YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

DESIGN AND COMPUTATIONAL OPTIMIZATION OF AN INTEGRATED SHADING DEVICE INTO A BUILDING

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I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a dissertation for the degree of master of science.

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ABSTRACT

DESIGN AND COMPUTATIONAL OPTIMIZATION OF AN INTEGRATED SHADING DEVICE INTO A BUILDING

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Most of the countries in the world are outfacing the reduction of energy consumption, even though electrical appliances began to be used extensively in buildings. Architectural aspects should be reappraised to decrease this energy consumption. Overheating issue is one of these aspects, and it is originated by large glazed facades. To overcome this overheating problem, shading elements should be necessarily integrated at an early-design stage in the design process. Especially in summer time, shading elements are significantly necessary to protect the window from solar radiation. Therefore, shading devices should be considered as an integral part of the façade design during the conceptual phase of the building design. This thesis aims to develop a shading device in a building by using parametric modelling techniques in combination with Intelligent Decision Support tools, optimization methods, and simulation techniques. The study is about how to design more efficient shading element for summer and winter time in general. The objectives considered in this study are daylight and total energy consumption which includes heating and cooling energy consumptions. An application of the method is presented, focusing on the design of a shading device integrated to the one of the buildings at Yaşar University in Izmir, Turkey.

Keywords: Shading device, daylight, energy, optimization, simulation, Intelligent Decision Support tools.

ÖZET

BİR BİNAYA ENTEGRE EDİLEBİLEN GÖLGELEME ELEMANININ TASARIMI VE BİLİŞİMSEL OPTİMİZASYONU

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Dünyadaki birçok ülke elektrikli aletlerin yaygın bir şekilde kullanılmaya başlanmasına rağmen enerji tüketimini azaltmak için çaba harcamaktadır. Bu enerji tüketimini azaltmak için mimaride bakış açıları yeniden değerlendirilmelidir. Aşırı ısıtma konusu bu bakış açılarından biridir ve büyük cam cepheler buna neden olmaktadır. Aşırı ısıtma konusu ile baş etmek için gölgeleme elemanları tasarım sürecinin ilk aşamalarında entegre edilmelidir. Özellikle yazın, gölgeleme elemanları pencereyi solar radyasyondan korumak için önemli ölçüde gereklidir. Bu yüzden gölgeleme elemanları bir bina tasarımının konsept aşaması boyunca cephe tasarımına entegre düşünülmelidir. Bu tez parametrik modelleme teknikleri ile birlikte Akıllı Karar Verme Desteği araçları, optimizasyon methodları, ve simulasyon teknikleri yardımıyla binaya uygun bir gölgeleme elemanı geliştirmeyi amaçlamaktadır. Bu çalışma hem yaz hem de kış mevsimi için nasıl daha verimli bir gölgeleme elemanı tasarlanması gerektiği hakkındadır. Bu çalışmada düşünülen amaçlar doğal ışık ve ısıtma ve soğutma enerjisi tüketimini kapsayan total enerji tüketimidir. Sunulan methodun uygulaması İzmir, Türkiye'de yer alan Yaşar Üniversitesi'ndeki bir binaya entegre edilebilen bir gölgeleme elemanı tasarımına odaklanmaktadır

Anahtar sözcükler: Gölgeleme elemanı, doğal ışık, enerji, optimizasyon, simulasyon, Akıllı Karar Verme Destek araçları.

To my father Architect Kenan KIRIMTAT…

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After three years on Master of Science programme in the Department of Architecture of Yaşar University, I wish that this study, which provides the ideal opportunity to expand my professional skills, would be a crucial step for my academic career. During this process, there are so many people, each of whom I am grateful to.

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I also would like to express my deeply thankfulness to my father **Architect Kenan Kırımtat** who always supports, encourages, and motivates me during the most difficult times. This study could not be realized without his promotion. Moreover, my mother **Yasemin Kırımtat** and my sister **Gökçe Kırımtat** also have a big support for me during this thesis process. I also would like to thank them.

Ayça KIRIMTAT
İzmir, 2016

TEXT OF OATH

I declare and honestly confirm that my study, titled “Design and Computational Optimization of an Integrated Shading Device into a Building” and presented as a Master’s Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions, that all sources from which I have benefited are listed in the bibliography, and that I have benefited from these sources by means of making references.

