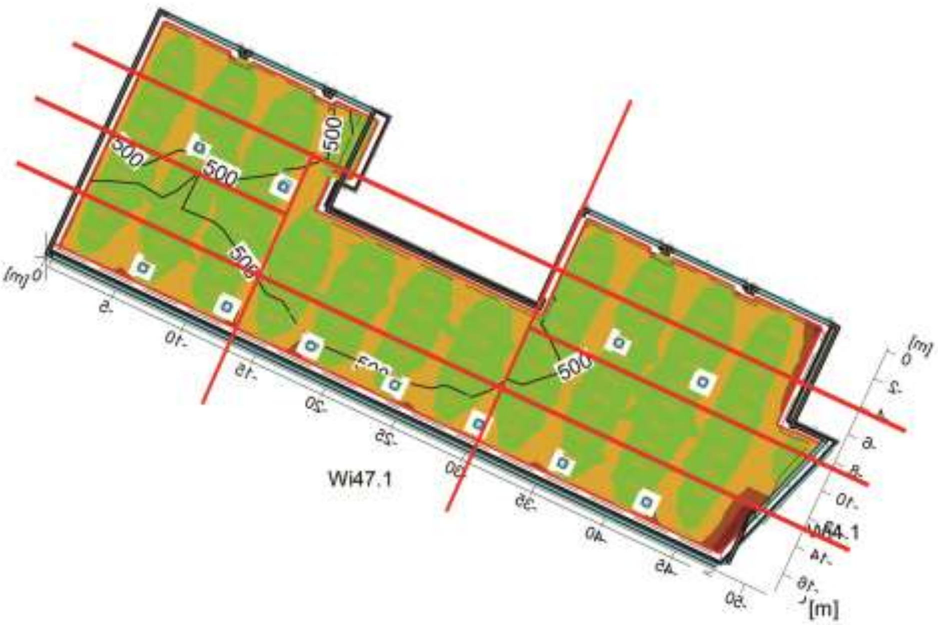


Figure C.46 : Meshes of Type floors, Block B-June 21st-9:00-Clear sky model.

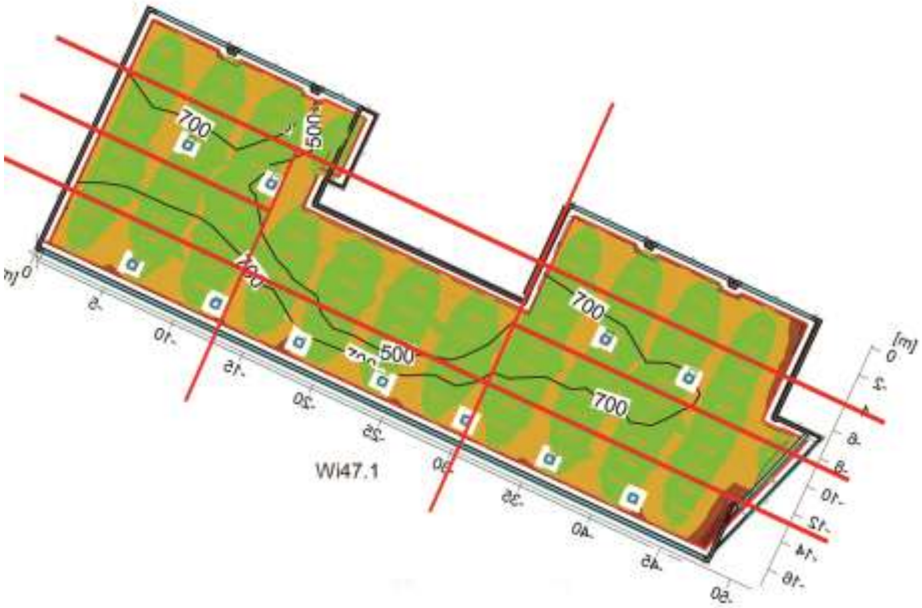


Figure C.47 : Meshes of Type floors, Block B-June 21st-12:00-Clear sky model.

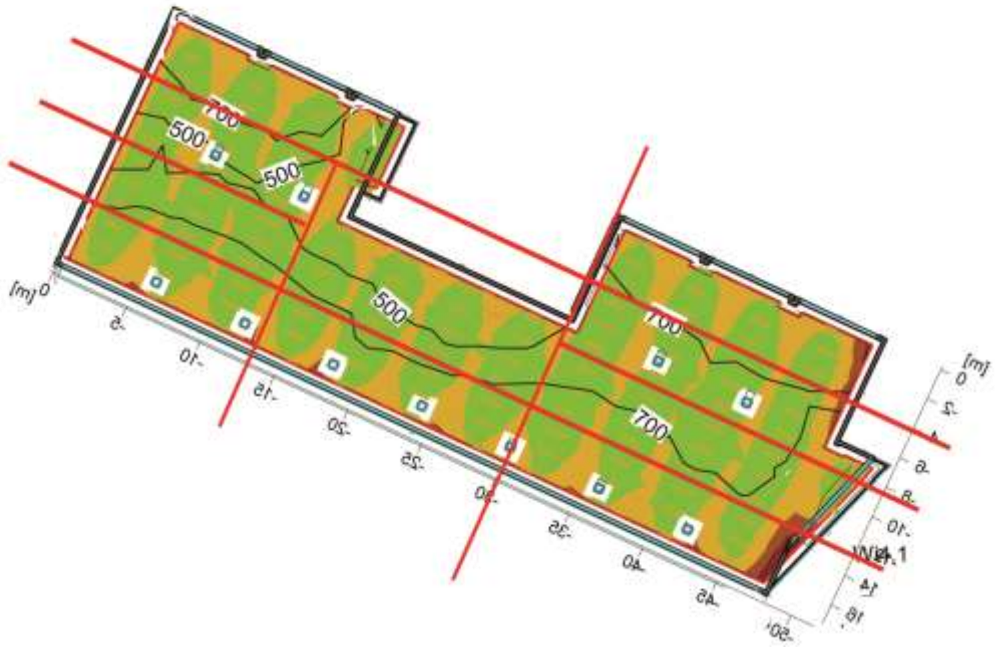


Figure C.48 : Meshes of Type floors, Block B-June 21st-15:^{00}-Clear sky model.

