YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

SHADING DEVICE DESIGN AND OPTIMIZATION VIA GENETIC ALGORITHM BY USING SURFACE TEMPERATURE METRIC AND ELECTRICITY LOAD

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ABSTRACT

SHADING DEVICE DESIGN AND OPTIMIZATION VIA GENETIC ALGORITHM BY USING SURFACE TEMPERATURE METRIC AND ELECTRICITY LOAD

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The world population is increasing over the years. More and more natural resources are needed to meet the growing population needs. However, natural resources are limited and should be consumed wisely in order to be used in the following years. In this context, architects and engineers have great responsibility for the management of resources. It is their responsibility to provide adequate resources for future generations and to meet the needs of today. Therefore, the concept of sustainability has emerged over the years and has been one of the most emphasized issues today. Sustainability also has an important place in architectural design. Sustainable use of resources is supported by reducing energy use in buildings. Because people spend an important part of their time indoors. Most people are in office space during the daylight hours. In this thesis, an optimization study was carried out to reduce energy use in office buildings by using shading element. Shading elements, especially in the south facade of glass with solar radiation control by preventing overheating. In this study, the variables of the organic, triangular geometry shading element integrated into the southern façade are solved as a multi-objective optimization problem by the evolutionary algorithm which is HypE genetic algorithm. One of the two purposes of the problem is keeping the internal temperature of the glass between 20℃ and 27℃ for every hour of the year and the other is the minimum energy consumption for the interior lighting. The horizontal shading element and the flat triangular geometry shading element together with the shading element without the shading element have been studied and compared for the performance evaluation of this proposed organic triangular geometry shading element. Firstly, the shading element and without energy simulation of the test geometry for each shading element was modeled in the "Grasshopper", which is an add-on of Rhinoceros, and the variables "Ladybug-

Honeybee" were identified in its program. The "Octopus" Grasshopper plug-in connects the prepared variables to give a two-dimensional optimization problem "pareto front" based result set. The results are evaluated by selecting from the group. The evaluation criteria are the operative temperature, the indoor temperature, the energy obtained from the total sunlight. As a summary, three main issues have been concluded. First it is seen that which type has better performance which is organic, triangular based geometry. Secondly, Shading device geometry can be found with generative model via evolutionary algorithms. It is shown one more time that evolutionary algorithms are applicable to complicated architectural problems. At least, in the evaluating phase of the shading devices, a new metric which is surface temperature metric is referred in the study. The success of the new metric is a good comparing element for the study and the metric may help the further studies in the literature.

Key Words: shading devices, energy efficient design, multi-objective optimization, energy simulation, genetic algorithms

ÖZ

ELEKTRIK YÜKÜ VE YÜZEY SICAKLIK METRIĞI ILE GENETIK ALGORITMALAR KULLANILARAK GÖLGELEME ELEMANI OPTIMIZASYONU VE TASARIMI

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Dünya nüfusu yıllar içerisinde artmaktadır. Artan nüfusun ihtiyaçlarını karşılamak için her geçen gün daha fazla doğal kaynak kullanılması gerekmektedir. Ancak doğal kaynaklar sınırlıdır ve ileriki yıllarda da kullanılabilmesi için tamamının tüketilmemesi gerekmektedir. Bu bağlamda mimar ve mühendisler üzerinde kaynakların yönetilmesi ile ilgili büyük sorumluluk mevcuttur. Gelecek nesillere yeterli miktarda kaynak bırakılması ve günümüzün ihtiyaçlarının karşılanması onların sorumluluğundadır. Bu nedenle, sürdürülebilirlik kavramı yıllar içerisinde ortaya çıkmış ve günümüzde üzerinde en çok durulan konulardan biri olmuştur. Sürdürülebilirlik, mimari tasarımda da önemli bir yer edinmektedir. Binalarda enerji kullanımı azaltılarak kaynakların sürdürülebilir kullanımı desteklenmektedir. Çünkü insanlar, vakitlerin önemli bir kısmını iç mekanlarda geçirmektedirler. Gündüz gün ışığından en çok yararlanılan saatlerde çoğu insan ofis mekanları içindedirler. Bu tez kapsamında da gölgeleme elemanı kullanılarak ofis binalarında enerji kullanımının düşürülmesi ile ilgili optimizasyon çalışması yapılmıştır. Gölgeleme elemanları özellikle güney cephesi cam olan binalarda güneş ışınımının kontrolünü sağlayarak aşırı ısınmaya engel olmaktadır. Bu çalışmada, güney cepheye entegre edilmiş organik, üçgensel geometrili gölgeleme elemanının değişkenleri, evrimsel algoritma olan HypE genetik algoritmasıyla çok amaçlı optimizasyon problemi olarak çözülmüştür. Problemin iki amacından biri cam iç yüzey sıcaklığının yıl içerisindeki her saat için 20°C ile 27°C dereceler arasında değer almasının maksimum seviyede olması diğeri ise iç mekanın aydınlatılması için minimum enerji harcanmasıdır. Önerilen bu organic üçgensel geometrili gölgeleme elemanının performans

değerledirmesi için bilinen yatay gölgeleme elemanı ve düz üçgensel geometrili gölgeleme elemanı ile beraber gölgeleme elemanının bulunmadığı örnekler çalışılmış ve karşılaştırılmıştır. Öncelikle her bir gölgeleme elemanı için test geometrisinin gölgeleme elemanlı ve elemansız enerji simulasyonu Rhinoceros eklentisi olan Grasshopper'da modellenmiş ve onun eklentisi olan Ladybug-Honeybee programında değişkenler belirlenmiştir. "Octopus" Grasshopper eklentisi hazırlanan değişkenlere bağlanarak iki amaçlı optimizasyon problemine "pareto front" temelli sonuç kümesi vermektedir. Alınan sonuçlar kümeden seçilerek değerlendirilir. Değerlendirme kriterleri operatif sıcaklık, iç mekan sıcaklığı, toplam güneş ışığından kazanılan enerjidir. Özet olarak, üç ana konu sonuçlandırılmıştır. İlk önce hangi tipin organik, ü çgen tabanlı geometri olan daha iyi performansa sahip olduğu görülmektedir. İkinci olarak, gölgelendirme aygıtı geometrisi, evrimsel algoritmalar yoluyla ü retken modelde bulunabilir. Evrimsel algoritmaların karmaşık mimari problemlere uygulanabileceği bir kez daha gösterilmiştir. En azından, gölgelendirme düzeneklerinin değerlendirme aşamasında, çalışmada yüzey sıcaklığı metriği olan yeni bir metrik belirtilmiştir. Yeni metriğin başarısı, çalışma için iyi bir karşılaştırma elemanıdır ve metrik, literatürdeki diğer çalışmalara yardımcı olabilir.

Anahtar Kelimeler: gölgeleme elemanı, enerji etkin tasarım, çoklu amaçlı optimizasyon, enerji simulasyonu, genetik algoritmalar

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Ayşegül Öykü Görgün
İzmir, 2019

TEXT OF OATH

I declare and honestly confirm that my study, titled "SHADING DEVICE DESIGN AND OPTIMIZATION VIA GENETIC ALGORITHM BY USING SURFACE TEMPERATURE METRIC AND ELECTRICITY LOAD" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Ayşegül Öykü Görgün

Signature

…………………………………..

July 22, 2019

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

FAO	Food and Agriculture Organization of United Nations
IFAD	International Fund for Agricultural Development
UNICEF	United Nations International Children's Emergency Fund
WFP	World Food Programme
NHAPS	National Human Activity Pattern Survey
IEA	International Energy Agency
HVAC	Heating, Ventilation, Air Conditioning
3D	3 Dimentional
ifc	Industry Foundation Classes
CFD	Computational Fluid Dynamics
MOO	Multi Objective Optimization
EPW	EnergyPlus Weather
HypE	Hypervolume Estimation Algorithm
SPEA 2	Strength Pareto Evolutionary Algorithm
ASHRAE	American Society of Heating Refrigerating and Air Conditioning Engineers
N/A	Not Available
RAD	Radiance
RGB	Red Green Blue
CHSD	Conventional Horizontal Shading Device
FTGB	Flat Triangular Grid Base
OTGB	Organic Triangular Grid Base
T0	Type 0
T1	Type1

T3	Type 3
GA	Genetic Algorithms
STM	Surface Temperature Metric
ELL	Electrical Lighting Load
NHIB	Number of Hours In Between
TNHY	Total Number of Hour of the Year
CPU	Central Processing Unit
Pro	Professional
m	Meter
GHz	Giga Hertz
GB	Giga Byte

SYMBOLS:

U-Value	Thermal Transmittance
h	Height
l	Length
d	Depth
l_w	Window Length
h_w	Window Height
%	Percentage
º	Angle Degree
°C	Centigrade Degree

CHAPTER 1
INTRODUCTION

The world population is growing year after year. In 2017 world population reached to 7.6 billion according to the data of the United Nations. In addition to that world population is expected to reach to 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100 according to medium variant projects made by the United Nations(United Nations, 2017). Thus, both, the world population and the usage of the natural sources are increasing. This increase brings a lot of problems in its wake such as undernourishment, economic problems, social issues, health issues over-consuming energy sources etc.(FAO, IFAD, UNICEF, WFP, 2018).

In this respect, protecting the natural sources is people responsibility. Therefore, people had better live more carefully in order to provide the sustainability of the natural sources to the next generations. Sustainability is defined as the quality of being able to go on beyond a period of time by the Cambridge Dictionary and usage of that word has become widespread in literature since beginning of the 1990s (Kuhlman & Farrington, 2010). Additionally, sustainability is the intersection of three main dimensions, which are economy, environment and society as seen in Figure1.1 (Keiner, 2006).

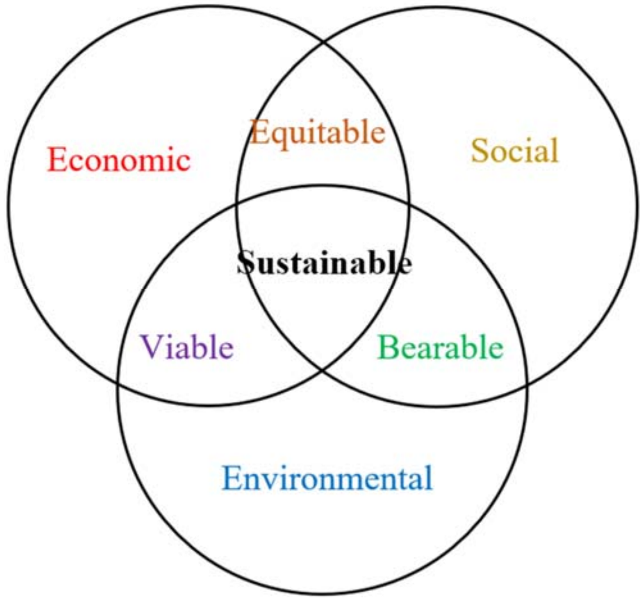


Figure 1 Sustainability Venn Shema

According to the National Human Activity Survey (NHAPS), people spend their times indoors mostly (Klepeis et al., 2001). As outcome of the survey, participants spent 68.7 percent of their time in the residential buildings, Other indoor locations have 11 percent, office-factory has 5.4 percent of the time spent. In a vehicle and outdoor, people spent just total 13.1 percent of their times. It means that the indoor environmental quality is one of the most important worthiness for them. If the indoor air temperature, humidity or air quality get worse, people will begin to open the windows or air conditioner to improve indoor air quality. If it is possible, this action will cause to reduce the amount of over energy consumption. In most of the high-rise buildings occupants never have the chance to open windows or change the air conditioner performance, for instance, Burj Khalifa in Dubai, United Arab Emirates.

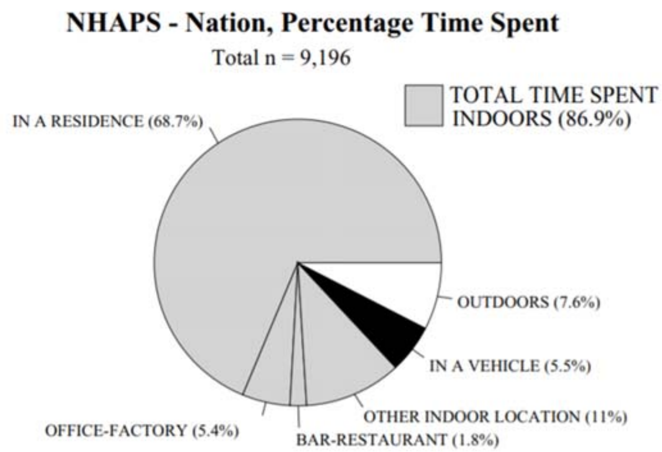


Figure 2 Spending Time Indoors (Klepeis et al., 2001)

International Energy Agency (IEA) publishes overview every year about energy consumption. According to this overview (2016), the energy consumption in residential and commercial and public services are up to 30% of total final consumption (Agency, 2018). Some IEA member countries consume energy more than 50 percent in buildings for heating and cooling directly (International Energy Agency, 2008).

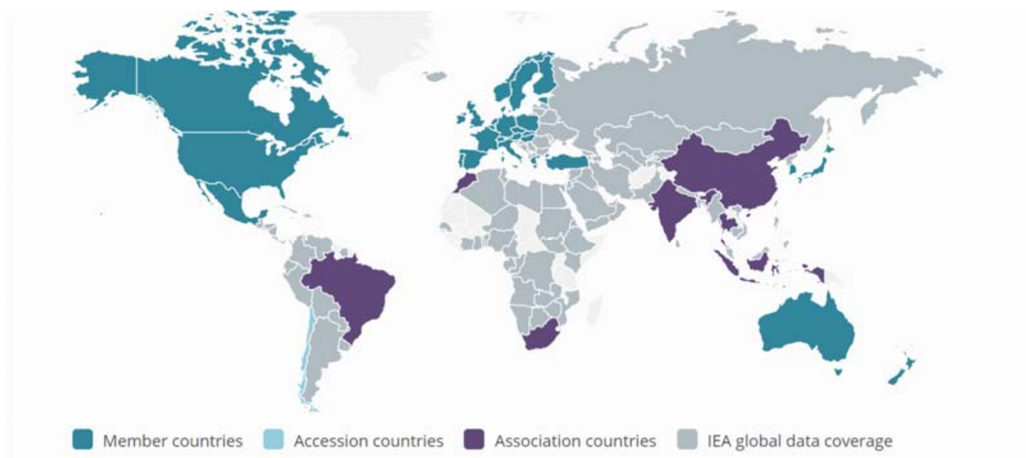


Figure 3 International Energy Agency

The buildings consume most of the total energy usage in the world. In the time line of architecture, this problem has always occurred, in response to this, architects and engineers have searched for solutions. Over energy usage in buildings may originate from several reasons. These are not only limited by lack of insulation, design errors, building program but also many others. Accordingly, one of the most important reasons is the flow of the energy from inside to outside or its reverse. This is gathered from the thermal transmittance value (U-value) of windows and walls. The bigger part of the heat losses is from the windows due to the losses through its U-values; therefore building envelope design has an important role to decrease the heat transfer from the glass (Mirrahimi et al., 2016). Solution to this problem is either to prevent the problem at the very beginning or to enhance the situation by retrofitting. This study aims to find solution to that problem on design stage.

Architects and engineers have an important role to decrease of the energy consuming for years. They have brought a matter to a solution in order to minimize the damage of the over energy consumption. In their solutions, they benefit from both natural cycle specifications like the motion of the sun and natural ventilation, and geometric specifications of their design such as orientation of the building, opening ratio etc. They assist the architect or engineer to design the living space better for human and nature.

There are several causes that increase the building's heating and cooling loads such as huge amount of radiation, lack of infiltration, wrong orientation of building and so on. Designers have developed passive and active systems to be up to loads. The passive systems that are connected with designing the building conveniently to conditions its location works without stimuli and actuators. The active systems help the passives to be applicable for the instantaneous conditions, at the same time they can be an individual system. For instance, the shading devices can be fixed when they get involved in the passive systems. The passive system can turn into an active system when a mechanism is attached to the system to make it kinetic, adaptive or responsive. On the other hand, ventilation system can be passive or active individually such as HVAC system (Heating-Ventilation-Air Condition) integration (active) and natural ventilation (passive). After all, these systems affect the indoor environmental quality positively, if they integrated according to the needs and requirements.

1.1. THE AIM OF THE STUDY

Architects and engineers encounter a lot of problem in design phase. They have to make a decision about some issues. In order to come through the issues, they develop their own procedures based on international standards. However, some problems are not identified in these standards. In that point, they are alone while making a decision that affects the user of the design directly.

First, as a good question, how can be evaluate the shading devices which form via genetic algorithms by using developed metrics? And how much be convenient its design phase to improve itself? Does the shading devices be more organic provide performing better? When joining these questions in a study, an optimization and form finding approaches comes up to light. The study come into existence from these questions.

In the light of the knowledge mentioned above and to find a solution the research questions, goal of the study is designated. This study aims decreasing over energy consumption for cooling in office buildings with south glazing façade by using fixed organic shading devices without decreasing the indoor luminousness.

1.2. THE SCOPE OF THE STUDY

The scope of this thesis includes the optimization of an energy efficient shading device integrated onto the south facing façade of an imaginary test box. The location of the test box is assumed to be in Izmir, Turkey. The building function is assumed to be an open office area for the test box as people spend their time in the work place most. When simulation geometry is generated, the walls, the floor and the roof are accepted as adiabatic surfaces. Escaping energy from other facades except for the south façade is blocked. Geometry of shading device is modelled like a double skin with triangle openings that surround the south façade. Every single object like box surfaces and shading devices are parts of the simulation. It is not easy to find the form of the shading device geometry that perform better because of the amount of the variables. The multi objective optimization with genetic algorithms as a meta-heuristic approach is preferred to save time during simulation process.

The modeling has been done in Rhinoceros 3D Modelling Plug-in Grasshopper, while the simulations have been done in Open Studio based Ladybug-Honeybee (Sadeghipour Roudsari, Pak, & Smith, 2013) which is a Grasshopper plug-in and the optimization has been done in Grasshopper Plug-in Octopus. In order to optimize the geometry of the shading device, a genetic algorithm is used. The hourly values of both the electrical lighting load and surface temperature metric are the outputs of the simulation that have been utilized as objectives of the multi objective optimization.

1.3. THE LIMITATIONS OF THE STUDY

This study has potential limitations. First, some limitations are presented to understand the performance of the shading device clearly. This study has been done for only one zone and the test box is single floor area. The zone program is selected open office area. Through a year, performance of the shading devices integrated south façade glazing evaluated. Multi-objective optimization has been done with just one genetic algorithm and it has 100 population and 50 generations. Population size and generation count are limited due not increase the computational time it takes to run the simulation and optimization.

In addition to this, shading devices are assumed that they are fixed on the south façade. So, their structural performance in terms of stability and durability is not in the scope of this thesis. Productions of the shading devices are not involved in the study also. Just they are given in the conclusion as a further study.

1.4. THE DEFINITIONS OF THE TERMS

The terms are explained in this part of the study, because after this chapter they are used frequently.

The Surface Temperature: In this thesis the surface temperature states the mean temperature value of the glazing indoor surface for each hour of the year. Increasing the surface temperature means that the indoor air temperature and the radiation are also increasing. Thermal comfort of the space is positively affected by keeping this value in between comfort values.

Indoor Air Temperature: Indoor air temperature is the mean air temperature for each hour of the year of indoor space. The value is directly related with human indoor comfort. Higher indoor temperatures in summertime reduce the thermal comfort of space. This causes the cooling load to increase to keep the occupants of the space in a comfortable state.

The Operative Temperature: Temperature of an imaginary environment in which, with equal wall (enclosing areas) and ambient air temperatures and some standard rate of air motion, the human body would lose the same amount of heat by radiation and convection as it would in some actual environment at unequal wall and air temperatures and for some other rate of air motion (Radu et al., 2012).

Solar Gain: The (passive) solar (heat) gain is the sum of the radiation comes from outside to inside unless they are reflected. The glazing surfaces provides the solar radiation which heats up the space and create greenhouse effect. Controlling the solar gain plays an important role on achieving space with good thermal performance.

Cooling Load: The cooling load is the amount of energy to keep the indoor space in the comfort zone especially during summertime for the occupants of the space.

Electrical Lighting Load: The space needs to be illuminated for people to perform certain tasks which requires different required illumination values. If the daylight performance of the space is not enough additional artificial lighting is also required to provide required illumination. The electrical lighting load is the energy consumption of the artificial lighting.

The Surface Temperature Metric: The surface temperature metric how much the surface is in between 20°C and 27°C by counting the hours when the surface is in between selected temperatures then dividing it by the value of 8760 which is a year in hours.

Pareto Front: Pareto front is the set of non-dominated solutions which being chosen as optimal, if no objective can be improved without sacrificing at least one other objective.

Multi Objective Optimization: Problems are related more than one objective in the real world are called multi objective problems. In mathematics most related two objective optimize to solve the complex problems. This technique of the optimization is called multi objective optimization.

Genetic Algorithm: Genetic algorithms are algorithms that are usable for the solving optimization problems with their lifelike behavior. They based on natural selection and genetics.

Evolutionary Algorithms: Evolutionary algorithms are population based metaheuristic algorithms. They have several phase which are used by originating biological evolution, such as mutation, crossover, selection, reproduction, termination.

1.5. THE OUTLINE OF THE THESIS

This thesis is composed of five chapters. Chapter 1 is the introduction of the study. It includes general acknowledgement, scope, limitations, aim of the study. This information let the reader understand process.

Chapter 2 explains development of the energy efficient design and the studies in the literature in similar context.

Chapter 3 expresses the history and the usage of the shading devices. First, place of the shading devices in literature, types of the shading devices and their aims are demonstrated, and after that, the development of the shading devices in time and their samples since the first use of shading device term are explained.

In Chapter 4 Methodology, three phases of the study are expressed in the different sections. These phases are form finding, simulation and optimization and their sub-sections. Chapter 4 is the most annotative chapter to learn the methodology. It refers geometry of test box and shading elements, simulation, inputs outputs and settings and the optimization methods.

Chapter 5 is the Results and Discussion demonstrates the results of the simulation and optimization. Performance of the types are evaluated in regard of different outputs in this chapter.

Finally, the inferences and progress of the work and further study are explained in the Chapter 6.

CHAPTER 2
LITERATURE REVIEW

2.1. PERFORMANCE BASED DESIGN

Performance based design is an approach to complex design of the buildings. Meaning of the performance often is depicts as a commonly used phrase in architecture (Shi, 2010). There are three fundamental aspects of performance based architectural design. First of all is structural performance of the design. Because buildings have the most important reason of the existence provide protection area safely. Secondly, another important point is Building physics performance. It includes solar control, thermal performance, humidity ratio, ventilation etc. It is associated the human comfort directly. In this chapter, the sub-titles of this subjects are examined. Third of the performance subject is the aesthetic performance which is also important one. All the time, buildings are seen a sign by the public. They ascribe a meaning to the buildings, hence the appearance, indoor color, texture and decoration, circulation have huge significances.

2.1.1. ENERGY EFFICIENT DESIGN

There are so many studies in the literature about minimizing energy consumption in the buildings. Researchers focus on this subject and find a solution for a while so the review papers are prepared as the result of this studies(Zhao & Magoulès, 2012). Additionally, lots of research also compared the conventional buildings and low energy building, in researches, some of them are about the residential buildings, some of them are about the office buildings and others. In the result of this researches, office buildings consume extremely big amount of energy (Pérez-Lombard, Ortiz, & Pout, 2008). Also, some of the studies focus on the indoor parameters, while others focus on the outdoor parameters. In the previous sections, why the façade design is so serious and affect the indoor environmental quality directly. If the glazing façade is used, opaque façade elements may be integrated in order to avoid over-heating problem. These elements are called shading devices. Furthermore, in several cases, shading devices with any openings become a double skin that covers the building's primary skin. These may cause overheating if they do not have air passages. In this study, building surrounded by a double skin with openings is discoursed.