Ayça KIRIMTAT

Izmir, 2016

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INDEX OF SYMBOLS AND ABBREVIATIONS

Symbols	Explanations
d_h	density of horizontal louvers in z direction
w_h	width of horizontal louvers
r_h	rotation angle of horizontal louvers
d_v	density of vertical louvers in y direction
w_v	width of vertical louvers
r_v	rotation angle of vertical louvers
w_o	width of overhang
r_o	rotation angle of overhang
w_{L1}	first width of first louver
w_{L2}	second width of first louver
w_{L3}	third width of first louver
w_{L4}	fourth width of first louver
w_{L5}	first width of second louver
w_{L6}	second width of second louver
w_{L7}	third width of second louver

w_{L8}	fourth width of second louver
w_{L9}	first width of third louver
w_{L10}	second width of third louver
w_{L11}	third width of third louver
w_{L12}	fourth width of third louver
w_{L13}	first width of fourth louver
w_{L14}	second width of fourth louver
w_{L15}	third width of fourth louver
w_{L16}	fourth width of fourth louver
w_{L17}	first width of fifth louver
w_{L18}	second width of fifth louver
w_{L19}	third width of fifth louver
w_{L20}	fourth width of fifth louver
w_{L21}	first width of sixth louver
w_{L22}	second width of sixth louver
w_{L23}	third width of sixth louver
w_{L24}	fourth width of sixth louver
w_{L25}	first width of seventh louver

w_{L26}	second width of seventh louver
w_{L27}	third width of seventh louver
w_{L28}	fourth width of seventh louver
w_{L29}	first width of eighth louver
w_{L30}	second width of eighth louver
w_{L31}	third width of eighth louver
w_{L32}	fourth width of eighth louver
w_{L33}	first width of ninth louver
w_{L34}	second width of ninth louver
w_{L35}	third width of ninth louver
w_{L36}	fourth width of ninth louver
w_{L37}	first width of tenth louver
w_{L38}	second width of tenth louver
w_{L39}	third width of tenth louver
w_{L40}	fourth width of tenth louver
ra_{L1}	rotation angle of first louver
ra_{L2}	rotation angle of second louver
ra_{L3}	rotation angle of third louver

ra_{L4}	rotation angle of fourth louver
ra_{L5}	rotation angle of fifth louver
ra_{L6}	rotation angle of sixth louver
ra_{L7}	rotation angle of seventh louver
ra_{L8}	rotation angle of eighth louver
ra_{L9}	rotation angle of ninth louver
ra_{L10}	rotation angle of tenth louver

Abbreviations

TEC	Total Energy Consumption
UDI	Useful Daylight Illuminance
NSGA-II	Non-Dominated Sorting Genetic Algorithm II

CHAPTER 1

INTRODUCTION

1.1 Motivation

There is an important necessity for the reduction of the effects of global warming all around the world. This problem brings the need for reduction of green gas emissions in its wake. Therefore, European Union has an aim of reduce the greengas emissions at least 20% by 2050 (EU, EPDB recast, 2010). While buildings all around the world becomes extensive, precautions should be taken for both existing and new buildings to provide energy efficiency. One of the most important precautions is using shading devices in buildings. They are quite necessary since they prevent overheating during cooling period.

Furthermore, European policies underline the importance of energy efficiency to accentuate energy guarantee and climate change according to Carvalho (2013). Around 40% of the total final energy use and 36% of the total CO_2 emissions of the EU Member States are disposed of by buildings in the European Union (Efficiency E.). If we look from the viewpoint of energy conservation in buildings, shading devices are really necessary for highly glazed facades. Architects and engineers provide facades with large, glazed portions in buildings for daylight and external view. A risk of creating high heating and cooling loads in these buildings should not be forgotten (Wall and Poirazis, 2008; Hien Et Al., 2005). Overhangs (Lee and Tavil, 2005), external roller shades (Tzempelikos and Athienitis, 2007), venetian blinds (HS and Binder, 2008) and internal shading (Florides and Kalogirou, 2000) are some of the shading device types to provide energy efficiency in buildings. As mentioned following parts, different researchers have studied these shading devices in various cases. Moreover, these studies underline the significance of the use of these shading device types in buildings.

In Platzer's research (2001), there are two reasons to use shading device in a building: first one is to prevent direct sunlight and solar radiation into the building in summer time and second one is to allow solar gains in winter time. In winter and summer time, natural light is necessary for interior spaces. Moreover, there are other architectural aspects that should be taken into consideration such as the building type, building form, orientation, and the latitude at the same time mounting shading devices into glazed facades in any building. The shading device type affects the level of desirable natural light, thermal comfort and visual comfort (Kim, 2010).