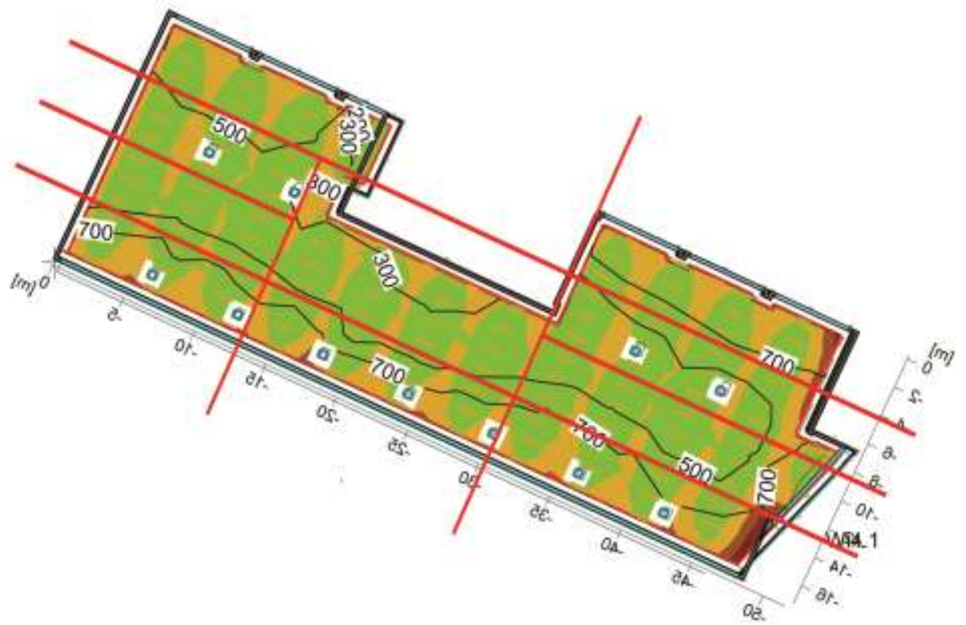


Figure C.49 : Meshes of Type floors, Block B-June 21st-17:^{00}-Clear sky model.

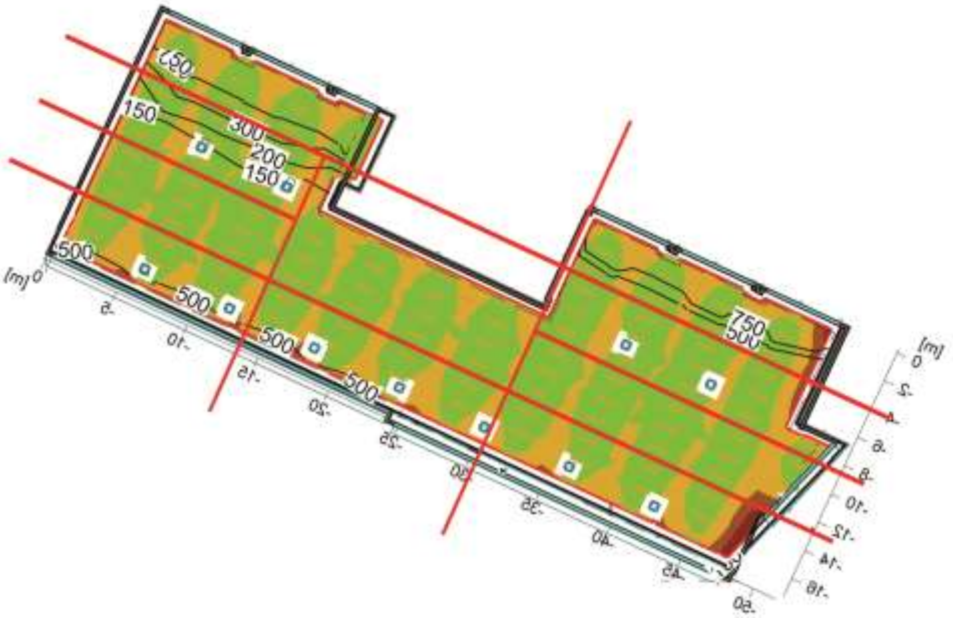


Figure C.50 : Meshes of 2nd floor, Block B-December 21st-9:^{00}-Overcast sky model.

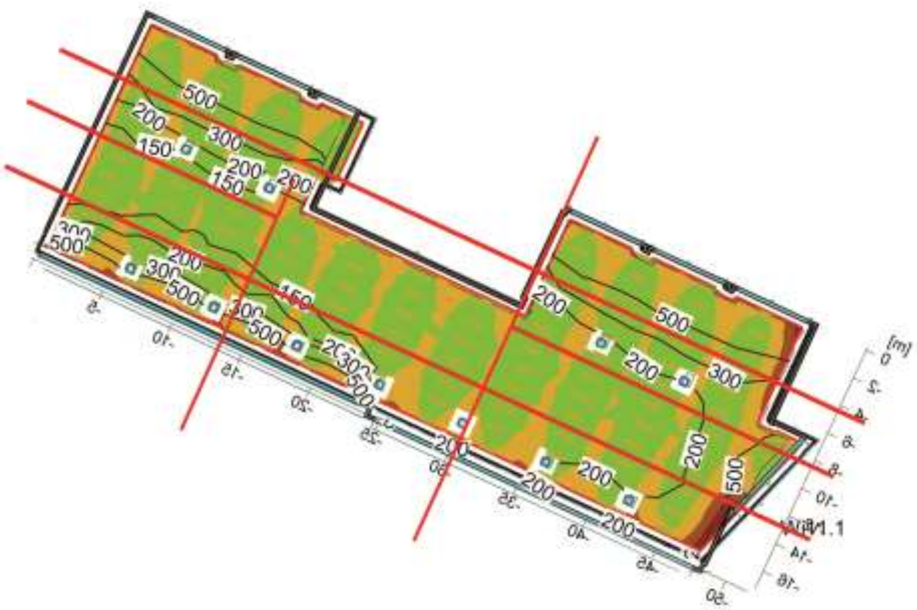


Figure C.51 : Meshes of 2nd floor, Block B-December 21st-12:^{00}-Overcast sky model.