2.1.1.1. Passive Systems

Passive building design is the efficient way to reduce the energy infiltration via design and natural resources. Main components of passive design may be summarized as envelope, orientation, fenestration, walls, roofs, floors and vegetation. As a strategy of passive design without any actuator or stimuli, the buildings design energy efficient by helping insulation or thermal storage materials, additional components such as shading devices. Passive systems generally consist of passive cooling and heating. The envelope of building, orientation and glazing are the primary element for the passive design (Pacheco, Ordóñez, & Martínez, 2012).

There are also a lot of secondary passive design strategies that are utilized in the design of passive building structure such as wind protection, green roofs (Porteros et al., 2014).

Table 1 Passive Systems

Passive System Solutions		
Heating	Cooling	Thermal Energy Storage
Double Skin Facade	Shading Devices	Thermal Mass
Wall Solutions (Trombe, Water)	Ventilation Solutions (Natural, Night)	Phase Change Material
Greenhouse, sunspace, winter garden	Evaporative Cooling	Under Ground Spaces
Direct and Indirect Solar Gain	Stack Effect	
Solar Chimney		
Orientation		

2.1.1.2. Active Systems

Beside the passive systems there are number of active systems too such as HVAC. These systems are mostly setting the buildings where cannot apply passive systems like skyscrapers. It may consume huge amount of electrical energy. Therefore, a paradigm is showed up because the usage of the active systems is expected to decrease the energy consumption. Consequently, the active systems are not preferred in this study.

2.1.2. EVALUATION OF THE ENERGY EFFICIENT DESIGN

In the literature, energy efficient design performs depending on some criteria. These are dimensions of the opening ratios and the locations, the orientation of the buildings, the geometric design, the insulation material, circulation of the ventilation. Before implementation of any solution to the buildings, efficiency of the systems may be checked via simulation tools and optimized their parameters. Mostly in architectural problems, decision variables have floating numbers and due to number of variables it is not an easy task to decide. Therefore, optimization helps architect to make a decision about parameters.

2.1.2.1. Simulation

A lot of study works on the energy efficient building simulation, they include different zone, programs, climates, location, parameters, tools. In this section, some of these studies are explained and development of this subject is demonstrated. Relevant works with this thesis and differences between of the are examined also.

From the beginning of the use of computer aided design tools, simulation approaches are developed also. Some of them have data-driven models and the others have law-driven models. In law-driven models, firstly detailed physical model is set up then data is simulated. In the data-driven models, the process is like that respectively measuring data, setting up statistical model and setting up detailed physical model (Coakley, Raftery, & Keane, 2014). The simulation tools are compared with their capability and ease of their use many times (Allegrini et al., 2015). In Allegrini's study it is easily seen that the "EnergyPlus" which is energy simulation program has bigger capacity than most of the other programs. "EnergyPlus" provide the user detailed building simulations. The "EnergyPlus" is a simulation application and its inputs and outputs are based on text documents (Crawley, Hand, Kummert, & Griffith, 2008). OpenStudio is a software to aid all building zones energy modeling via EnergyPlus and a Radiance which is daylight simulation tool ("Open Studio," n.d.). Also, OpenStudio takes the geometry from Ladybug-Honeybee and send to "EnergyPlus" in ifc format. It was created by the National Renewable Energy Laboratory for the U.S. Department of Energy (Rallapalli, 2010). Energy simulation can be done in some others too, such as Diva for Rhino, Design Builder. Daylight simulation also can be done in different tools which is Daysim. There are examples of simulations of the buildings which are analyzed in that software. For example, Diva for Rhino is used for calculating he annual energy consumption in Jouri Kanters et al. study (Kanters, Wall, & Dubois, 2014).

The literature review becomes distinct in simulation types. Mainly, three simulation-based results are shown. These are daylight simulation, energy simulation and CFD simulation in researches. This research focus on daylight and energy simulation in the literature. Energy and daylight simulation of the buildings contain several criteria. First, purpose of the building separates the research for example residential and the commercial buildings. In a study, in residential building, double skin façade modelling has been tried with different geometry compositions. These geometries implemented to the each façade are compared in respect of their energy performance like this thesis (Zomorodian & Tahsildoost, 2018). In a different case, the shadings and glazing type configuration are modelled in hot humid climate. Double glazing and egg create shading devices reduce the energy usage in the study (Khin, Lau, Salleh, Lim, & Sulaiman, 2016).

The subject of this thesis; shading devices are analyzed in various cases with different types. The types of the shading devices are explained in Chapter 3 but first, simulations of the sample cases are shown in this section. For example, louvres that are a type of a shading devices uses to protect the indoor from the over-heating. In a study they used for both control the solar radiation and collect the solar gain to heat the water (Palmero-Marrero & Oliveira, 2006). Comparing the shading device types is an important assessment to see the performance of the devices. Samples of the comparison were studied before by some researchers (Dubois, 2003).

2.1.2.2. Optimization

Optimization means “an act, process, or methodology of making something (such as a design, system, or decision) as fully perfect, functional, or effective as possible” according to Merriam- Webster Dictionary. After the first use this term, it is developed by researchers and scientist in time. Today, optimization is utilized to solve the complex problems of any department of science as a solving approach.

Optimization approaches in architecture is used for many years to minimize the energy demand and consumption of the buildings. Providing the thermal performance require to be achieve some problems such as both keep the large opening for visualization and decrease the cooling load. Like these the problems are conflictive necessities for the architect due to amount of the variables. Another challenge is that the value of variables is not discrete. It causes the problem does not solve deterministic approach. Therefore, the optimization approaches are used frequently in the architectural problems in the design phase.

By using the computer-based simulation tools and rising algorithmic design, solving complex design problems becomes to main topic of the academia. Various methods are applied to the design problems which are found for engineering problems first. Then specifically design solution methods are found and applied in time. According to research of Nguyen, even existed studies about building related optimization in literature in 1990s, after 2008 rate of incidence of the optimization methods of building has raised rapidly (Nguyen, Reiter, & Rigo, 2014).

In 1990, N. M. Bouchlaghem and K. M. Letherman studied on optimization method to solve passive building thermal design problems. Their study clearly shows that the standard numerical optimization methods can be applied for solving the thermal design.

After former studies on optimization, multi-objective optimization methods are more applicable for the problems have conflicting multi objectives due to provide non-dominating sorting. This methodology lets the designer pick intended solution from Pareto front. The solution may be chosen by the designers according to their design concerns (Touloupaki & Theodosiou, 2017b).

Genetic algorithms which are very suitable for the multi-objective optimization problems can be explained a sorting method that are like natural genetic process. They have individuals or chromosomes as a solution vector, and they are composed of genes which are discrete units. Population is also a genetic algorithm term that includes individuals. Then the solutions make new solution by manipulating the solution with two factor which are mutation and crossover like the natural genetic variability.

According to general known, two parents combined to create a new child offspring (Konak, Coit, & Smith, 2006).

In literature, previously, researches about that approaches have been done. Energy efficient building envelope is a popular problem for optimization studies. In Tuhus-Dubrow's study, they minimize energy usage in residential with optimization tool that developed by them by changing the building layout shape and envelope material features (Tuhus-dubrow & Krarti, 2010). In a different case, with a diversified approach (deterministic optimization), shading devices are optimized according to daylight efficiency (Manzan, 2014). In early design stage, some studies are done about minimizing energy usage in free-form building envelope with genetic algorithms (J. T. Jin & Jeong, 2014).

Multi-objective optimization uses in some other studies, Wang et al. use the strategy to solve green building design problems which are life cycle cost and life cycle environmental impact (Wang, Zmeureanu, & Rivard, 2005). The end of the study, they found solution which cost effective and faced the negative effect of the waste.

As a similar study of Toutou is about multi objective optimization building material specifications. And in that study, as a generative model tool Grasshopper, as a simulation tool Ladybug-Honeybee and as a optimization tools Galapagos and Octopus are utilized (Toutou, Fikry, & Mohamed, 2018). In the result of the study, process of the optimization is clarified and best daylight and energy performance solution is shown.

Objectives are selected to tackle design problems according to the type of the problem. In some problems Useful Daylight Index (UDI), Summer discomfort, heating and lighting load are selected (A. Zhang et al., 2017), in another long-term percentage of dissatisfying was selected (Carlucci, Cattarin, Causone, & Pagliano, 2015).

The following reviews of the literature includes energy simulations of some samples with and without optimization methods and they explain that which parameters are evaluated in that studies.

Table 2 Literature Review

References	Year	Author(s)	Paper Name	Studied Location	Simulation Type	Simulation Tool	Optimization	Parameters	Objectives	Shading Type	Glazing Type	Climate Type	Building Type	Study Type	Notes
(A. H. Sherif, Sabry, & Gadelhak, 2012)	2012	Ahmed H. Sherif Hanan M. Sabry Mahmoud I. Gadelhak	The impact of changing solar screen rotation angle and its opening aspect ratios on Daylight Availability in Residental Desert building	Jeddah - Saudi Arabia	Daylight Simulation	Diva for Rhino (Radiance and Daysim)	No			Egg Crate	No glazing type is mentioned.	Hot Arid	Residential	Theorical	In the study, Dynamic Performance Metric and Daylight Glare Probability metric are utilized to evaluate the solar screen. Division ratio is an significant aspect which is selected 3:1 after simulations.
(Al-Masrani, Al-Obaidi, Zalin, & Aida Isma, 2018)	2018	Salwa M. Al-Masrani Karqam M. Al-Obaidi Nor Azizah Zalin M.I. Aida Isma	Design Optimization of Solar Shading System for tropical office buildings: Challenges and future trends	Kuala Lumpur - Malaysia Libreville - Gabon Fortaleza - Brazil											In this study 3 phases are discussed which are design phase of the shading elements, passive systems with zero energy consumption and active systems with mechanical devices.
(Lim, Hirning, Keumala, & Ghafar, 2017)	2017	Gene-Harn Lim Michael Barry Hirning Nila Keumala Norafida Ab. Ghafar	Daylight performance and users' visual appraisal for green building office in Malaysia	Putrajaya, Kuala Lumpur -Malaysia	No	No	No	No	No	Light Shelf,Eave Egg Crate, Diagonal Glazing	Glazing Transmittence: %53, %54 Blind Transmittence : %8, %30	tropical and sub-tropical climates	Green Office Buildings	Experimental	2 different building are used for this study which evaluate the Daylight Factor. It is shown that the results are more related with users and space than designer in terms of daylight effectiveness.
(Beaman, 2010)	2010	Michael Leighton Beaman Stefan Bader	Responsive Shading Intelligent Façade Systems	Austin Texas - USA	Responsive							Sub tropical humid climate	Test Box	Experimental	The experimental study shows the extrusion how much important.
(Q. Jin, Favoino, & Overend, 2017)	2017	Fabio Favoino Qian Jin Mauro Overend	Design and control optimization of adaptive insulation system for office buildings. Part 2: AA parametric study for a temperate climate	Ludwigshafen Germany								Temparate continental climate	Office	Theorical	The study evaluates the adaptive insulation of the building. The design choices and the control strategies are lead to improve the performance according to this study.
(Chi, Moreno, & Navarro, 2018)	2018	Doris A. Chi David Moreno Jaime Navaro	Correlating daylight available metric with lighting, heating and cooling energy consumption	Seville	Daylight Simulation Thermal Performance	Diva for Rhino (Radiance and Daysim)	Corelation	Perforation Percentage Matrix of Hole	Lighting, Cooling, Heating Energy	Perforetion 2D	Visible Transmittance : %78.1 Solar Transmittance : %60.4 SHGC : 0.703 U-Value : 2.785 W/m2K	Warm and Temperate	Open Office	Simulation	The study examines the performance of the sun screen by using DAv metric and energy consumption nad by changing percentage of the opening. The results shows the relation between overlit area and cooling energy.
(A. Sherif, El-Zafarany, & Arafa, 2012)	2012	A. Sherif A. El-Zafarany R. Arafa	External perforated window Solar Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments	Kharga Oasis - Egypt	Thermal Performance	Energy Plus	Corelation	Perforation Ratio Depth Ratio	Lighting, Cooling, Heating Energy	Egg Crate	No glazing type is mentioned.	Hot Arid	No input data is given.	Simulation	The study evaluates the solar screen performance by changing perforation ratio and depth. In the result, they found the optimum ratios which are %80 - %90 for perforation and 1:1 for depth.

References	Year	Author(s)	Paper Name	Studied Location	Simulation Type	Simulation Tool	Optimization	Parameters	Objectives	Shading Type	Glazing Type	Climate Type	Building Type	Study Type	Notes
(Su, Li, & Xue, 2017)	2017	Ziyi Su Xiaofeng Li Fei Xue	Double-skinfacade optimization design for different climate zones in China	Harbin, Beijing, Shanghai, Guangzhou China	CFD		Corelation	Type of oppening opening width	Heat Gain RCI	Double facade		Extreme Cold Region Cold Region Hot-summer and cold winter Region Hot summer and warm Winter Region		Theorical	This study presents the hourly and total heat gain values for double skin facades by using Computational Fluid Dynamics Methods. It is found optimal solutions in the result of the study.
(Zomorodian & Tahsildoost, 2018)	2018	Zahra S. Zomorodian Mohammad Tahsildoost	Energy and carbon analysis of double skin facade in the hot and dry climate	Tahran - Iran	Energy Simulation	Energy Plus Design Builder	Corelation		Energy Carbon Cost	Double facade	Glass (internal) U:5.50 Glass (external) U: 2.40 Window frame (aluminum) Internal glass U:4.70 External glass U: 0.75	Bsk	Office	Theorical	With the dynamic simulation the main problem of the double skin façade are studied in this study. The result of this study is shown that the energy consumption is reduced from 7,9% to 14,8%.
(Khoroshiltseva, Slanzi, & Poli, 2016)	2016	Marina Khoroshiltseva Debora Slanzi Irene Poli	A Pareto based multi objective optimization algorithm to design energy efficient shading devices	Madrid	Daylight Simulation Thermal Performance	Static Shading Device	Yes Evolutionary Algorithm based Harmony Search		Change in Energy Demand Area Overheating	Static Overhang	No glazing type is mentioned.	Mediterranean	Residential	Simulation	This study shows that the multi objective optimization approach provide an effective procedure to find optimal shading device when the conflicting objects are used.
(Manzan, 2014)	2014	Marco Manzan	Genetic Optimization of External Fixed Shading Devices	Rome, Trieste - Italy	Daylight Simulation Thermal Performance	Daysim	Yes NSGA-II Mode Frotier Tool	Angle Length	Length Energy Consumption Daylight	Conventional Horizantal Shading Device	Standart double glass high performanc glazing system	warm-temperate subtropical climate Marine West Coast Climate	Office	Simulation	The shading device is studied for the reducing cooling load in summers by using genetic optimization to find optimal geometry of the device. The result shows that the electrical lighting must be taken into account in energy efficient design.
(Niloufar, Khodadadi, & von Buelow, 2014)	2014	Niloufar Emami Anahita Khodadadi Peter Von Buelow	Design of Shading Screens Inspired by Persian Geometric Patterns: An Integrated Structural and Daylighting Performance Evaluation	Phoenix - Arizona - USA	Daylight Simulation Min 500 lux Structural Performance	Diva for Rhino (Radiance and Daysim) ANSYS	Yes Non-Destructive Dynamic Population GA (ParaGEN)	Depth of Screen Perforation Ratio Sectional Sbtruct Curve	Daylight (Mean Daylight Autonomy) Structural Performance	Persian Geometric pattern	Single Pane	Cooling Dominant Location	Office	Theorical	The Persian geometric shading devices are studied in terms of structural and daylight performance. In similar climatic regions, different types of the Persian shading devices can be usable in this study result.
(Ahmed Sherif, El-zafarany, & Arafa, 2013)	2013	A. Sherif A. El-Zafarany R. Arafa	Evaluating the energy performance of external perforated solar screens: effect of screen rotation and aspect ratio	Kharga Oasis - Egypt	Daylight Simulation Thermal Performance	Energy Plus	Corelation	Angle	Energy Consumption	Conventional Horizantal Shading Device	No glazing type is mentioned.	Hot Climate	No input data is given.	Theorical	External solar screens are compared with different dimensions of perforation ratio in this study. The result of that provide energy saving approximately %16.

References	Year	Author(s)	Paper Name	Studied Location	Simulation Type	Simulation Tool	Optimization	Parameters	Objectives	Shading Type	Glazing Type	Climate Type	Building Type	Study Type	Notes
(Azadeh Omidfar, 2015)	2015	Azadeh Omidfar	Performance evaluation of complex facades using various shading systems with ornamental patterns	New York - USA	Daylight Simulation	Diva for Rhino (Radiance and Daysim) STAADPro	Yes Gene arch DOE2	Pattern density	Radiation Daylight Autonomy	Vertical Varonoi	CIBSE void glass glazing double pane clear	Cold and Temperate	Office	Theorical	The various shading systems are studied via ParaGen methods.
(Yang, Sun, Turrin, Buelow, & Paul, 2015)	2015	Ding Yang Yimin Sun Michela Turrin Peter von BUElow Joop Paul	Multi-objective and multidisciplinary design optimization of large sport building envelopes : a case study	Guangzhou - China	Daylight Simulation Thermal Performance Structure analysis	Ladybug Honeybee Karamba	Computation Design Optimization Multidisiplinary Design Optimization Modefrontier NSGA-II	Plan dimention in the X axis roof height glazing ratio truss depth chord diameter chord thickness web diameter web thickness	DA Energy Use Intensity Total Mass	no shading device	No glazing type is mentioned.	humid subtropical monsoon	Sport Hall	Theorical	In this study three different discipline are studied at the same time and alone for evaluating the envelope of the large sport building.
(A. Zhang et al., 2017)	2017	Anxiao Zhang Regina Bokel Andy van den Dobbelsteen Yanchen Sun	Optimization of thermal and daylight performance of school buildings based on a multi- objective genetic algorith in the cold climate of china	Tianjin - China	Daylight Simulation Thermal Performance	Ladybug Honeybee	Yes Octopus SPA better NSGA-II	Interface type with outdoor	UDI Summer Discomfort Heating and Lighting	No or some overhang	No glazing type is mentioned.	cold	school	Theorical	The study investigates three different corridor type to increase UDI and reducing summer discomfort by using simulation and optimization tools.
(Carlucci et al., 2015)	2015	Salvatore Carlucci Giulio Cattarin Francesco Causone Lorenzo Pagliano	Multi-objective optimization of a nearly zero energy building based on thermal and visual discomfort minimization using a non-dominated sorting genetic algorithm (NSGA-II)	Mascalucia	Daylight Simulation	Energy Plus	java genetic algorith package	udi nsga-ıı	Long term percentage of dissatisfied	no shading device	No glazing type is mentioned.	Mediterranean Csa	office	Theorical	The study aims the decrease thermal and visual discomfort by using optimization in net zero energy buildings. In the result of this study, in order to effectively explore the large number of available building variants, some optimization approaches are recommended.
(Hou, Wang, Dang, Liu, & Zhang, 2016)	2017	Dan Hou Gang Liu Qi Zhang Lixiong Wang Rui Dang	Integrated Building Envelope Design Process Combining Parametric Modelling and Multi Objective Optimization				Matlab modeFRONTIER GenOpt GENE_ARCH ParaGen				No glazing type is mentioned.		Railway Station	Theorical	The case study illustrates that IBEDP is not only effective in minimizing the total energy con- sumption and envelope cost while maximizing the daylight utilization, but also useful in exploring diverse design solutions.

References	Year	Author(s)	Paper Name	Studied Location	Simulation Type	Simulation Tool	Optimization	Parameters	Objectives	Shading Type	Glazing Type	Climate Type	Building Type	Study Type	Notes
(Gagne & Andersen, 2012)	2012	Jaime Gagne Marilyne Andersen	A generative facade design method based on daylighting performance goals		Daylight Simulation	Sketch Up	GENE_ARCH micro GA	window to wall ratio Number of windows aspect ratio vertical location horizantal location window distribution overhang fins length of shading devices total glass transmissivity per cent specular transmission	Illuminance	over hang	No glazing type is mentioned.			Theorical	Successful daylighting design is a complex task which requires the designer to consider numerous design elements and their effects on multiple performance criteria. Results from single- and multi-objective case studies are presented to demonstrate a successful goal-driven design exploration process.
(L. Zhang, Zhang, & Wang, 2016)	2016	Longwei Zhang Lingling Zhang Yuetao Wang	Shape optimization of free-form buildings based on solar radiation gain and space efficiency using a multi objective genetic algorithm in severe cold zones of China	China	Daylight Simulation	Radiance	MOGA	Area dynamic variables static variables dependent variables	Total Radiation Space Efficiency Shape Coefficient	no shading device	No glazing type is mentioned.	cold	Community Center	Theorical	The design seeks to make buildings receive more direct sunlight within the limits of the user's comfort and simultaneously save energy and space. The proposed method, according to the basic process of architecture design, uses a performance-driven approach to find solutions that satisfy the requirements.
(Favoino, Jin, & Overend, 2017)	2017	Fabio Favoino Qian Jin Mauro Overend	Design and control optimization of adaptive insulation system for office buildings. Part 1: Adaptive technologies and simulation framework	LUDWİGSHAFEN GERMANY	Energy Simulation	Energy Plus	NSGA-II	Insulation		no shading device	highly transparent triple glazing	Cfa Hot summer cold winter	Office	Theorical	This paper is the first of a two-part study, which aims to evaluate the performance of adaptive insulation. In the result of the study the simulation model for adaptive insulation is validated qualitatively.
(Q. Jin et al., 2017)	2017	Fabio Favoino Qian Jin Mauro Overend	Design and control optimization of adaptive insulation system for office buildings. Part 2: AA parametric study for a temperate climate	Shanghai, China				U-Value R-Value				Temparate continental climate	Office	Theorical	For the case study considered in this paper, yearly energy savings and thermal comfort improvements of up to 50% could be achieved by adaptive insulation compared to an equivalent astatic insulation alternative.

References	Year	Author(s)	Paper Name	Studied Location	Simulation Type	Simulation Tool	Optimization	Parameters	Objectives	Shading Type	Glazing Type	Climate Type	Building Type	Study Type	Notes
(Hamdy, Nguyen, & Hensen, 2016)	2016	Mohamed Hamdy Anh-Tua Nguyen Jan L.M. Hensen	A performance comparison of multi objective optimization algorithms for solving nearly-zero-energy-building design problems				Gen Opt	Package of building envelope (PBenv.) Efficiency of lighting and appliances Type of heat recovery unit (efficiency%) Efficiency of auxiliary systems (fans and pumps) Size of buffer tank (Vtank) Insulation level of the buffer tank (Thins) Area of solar thermal collectors Area of photovoltaic module (Apv) Overall efficiency of the photovoltaic Slope angle of photovoltaic module Azimuth angle of photovoltaic module Type of primary heating unit Size of the primary heating unit Supply water temperature from the primary heating unit (Ts) Operating hour start at Operating hour stop at	Primary Energy Life cycle cost Global Cost				Residential	Theorical	Integrated building design is inherently a multi-objective optimization problem where two or more conflicting objectives must be minimized and/or maximized concurrently. The study found that 1400-1800 were minimum required number of evaluations to stabilize optimization results of the building energy model.
(J. T. Jin & Jeong, 2014)	2014	Jeong-Tak Jin Jae-Weon Jeong	Optimization of a free-form building shape to minimize external thermal load using genetic algorithm	Tocumen yangon Lagos Phoenix Tehran Cairo Hong Kong San Francisco London Seoul Chicago Moscow Barentsburg Ipaluit	Energy Simulation	Grasshopper ?	Yes Galapagos	top polygon top length height tilt angle twisted angle azimuth angle	Energy Consumption	Free-form facade	No glazing type is mentioned.	Tropical Arid Temperate Cold Polar	No information	Theorical	This study aimed to propose an optimization process for a free-form building shape in terms of the thermal load characteristic in the early design stage. The results showed that the proposed process could rapidly predict and optimize the variation of the heat gain and loss characteristics that was caused by changing the building shape.
(ElGhazi, Wagdy, Mohamed, & Hassan, 2014)	2014	Y. Elghazi A. Wagdy S. Mohammed A. Hassan	Daylighting Driven Design: Optimizing Kaleidocycle Facade for Hot Arid Climate	Cairo - Egypt	Daylight Simulation	Diva	Yes	opening size rotation angle	Daylight autonomy	kaleidocycle	VT=%80		Living Room	Theorical	This paper presents a facade based on origami: kaleidocycle rings that can be morphed enhancing daylight performance in residential spaces, which complies with both LEED V4 and Daylight availability.
(Mahmoud & Elghazi, 2016)	2015	Ayman Hassaan Ahmed Mahmoud Yomna Elghazi	Parametric-based design for kinetic facade to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns	Cairo - Egypt	Daylight Simulation								Office		It presents a method for the evaluation of kinetic facades system performance using experimental approach. Possible configurations to enhance daylight performance are suggested.