Littlefair Et Al. (2010) states that shading devices provide energy efficiency. It was estimated in the Building Research Establishment case study that the integration of air conditioning in a 1960's open plan office would cause an increase of 55 kWh/m^2/year and £15/m^2/year. It is also indicated in this study that the use of shading devices and night ventilation could provide comfort with zero cooling energy consumption. These precautions have also high cost, but it is much less than cooling equipment installation. Moreover, even cooling equipment is used in a building, in less than 5 years the gain can happen (Littlefair Et Al., 2010). It is indicated in the Dubois' (2001) study that large energy savings (around 12 kWh/m^2/year) might be achieved by integrating seasonal awning on an office window on the south facade. Nevertheless, when fixed awning were used rather than seasonal one, the energy saving would be less than 12 kWh/m^2/year. For this reason, the shading devices must be removed in winter time.

Kim Et Al. (2012) expresses that green facades protect buildings from solar radiation by increasing thermal comfort for interior spaces. Only a required amount of solar radiation is transmitted into buildings. Leaves absorb most of the solar radiation to make photosynthesis and evapo-transpiration as well as decrease overheating in a building (Panagopoulos, 2008). Moreover, according to Sunakorn and Yimprayoon (2011) when the more leaves cover the facade, the building shows better thermal performance and energy-efficiency in hot climatic regions.

1.2 Problem Definition

Architects define architectural design as a complex task to solve. Especially, designing something new has higher expectations when scale and the complexity of geometries get bigger. Because of these reasons, it is very difficult to discover possible design solutions among all alternatives in the early stage of design process (Ekici, 2014). Shading device designs for buildings can be one of the best example of complex design problems. According to previous statements they also have a significant influence on the energy efficiency in buildings.

The design of shading devices with an objective of optimizing the energy efficiency is generally a complex high dimensional multi-optimization problem. According to Khoroshiltseva Et. Al. (2016), this problem contains leashed variables and they should be optimized regarding to conflictive objectives. These objectives might be to reduce the overheating time of the building, to provide high level of visual comfort, and to provide minimum level of energy consumption for heating, cooling and lighting.

In this research, a study was carried out with the renovation of a classroom located in one of the buildings in Yaşar University, İzmir, Turkey by designing a new shading device with optimization methods, simulation techniques in order to reduce total energy consumption which includes heating and cooling and increase daylight availability in interior space. Furthermore, the particular sunny climatic conditions of our case study lead to very high level of overheating problems. This results in high level of discomfort for occupants in interior space and high level of energy consumption. For these reasons, the focus point is finding optimal design solutions for a fixed shading device like external shading devices integrated to the classroom in a building. This multi-objective optimization problem is addressed by proposing a stochastic approach consisting of multi objective combined methodology based on NSGA-II and Pareto front.

1.3 Aim of the Research

The aim of this research is both to develop a computational design model for shading devices in buildings both for winter and summer time according to statements mentioned in the previous part and to integrate multi-performance criteria to this study. Thus, it is expected that this model will be useful in order to support design decision process while discovering suitable shading device design alternatives.

Furthermore, different simulation tools used in the studies about shading devices around the world so far were reviewed, collected and turned into a publication (Kirimtat Et. Al., 2016). As a result of this, we aimed to propose a shading device design integrated to a building by using optimization methods and simulation techniques. Specific types of shading devices, which are horizontal louvers, vertical louvers and overhang, were compared according to their daylight and energy performances. The most effective position was selected and used as a template for the proposed design.

1.4 Method of the Research

The method of this research is based on developing multi-performance based computational design model for a shading device integrated to a building for both winter and summer time by comparing them potential shading device types. In this context, the method of this thesis consists of simulation modeling for shading devices, developing multi-performance based computational shading device design model and results of the model. The method of this research described as follows (Figure 1.1):