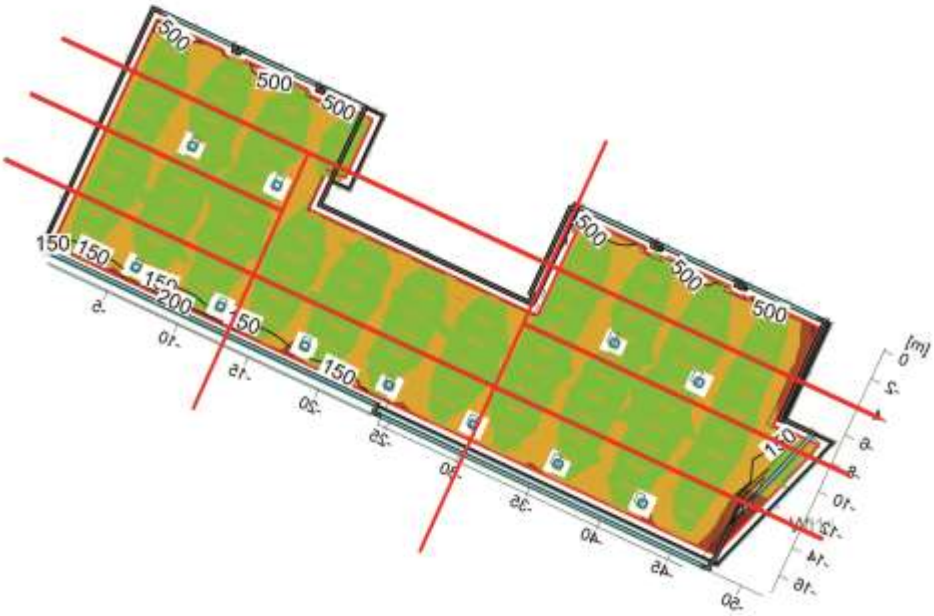


Figure C.52 : Meshes of 2nd floor, Block B-December 21st-15:00-Overcast sky model.

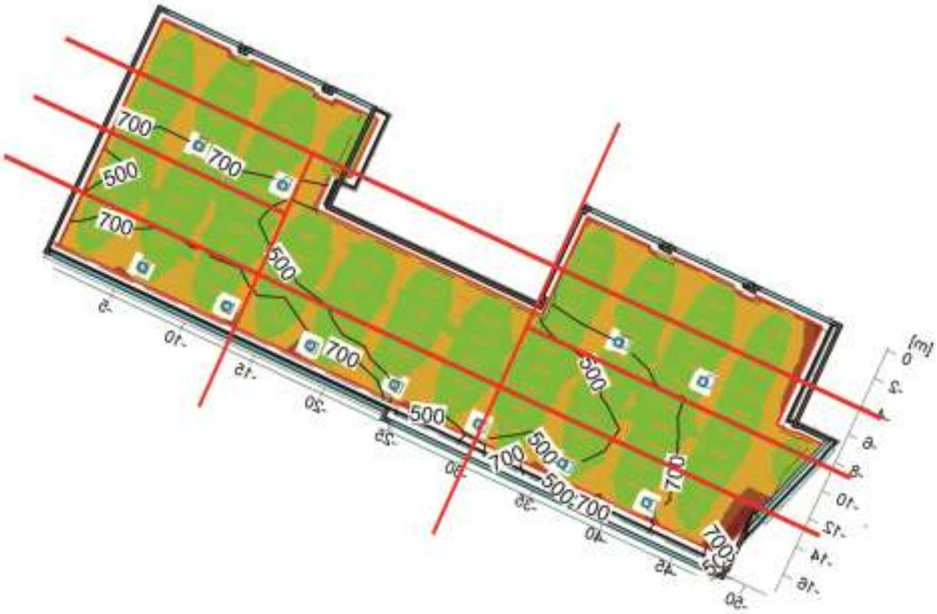


Figure C.53 : Meshes of 2nd floor, Block B-June 21st-9:00-Clear sky model.

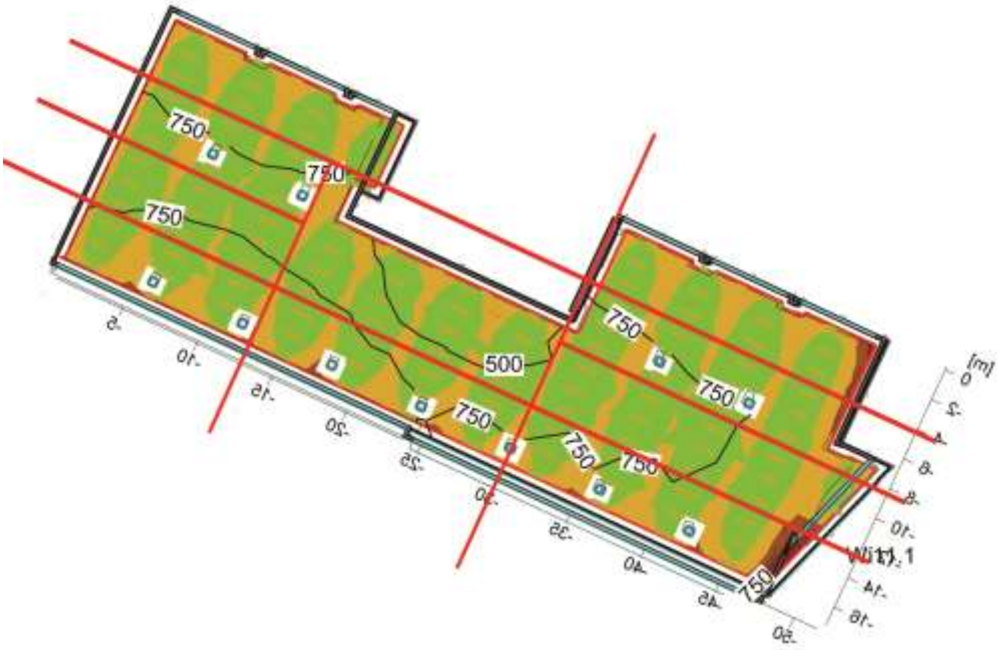


Figure C.54 : Meshes of 2^{nd} floor, Block B-June 21^{st}-$12:^{00}$-Clear sky model.