2.2. CONTRIBUTION TO THE LITERATURE

Even though MOO with genetic algorithm becomes widespread for architectural problems, there has been still gap. The study brings a new point of view to solve the over consumption of office buildings by using that methods. It is shown that the solving design problem with evolutionary algorithms may be used one more time. It can be seen easily that this thesis subject is different in some aspect from the studies in the literature. The study aims not only optimize the opening ratio but also extrusion value and angle, base geometry of the shading devices as a free-form geometry.

Additionally, with this approach the typology which is perform better is shown in the study. Another difference is the evaluation phase of the study. The results assess according to different metrics. The keeping the surface temperature in specific range let the indoor temperature be more comfortable for the users. The Surface Temperature Metric is not widespread metric to evaluate the shading device performance. It provides contribution to the literature both new evaluating approach and compatibility of the metric with other results. In addition, after the simulation tool Ladybug-Honeybee launched first in 2013 by Sadeghipour Roudsari, Mostapha, it was updated many times. These simulations were done in the last release of the tool, so they have current results.

CHAPTER 3
SHADING DEVICES

Shading devices are used to control the solar gain and heating in hot climates area. Their effect of the shading devices on the cooling energy and heating energy load could not be ignored in the design. They are reducing the cooling and lighting energy consumption (Tzempelikos & Athienitis, 2007).

Shading Devices should not only provide thermal comfort but also present a good visual comfort (Yener, 2002). Herewith, for keeping balance the visual comfort and thermal comfort some studies are done (Jan Wienold, 2007). At the end, the shading devices that provide them should have low costs and high reliability (Kuhn, Bühler, & Platzer, 2000).

Shading devices have many types as internal and external. As internal shading devices are horizontal and vertical blinds and Persian blinds and roller shades (Kirimtat, Koyunbaba, Chatzikonstantinou, & Sariyildiz, 2016). In this study, internal shading devices does not play a part because of the context and their performance is worse than externals (Atzeri, Cappelletti, & Gasparella, 2014), for this reason external shading devices are explained. There are three main external shading element types overhangs, horizontal or vertical louvers and light shelfs (Bellia, Marino, Minichiello, & Pedace, 2014). In addition to these types deciduous plants have the same function. The horizontal shading elements performs on the south façade better, verticals perform on the east and west facades better. In intercardinal points, egg create type should be better to shade the sun each way.

The shading devices can be separated two main division too. These are static and kinetic devices. Static elements after assembling cannot change or move for this reason they should be evaluated in so many perceptions. Kinetic shading devices can move rotate open close or other do other motions. They need to an actuator and stimuli. They may be stimulated by whether condition such as the temperature, lighting or occupants.

Their actuator also can be various type such as electrical, pneumatic etc. or they have passive actuator that based material specification like phase change material, shape memory materials.

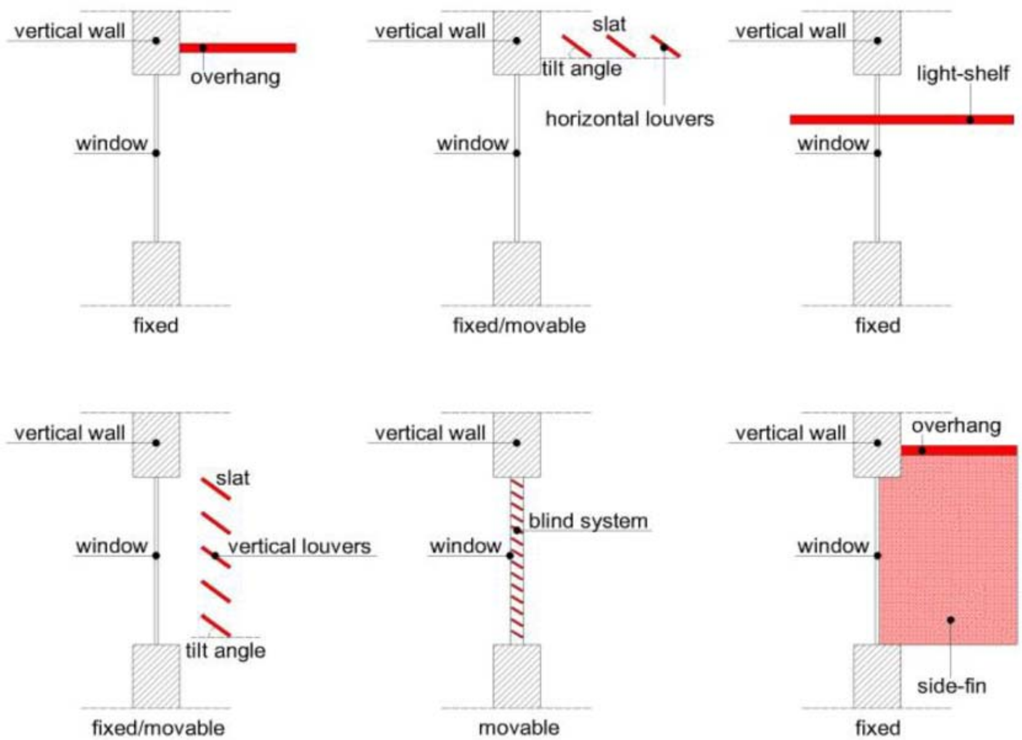


Figure 4 Shading Device Types(Bellia et al., 2014)

2.3. TYPES OF SHADING DEVICES

2.3.3. INTERNAL SHADING DEVICES

2.3.3.1. VENETIAN BLINDS

Venetian blinds consist of horizontal surfaces which are placed a part. They are used to control the daylight and glaring problem of the indoors. They are movable and have changeable angles. Venetian blinds may be applied on the south glazing parts of the building due to horizontal parts.

Figure 5 Venetian Blinds (photo by A.O.G. in a house)

2.3.3.1. VERTICAL BLINDS

Vertical blinds are used also in buildings with vertical surfaces like venetian blinds. They are preferred to apply because of ease of implementation and cost. They may be made in various textures and materials same as venetian blinds.

2.3.3.1. ROLLER BLINDS

Vision blinds have motion up and down around the cylindrical axes. They are used for both control the shading and privacy. When they are fully opened the cover the whole glazing area therefore, their material is very significant. If they have transparent material and texture, the sunlight will be filtered to the interior space and visual contact is provided to outdoor. On the contrary, if it is opaque, it may provide fully privacy and block the sunlight but no visual access to outdoor.

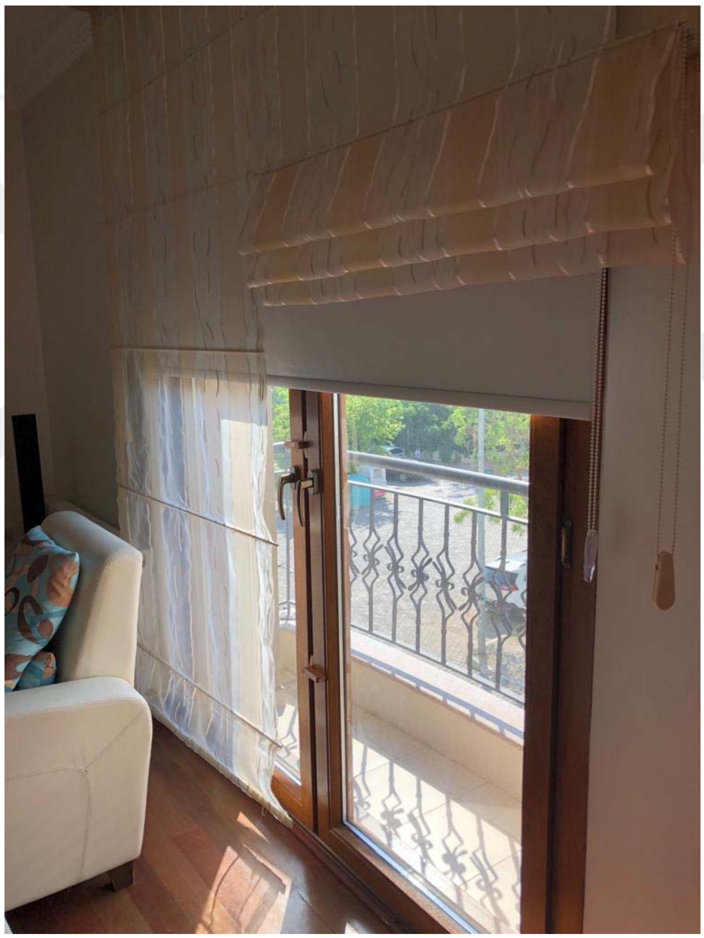


Figure 6 Roller Blinds (photo by A.O.G. in a house)

2.3.3.1. CURTAINS

Curtains are also similar to vision blinds in many respects. They are move horizontally and they made by from transparent to opaque any kind of fabric too.

Figure 7 Curtains (photo by A.O.G. in a house)

2.3.4. EXTERNAL SHADING DEVICES

2.3.4.1. OVERHANG

Overhangs are the horizontal building components upon the south facade windows that they provide shading in summer period mostly. They may be in various dimensions according to sun position and location.

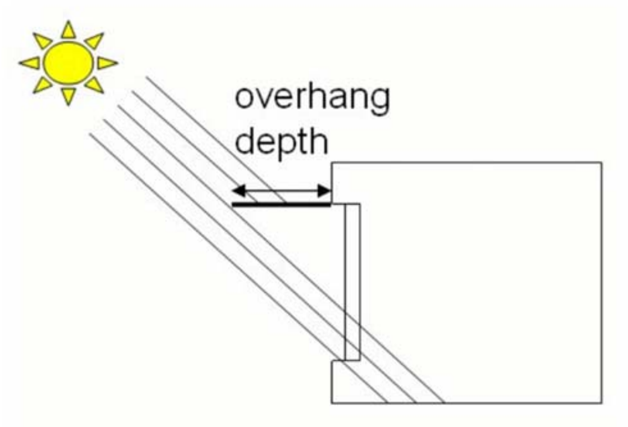


Figure 8 Overhangs (“Overhangs,” n.d.)

2.3.4.1. HORIZONTAL LOUVERS

Horizontal louvers are external shading devices that can be implied the outside of the windows and glazing. They block over-heating and glare. They give the visual comfort to users in the building although according to their dimensions they cause an obstacle to visual contact to outdoor. The horizontal louvers are used mostly on south façade. In this study also this type utilized to compare the shading devices. They made from several materials such as wood, composite, aluminum and so on. The important factor in the selection of the shading devices is color. The color choice affect how much light bounce from the surface of shading device to illuminate the space behind.

Figure 9 Horizontal Louvers (Kirimtat et al., 2016)

2.3.4.2. VERTICAL LOUVERS

Vertical louvers are also external shading devices like the horizontals. They implied outside of the windows and provide control daylight. The reason of the motion of the sun, mornings and afternoons the altitude of the sun is lower than other times in the day and the position of the sun near east or west. Therefore, the sunlight comes through the east or west façade with angle and horizontal. The vertical louvers are very useful on the east and the west facing of the buildings. The other specifications are same as horizontals.

2.3.4.3. EGG-CRATE

Egg-crate shading devices have bi-directional elements that protect the interior space from daylight and glare. In this type of shading devices that is with a depth sunlight may reflect to indoor.

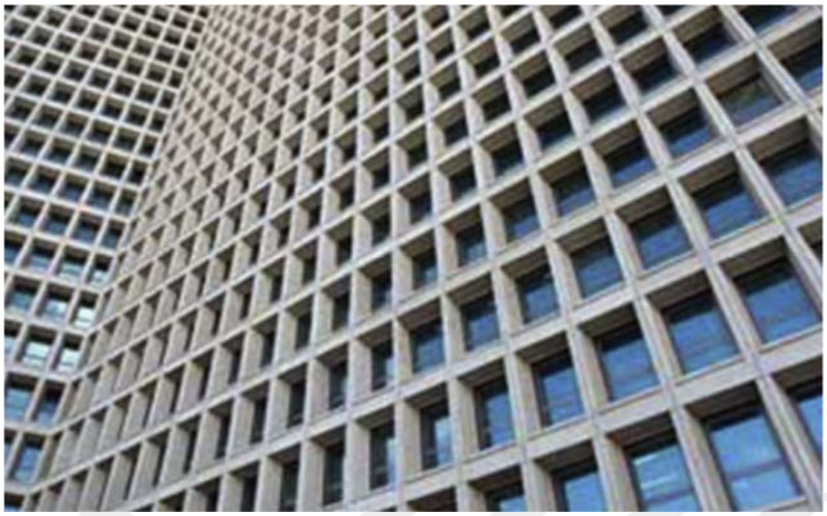


Figure 10 Egg-Crate (Lotfabadi, 2014)

2.3.4.1. DECIDUOUS PLANTS

Some plants called deciduous plants drops their leaves in winter periods and blossom in summer period again. The plants near the building ensure shading to the buildings from spring to autumn. Thereby, the plants may be accounted as a external shading elements.

Figure 11 Deciduous Plants (photo by A.O.G in a house balcony)

For shading, perforated panels may be used outside of the buildings. The panels with various amount of the openings can be utilized not only to block lighting penetration but also to demonstrate a visual concern. In relation to the ratio of the openings of the panels ensure homogenous visual to occupants.

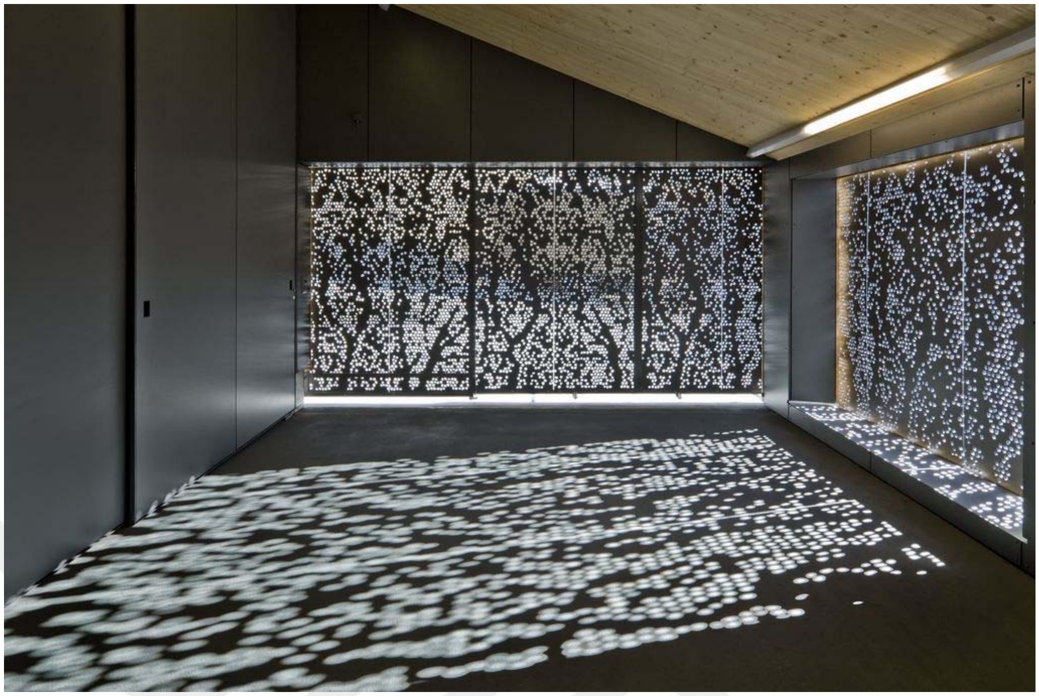


Figure 12 Perforated Panels ("Perforated Panels," n.d.)

2.3.4.2. HYBRID SHADING DEVICES

Some shading devices cannot be classified with types mentioned above. They may compose of more than one types. For example, in Chapter 3 explains a type of shading element is made by perforated panels and extrusions like egg-crates.

2.3.5. FIXED AND MOVABLE SHADING DEVICES

The both internal and external shading devices may be movable and fixed. It is preferred that the internal shading elements are movable mostly. The external shading devices may be both adaptive and static. Adaptive shading devices shades the interior space even though the sunlight angle changes. However, they need stimuli and actuator. It means that they consume some energy. Their stimuli also can be not only sensor-based system but also direct effect of human.

Figure 13 Al-Bahar Tower Responsive Kinetic Shading Devices ("Al-Bahar Tower Facade," n.d.)

Figure 14 One Ocean, Thematic Pavilion EXPO 2012 in Yeosu-si, Jeollanam-do, South Korea by Soma Architecture (*Kinetic Adaptive Shading Device*, n.d.)

2.3.6. DEVELOPMENT OF SHADIN DEVICES

To stay away from the overheating, when a building is designed, energy efficiency must be taken into consideration. Therefore, the methodology of the protection from the sun have been applied to buildings for many years. In this context, shading devices have been developed since the beginning of the use of them in many aspects. First of all, their design are not only conventional types but also, they may be hybrid types. The design of the shading devices takes the advantage of the emerging technologies. In addition to that the evaluation of their performance are done in many simulation programs.

CHAPTER 4
METHODOLOGY

In this chapter, the methodology of the study, the research approaches, the test box and tools which are utilized in this study are explained. To sum up the study starts with the generative model with test box, and simulation of generated shading device and continues with optimization until completion of the generation number. After that, from the solution cluster, one model is chosen and is evaluated. The flow is explained detailed below and showed in Figure 4.1.

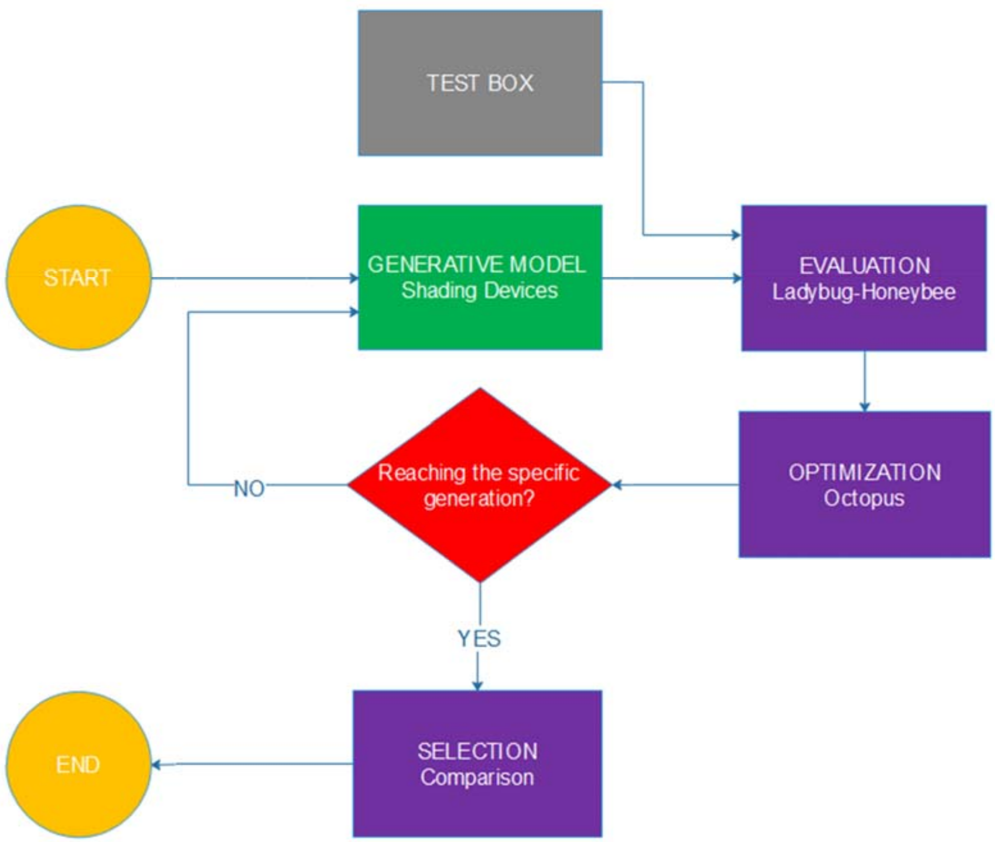


Figure 15 Flow Chart

In this study, there is a test box and various shading devices are assembled to south façade of the box. The test box has some selected criteria which are going to be explained further. This test box is an office space in Izmir, Turkey which is located on the southeast of Europe and at the junction of two continents which are Europe and Asia. Izmir has a warm temperate climate according to Köppen Csa climate class. According to ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), Izmir's climate zone is 3A.

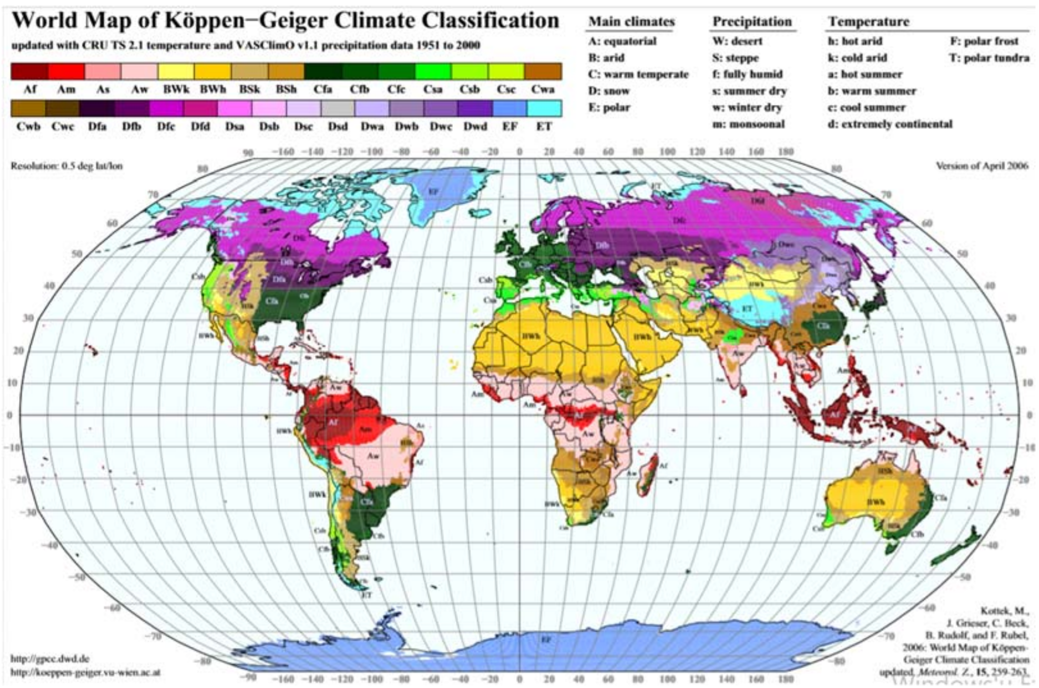


Figure 16 Köppen Climate Classification (*World Map of Köppen − Geiger Climate Classification Main climates*, 2000)

The test box bases a rectangular parallelepiped and its dimension of the edges are 10m, 5m, and 4m. This test box is south oriented with 3,6m height and 9m length window size. Also, the test box has 5m depth which is optimal size (approximately one and half times of the untreated window size) for light penetration (O`Connor, Lee, Rubinstein, & Selkowitz, 1997).