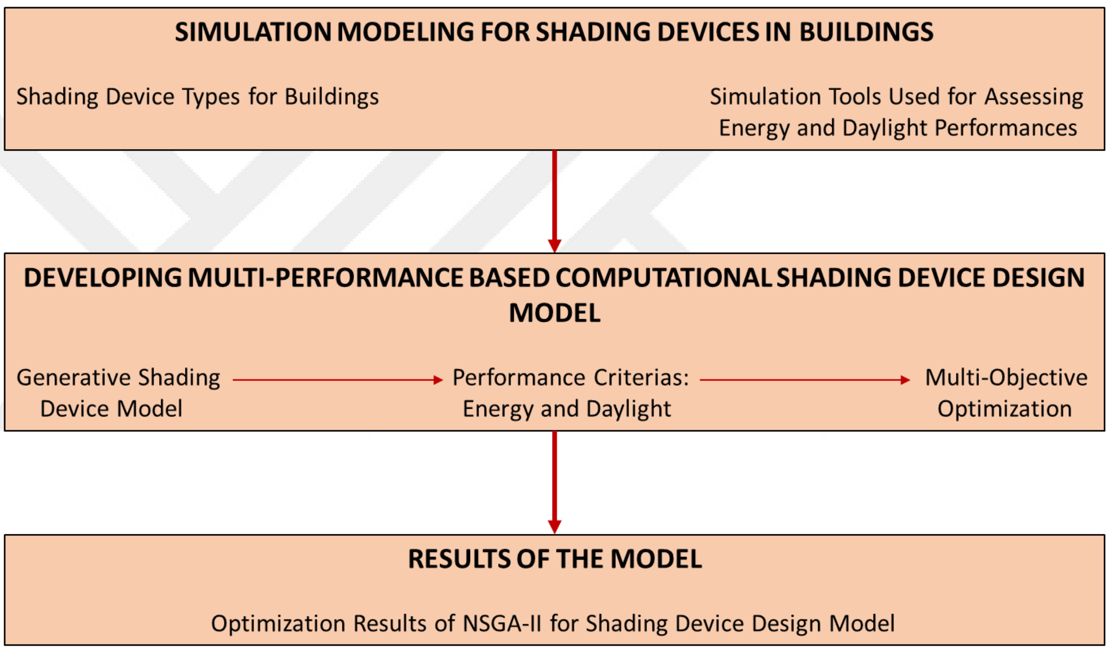

Figure 1.1. Method of the Research as Schematic Illustration

Simulation Modeling for Shading Devices: This section consists of shading device types for buildings and simulation tools used for assessing energy and daylight performances. Various shading device types have been studied and defined in order to develop and evaluate the generative shading device model. Furthermore, the importance of simulation modeling for shading devices approach during the conceptual phase of the building design was underlined.

Developing Multi-Performance Based Computational Shading Device Design Model: In this section, generative shading device model has been created according to decision variables and constraints. Then, performance criterias which are energy and daylight were set as objective functions. In addition to these, working procedure of

NSGA-II was explained in the context of computational optimization. Regarding to two objectives which are total energy consumption and useful daylight illuminance, multi-objective optimization was occurred.

Results of the Model: This is the final section that includes the results of NSGA-II algorithm for shading device design model. Many design solutions have been created according to two objectives.

1.4 Context of the Research

This research framework is based on simulation modeling on shading device types integrated to buildings. The aim is to investigate proper shading device design for selected case study building. Importance of shading devices for energy efficiency in buildings and reasons for using shading elements in buildings are surveyed. The use of shading devices was examined in this direction, from past to present. Fixed and movable shading device types were mainly studied. Overhangs, horizontal louvers, vertical louvers, and egg-crates as fixed types and venetian blinds, vertical blinds, roller shades, and deciduous plants as movable types were classified and explained.

The shading device model for selected case study building, which is developed during this research, depends on *"performance driven conceptual design"*. Sarıyıldız (2012) defined this method as a process which is a loop as *"form generation"*, *"performance evaluation"* and *"optimization"* steps. It can be seen in Figure 1.2.

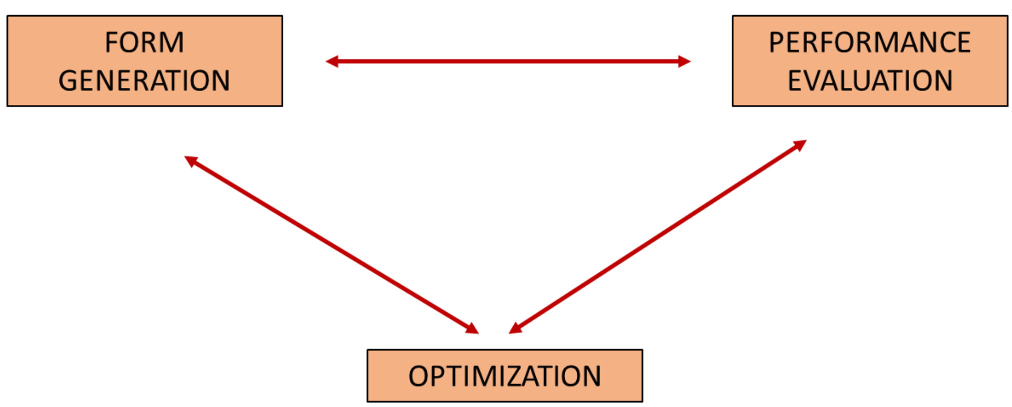

Figure 1.2. Process of Performance Driven Conceptual Design (Sarıyıldız, 2012)

Form generation has been developed in order to generate different geometry types for shading device designs in buildings. Thus, it is used to search many design solutions among different alternatives. This step focuses on new shading device design on the contrary to other shading device types which are horizontal louvers, vertical louvers and overhang.