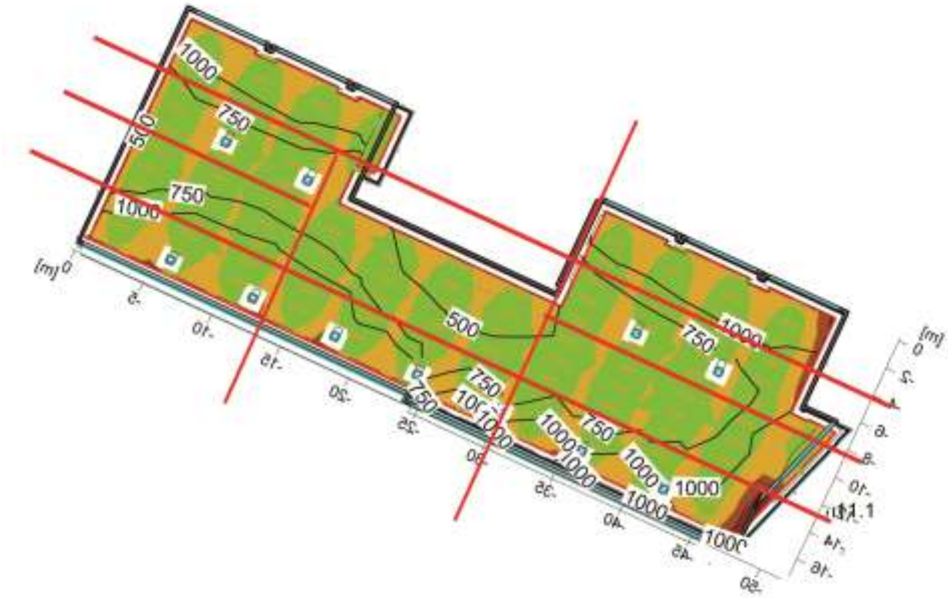


Figure C.55 : Meshes of 2^{nd} floor, Block B-June 21^{st}-$15:^{00}$-Clear sky model.

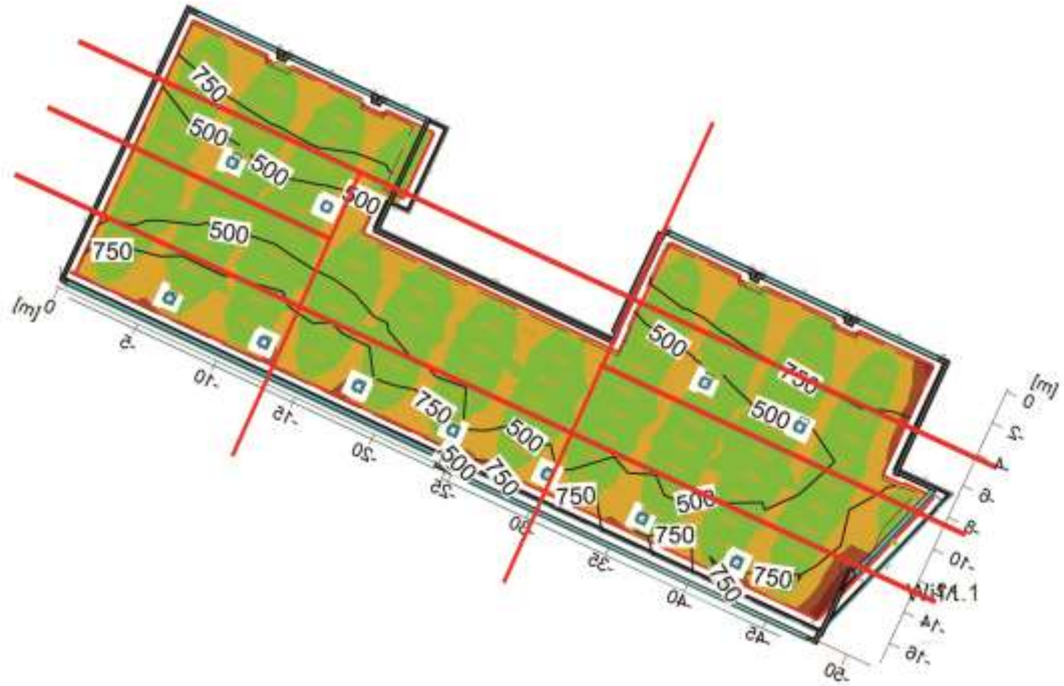


Figure C.56 : Meshes of 2nd floor, Block B-June 21st-17:00-Clear sky model.

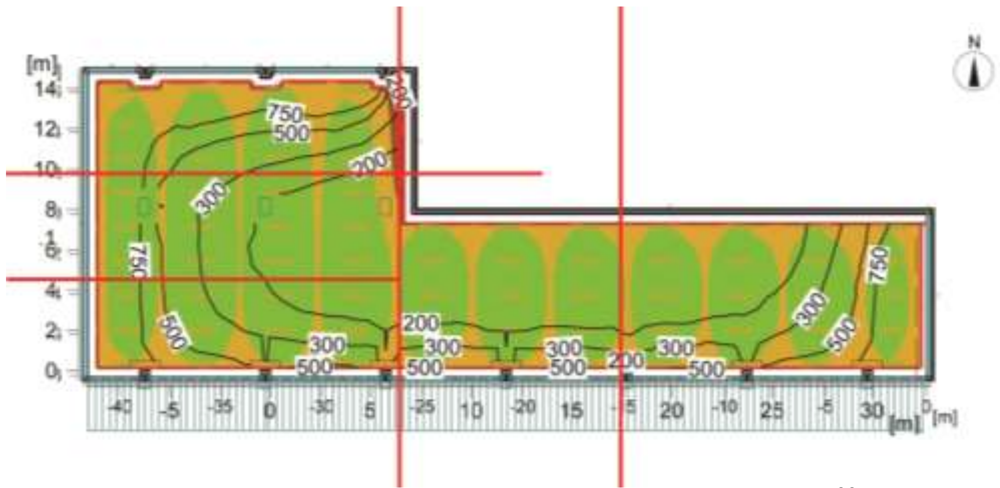


Figure C.57 : Meshes of Terrace floor, Block A-December 21st-9:00-Overcast sky model.