After the decision of the test box's orientation, dimensions and location, the zone program has been selected. So, many people spend their time mostly at work, therefore, the zone program is selected as open office. In the office-space, there are some problems in terms of indoor environmental quality. There are two important and conflicting factors that provide the good quality of the interiors. These are sufficient amount of illumination and requiring less of a cooling energy. Daylight is a major source to illuminate indoors. Lack of daylight, artificial lighting helps to illuminate interiors. That is a reason to increase electrical lighting load. These are two metrics are usable to measure electrical load according to occupancy schedule. Other factor cooling load can be measured with indoor temperature or impact of the global radiation.

Composing an environment with hourly sky model and outdoor temperature by importing the weather data is the precise method to generate a measurable model. This model bases on statistical EPW data. EPW data is arranged by World Meteorological Organization.

As a component of building shading devices are utilized in order to get under control the equilibrium of energy consuming for cooling and lighting. In other words, this study aims to find a form with optimal shape of shading device to keep balance between cooling load and lighting load. The recommended shading element has many decision variables to generate 3-dimensional shape and opening ratio. Due to the challenge of the manage that much amount of decision variables to generate the shading device geometry, it is not feasible to implement deterministic methods. For this reason, a heuristic approach with multiple objectives that gives a cluster that consist of solutions are near optimum instead of deterministic approach.

Three types of shading device are studied and compared against each other in terms of effectiveness. Therefore, the performance of each type of shading devices is compared with "test box" without a shading device to measure the effectiveness of them,. These types are separated as conventional horizontal, flat triangle grid base and organic triangle grid base. Each type of shading device is simulated through the year with Izmir EPW data. The test box behind the shading devices doesn't have any dynamic variables to change its geometry. Table 3 displays the property of the test box in detail.

Table 3 Test Box Dimensions

Part of Design	**Values**
Height (h)	4m
Length (l)	10m
Depth (d)	5m
Windows Length (l_w)	9m
Windows Height (h_w)	3,6m

After generation of the shading device geometry and evaluation those values feed into genetic algorithm and genetic algorithm creates individual of generation according to fitness values. Generating the shading device is provided by using optimization tool which works with HypE (Bader & Zitzler, 2010) genetic algorithm. Each types of shading devices have many variables, such as distance from the façade, opening ratio, extrusion amount, angle etc.

At the end of the optimization process, one of the options of the shading devices is selected which have minimum electric lighting energy from pareto front. Test box which have three different shading devices and without are compared in point of operative, air and outdoor temperature lighting energy load, solar radiation etc.

Detailed definition of the methodology of this study is explained below. This methodology is separated into five main sections that include simulation and optimization tool, volume, generation of the shading device geometries, simulation settings and optimization.

5.1. TOOLS

First of all, base geometry of the test box is formed with Grasshopper is a plug-in of Rhinoceros 3D which is computer aided design program, because generating the shading device geometries are more effective in grasshopper therefore in the literature there are so many examples (Touloupaki & Theodosiou, 2017a). Grasshopper is an algorithmic design tool for Rhino. 3D modelling with Grasshopper is very effective and it lets people use the other plug ins together. Grasshopper (GH) gives the user an empty canvas then the user calls a component from the GH library by typing. When generating a model in GH it visualizes in rhino's 3D space.

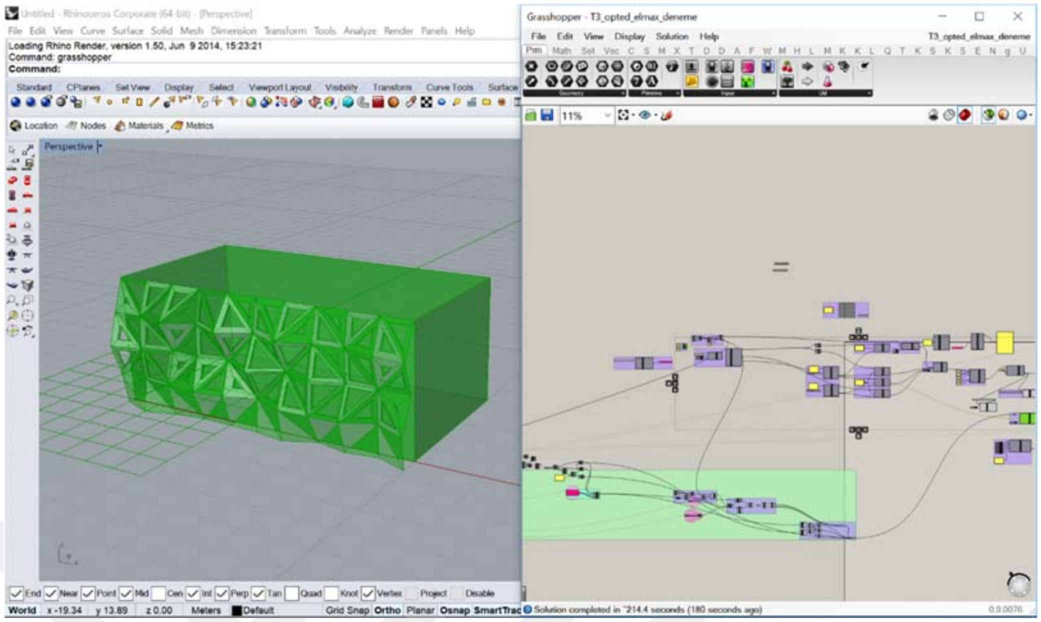


Figure 17 Sample View of the Model

The simulation of the performance of the shading devices integrated to the south façade of the building is made in Grasshopper. A plug-in of Grasshopper, Ladybug Honeybee provides energy simulations for the zones with program, occupancy, location and other simulation settings. Ladybug- Honeybee works with several simulation programs such as Energy Plus, Open Studio, Daysim, Radiance and Therm. In Ladybug – Honeybee, the test box defines as a zone with its program and Energy Plus Weather (EPW) data import in it. The zone program is set with occupancy data in simulation setup accordingly the topic of this study which is office space. Also, EPW data that comes from location of the site are given the program.

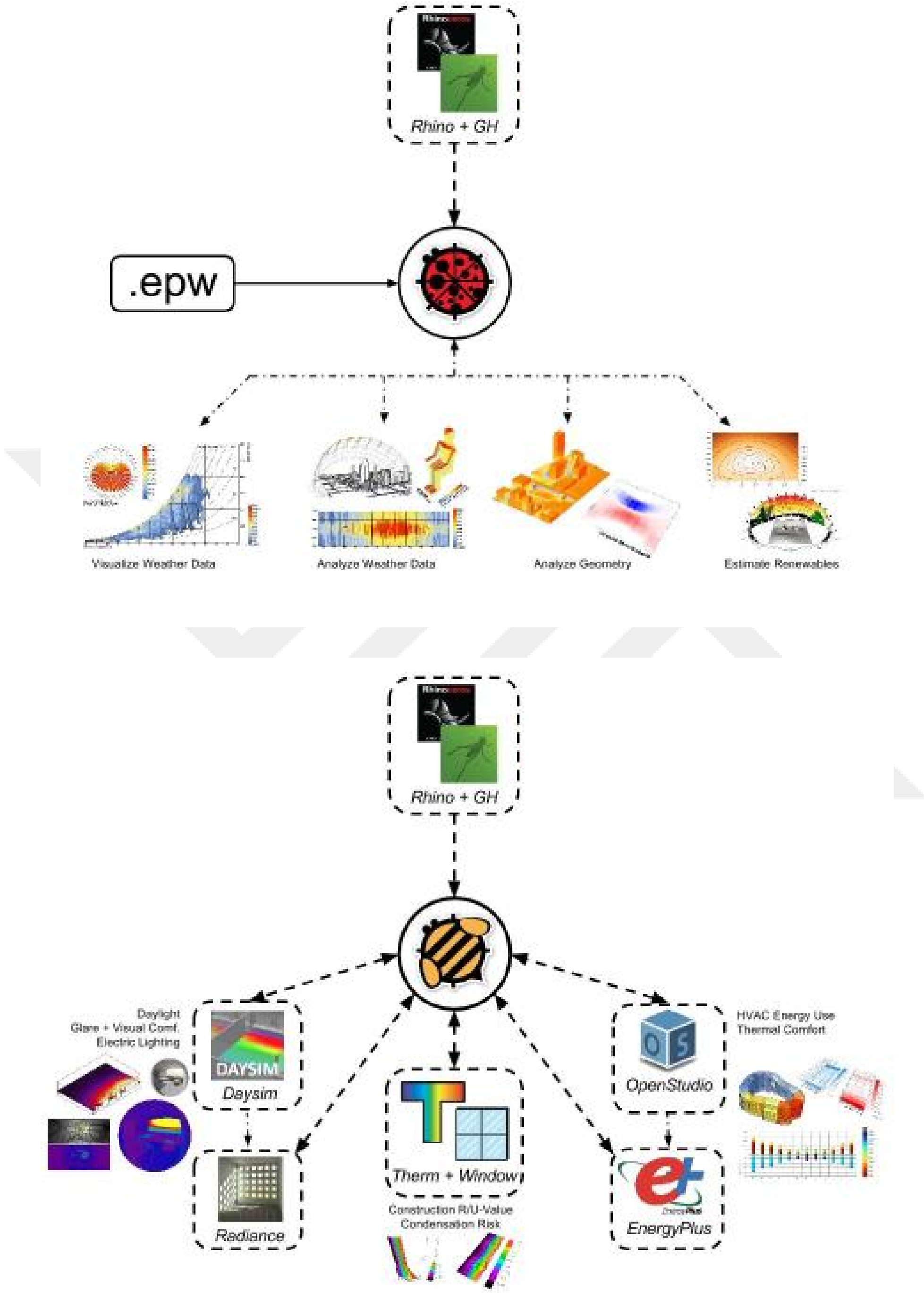


Figure 18 Ladybug, Honeybee Flow Charts

(https://www.food4rhino.com/app/ladybug-tools)

The optimization part of the study is made with another Grasshopper plug-in Octopus. It is made for formerly Multi-Objective Evolutionary Algorithms. Octopus uses evolutionary algorithms as a optimization tool(Vierlinger, 2015). These evolutionary algorithms are SPEA 2(Zitzler, Laumanns, & Thiele, 2014) and HypE (Bader & Zitzler, 2010). In this study, in order to solve the problems HypE is used. Inputs of the component of Octopus are objectives, parameters and constraints. In the Octopus user interface, number of generations and populations size and variable of optimization algorithm such as mutation rate, elitism etc. are defined.

5.2. TEST BOX

The test box has 10 meters of length, 5 meters of depth and 4 meters of height. All of the surface that cover the test box except for the south façade are assumed to be adiabatic. Components of the south façade are double glazing window and a thin frame which is made from default ASHRAE external wall material. Specifications of window, walls, floors and roof are given in the Table 3.2. in detail.

Table 4 Test Box Specifications

Surface Orientation	Material	Type
North	N/A	Adiabatic
East	N/A	Adiabatic
West	N/A	Adiabatic
South	ASHRAE 189.1-2009 extwall Climate zone 3	Outdoor
South Window	Double glazing (3-13-3)	Outdoor- Child Surface
Up	N/A	Adiabatic
Down	N/A	Adiabatic

There are some necessities about the geometry modelling in Grasshopper and its plug ins. Ladybug-Honeybee needs a closed zone to analyze the energy performance. Therefore, the test box geometry is generated in Grasshopper with box component. The glazing is integrated on the south façade of the test box which covers 90% of the façade area. It means 3,6m x 9m surface is comprised. Additionally, the window must be defined as a child surface in the ladybug-honeybee. For this reason, two surfaces are defined as glazing and wall.

Each surface has an "Energy Plus Construction" as a material definition normally but in this case, due to the walls, floor and roof are adiabatic, these definitions are used only for the south façade and window. There is a RAD Material in order to calculate the reflections. On all surfaces, RAD Material consist of the RGB Reflectance values to show the color of surface. Walls are white color and floor and roof are off white colors. After the surfaces specified, zone specifications and simulation settings are defined.

5.2.1. BASE GEOMETRY (T0)

The test box mentioned in previous section is named as T0. It means that it is the plain geometry of the test box. It has no shading device. After this section, in the comparisons test box will be referred as T0. In the Figure 4.5, T0 is shown.

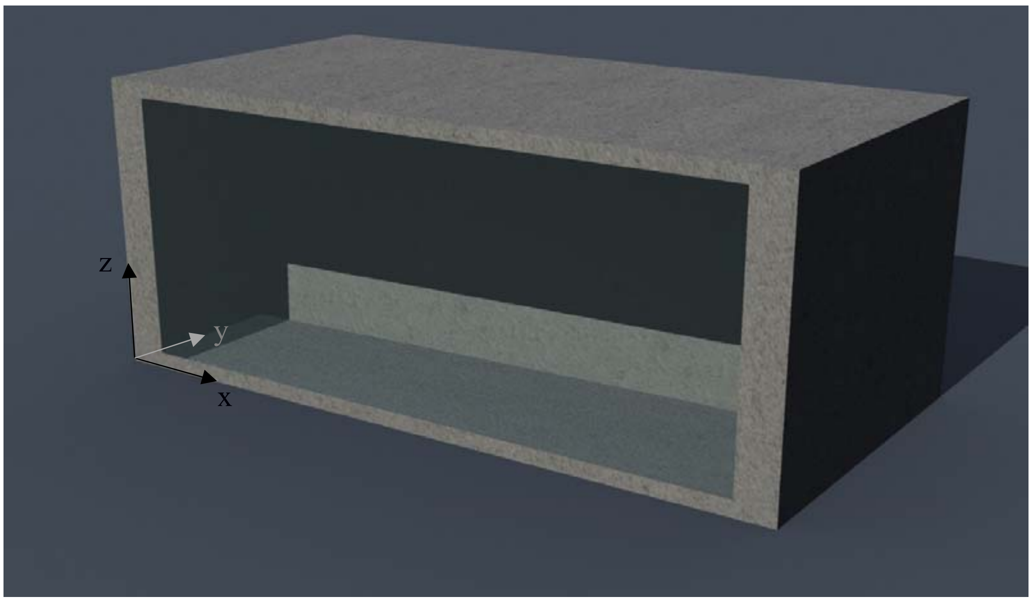


Figure 19 T0, Plain Geometry of Test Box

5.3. SHADING DEVICE GEOMETRY GENERATION

This section explains how the geometries of the types generate. Three types of shading devices are simulated to evaluate how well each of them perform.

5.3.1. SHADING DEVICE TYPE 1 (T1)

T1 is the conventional horizontal shading device (CHSD). It has been studied in the literature so many times (Datta, 2001). In this study, CHSD comprised by divided horizontal the south surface. After division, each line extrudes to the outside with angle. The division number, the angle and the extrusion amount are the optimization parameters. They are limited between specific values which are shown in tables in 5.6.

Horizontal shading devices are utilized on the south façades mostly as mentioned in Chapter 2 because of their performance. In this study, the effectiveness of the CHSD is important too owing to the fact that proposed geometry will be compared with it.

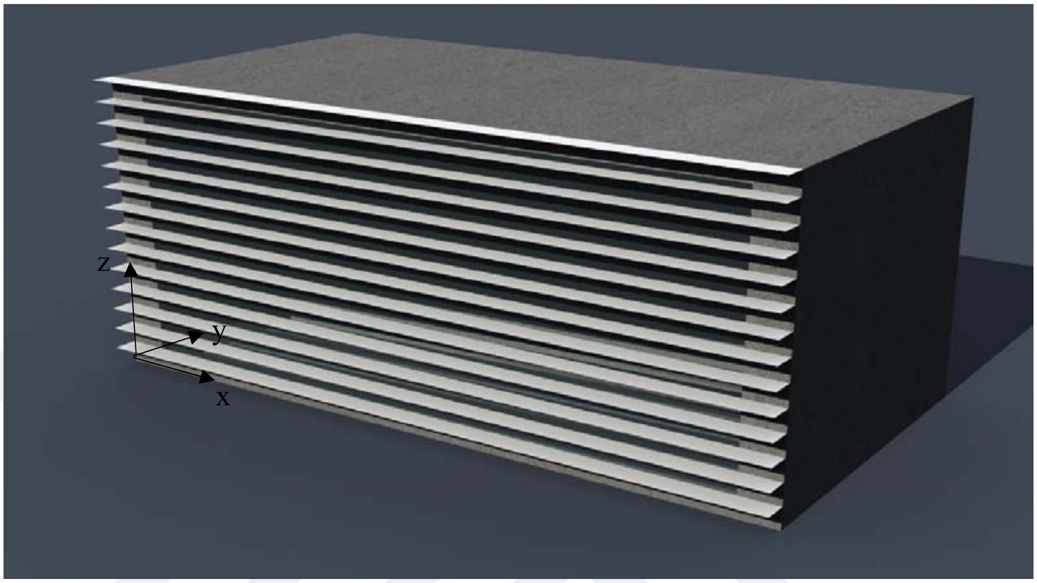


Figure 20 T1, Conventional Horizontal Shading Device

5.3.2. SHADING DEVICE TYPE 2 (T2)

Flat Triangle Grid Base (FTGB) shading device is the chosen as the shading device type 2 (T2). This shape is obtained by dividing and triangulating the projection of the south façade. First, surface of the south façade is copied forward 45cm and then divided into 10 vertically, and into 4 horizontally. Thus, the surface is transformed into 1m to 1m parts with 55 points. Secondly, the distance between the points of the highest level of the new generated surface and the south façade is set to zero. All points are both deconstructed and sorted according to their X axis values. And then, these points are sorted their Z axis values. Points on the same line are joined. When the lines form a loft surface, rectangle surfaces are showed up. But, due to this is not an intended shape, lines are exploded, and sub-surfaces are generated. Additionally, this surface is deconstructed again, and its vertices construct diagonal lines. After construction, these lines form a divided triangle loft surface. In addition to this, except for the ones that are below the line, which is at 75 cm high, the parts are scaled between ten percent to ninety percent. The percentage value was determined via the optimization tool. Together with, by selecting the edges of the scaled surfaces and the edges of the original surface are constructed loft. As the simulation errors when the surface is seen as one surface by it. Inside of the scaled triangles through the openings are placed. The edges of the scaled triangles are extruded to the south facade a little amount that is between 10 to 110 cm. Extrusion that is provide the reflectance was determined via optimization tool.

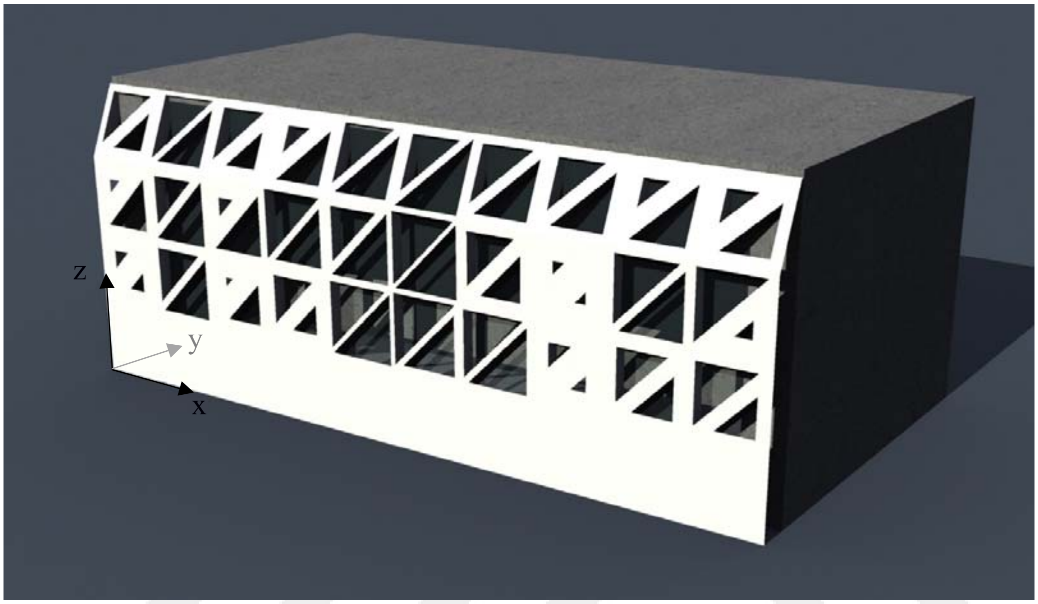


Figure 21 T2, Flat Triangle Grid Base Shading Device

5.3.3. SHADING DEVICE TYPE 3 (T3)

T3 is the Organic Triangle Grid Base Shading Device and similar to T2 in some aspects. The difference between T2 and T3 is being organic geometry of T3. South facade is divided into 10 to 10. Each point on the divided surface is moved back or forward in the range of 10 and 75 cm. In this geometry, it is not necessary to construct the sub-surfaces. Because, the lines that are generated after sorting may construct triangle surfaces. The other phases are the same with T2 shading device geometry generation.

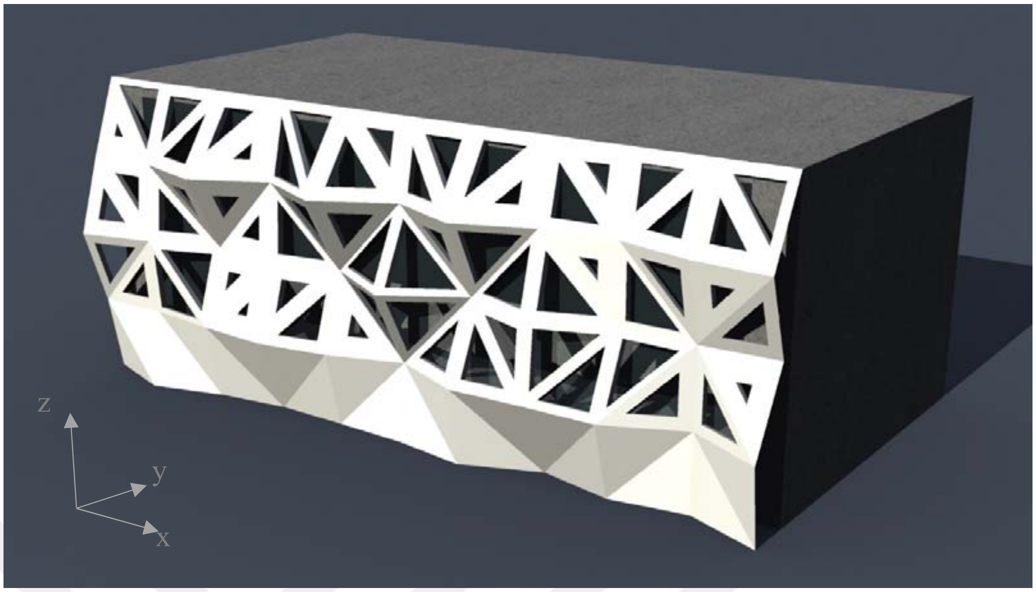


Figure 22 T3, Organic Triangle Grid Base Shading Device

5.4. SIMULATION SETTINGS

All settings are specified before the simulation in the Grasshopper canvas such as min lux value, building zone program, infiltration ratio, and others explains below. According to orientation, the box defined the zone is decomposed to sub-surfaces such as walls, roof and floors. The walls without an opening are defined as adiabatic. They have Radiance material with white paint. Their RGB reflectance is 1.000 for each color. Also roof and floor are defined as adiabatic and their RGB values are 0.763 for each color which means off-white color. These components of the box have no EP Construction because their materials changes nothing in the simulation due to being adiabatic. On the contrary, the window wall is chosen as an outdoor surface in order to provide the heat transmission. The opening is determined to be placed on the south facade. Its wall material is ASHRAE 189.1-2009 extwall Climate zone 3. Its window is composed of 3 mm double clear glass with 13 mm of air gap. The U value of the window is 2 W/m^2-K.