Multi performance evaluations step includes two different performance criterias, which have been applied in the computational shading device model in this study. These criterias are defined namely as *"useful daylight illuminance"* and *"total energy consumption: heating and cooling"*.

In optimization step, an algorithm namely NSGA-II (Deb Et. Al., 2002) is implemented in order to optimize performance values calculated for alternatives as the final step of the model. Optimization is carried out by the help of this algorithm and it gives the opportunity of searching different alternatives.

According shading device model developed in this research, it is possible to decrease and/or increase defined performance criterias. Moreover, one single computational model can not be effective for generating many solutions. For this reason, this study focuses on specific shading device model by comparing them with traditional examples in order to create many solutions by using multi-performace based computational design method.

CHAPTER 2

LITERATURE REVIEW

Most of studies about simulation modeling on shading device types have been gaining a value year by year while different simulation softwares are being developed. In Datta's study (2001) interesting studies were done by using TRNYS simulation tool. He investigated the thermal performance of a building by developing a shading model for windows. External fixed horizontal louvers are the shading device type used in the study that has various slat lengths and tilts. The four different Italian cities; Milano, Roma, Napoli, and Palermo were case study areas. Finding the proper shading device for each city was the aim of this study according to thermal performance of the building.

Tzempelikos and Athienitis (2007) obtained accurate hourly horizontal irradiance values for 1 year by using the same simulation tool which uses solar radiation engine. According to simulation, results of thermal and daylighting analysis were presented for offices. The first objective was to evaluate the effect of façade properties, glazing area and how shading affects the thermal and daylighting performance of offices in the early design stage. Making estimations about the glazing area and shading properties in that stage was the second objective. To conclude, for any building that has an important effect on its energy performance, detailed analysis should be conducted during the early design stage to make significant decisions.

According to Hien and Istiadji (2003) effects of 6 different shading device types integrated to a residential building in Singapore was investigated by using various simulation tools namely LIGHTSCAPE for natural light and PHOENICS Computational CFD package for natural ventilation. The first phase was analysis for field measurement of velocity, temperature and illuminance, and the second one was the simulation of a residential flat with external shading device for 4 different time periods. Then, results of field measurements and simulations have been compared. It was concluded from that study that the do not increase daylighting and natural ventilation are not increased significantly by vertical shading devices when they are used in mentioned positions.

Lee and Tavil (2005) used DOE-2 simulation program to estimate the probable energy savings when electrochromic (EC) windows were mounted. Energy efficiency and visual comfort were analyzed by testing the EC windows. Moreover, overhangs were mounted with the EC windows to prevent direct sun inside. Authors computed total primary annual energy use, peak electric demand, average annual daylight illuminance, and average annual daylight glare index for private offices in Houston and Chicago. To conclude, in hot and cold climates like Houston’s and Chicago’s, when the window area is large, EC windows reduce the average annual daylight glare index and reveal significant annual energy use savings. Unfortunately, low angle direct sun cannot be prevented by the overhang, so that there should be extra interior shading device besides the EC windows.

Hammad and Hijleh (2010) assessed the energy consumption of external dynamic louvers’ integration to office building’s facade in Abu Dhabi-UAE by analyzing with Integrated Environmental Solutions-Virtual Environment (IES-VE) software. This simulation tool is suitable for all purpose and user friendly. On the south façade horizontal louvers were used, and on the east and west facades vertical louvers were used. The effect of external dynamic louvers on the energy consumption was analyzed as the aim of this study. The authors both predicted and evaluated the energy performance of the building when the horizontal louvers were integrated on the south; the vertical louvers were integrated on the east and west facades by using IES-VE software.

Mandalaki et. al. (2012) investigated the relationship between how much energy should be used for heating, cooling and illuminating a space, and the energy that the PV integrated shading device can generate for this space by using Ecotect, Radiance. A single office room was analyzed for two different Mediterranean cities which are Athens and Chania, Crete in Greece. The simulation software was used to evaluate the thermal behavior of the chosen shading device types. On the other hand, both simulation software and a test box were used to assess the daylight. As a focus of this study, the space quality of office interiors can be increased by shading devices at the same time consuming less energy.