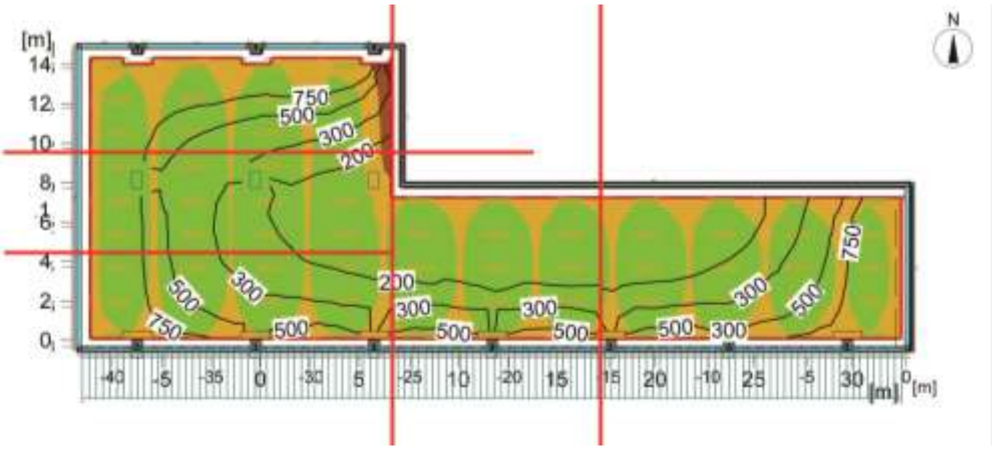


Figure C.58 : Meshes of Terrace floor, Block A-December 21st-12:^{00}-Overcast sky model.

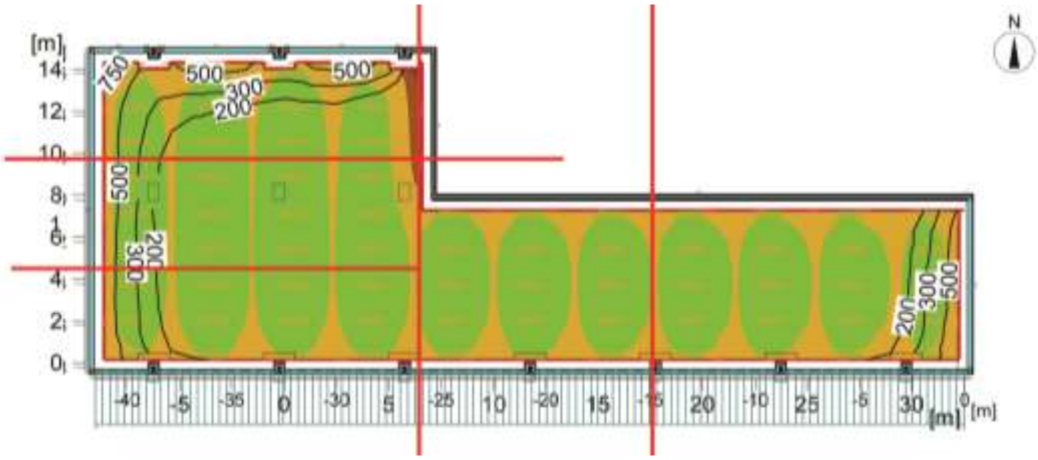


Figure C.59 : Meshes of Terrace floor, Block A-December 21st-15:^{00}-Overcast sky model.

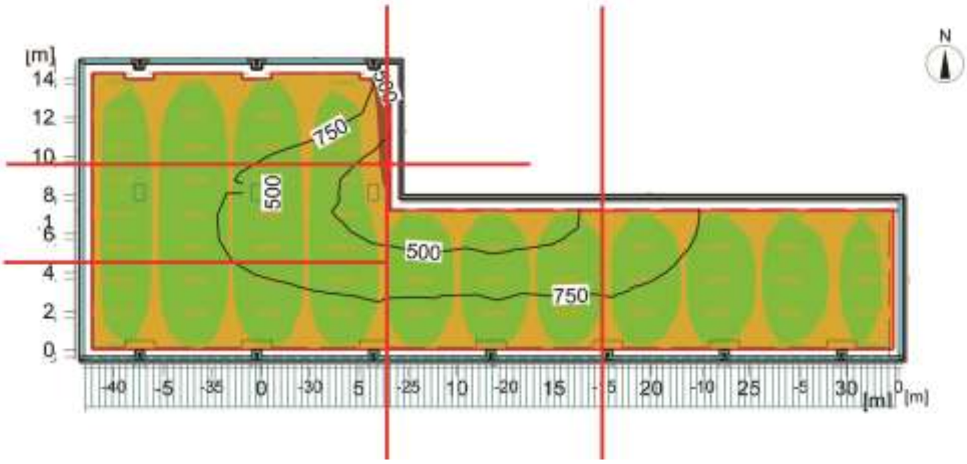


Figure C.60 : Meshes of Terrace floor, Block A-June 21st-9:^{00}-Clear sky model.