After materials are chosen, all the surfaces are joined, and the zones are created. There are some zone thresholds their acknowledgements are given to the simulation. The zone is not conditioned. And their cooling and heating set points and setbacks do not make sense because of the conditions but, daylight illuminance set point is set to 300 lux. According to some studies, illumination values for working spaces is recommended between 200 and 500 lux (Shameri et al., 2013). And according to other some studies 300 lux is the minimum lighting value for working area (Konis, 2013). The simulation read the daylight value on the table level 75cm height. In addition to that, zone loads are set to zero mostly except lighting density per area.

The other important data is RGB values of the shading devices. The red, green and blue reflectance are 1,0, it means that the color of the shading device is white.

5.5. SIMULATION OUTPUTS

The outputs are arranged in the Grasshopper canvas. The outputs are the zone energy loses and gains, the zone energy use, the zone comfort metrics, the comfort map variables, the zone HVAC parameters, the surface temperature analysis, the glazing solar analysis and the time step which is hourly.

After simulations are run, the outputs of the test box with each type of shading devices are compared with the test box without shading devices. The outputs are the interior operative temperature, the interior air temperature, the surface temperature and the electrical lightings. The operative temperature is average of the mean radiant and room air temperatures (Shameri et al., 2013). The air temperature is the mean temperature of the indoor for each hour according to simulation. Surface temperature defines the temperature of the south façade of the box. The output as electrical lighting defines the consumption of the electrical energy for lighting of the volume. These outputs are utilized in the comparison between T0, T1, T2 and T3.

In addition to these, in the comparison of the volumes with all types and without shading device in the one chart operative temperature and the outdoor temperature are used in the Chapter Five.

5.6. OPTIMIZATION

As another phase of the study is optimization of the geometry of the shading devices. In the literature there are many optimization studies related to the architectural problems as mentioned in Chapter 2. Architectural optimization problems cannot be solved easily with deterministic approach, because of their huge number of variables. In this study, Genetic Algorithms are used to compose of cluster of non-dominated solution.

Optimization approach has a process that includes several inputs; objectives, constraints, crossover rates, mutation probability and rate, elitism, population size and maximum generation number. These parameters are very important component for the optimization methods.

Table 5 Optimization Values

Name	Rate
Elitism	0.5
Mutation Probability	0.1
Mutation Rate	0.5
Crossover Rate	0.8
Population Size	100
Max Generation	50

Additionally, architectural problems have variables which may be floating or discrete number. Thermal and daylight performance has also floating number of variables. In addition to that they may have many objectives which are conflict each other too. Providing an equilibrium to these objectives is very complex and hard. When solve the problems via optimization, with single, multi or many objective conceptions the researcher's approach.

5.6.4. OBJECTIVE FUNCTIONS

The objectives of the problem are surface temperature metric (STM) and electrical lighting load (ELL). The lighting load can be given from the result component of the Ladybug-Honeybee but surface temperature metric should be calculate before getting in Octopus. The optimization problem can be explained with mathematical notation as below:

$$\text{minimize}(O_1, O_2, \dots)$$

$$\text{minimize}(STM, ELL)$$

$$STM = (-1) * \frac{NHIB}{TNHY}$$

NHIB: The Total Number of Hour In Between (bigger than 20 and smaller than 27)

If the temperature is between 20℃ and 27℃ degrees, number will take 1.

If the temperature is not between 20℃ and 27℃ degrees, number will take 0.

The NHIB is sum of these values above.

TNHY: Total Number of Hour of the Year which is 365x24=8760 hour.

5.6.4.1. THE SURFACE TEMPERATURE METRIC

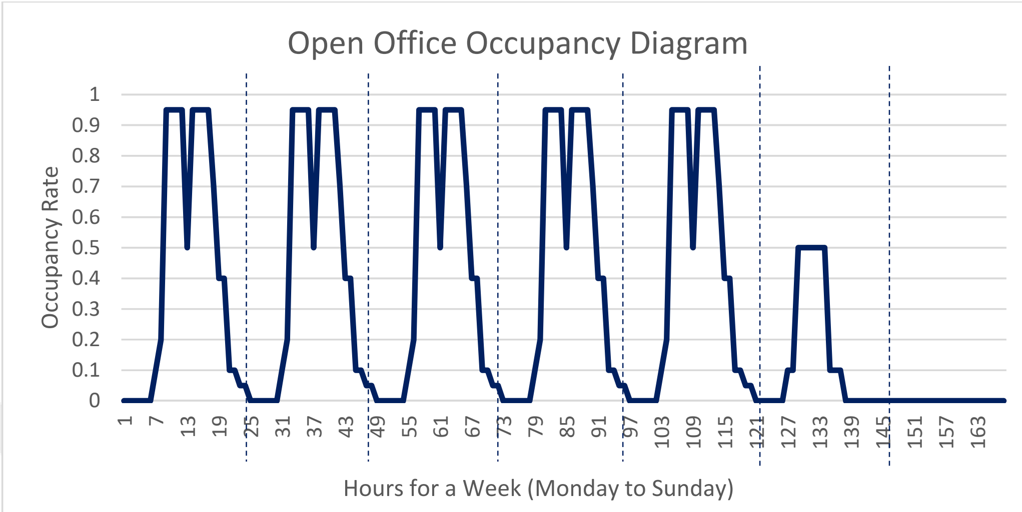
The surface temperature metric like mentioned before is a ratio of the comfort temperature as an hour to total number of hours of the year. This metric has an important role of this study because it provides an equilibrium to façade design in terms of opening ratios. It may take values according to surface temperature between 0 and 1. 0 means the surface temperature never be between 20℃ and 27℃ degrees. The temperature might be lower than 20℃ or higher than 27℃ degrees. In that two conditions, to bring the indoor air temperature or operative temperature to comfort zone, energy should be consumed for heating or cooling. As the test box is located in Izmir where is hot climate region, openings of the shading devices try to close. For this reason, this metric should not be used alone without considering electrical lighting load.

5.6.4.2. THE ELECTRICAL LIGHTING LOAD

The illuminance plays a significant role as well as surface temperature for the indoor environmental quality. For every activity, indoors should be illuminated enough. Due to the test box is open office area the minimum lux level is set 300 lux. In this case occupancy use this area in weekdays. Illuminance loads in that days are more than weekends. The schedule of the occupancy is given below. The sky is another important factor for the illuminance but the most effective factor of that is opening ratio. Therefore, the electrical lighting load is chosen another objective function. In this study, Electrical Lighting Load refers the energy consumption in order to keep the illuminance level in minimum 300 lux when the area used.

The Electrical Lighting Load is related directly occupancy ratio that shown in Table 6. The ratio which is selected in the comparison includes ratio with three different density. These days are Friday and Monday for weekdays, Saturday and Sunday for weekends.

Table 6 Occupancy Ratio



These objective functions show that they are conflicting each other. If the single objective optimization was chosen, shading device would be more closed or open. For this reason, these objective functions are kept in balance the opening ratio of the shading devices.

5.6.5. DECISION VARIABLES

The decision variable is a quantity that is determined by decision-maker in order to solve the problem. The variable describes a range of number which may be not only discrete values but also continuous numbers. Decision variables are also parameters to shape the geometry of shading devices. This study has both discrete and continuous variables which are mentioned below. T1's variables are horizontal division, extrusion and angle of the extrusions. Angle may get the value between -30º and +30º, horizontal division is also discrete between 3 and 20. Only Extrusion values for each type of shading devices have range as continuous numbers between 0.10 and 0.50 with 2 value after coma. For T2 and T3 except the angle of the extrusion all parameters have continuous numbers with some ranges.

"Horizontal Division" is number of the horizontal plane of the shading devices. The surface might be divided from 3 times to 20 times horizontally. And all lines constitute the planes with "Extrusion". "Opening Ratio" states the ratio of the triangle gaps among the shading device surfaces. Every opening might have different ratio. Last the "Distance from Façade" shows the motion of each points of the divided surface of the shading device (except top points) from 10 cm to 0.75 cm for once. Top points for all types of shading devices have 0m distance from the glazing. These values are being tried by optimization tools randomly and after generations they converge to the optimal solutions.

Also, variables are explained with a table below:

Table 7 *T1 Parameter Domain*

Variable Name	**Domain**
Horizontal Division	3 - 20
Extrusion	0.10 – 0.50 (m)
Angle	-30º – 30º

Table 8 T2 Parameter Domain

Variable Name	**Domain**
Opening Ratio	0.10% – 0.90%
Extrusion	0.1 – 1.1 (m)
Angle	-30º – 30º

Table 9 T3 Parameter Domain

Variable Name	**Domain**
Distance from Facade	0.10 – 0.75 (m)
Opening Ratio	0.10% – 0.90%
Extrusion	0.1 – 1.1 (m)
Angle	-30º – 30º

Also, variables are explained with figures below:

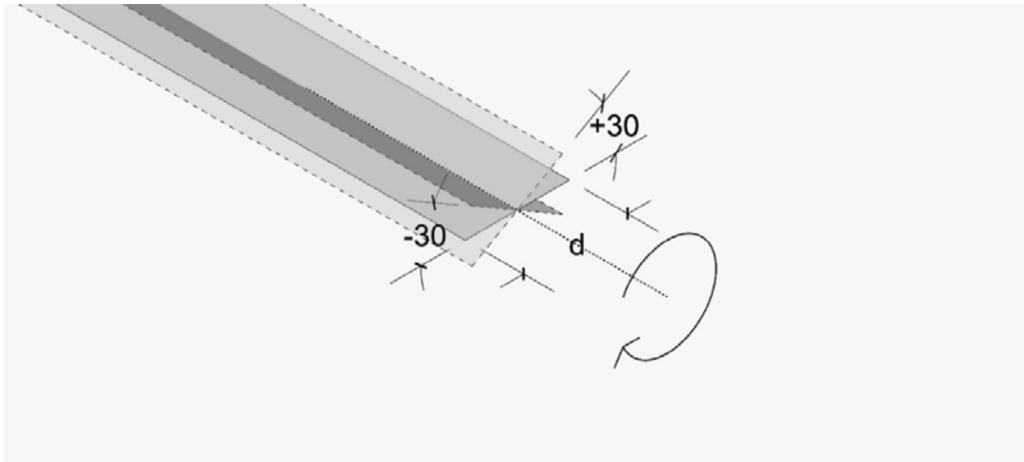


Figure 23 Angle of the Shading Device extrusion

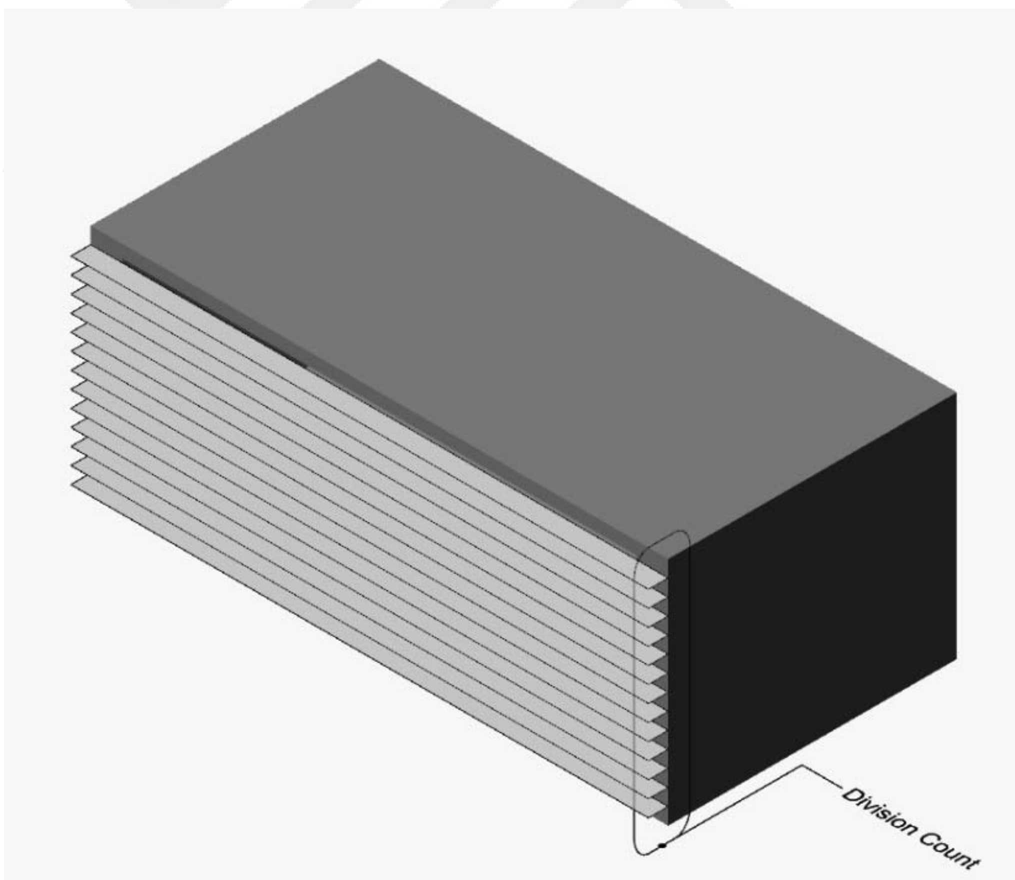


Figure 24 Vertically Division Count of the Shading Device

CHAPTER 6
RESULTS AND DISCUSSION

This chapter explains the results of the study. The results comprise of two main part, optimization results and simulation results. Optimization results describe the Pareto-optimal solutions, non-dominated population size, last generation parameter values they are given in 4.7.

Simulation results demonstrate how well the proposed shading devices. Comparisons are given below for the specific days of the year in January for winter term, June and September for the summer period. Some of the values of three types of the shading devices are compared in charts which are shown below. These values are surface temperature, operative temperature and solar gain. In addition to that other values (indoor air temperature, electrical lighting) of each surface temperature are compared in charts. Also, for each shading device, there are six measure point in the test box in order to measure the daylight.

For entire optimization phase of the study a workstation has been utilized. The workstation has 16gb ram and 64-bit processor which is Intel(R) Core (TM) i7-4790K CPU @ 4.50 GHz. The operating system was Windows 7.

After optimization, all energy and daylight simulations of selected shading devices from pareto fronts have been done in a computer. The computer has 8 GB Ram and 64-bit processor which is Intel(R) Core (TM) i5-5257U CPU @ 2.70 GHz. The operating system was Windows 10 Pro.

5.7. SELECTION OF THE RESULTS

The results for each type of shading devices are selected from Pareto-Front. In this study, the results are selected with best STM and worst ELL in the last generation. Because of that STM provide a comfortable air temperature for the occupants but it has wide range like number of the hours of the year. The ELL keeps the STM in a balance in terms of opening ratios.

6.1. OPTIMIZATION RESULTS

6.1.6. T1

T1 has 153 non-dominated solution and 23 dominated solution in the last generation of 50 generations. The result of the last generation parameters are given in the table below.

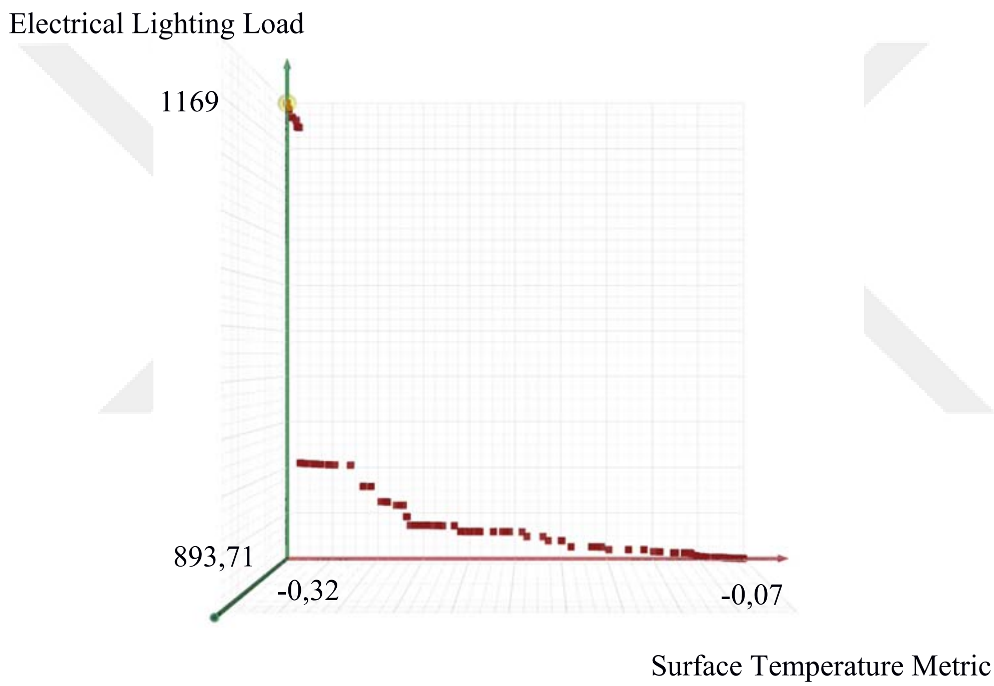


Figure 25 T1 Pareto front with non-dominated solutions

The individual which has maximum electrical lighting load and minimum surface temperature metric is chosen from the pareto. In the pareto, continuous solutions are seen with lower ELL but for the comparison the maximum ELL one is preferred. As an architectural solution, all the individuals in this chart have one more good objective than each other. The yellow point is the selected solution. In the pareto front there is some continuity in the lower value of the surface temperature.

The values of the chosen solution:

Table 10 T1 Parameter Domain

Parameter	Values
Opening Ratio	16
Extrusion	0.34m
Angle	0

6.1.7. T2

The pareto front of the last generation of the type 2 has 20 non dominated solution and 180 dominated solution.

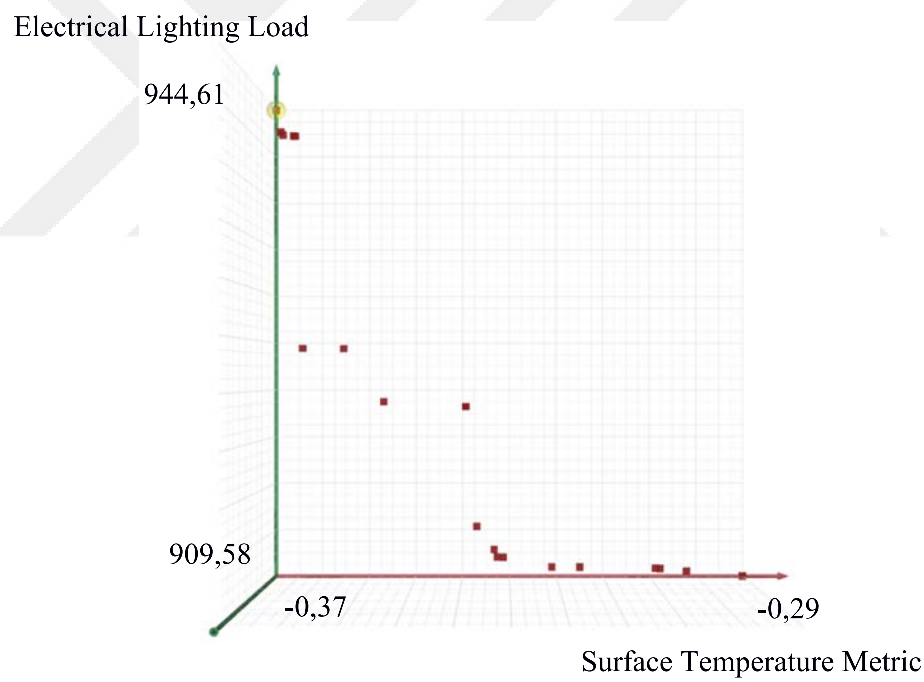


Figure 26 T2 Pareto front with non-dominated solution and history

This figure shows the pareto front with history, non-dominated and dominated solutions. In this type, the pareto does not have a perfect curve. Most of the solution are came together in heaps in specific locations. The parallel lines with STM are the locations that the clusters become. The yellow one is the selected solution of the last generation.

Table 11 T2 Parameter Domain

Parameter	Values
Extrusion	0.2m
Angle	-27

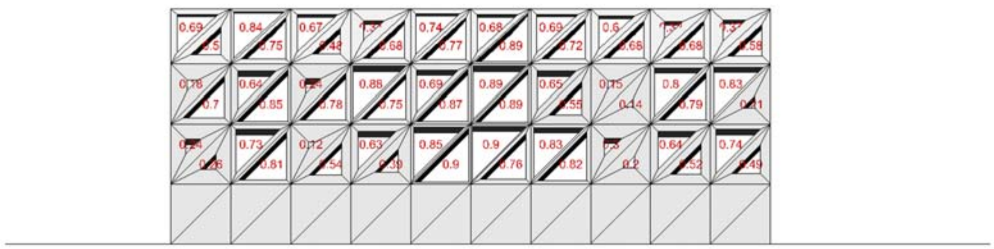


Figure 27 T2 Opening Ratios

The opening ratios shows the opening are not so closed even the solution belongs the ELL maximum solution. The shading device is worked very effective.

6.1.8. T3

The pareto front of the last generation of the type 2 has 20 non dominated solution and 180 dominated solution.

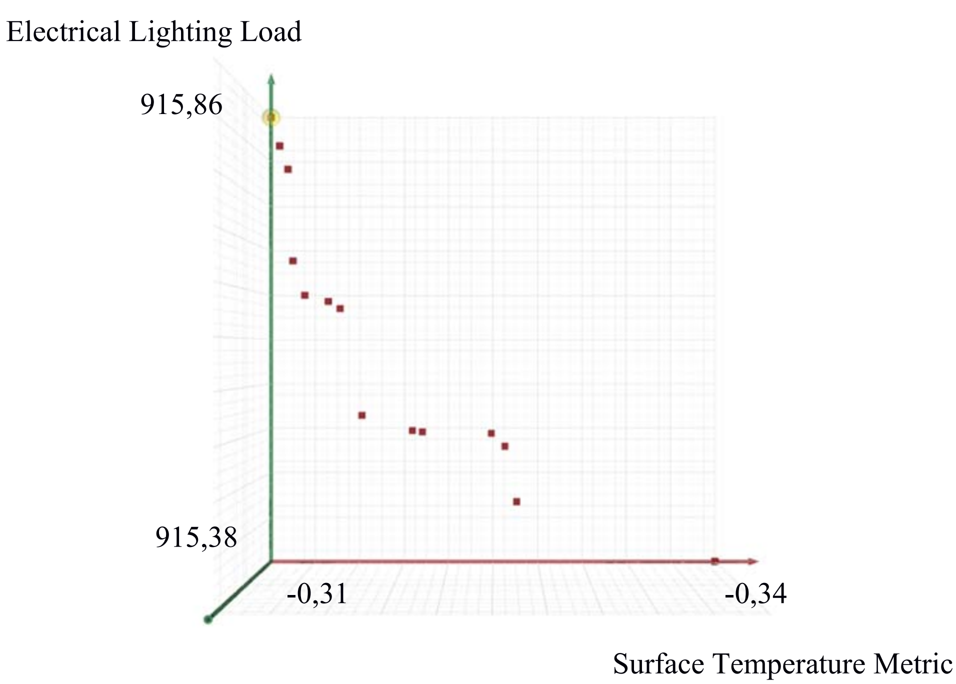


Figure 28 T3 Pareto front with non-dominated solution and history

In this type, it is seen clearly that the pareto front so homogeneous. The ELL has smallest range than the other types. The yellow one is the solution which is shown.