Aldawoud (2013) used DesignBuilder software to model a typical office building located in Phoenix, Arizona, U.S. The effects of external solar shading devices and the electrochromic glazing system on the energy performance of buildings were evaluated.

It was revealed in the study that the effects of external shading devices and electrochromic glazing are changing when external and internal load conditions are also varying. Moreover, on condition that all windows are mounted on east, south, or west façade, there is highly critical reduction in yearly peak cooling loads thanks to the electrochromic glazing at the same time solar heat gains are being controlled in hot summer days. On the other hand, recession in cooling loads can be provided by overhangs and vertical fins.

According to Yao (2014) a study was conducted in a six-story high residential building in Ningbo city, China. Author modeled a south-facing room in this building by using EnergyPlus software. It was shown in the study that energy performance, indoor thermal and visual comfort were crucially affected by movable solar shading devices. Moreover, it was revealed from this study that theres is a major need for movable shading devices in hot summer and cold winter zones of China. In the study of Atzeri et. al. (2014) an open-space office located in Rome was simulated with various configurations in EnergyPlus 8. Authors compared the performances of indoor and outdoor shading devices with regards to overall primary energy use, thermal and visual comfort. As a conclusion of simulation results, at the same time the cooling needs was decreasing, the heating needs was slightly increasing for external shading devices. On the other hand, for internal shading devices, while a significant rise in cooling needs was seen, reduction in heating loads could not be carried out.

It is derived from above studies that experimental or/and simulative studies have been done to analyze the performance of any shading device type integrated to the facades of buildings located in different climatic regions. Different performances are shown by several shading device types for inhabitants' demands in various building types. The thermal performance of a building is increased by a shading device; at the same time the natural light amount is decreased in that building. The priorities of the occupants can control the performance of a shading device. All comfort requests like visual, thermal and etc. cannot be satisfied at the same time.

Aldawoud (2013) states that building's intended use and local climatic conditions affect any shading device design. It is significant to find a suitable strategy for shading and it can dramatically reduce building running costs, increase energy efficiency of the building, and reduce environmental effects. Choosing the right shading device and preventing inappropriate implementations depend on accurate and detailed information. Because of that, performance analysis of the building is necessary. Different digital tools have been developing for making these analyses. Some of the inputs in these digital tools are the detailed weather data and local climatic characteristics of the building's location. Accordingly, developing a scheme to find the most appropriate shading device for a building based upon passive design issues is necessary.

2.1 Categorization of Shading Devices

Bellia Et Al. (2014), categorized shading devices simply as in Table 1. According to their study shading devices in buildings can be separated into two parts which are fixed shading devices and movable shading devices. Each of them has their own categories in itself. Fixed shading devices can be categorized as external and internal types as they can be integrated both exterior and interior part of buildings. On the other hand, movable shading devices are separated into three parts. Also, they can be integrated both exterior and interior parts of the building, they can be intermediate which is a part of window itself.

	External	Intermediate	Internal
Fixed Shading Devices	+	–	+
Movable (manual or automated) Shading Devices	+	+	+

Table 1. Categorization of Shading Device Types in Buildings (Bellia Et Al., 2014)

2.1.1 Fixed Shading Devices

In buildings, fixed shading devices can be integrated with façade of the building or inside the windows. Controlling solar radiation and saving energy can be provided by the use of external fixed shading devices in buildings. However, these shading devices do not allow the daylight entity most of the time; they also can create artificial light inadequacy and prevent the solar radiation inside in heating period (Mandalaki Et Al., 2012). To sum up, the use suitable type of shading device in the correct place and time period is quite important with regard to daylight availability, thermal and visual comfort. To give an example, generally in Mediterranean climates, the use of external fixed shading devices is necessary for south facing facades. Thermal loads are reduced by fixed shading devices in summer period and also intense summer daylight is manupulated. Besides, while visual comfort is increased, glare is decreased by fixed shading devices (Fontoynont; Mehrotra, 2005; Yoo and Manz, 2011). Because of these, fixed shading devices should be used on the south facades, if there are openings, especially in Mediterranean climates.

Dubois and Tzempelikos and Athienitis (2007) say that fixed shading devices sometimes break the balance between the decrease of cooling loads in summer time and the unfavorable increase of heating loads in winter time. The examples of fixed shading devices from İzmir, Turkey applied on the exterior facade of an office building and a hotel are seen in Figure 2.1 and Figure 2.2 respectively.