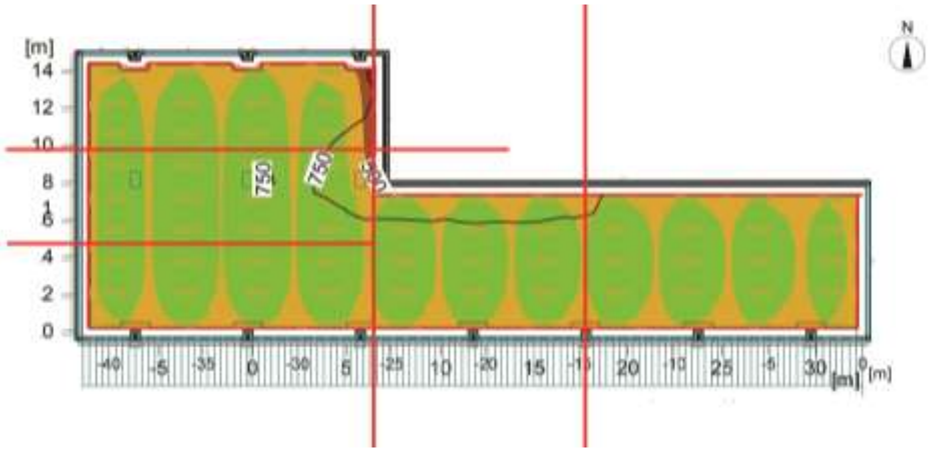


Figure C.61 : Meshes of Terrace floor, Block A-June 21st-12:00-Clear sky model.

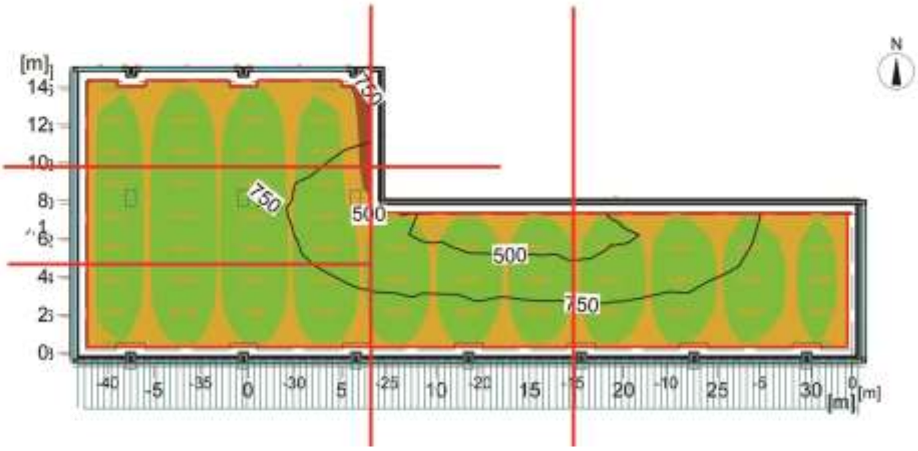


Figure C.62 : Meshes of Terrace floor, Block A-June 21st-15:00-Clear sky model.

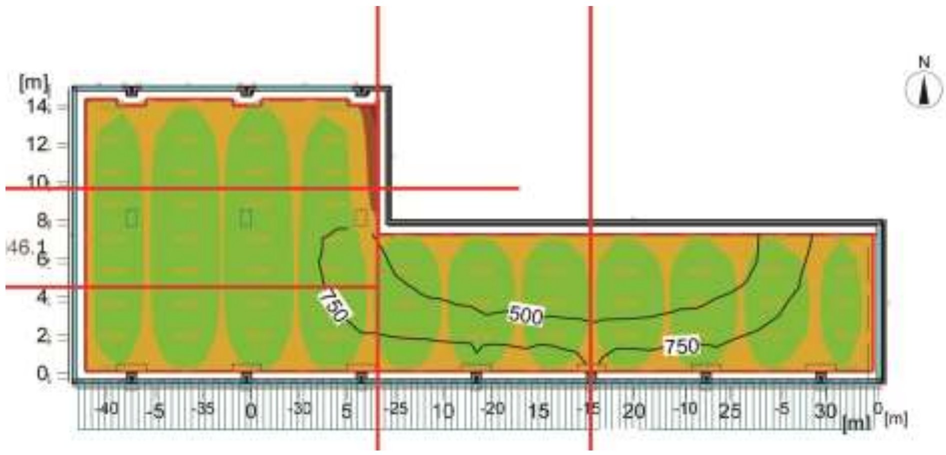


Figure C.63 : Meshes of Terrace floor, Block A-June 21st-17:00-Clear sky model.

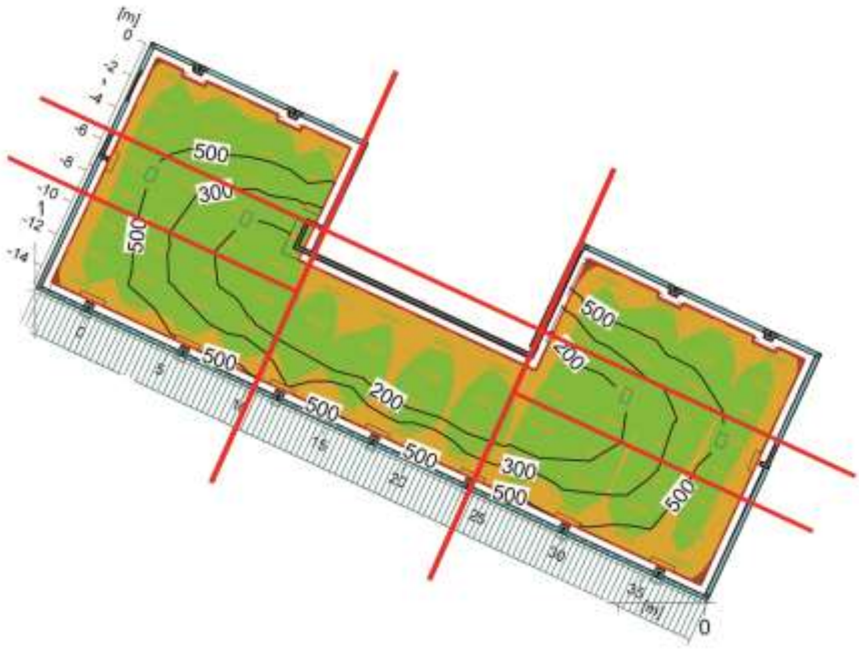


Figure C.64 : Meshes of Terrace floor, Block B-December 21st-9:00-Overcast sky model.