Table 12 T3 Parameter Domain

Parameter	**Values**
Extrusion	0.2m
Angle	-27

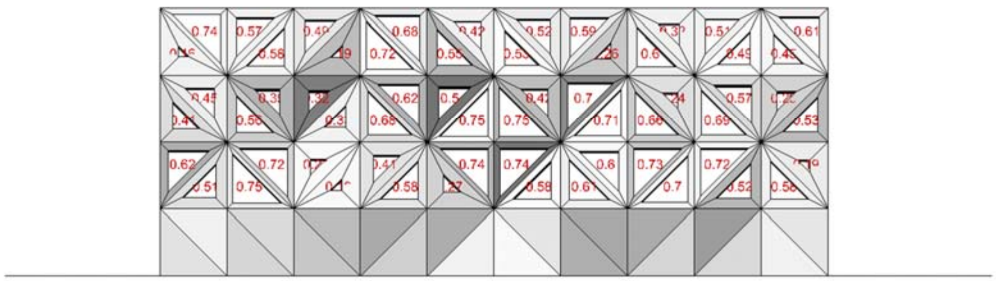


Figure 29 T3 Opening Ratios

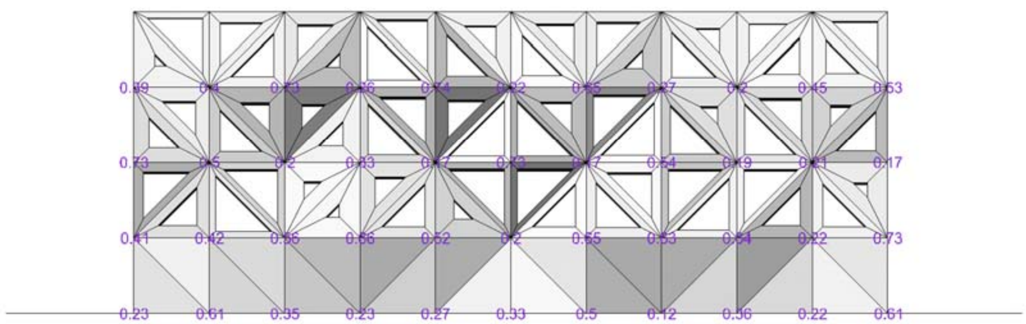


Figure 30 T3 Point Distance (m)

6.2. SIMULATION RESULTS

After optimization has finished, for each shading device, a geometry has been chosen from the solution cluster in the 50th generation. The chosen geometries individually have maximum electrical light values in the pareto front, so they have minimum surface temperature metric. The charts of some values mentioned before are shown for every types of shading devices. Charts demonstrate the three days in a row of three months which represent winter period, beginning of the summer period and ending of the summer period. The dates of the period are chosen 2nd, 3rd and 4th of June for "Summer Period - 1", 8th,9th and 10th of September for "Summer Period – 2" and 28th, 29th and 30th of January for "Winter Period" because of outdoor temperature fluctuates.

The occupancy ratio of these periods are shown in Figure31, 32, 33.

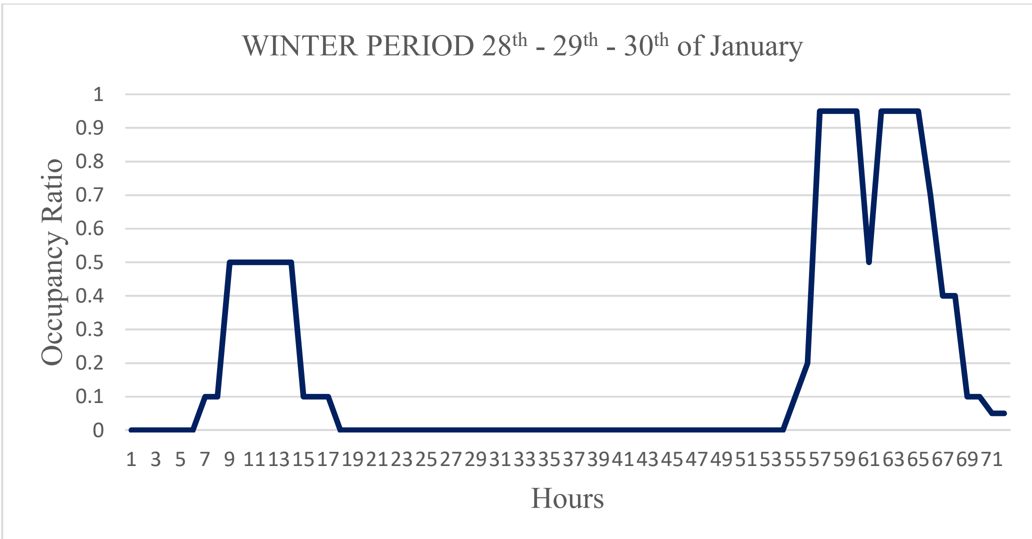


Figure 31 T0 Winter Period Values

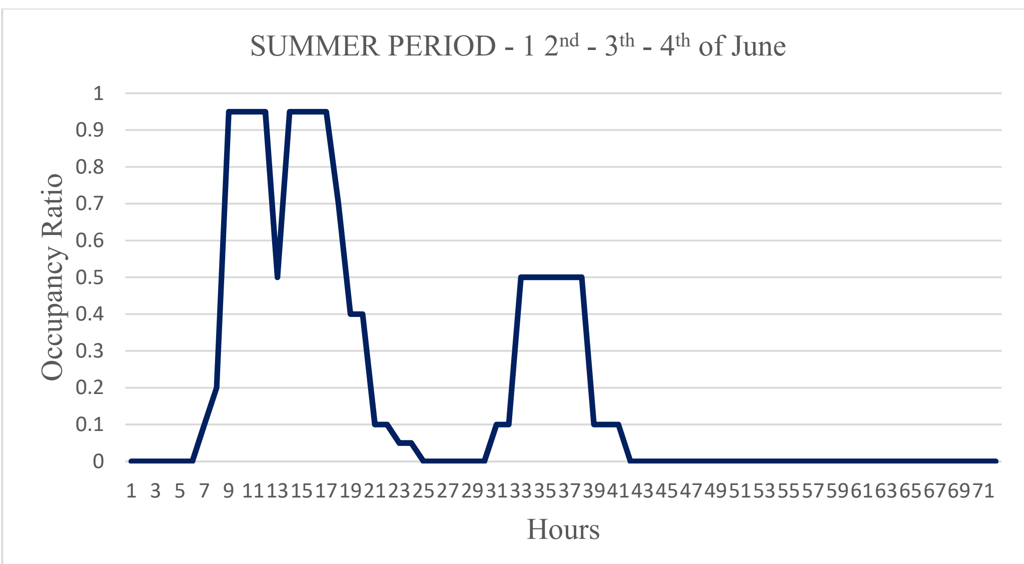


Figure 32 Summer Period 1 Occupancy Ratio

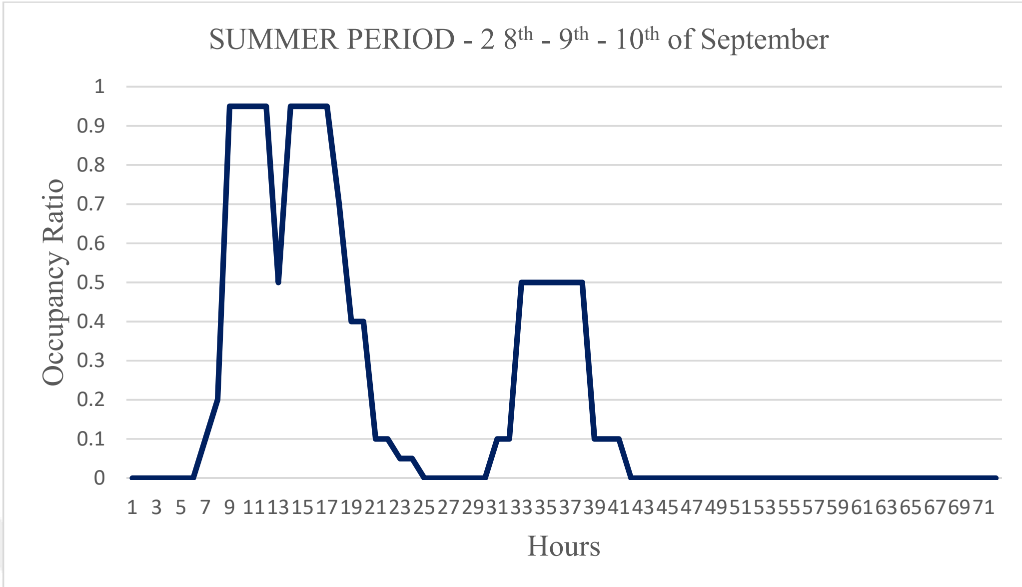


Figure 33 Summer Period 2 Occupancy Ratio

6.2.9. TYPE 0 (T0)

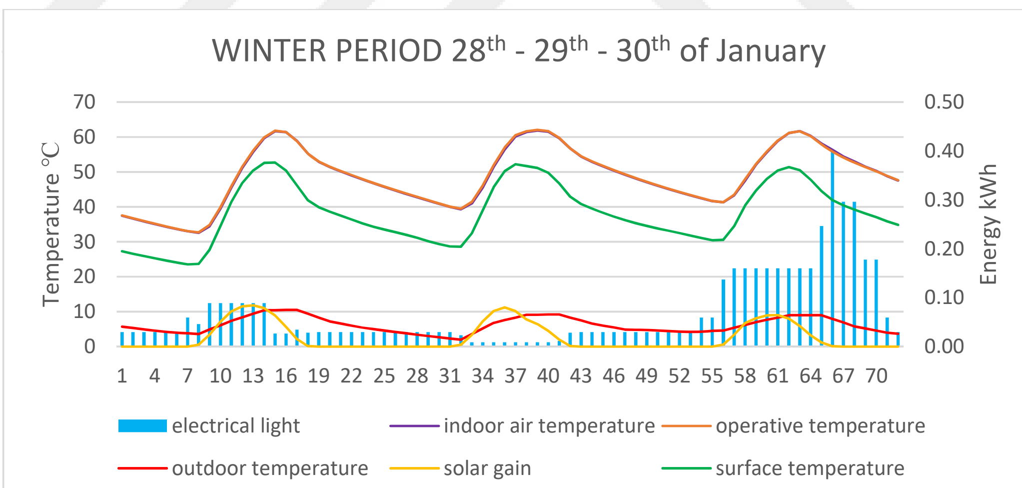


Figure 34 T0 Winter Period Values

In all three day, the operative temperature and the surface temperature are almost same. The outdoor temperature is reached the maximum 11℃ degree in the first day and minimum 0°C degree. The electrical lighting load 3rd day of the this chart reaches the 0,40 kWh. In addition, the maximum value of the solar gain is 10.15 kWh in 2nd day.

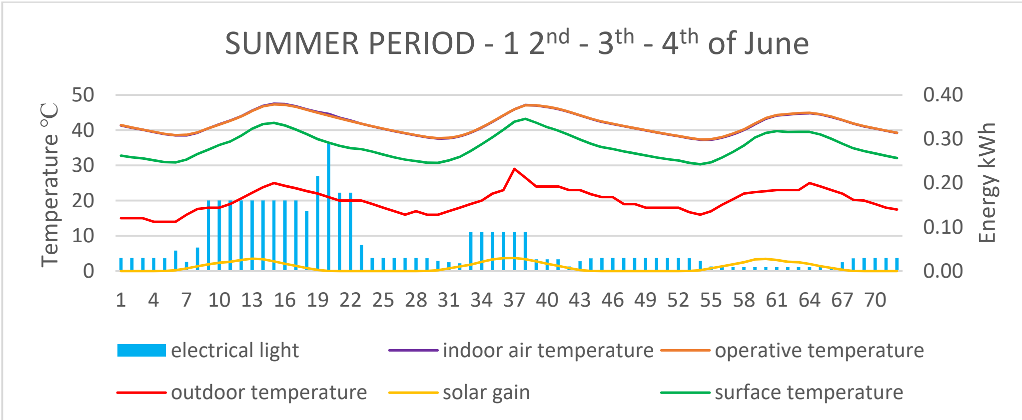


Figure 35 T0 Summer Period -1 Values

In summer period the sunlight comes through the surface of the buildings more angled. It is expected that the total of the lighting load decrease in the summer period. The operative and the air temperature are almost same in this period too. And all temperature values with solar gain have near ratio of the fluctuation.

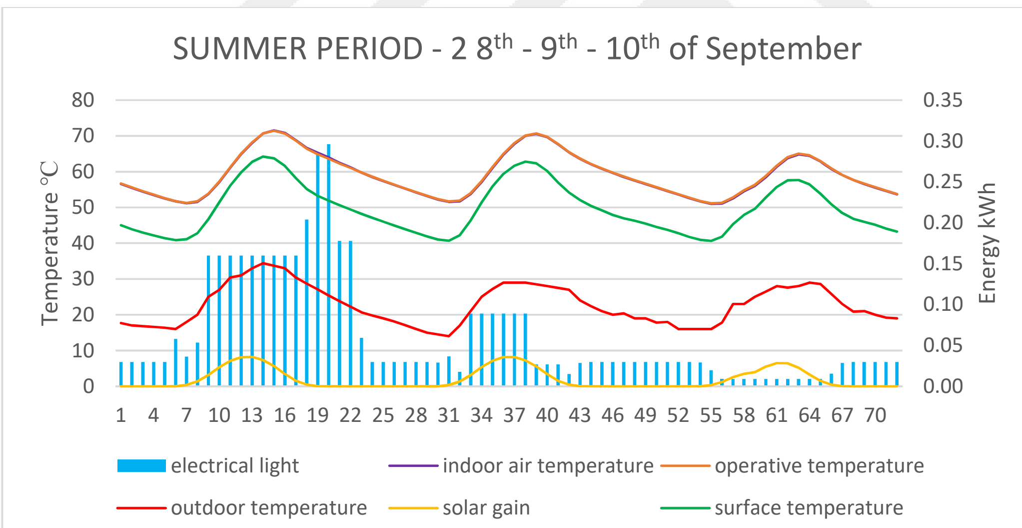


Figure 36 T0 Summer Period -2 Values

This type (Type 0) has no shading device integrated to the test box. The surface of the building except for south façade modelled as adiabatic that is mentioned before. Moreover, altitude of the sun in winter period is lower than it is in summer period. The result of these three reasons, indoor air temperature and the operative temperature reach 60℃ degrees in winter period and 70℃ degrees in September. Also, these two values are almost same.

6.2.10. TYPE 1 (T1)

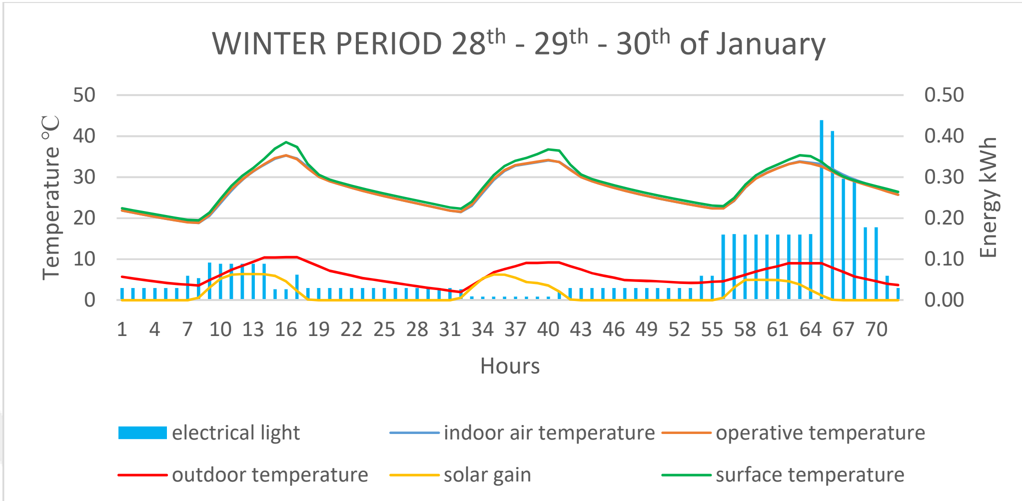


Figure 37 T1 Winter Period Values

In this type the shading device has horizontal parts to control the lighting through the all mid-day period. In winter period, the shading device does not interfere with the increasing of the indoor temperature to intended level. When the outdoor temperature is 3℃ or 4℃ the indoor air and operative temperature are between 19℃ and 20℃. The peak point of the surface temperature in the winter period is higher than the surface and air temperature.

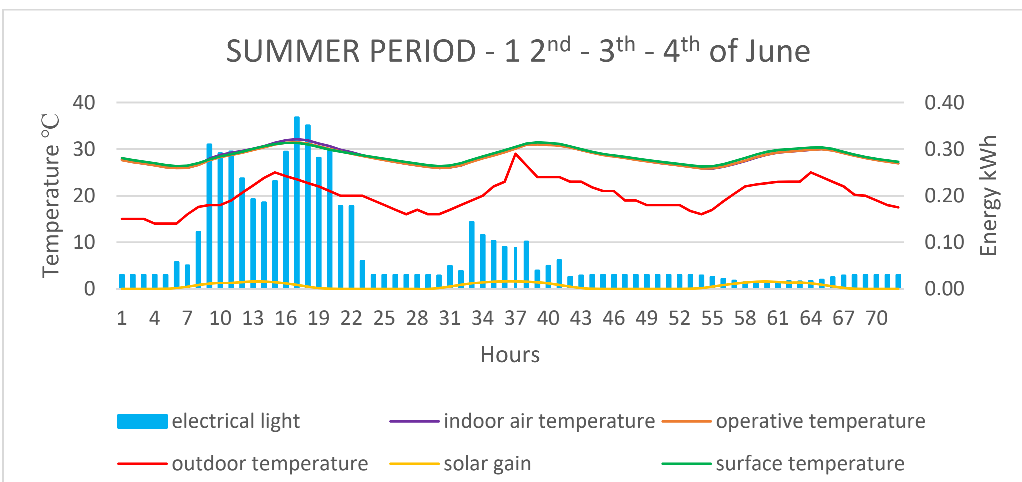


Figure 38 T1 Summer Period -1 Values

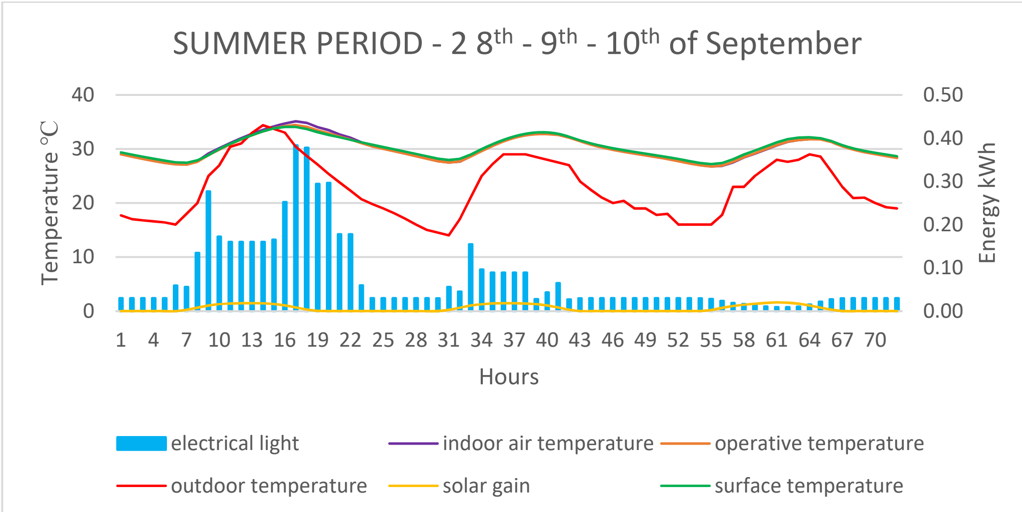


Figure 39 T1 Summer Period -2 Values

This type (Type 1) of shading device is stated as the conventional horizontal shading devices. The chosen shading device has fifteen horizontal plate on the south façade. The shading device decrease the temperature a degree in first day of the summer period-2. The change of temperature is smaller level than T0 due to the using the shading devices.

6.2.11. TYPE 2 (T2)

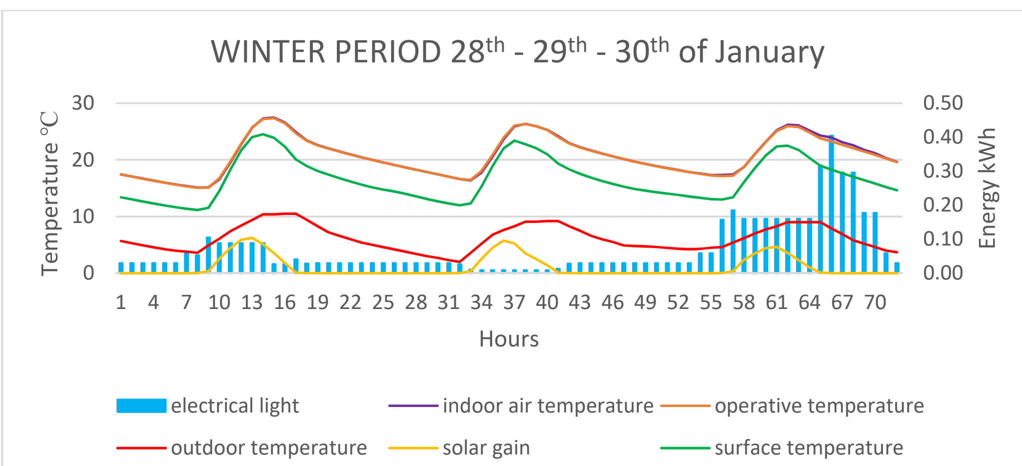


Figure 40 T2 Winter Period Values

The T2 provide the comfort of the indoor with optimal temperature in winter period. While the outdoor temperature is 10°C degree, the indoor temperature are between 20°C and 25°C degrees. This space is the best temperature for the indoor environmental quality.