Figure 2.1. Fixed Shading Devices Mounted on the Exterior Part of the Is Bankasi Building in Konak, Izmir, Turkey (Kirimtat Et. Al., 2016)

Figure 2.2. Fixed Shading Devices Mounted on the Exterior Part of the Key Hotel Building in Konak, Izmir, Turkey (Kirimtat Et. Al., 2016)

2.1.1.1 Overhang

An overhang is a horizontal surface that provides shade over a window. They are integrated to window exteriors horizontally. Shape, type, depth, and height of overhangs differ when the sun condition is changed. In order to reduce glare and solar heat gain during summer time and allow sunlight during winter time, it is quite important to shade a window in temperate climates. They can be achieved by a fixed overhang to shade in cooling period and allow solar radiation in heating period, because the sun rises in the sky during the cooling period (SHADING DEVICES). Figure 2.3 shows an overhang sample in a house.

Figure 2.3. Overhang Sample in a House in Alaçatı, Izmir, Turkey (Kirimtat Et. Al., 2016)

2.1.1.2 Horizontal Louvers

On an exterior part of a window or glazed opening horizontal louvers can be integrated. These louvers are long enough and they can protect a building from high summer sun, and allow low winter sun to inside of this building during winter time.

The distance between louvers, the latitude the building is located in, and the climate type seen in that region affect the proper width of louvers. Moreover, cost is affected by the size of louvers. Fixed louvers can prohibit a small portion of desirable solar radiation in winter time. For this reason, the top face of the louvers should have a light color. Through this, the intercepted sunlight can be reflected deeply into a building (Architecture 2030). The horizontal louvers mounted on the facade of an office building are demonstrated in Figure 2.4, 2.5, 2.6.

Figure 2.4. Horizontal Louvers Mounted on the Exterior Part of the Univera Office Building in Karşıyaka, Izmir, Turkey (Kirimtat Et. Al., 2016)

Figure 2.5. Horizontal Louvers Mounted on the Exterior Part of the Faculty of Education Aristotle University of Thessaloniki in Greece (Kirimtat Et. Al., 2016)

Figure 2.6. Exterior Louvers Mounted on the Exterior Part of the Swiss Hotel Grand Efes Building in Konak, Izmir, Turkey (Kirimtat Et. Al., 2016)

2.1.1.3 Vertical Louvers

Effective shading can be provided by vertical louvers mainly on east and west facades. Moreover, in order to increase the insulation value of the glass in winter time, vertical louvers can act as a windbreak. Louvers' angle can also be designed angular in terms of sun's position and they can be movable. Total shading occurs when vertical fins, which are perpendicular to the wall, create vertical shadow angle. When fins have inclined angle, an asymmetrical shading mask is created. Besides, in order to isolate or to allow daylight and solar radiation, vertical fins' position can be arranged (SHADING DEVICES). The vertical louvers in a residential building are seen in Figure 2.7, 2.8, 2.9, 2.10.

Figure 2.7. Vertical Louvers Mounted on the Exterior Part of a House in Alaçatı, Izmir, Turkey (Kirimtat Et. Al., 2016)

Figure 2.8. Vertical Louvers Mounted on the Exterior Part of Language School Aristotle University of Thessaloniki in Greece (Kirimtat Et. Al., 2016)

Figure 2.9. Vertical Louvers Mounted on the Exterior Part of the Observatory of Aristotle University of Thessaloniki in Greece (Kirimtat Et. Al., 2016)

Figure 2.10. Vertical Louvers Mounted on the Exterior Part of the Museum of Byzantine Culture, Thessaloniki in Greece (Kirimtat Et. Al., 2016)

2.1.1.4 Egg-Crate

Since they have vertical and horizontal shading elements as seen in Figure 2.11. egg-crates prevent solar radiation from different directions. Horizontal elements can control ground glare. Movable egg-crates allow controllable shading mask characteristics with horizontal elements while asymmetrical shading masks are created by inclined vertical fins. On the other hand, by the help of fixed type egg-crates seasonal variations do not occur in critical shading angles. Besides, fixed type egg-crates cannot provide solar gain in winter. The egg-crate can create proper shading in regions with hot climate, because shading components have a high shading efficiency. However, they do not allow daylight, view and solar gains in winter since they are rather massive structures (SHADING DEVICES).