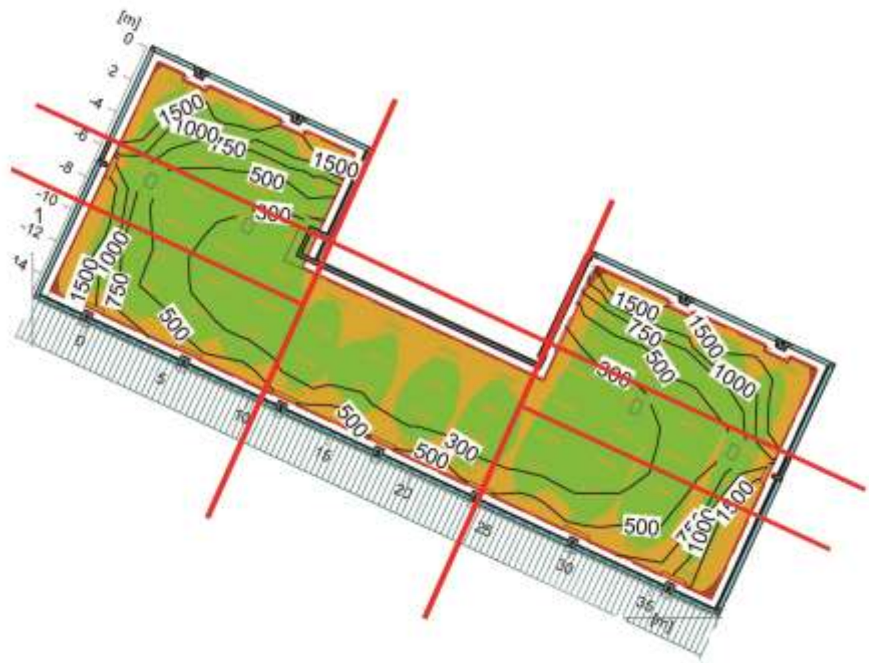


Figure C.65 : Meshes of Terrace floor, Block B-December 21st-12:00-Overcast sky model.

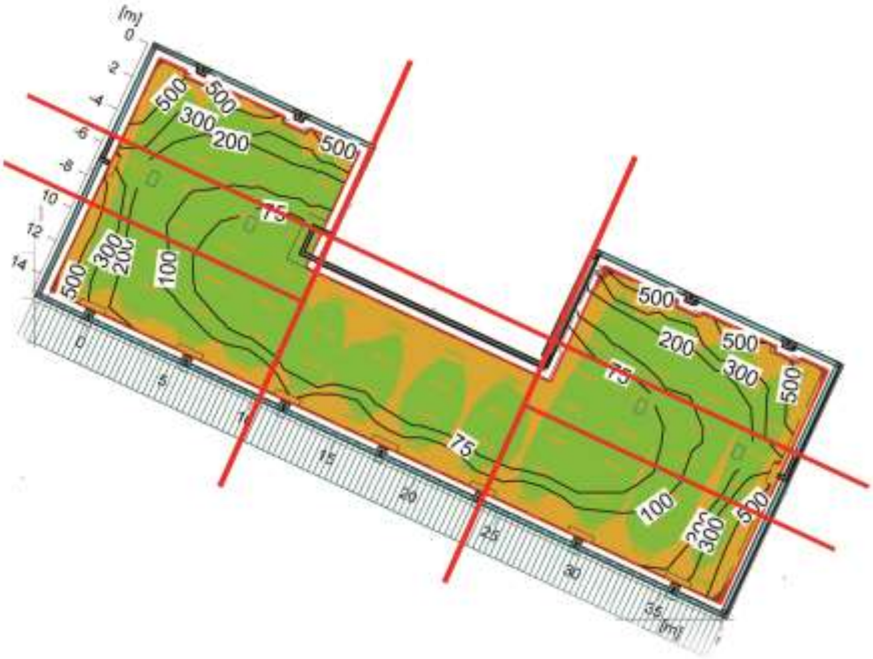


Figure C.66 : Meshes of Terrace floor, Block B-December 21st-15:00-Overcast sky model.

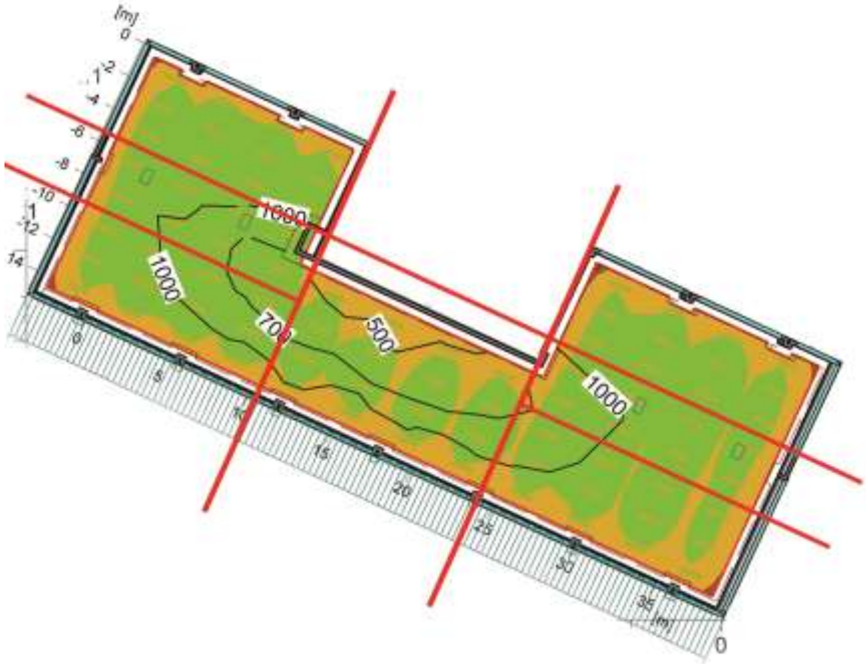


Figure C.67 : Meshes of Terrace floor, Block B-June 21st-9:00-Clear sky model.