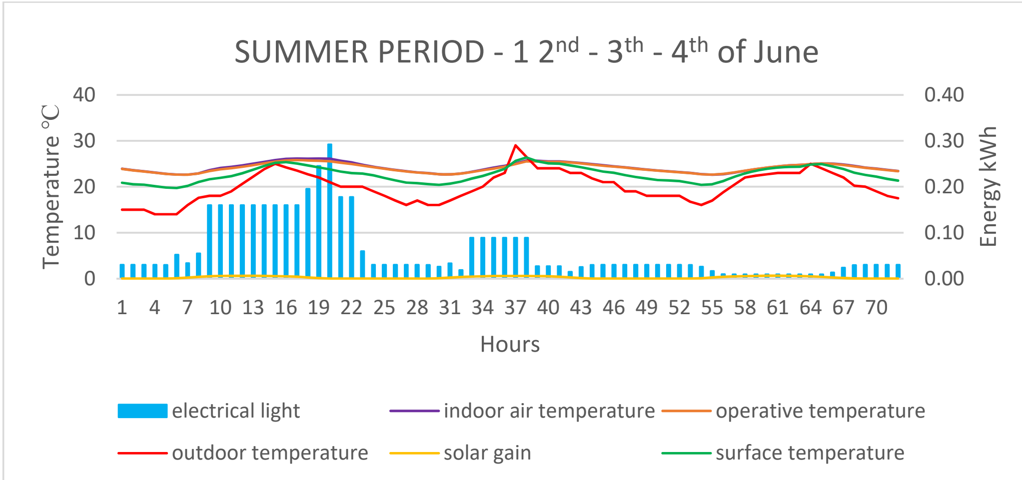


Figure 41 T2 Summer Period -1 Values

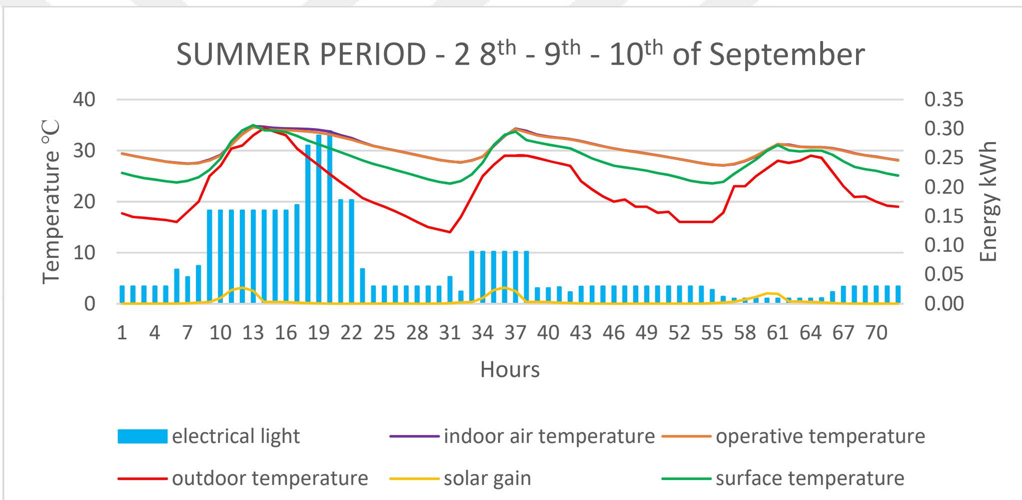


Figure 42 T2 Summer Period -2 Values

This type (Type 2) has the rectangle grid and flat surface. Through the winter period, this type keeps the indoor temperature intended level and in the summer period sometimes decrease the outdoor temperature. Because the test box has adiabatic surfaces, the indoor temperature is very high in three cases although this type decrease the indoor surface air and operative temperature.

6.2.12. TYPE 3 (T3)

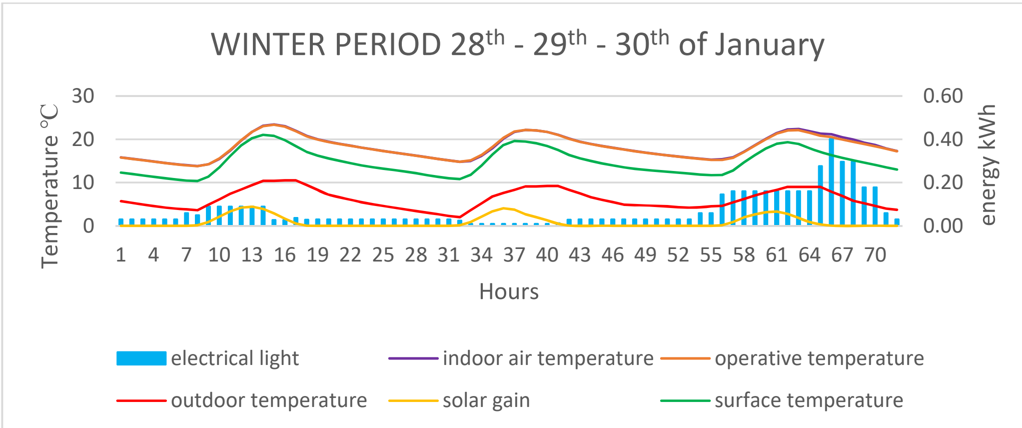


Figure 43 T3 Winter Period Values

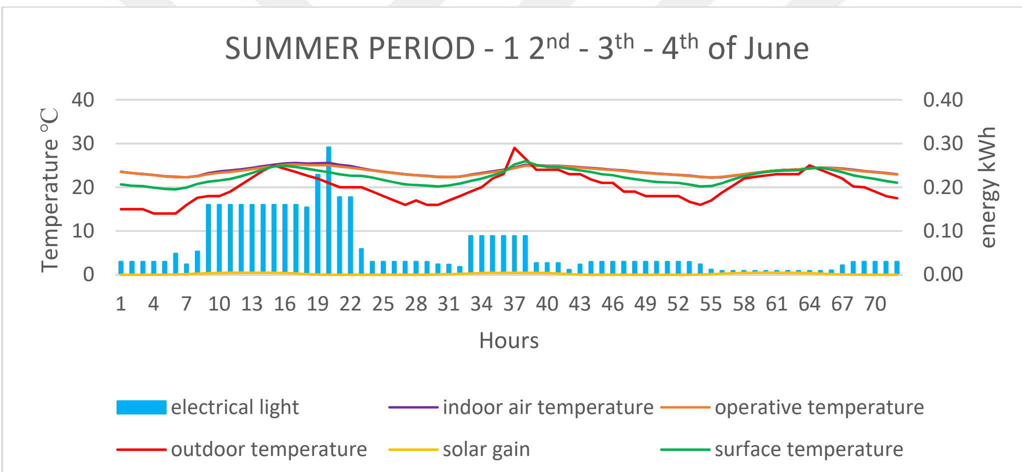


Figure 44 T3 Summer Period -1 Values

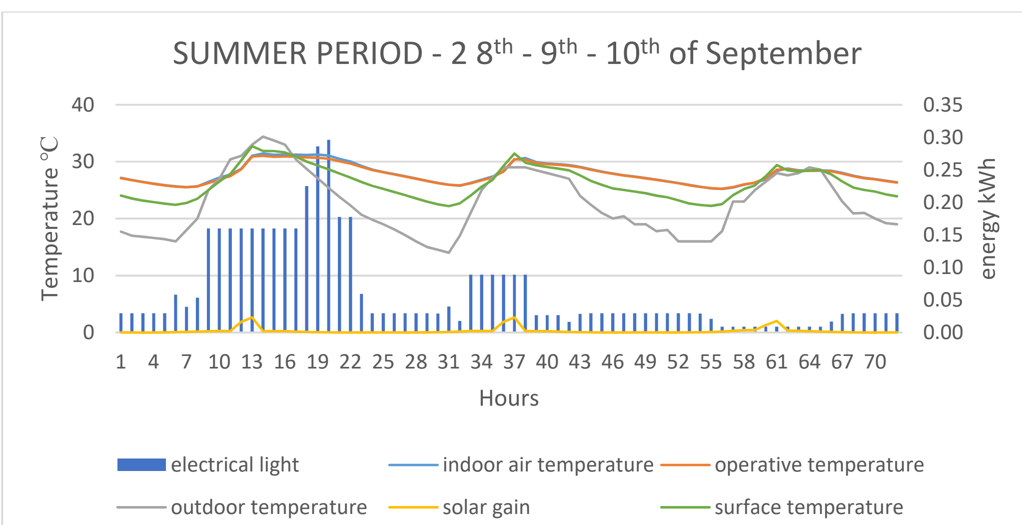


Figure 45 T3 Summer Period -2 Values

This shading device has an organic rectangle grid shape. In summer it performs well, and it decrease the temperature under the outdoor temperature levels. In winter, it keeps the temperature mostly between 15°C and 23°C.

6.3. COMPARISON OF THE ENERGY SIMULATIONS

In this section, types are compared each other regarding to solar gain, operative temperature and the surface temperature by referring the other outcomes of their simulations. As seen above, results belong to three days of winter and six days of summer period for all types.

6.3.1. SOLAR GAIN

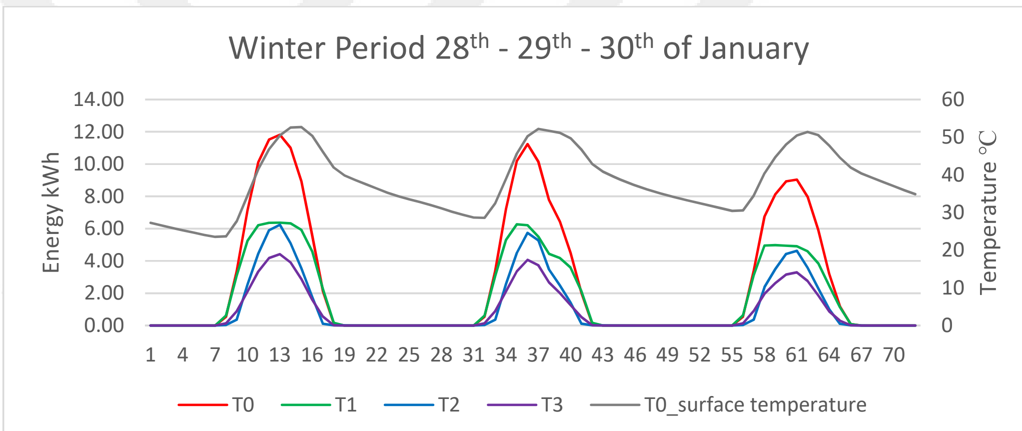


Figure 46 Winter Period Solar Gain Comparison

As seen in Figure 46 Solar Gain takes values with a wide on 28th, 29th and 30th of January. T3 has smallest values for this period approximately 3kWh but T0 has biggest values in that period approximately 11 kWh. This chart shows that in winter period T3 can blocked the solar gain best. T1 has smaller values than T0 and T2 has smaller than T1.

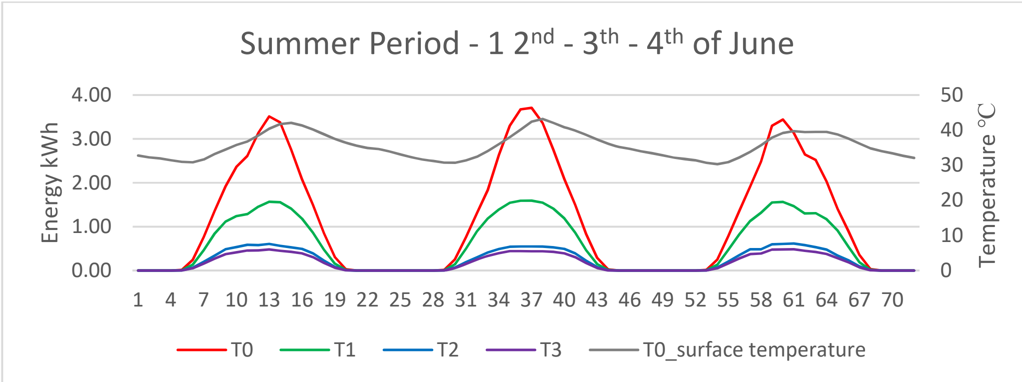


Figure 47 Summer Period - 1 Solar Gain Comparison

As seen in Figure 47 Solar Gain takes values with a wide range too on 2th, 3th and 4th of June like in January. But the difference in summer periods daytime is longer than winter so the gaining of the solar radiation expands the over the day but due to the altitude is higher than the winter period the solar gain values which is measured with amount of radiation perpendicular the glazing are smaller than that period. In addition to that like the winter T3 has smallest values for this period approximately 0.5 kWh and T0 has biggest values in that period approximately 3.5 kWh. This chart shows that in winter period T3 can blocked the solar gain best. T1 has smaller values than T0 and T2 has smaller than T1.

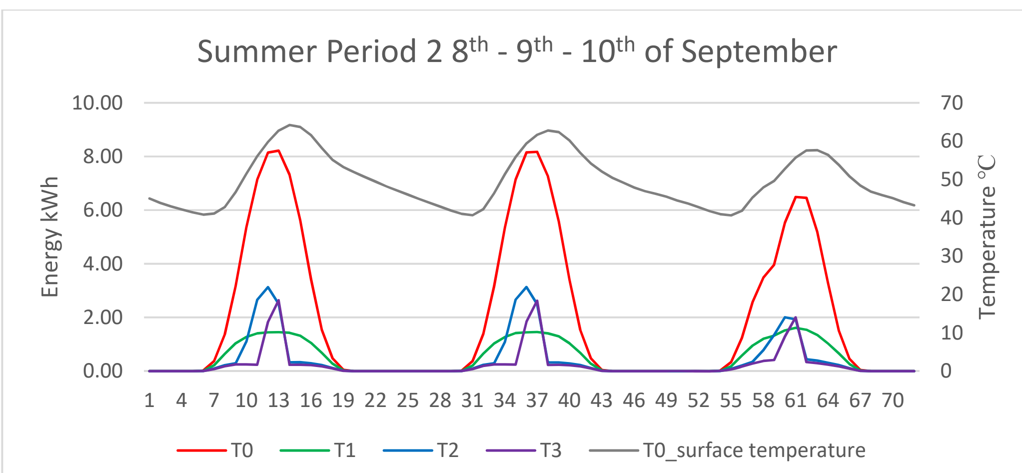


Figure 48 Summer Period - 2 Solar Gain Comparison

As seen in Figure 48 Solar Gain takes values with a wide on 8th, 9th and 10th of September. The daytime is approximately 14 hours of the day at the start of September. This chart shows that T1 allows the sun come thorough the window for all day, the others do not allows in mornings and evenings but they allows it in midday more due to the their triangle and cover shape.

6.3.2. OPERATIVE TEMPERATURE

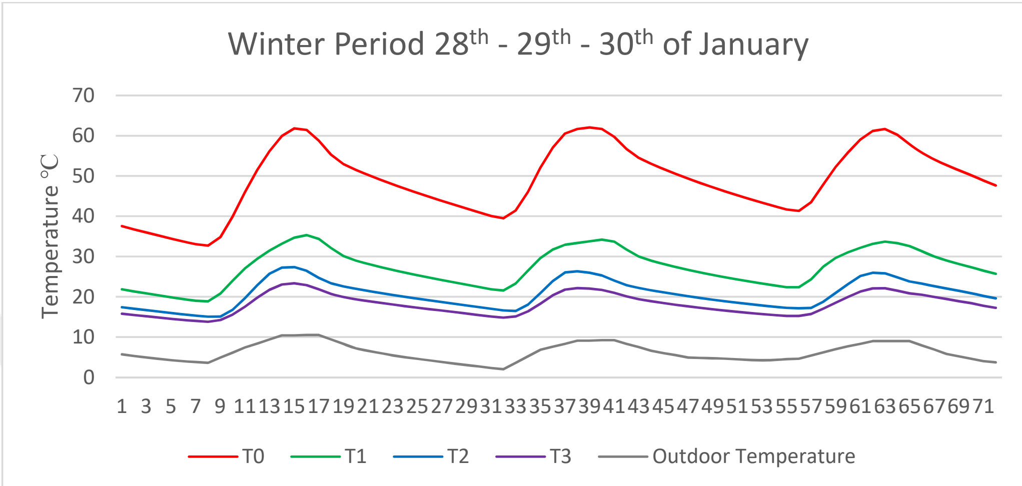


Figure 49 Winter Period Operative Temperature Comparison

As seen in Figure 49 The operative temperature for 28^{th}, 29^{th} and 30^{th} of January has numerous values which are 10,40℃, 23,35℃, 27,36℃, 34,66℃, 61,82℃ at 15 o’clock of the 28^{th} day of January for outdoor temperature, T3, T2, T1, T0. These degrees show similarity in the other days in the chart. This chart demonstrates that the decreasing of the operative temperature is different for each type of shading devices. The biggest decreasing ratio belongs to T3 and then T2 and then T1 in comparison to T0.

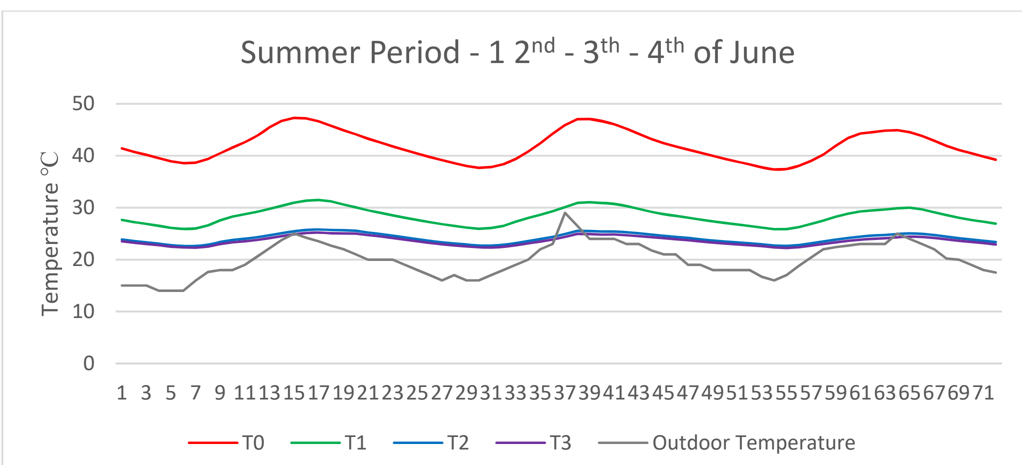


Figure 50 Summer Period – 1 Operative Temperature Comparison

As seen in Figure 50 The operative temperature for 2th, 3th and 4th of June has numerous values which are 25°C for outdoor temperature, T3 and T2, 30,97°C for T1, and 47,29°C for T0 at 15 o'clock of the 2th day of June. The T0 has smaller values in this period than winter period because of same with the solar gain. The altitude of the sun is higher than winter, so the radiation does not affect like in winter period. For this reason, indoor operative temperature does not rise a lot.

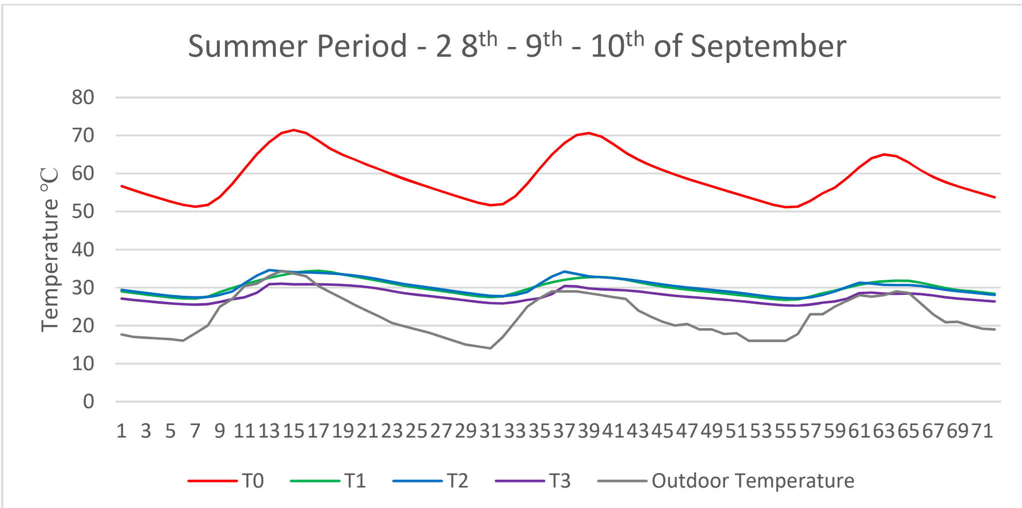


Figure 51 Summer Period – 2 Operative Temperature Comparison

As seen in Figure 51 The operative temperature for 8th, 9th and 10th of September has numerous values which are 30,86°C for T3, 33,70°C for T1, T2 and outdoor temperature, and 71,44°C for T0 at 15 o'clock of the 8th day of September.

These charts demonstrate the operative temperature of each types. In all charts, the performance of the T3 is better than the other can be seen. The T3 decreases the temperature in all period 30°C as a medium value. In summer periods, T2 and T3 are competitive although T3 has lower ELL values that shown in Table 11 and lower degree in winter period. When the indoor environment is adiabatic T3 is better than the others but it should be tried with real test box and with conductive surface.

6.3.3. SURFACE TEMPERATURE

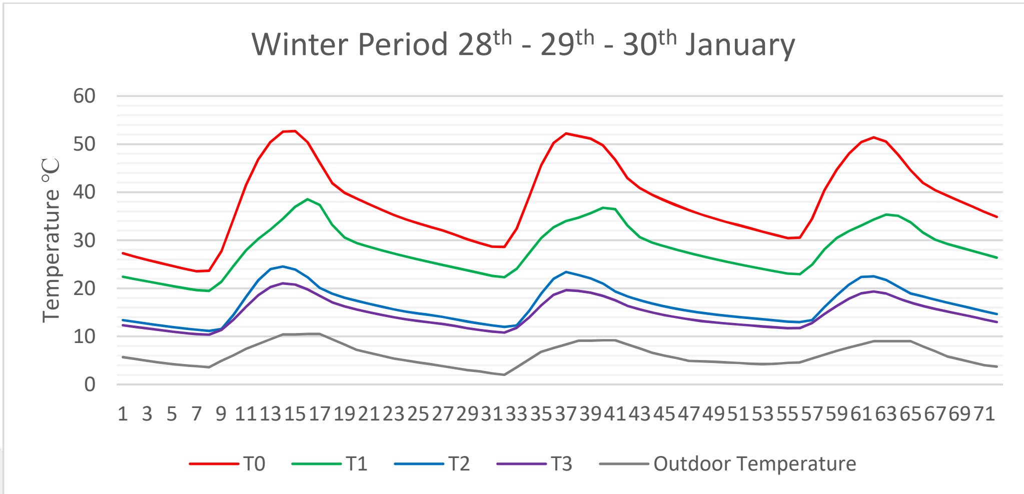


Figure 52 Winter Period Surface Temperature Comparison

When the surface temperature metric is analyzed, it is seen that the temperature value of the first day without shading device is approximately 53°C degree. The shading devices decrease that value to 36,97°C, 23,90°C, 20,78°C degrees while the outdoor surface temperature is 10,40°C degree for the winter period. The peak temperature of the other days are same almost.

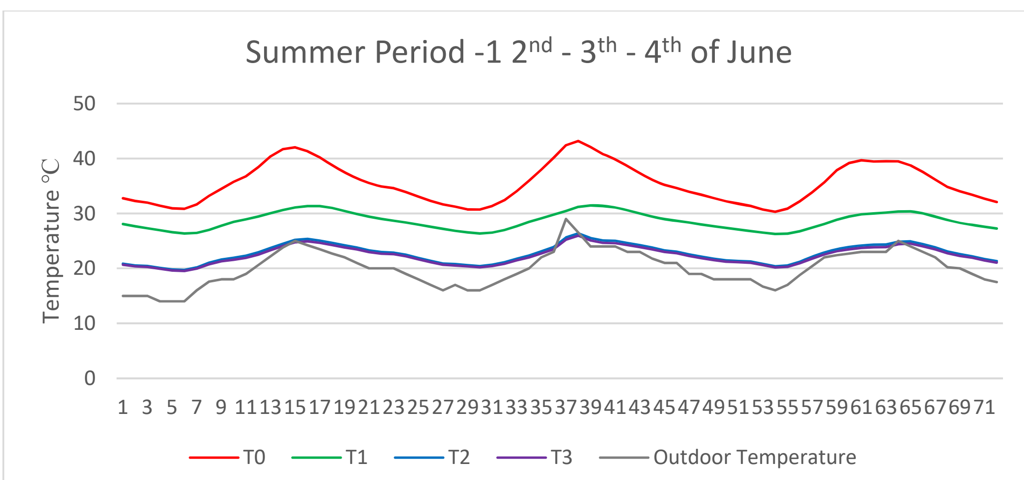


Figure 53 Summer Period – 1 Surface Temperature Comparison

In the summer period T2 and T3 values takes same readings nearly for each three days. Even so they decrease the temperature incredibly from 42°C degree to 24°C degree for first and second day of the chart. In the second day they take lower value than outdoor temperature.

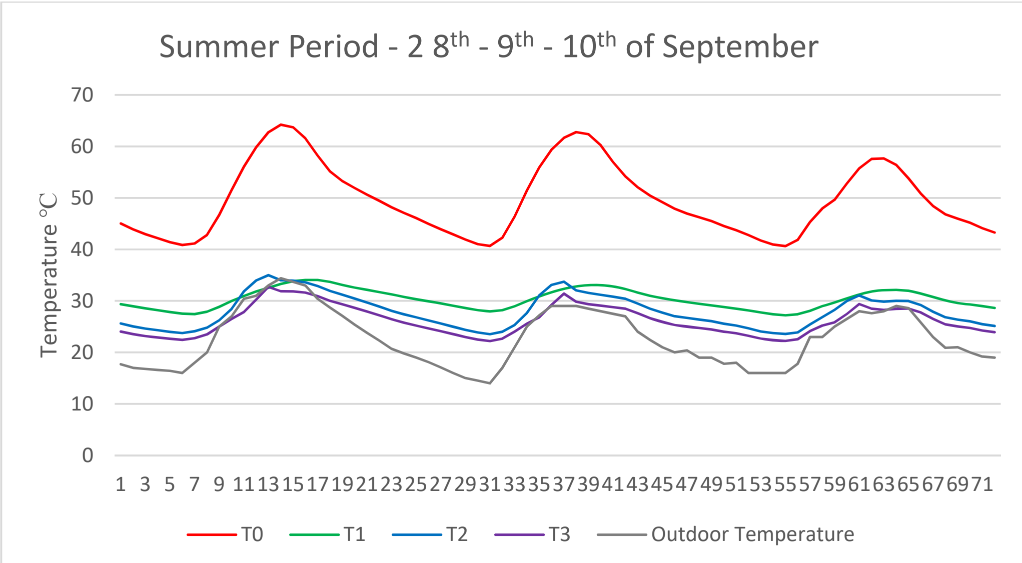


Figure 54 Summer Period – 2 Surface Temperature Comparison

These charts show the surface temperature comparisons which is an objective of the optimization problem. It can be seen from Figure 47, 48,49 that T3 is the best choice for reducing the surface temperature most considering that data. At the same time, the electrical lighting load is another of the optimization objective. Because of that surface temperature should not be evaluated individually. According to both objectives, T3 is the best solution. Total electrical light that the other objective of the optimization is given below:

Table 13 Total ELL and STM of Each Type

Types	Total Electrical Light Energy (kWh)	Surface Temperature Metric
T0	904,955	-0.13379
T1	1169,486	-0.303881
T2	944,604	-0.368607
T3	916,861	-0.336187

Table 14 The Surface Temperature Outputs

Types	Surface Temperature Number of Hour (20°C - 27°C)	Mean Surface Temperature of The Year
T0	1172	37.122332
T1	2662	22.725707
T2	3229	23.682052
T3	2945	20.448775

Total electrical light energy gives the necessary value to illuminate the interior volume to minimum 300 lux. The electrical light value of the T0 is the minimum amount among all types but it has no shading device. Therefore, the surface and the operative temperatures take extreme readings in T0.

CHAPTER 5
CONCLUSION

This research evaluates the performance of the organic and triangle grid base shading device applied to the south façade of the office building. The evaluation of the shading devices is done by comparing the energy performance of the test box with the device and with other shading devices such as conventional horizontal and flat triangle grid base and without shading devices.

The result of the study, in most of the periods of the year, proposed type of shading device which is OTGB performs better than the others. This 3-dimensional shading device in the specific limits gives to designer organic shape. On the contrary, to conventional simulation methods, in this study both the simulation and the optimization tools are utilized together to generate organic shading device form. The results may aid architects on deciding façade design. Because, this study shows also that when a multi objective optimization tool is used, designer have a solution cluster. This procedure provides design options in a reasonable time.

To sum up, the study has three main phases. These are form finding, energy efficiency evaluating and optimization. First of all, the form finding phase involve the form generation. By doing this, the surface copied from south façade of the test box is manipulated. The distance of all points of that surface between the façade and the opening ratios are changed different each other. Extrusions are changed for all opening edges. Also, the angle of extrusions is changed according to how it performs better. This phase let the shading device has behavior. The form of the shading devices may change in terms of the building shape, orientation location, climate type, zone program and occupancy. Therefore, it is usable for architects in many cases.

The performance evaluation is the second phase. In this phase, geometry of the shading device is an input for the energy simulation. The energy simulation is done by

Ladybug-Honeybee tool for Grasshopper Rhino. In the simulation, especially operative and surface temperature and electrical lighting are evaluated.

The last phase is the optimization part. After each change, the model generates new design alternative with different variable values to find better performing one according to energy simulation result. In deterministic approach, it takes a lot of time and it may not find feasible solution in a reasonable time. For this reason, genetic algorithms with meta heuristic approach are utilized. The algorithm has done the simulation automatedly. The optimization does not have have a weighted objective function since it is multi objective.

As a summary of the results of the study;

- The shading devices decrease the indoor temperatures at least 10℃ degrees against the without shading devices.
- T1 helps to reduce the temperature values in summer and winter period but it is not enough for the summer period to reach comfort temperature.
- T2 which is FTGB shading devices decrease the temperature approximately 10 ℃ degrees in winter period against the T1. Electrical lighting load of the test box with T3 is 904,644kWh, it performs better than T1.
- T3 reduce the surface, operative and air temperature approximately 15℃ in winter period against the T1. Electrical lighting load of the test box with T3 is 916,861kWh all over the year.
- In summer period, three types of shading devices reduce surface, operative and indoor air temperature dramatically. Even though all shading devices decrease the temperature approximately same values against without shading devices. T3 may be chosen better than the others in respect of electrical lighting and reducing ratio of the temperature for whole year.

After the summarizing of the results, it is explained that the future works of the study. Further study of this thesis can include many different aspects in addition to the ones selected in this study. The sum up the future projections;

- For test box:
    - The material definition may be added to the simulation to increase the precision of the simulation. Multi-zone building may be studied in future work, because the high-rise buildings became prevalent.
- Shading Devices;
    - The types of the shading devices may be adaptive because of adapting the seasonal variation. Adaptation is done by using the specification of the emerging materials such as shape memory alloys, phase change materials, etc.
    - The optimization of the shading devices may use in shorter time period and the opening ratios and shapes are apply to the adaptive shading devices.
    - The geometry of the shading devices are made by triangulated surfaces, the other meshing operators can be utilized to find design alternative with different geometrical characteristics.

REFERENCES

Agency, I. E. (2018). World energy balances: overview. *Word Energy Balances 2018*, (c), 24. https://doi.org/10.15713/ins.mmj.3

Al-Bahar Tower Facade. (n.d.). Retrieved May 13, 2019, from https://www.archdaily.com/270592/al-bahar-towers-responsive-facade-aedas/adic-jpeg-492x0_q85_crop-smart

Al-Masrani, S. M., Al-Obaidi, K. M., Zalin, N. A., & Aida Isma, M. I. (2018). Design optimisation of solar shading systems for tropical office buildings: Challenges and future trends. *Solar Energy*, *170*(April), 849–872. https://doi.org/10.1016/j.solener.2018.04.047

Allegrini, J., Orehounig, K., Mavromatidis, G., Ruesch, F., Dorer, V., & Evins, R. (2015). A review of modelling approaches and tools for the simulation of district-scale energy systems. *Renewable and Sustainable Energy Reviews*, *52*, 1391–1404. https://doi.org/10.1016/j.rser.2015.07.123

Atzeri, A., Cappelletti, F., & Gasparella, A. (2014). Internal versus external shading devices performance in office buildings. *Energy Procedia*, *45*, 463–472. https://doi.org/10.1016/j.egypro.2014.01.050

Azadeh Omidfar. (2015). *Performance evaluation of complex facades using various shading systems with ornamental patterns*. (December).

Bader, J., & Zitzler, E. (2010). HypE: An Algorithm for Fast Hypervolume-Based Many-Objective Optimization. *Evolutionary Computation*, *19*(1), 45–76. https://doi.org/10.1162/EVCO_a_00009

Beaman, M. L. (2010). *263 | 412*. 263–269.

Bellia, L., Marino, C., Minichiello, F., & Pedace, A. (2014). An overview on solar shading systems for buildings. *Energy Procedia*, *62*, 309–317. https://doi.org/10.1016/j.egypro.2014.12.392

Carlucci, S., Cattarin, G., Causone, F., & Pagliano, L. (2015). Multi-objective optimization of a nearly zero-energy building based on thermal and visual discomfort minimization using a non-dominated sorting genetic algorithm (NSGA-II). *Energy and Buildings*, *104*(2015), 378–394.

https://doi.org/10.1016/j.enbuild.2015.06.064

Chi, D. A., Moreno, D., & Navarro, J. (2018). Correlating daylight availability metric with lighting, heating and cooling energy consumptions. *Building and Environment*, *132*(January), 170–180. https://doi.org/10.1016/j.buildenv.2018.01.048

Coakley, D., Raftery, P., & Keane, M. (2014). A review of methods to match building energy simulation models to measured data. *Renewable and Sustainable Energy Reviews*, *37*, 123–141. https://doi.org/10.1016/j.rser.2014.05.007

Crawley, D. B., Hand, J. W., Kummert, M., & Griffith, B. T. (2008). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment*, *43*(4), 661–673. https://doi.org/10.1016/j.buildenv.2006.10.027

Datta, G. (2001). Effect of fixed horizontal louver shading devices on thermal perfomance of building by TRNSYS simulation. *Renewable Energy*, *23*(3–4), 497–507. https://doi.org/10.1016/S0960-1481(00)00131-2

Dubois, M. C. (2003). Shading devices and daylight quality: An evaluation based on simple performance indicators. *Lighting Research & Technology*, *35*(1), 61–74. https://doi.org/10.1191/1477153503li062oa

ElGhazi, Y. S., Wagdy, A., Mohamed, S. A. A., & Hassan, A. (2014). DAYLIGHTING DRIVEN DESIGN : OPTIMIZING KALEIDOCYCLE FACADE FOR HOT ARID CLIMATE Cairo University , Cairo , Egypt The American University in Cairo , Cairo , Egypt Al Azhar University , Cairo , Egypt Future University in Egypt , Cairo , Egypt. *BauSIM2014 - IBPSA-Germany*, (September), 314–321. https://doi.org/10.13140/RG.2.1.3198.4408

FAO, IFAD, UNICEF, WFP, W. (2018). The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition. Rome, FAO. Licence: CC BY-NC-SA 3.0 IGO. In *Building climate resilience for food security and nutrition.* https://doi.org/10.1093/cjres/rst006

Favoino, F., Jin, Q., & Overend, M. (2017). Design and control optimisation of adaptive insulation systems for office buildings. Part 1: Adaptive technologies and simulation framework. *Energy*, *127*, 301–309.

https://doi.org/10.1016/j.energy.2017.03.083

Gagne, J., & Andersen, M. (2012). A generative facade design method based on daylighting performance goals. *Journal of Building Performance Simulation*, *5*(3), 141–154. https://doi.org/10.1080/19401493.2010.549572

Hamdy, M., Nguyen, A. T., & Hensen, J. L. M. (2016). A performance comparison of multi-objective optimization algorithms for solving nearly-zero-energy-building design problems. *Energy and Buildings*, *121*, 57–71. https://doi.org/10.1016/j.enbuild.2016.03.035

Hou, D., Wang, L., Dang, R., Liu, G., & Zhang, Q. (2016). Integrated Building Envelope Design Process Combining Parametric Modelling and Multi-Objective Optimization. *Transactions of Tianjin University*, *23*(2), 138–146. https://doi.org/10.1007/s12209-016-0022-1

International Energy Agency. (2008). Energy Efficiency Requirements in Building Codes , Energy Efficiency Policies for New Buildings. *IEA Information Paper*, (March), 1–85. https://doi.org/10.1.1.378.1012

Jan Wienold. (2007). Dynamic simulation of blind control strategies for visual comfort and energy balance analysis. *Building Simulation 2007*, 1197–1204.

Jin, J. T., & Jeong, J. W. (2014). Optimization of a free-form building shape to minimize external thermal load using genetic algorithm. *Energy and Buildings*, *85*, 473–482. https://doi.org/10.1016/j.enbuild.2014.09.080

Jin, Q., Favoino, F., & Overend, M. (2017). Design and control optimisation of adaptive insulation systems for office buildings. Part 2: A parametric study for a temperate climate. *Energy*, *127*, 634–649. https://doi.org/10.1016/j.energy.2017.03.096

Kanters, J., Wall, M., & Dubois, M. (2014). Typical values for active solar energy in urban planning. *Energy Procedia*, *48*, 1607–1616. https://doi.org/10.1016/j.egypro.2014.02.181

Keiner, M. (2006). The future of sustainability. *The Future of Sustainability*, (January), 1–257. https://doi.org/10.1007/1-4020-4908-0

Khin, A., Lau, K., Salleh, E., Lim, C. H., & Sulaiman, M. Y. (2016). Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates : The case of Malaysia. *International Journal of Sustainable Built Environment*, *5*(2), 387–399. https://doi.org/10.1016/j.ijsbe.2016.04.004

Khoroshiltseva, M., Slanzi, D., & Poli, I. (2016). A Pareto-based multi-objective optimization algorithm to design energy-efficient shading devices. *Applied Energy*, *184*, 1400–1410. https://doi.org/10.1016/j.apenergy.2016.05.015

Kinetic Adaptive Shading Device. (n.d.). Retrieved from https://www.archdaily.com/236979/one-ocean-thematic-pavilion-expo-2012-soma/5001233f28ba0d2c9f000af2-one-ocean-thematic-pavilion-expo-2012-soma-photo

Kirimtat, A., Koyunbaba, B. K., Chatzikonstantinou, I., & Sariyildiz, S. (2016). Review of simulation modeling for shading devices in buildings. *Renewable and Sustainable Energy Reviews*, *53*, 23–49. https://doi.org/10.1016/j.rser.2015.08.020

Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., … Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *Journal of Exposure Analysis and Environmental Epidemiology*, *11*(3), 231–252. https://doi.org/10.1038/sj.jea.7500165

Konak, A., Coit, D. W., & Smith, A. E. (2006). *Multi-objective optimization using genetic algorithms : A tutorial*. *91*, 992–1007. https://doi.org/10.1016/j.ress.2005.11.018

Konis, K. (2013). Evaluating daylighting effectiveness and occupant visual comfort in a side-lit open-plan office building in San Francisco, California. *Building and Environment*, *59*, 662–677. https://doi.org/10.1016/j.buildenv.2012.09.017

Kuhlman, T., & Farrington, J. (2010). What is sustainability? *Sustainability*, *2*(11), 3436–3448. https://doi.org/10.3390/su2113436

Kuhn, T. E., Bühler, C., & Platzer, W. J. (2000). Evaluation of overheating protection with sun-shading systems. *Solar Energy*, *69*(SUPPLEMENT), 59–74. https://doi.org/10.1016/S0038-092X(01)00017-2

Lim, G. H., Hirning, M. B., Keumala, N., & Ghafar, N. A. (2017). Daylight performance and users' visual appraisal for green building offices in Malaysia. *Energy and Buildings*, *141*, 175–185. https://doi.org/10.1016/j.enbuild.2017.02.028

Lotfabadi, P. (2014). High-rise buildings and environmental factors. *Renewable and Sustainable Energy Reviews*, *38*, 285–295. https://doi.org/10.1016/j.rser.2014.05.024

Mahmoud, A. H. A., & Elghazi, Y. (2016). Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns. *Solar Energy*, *126*, 111–127. https://doi.org/10.1016/j.solener.2015.12.039

Manzan, M. (2014). Genetic optimization of external fixed shading devices. *Energy and Buildings*, *72*, 431–440. https://doi.org/10.1016/j.enbuild.2014.01.007

Mirrahimi, S., Mohamed, M. F., Haw, L. C., Ibrahim, N. L. N., Yusoff, W. F. M., & Aflaki, A. (2016). The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot-humid climate. *Renewable and Sustainable Energy Reviews*, *53*, 1508–1519. https://doi.org/10.1016/j.rser.2015.09.055

Nguyen, A., Reiter, S., & Rigo, P. (2014). A review on simulation-based optimization methods applied to building performance analysis. *APPLIED ENERGY*, *113*, 1043–1058. https://doi.org/10.1016/j.apenergy.2013.08.061

Niloufar, E., Khodadadi, A., & von Buelow, P. (2014). Design of Shading Screens Inspired by Persian Geometric Patterns : An Integrated Structural and Daylighting Performance Evaluation. *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium IASS 2014*, (August 2015).

O`Connor, J., Lee, E., Rubinstein, F., & Selkowitz, S. (1997). *Tips for daylighting*. Retrieved from https://www.osti.gov/servlets/purl/532706

Open Studio. (n.d.). Retrieved May 11, 2019, from https://www.openstudio.net/

Overhangs. (n.d.). Retrieved May 12, 2019, from http://designadvisor.mit.edu/design/help/overhang.html

Pacheco, R., Ordóñez, J., & Martínez, G. (2012). Energy efficient design of building:

A review. *Renewable and Sustainable Energy Reviews*, *16*(6), 3559–3573. https://doi.org/10.1016/j.rser.2012.03.045

Palmero-Marrero, A. I., & Oliveira, A. C. (2006). Evaluation of a solar thermal system using building louvre shading devices. *Solar Energy*, *80*(5), 545–554. https://doi.org/10.1016/j.solener.2005.04.003

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings*, *40*(3), 394–398. https://doi.org/10.1016/j.enbuild.2007.03.007

Perforated Panels. (n.d.). Retrieved May 12, 2019, from https://www.archdaily.com/catalog/us/products/8504/shading-screens-perforated-facade-panels-bruag/79062

Porteros, M., Vega, S., Gutiérrez, A., Montero, C., Navarro, I., Rodriguez-Ubinas, E., … Castillo-Cagigal, M. (2014). Passive design strategies and performance of Net Energy Plus Houses. *Energy and Buildings*, *83*, 10–22. https://doi.org/10.1016/j.enbuild.2014.03.074

Radu, A., Barreira, E., Saber, H., Hens, H., Vinha, J., Vasilache, M., … Maref, W. (2012). *Heat , Air and Moisture Transfer Terminology Parameters and Concepts*.

Rallapalli, H. S. (2010). A Comparison of EnergyPlus and eQUEST Whole Building Energy Simulation Results for a Medium Sized Office Building. *A Thesis Presented in Partial Fulfillment of the Requirements for the Degree Master of Science*, (November), 210.

Sadeghipour Roudsari, M., Pak, M., & Smith, A. (2013). Ladybug: a Parametric Environmental Plugin for Grasshopper To Help Designers Create an Environmentally-Conscious Design. *13th Conference of International Building Performance Simulation Association*, 3129–3135.

Shameri, M. A., Alghoul, M. A., Elayeb, O., Zain, M. F. M., Alrubaih, M. S., Amir, H., & Sopian, K. (2013). Daylighting characterstics of existing double-skin fac ̧ ade office buildings. *Energy & Buildings*, *59*, 279–286. https://doi.org/10.1016/j.enbuild.2012.12.025

Sherif, A., El-Zafarany, A., & Arafa, R. (2012). External perforated window Solar

Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments. *Energy and Buildings*, *52*, 1–10. https://doi.org/10.1016/j.enbuild.2012.05.025

Sherif, A. H., Sabry, H. M., & Gadelhak, M. I. (2012). The impact of changing solar screen rotation angle and its opening aspect ratios on Daylight Availability in residential desert buildings. *Solar Energy*, *86*(11), 3353–3363. https://doi.org/10.1016/j.solener.2012.09.006

Sherif, Ahmed, El-zafarany, A., & Arafa, R. (2013). Evaluating the Energy Performance of External Perforated Solar Screens: Effect of Screen Rotation and Aspect Ratio. *SB 13 - Sustainable Building*, *1*(5), 102–108.

Shi, X. (2010). Performance-based and performance-driven architectural design and optimization. *Frontiers of Architecture and Civil Engineering in China*, *4*(4), 512–518. https://doi.org/10.1007/s11709-010-0090-6

Su, Z., Li, X., & Xue, F. (2017). Double-skin façade optimization design for different climate zones in China. *Solar Energy*, *155*, 281–290. https://doi.org/10.1016/j.solener.2017.06.042

Touloupaki, E., & Theodosiou, T. (2017a). Energy performance optimization as a generative design tool for nearly zero energy buildings. *Procedia Engineering*, *180*, 1178–1185. https://doi.org/10.1016/j.proeng.2017.04.278

Touloupaki, E., & Theodosiou, T. (2017b). Optimization of Building form to Minimize Energy Consumption through Parametric Modelling. *Procedia Environmental Sciences*, *38*, 509–514. https://doi.org/10.1016/j.proenv.2017.03.114

Toutou, A., Fikry, M., & Mohamed, W. (2018). The parametric based optimization framework daylighting and energy performance in residential buildings in hot arid zone. *Alexandria Engineering Journal*, *57*(4), 3595–3608. https://doi.org/10.1016/j.aej.2018.04.006

Tuhus-dubrow, D., & Krarti, M. (2010). Genetic-algorithm based approach to optimize building envelope design for residential buildings. *Building and Environment*, *45*(7), 1574–1581. https://doi.org/10.1016/j.buildenv.2010.01.005

Tzempelikos, A., & Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. *Solar Energy*, *81*(3), 369–382. https://doi.org/10.1016/j.solener.2006.06.015

United Nations. (2017). Volume II: Demographic Profiles (ST/ESA/SER.A/400). *World Population Prospects - The 2017 Revision*, *II*. https://doi.org/10.1017/CBO9781107415324.004

Vierlinger, R. (2015). *D IPLOMARBEIT Master Thesis Multi Objective Design Interface*. (April 2013). https://doi.org/10.13140/RG.2.1.3401.0324

Wang, W., Zmeureanu, R., & Rivard, H. (2005). Applying multi-objective genetic algorithms in green building design optimization. *Building and Environment*, *40*(11), 1512–1525. https://doi.org/10.1016/j.buildenv.2004.11.017

World Map of Köppen − Geiger Climate Classification Main climates. (2000). 2000.

Yang, D., Sun, Y., Turrin, M., Buelow, P. von, & Paul, J. (2015). Multi-objective and multidisciplinary design optimization of large sports building envelopes : a case study. *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium "Future Visions,"* (August).

Yener, A. K. (2002). A method of obtaining visual comfort using fixed shading devices in rooms. *Building and Environment*, *34*(3), 285–291. https://doi.org/10.1016/s0360-1323(98)00024-9

Zhang, A., Bokel, R., van den Dobbelsteen, A., Sun, Y., Huang, Q., & Zhang, Q. (2017). Optimization of thermal and daylight performance of school buildings based on a multi-objective genetic algorithm in the cold climate of China. *Energy and Buildings*, *139*, 371–384. https://doi.org/10.1016/j.enbuild.2017.01.048

Zhang, L., Zhang, L., & Wang, Y. (2016). Shape optimization of free-form buildings based on solar radiation gain and space efficiency using a multi-objective genetic algorithm in the severe cold zones of China. *Solar Energy*, *132*, 38–50. https://doi.org/10.1016/j.solener.2016.02.053

Zhao, H. X., & Magoulès, F. (2012). A review on the prediction of building energy consumption. *Renewable and Sustainable Energy Reviews*, *16*(6), 3586–3592. https://doi.org/10.1016/j.rser.2012.02.049

Zitzler, E., Laumanns, M., & Thiele, L. (2014). SPEA2: Improving the Strength

Pareto Evolutionary Algorithm. *Igarss 2014*. https://doi.org/10.1007/s13398-014-0173-7.2

Zomorodian, Z. S., & Tahsildoost, M. (2018). Energy and carbon analysis of double skin façades in the hot and dry climate. *Journal of Cleaner Production*, *197*, 85–96. https://doi.org/10.1016/j.jclepro.2018.06.178