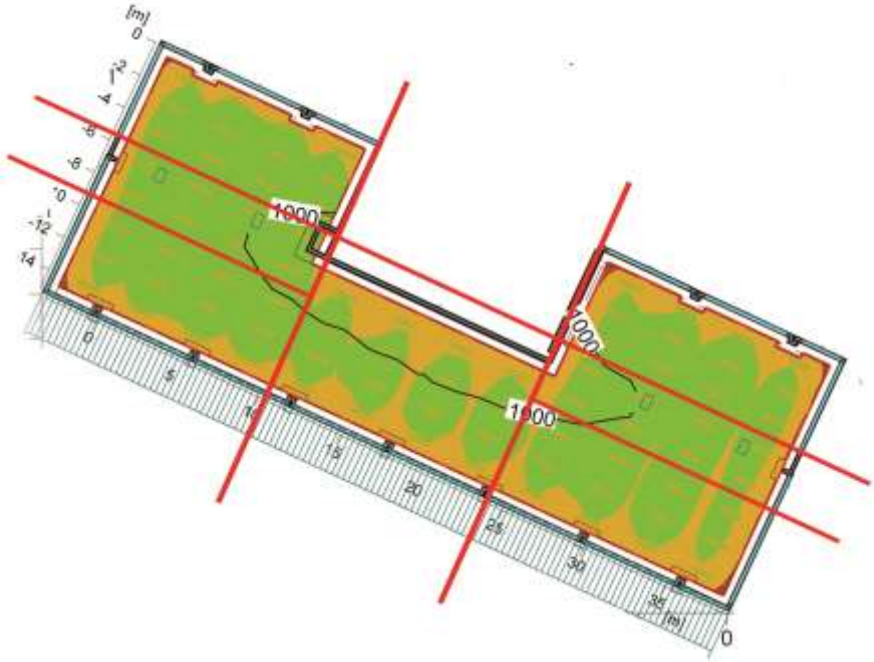


Figure C.68 : Meshes of Terrace floor, Block B-June 21st-12:00-Clear sky model.

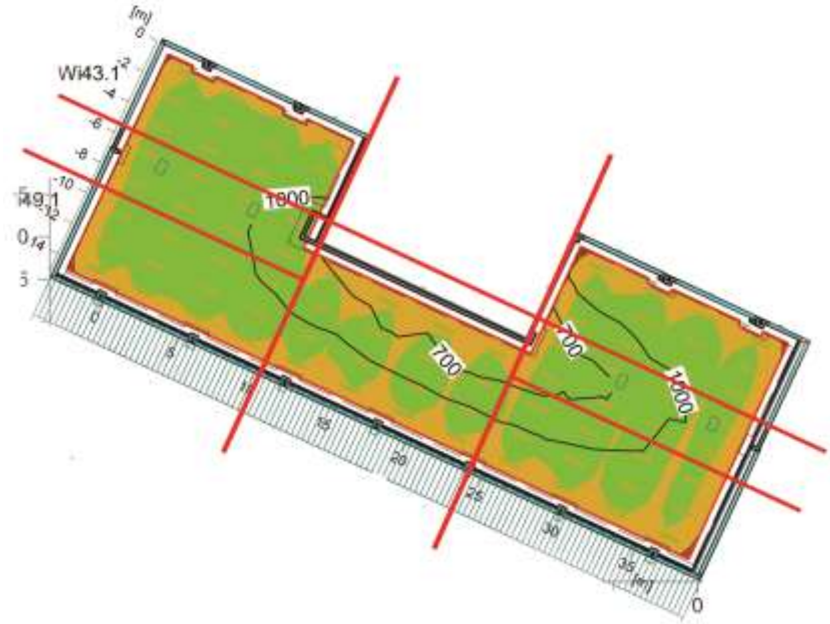


Figure C.69 : Meshes of Terrace floor, Block B-June 21st-15:00-Clear sky model

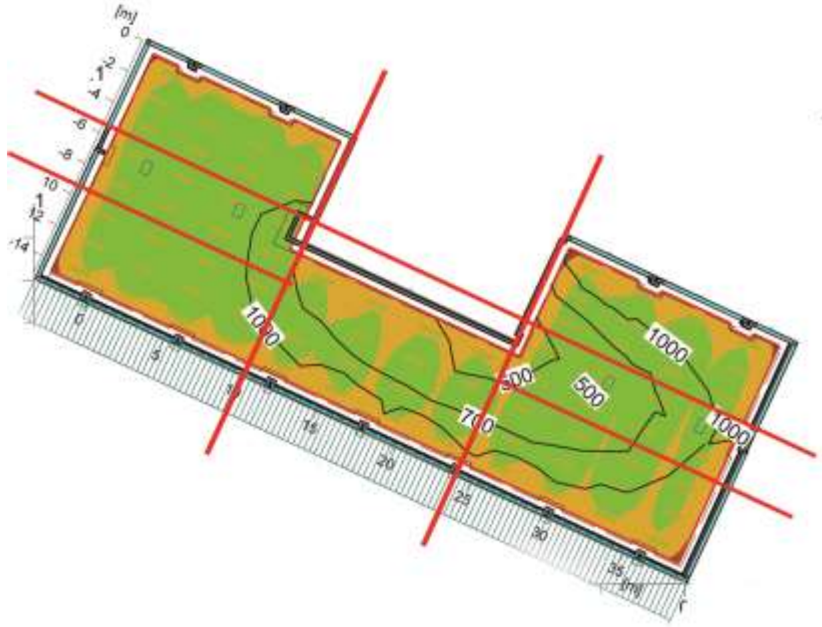


Figure C.70 : Meshes of Terrace floor, Block B-June 21st-17:00-Clear sky model.

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PUBLICATIONS/PRESENTATIONS ON THE THESIS

Mahmoudi, A., Yener, A. K., 2014; Analysis on Building Integrated Photovoltaic Systems' Effect on Lighting Energy Performance, *Second Building Simulation and Optimization conference*, 23-24 June, London, UK.