Figure 2.11. Egg-crate Shading Device Integrated on the Facade of Izmir Chamber of Commerce Building in Konak, Izmir, Turkey (Kirimtat Et. Al., 2016)

2.1.2 Movable Shading Devices

Kim Et. Al. (2007) states that movable shading devices have more advantages than fixed shading devices. Because they can permit winter sun and block direct summer sun by being controlled. At the present time, structurally and economically, glass curtain wall systems are generally implemented on the exterior façade of high rise buildings. For this reason, large amount of direct sunlight and solar radiation are occurred fatefully. Moreover, it creates undesirable working environment inside. In order to prevent and control undesirable daylight and solar radiation, movable shading devices such as venetian blinds, vertical blinds, and roller shades are used (Park Et Al., 2007; Mettanant and Chaiwiwatworakul, 2014).

2.1.2.1 Venetian Blinds

In order to control the daylight penetrated through the glass to the interior, venetian blinds are generally used especially in commercial buildings. Venetian blinds are quite effective for privacy, visual and thermal comfort. They consist of separate, equally-spaced horizontal louvers. Since venetian blinds have a discrete nature their optical and thermal properties are complex. The parameters which affect behavior of venetian blinds are the louver characteristics, tilt angle and angle of incidence for solar radiation. Moreover, the rotation angle, shape, size, configuration and color of slats affect the transmittance, absorptance and reflectance of the venetian blind integrated window. Standard dimensions of venetian blinds are 2.5 cm width, also they are spaced at 2.2 cm vertically and placed 2.5 cm away from the surface of the glass in commercial construction. (Tzempelikos, 2008; Galasiu Et Al., 2004; Clark Et Al., 2013). Figure 2.12 is an example of venetian blinds mounted in a library building.

Figure 2.12. Venetian Blinds Mounted on the Interior Facade of the TU-Delft Main Library Building in Delft, Netherlands (Kirimtat Et. Al., 2016)

2.1.2.2 Vertical Blinds

As Mettanant and Chaiwiwatworakul (2014) said the vertical blinds are used extensively especially in commercial and residential buildings as internal shading devices. In vertical blinds, seen in Figure 2.13, in order to prevent the direct sunlight inside, the blind slats are controlled manually or automatically. Vertical blinds can achieve daylight and solar radiation control, energy efficiency and beautiful view by being mounted on large windows or patio doors. Moreover, they have quick and easy installation. Different types of fabric, wood, plastic or metal can be used for the slats of the vertical blinds. Besides, vertical blinds have a wide range of texture, color and design. Thus, vertical blinds satisfy the occupant and save energy at a higher level.

Figure 2.13. Vertical Blinds Mounted on the Interior Part of an Office Building in Konak, Izmir, Turkey (Kirimtat Et. Al., 2016)

2.1.2.3 Roller Shades

In order to manage daylight and glare control, roller shades can be used manually and automatically. Roller shades are extensively integrated to office and residential buildings. Space lighting, heating and cooling are affected by roller shade usages. The automated versions of roller shades affect energy savings in a positive way according to latest literature. The roller shades have two positions: open or closed completely. These two positions cause some problems like inefficient daylight, visual discomfort and overheating (Tzempelikos and Shen, 2013). Figure 2.14 demonstrates the application sample in a flat.

Figure 2.14. Roller Shades Mounted on the Interior Part of a Flat in Çigli, Izmir, Turkey (Kirimtat Et. Al., 2016)

2.1.2.4 Deciduous Plants

In order to shade the building in summer, deciduous plants are used extensively. They are quite sensitive to seasonal climatic changes as they behave like dynamic solar shading devices. For instance, when they grow enough in summer time, they prevent the solar radiation, direct sunlight, and undesirable glare inside the building. In winter time, they allow the solar radiation inside the building as the leaves shed. This situation provides decreasing in the heating loads. Since the use of deciduous plants for moderating the microclimate of buildings is less than other shading elements in recent years, it is not possible to find many scientific research about climbing plants (Ip Et Al., 2010).

Figure 2.15. Deciduous Tree Used for Shading the House, Bornova, Izmir, Turkey (Kirimtat Et. Al., 2016)

Figure 2.16. Deciduous Tree Used for Shading the House, Bornova, Izmir, Turkey (Kirimtat Et. Al., 2016)

2.2 Discussion on Previous Studies about Simulation Modeling on Shading Devices in Buildings from 1996 to 2015

It is shown that in order to estimate the energy performance of buildings in the last few decades, simulation modeling is quite necessary. According to the complicated relationship between design characteristics, climate, and occupants, mechanical and electrical systems in a building, making simulations is one of the powerful method to cope with these issues. During the design process, simulation tools can manage the feedback loops between the design decisions and the evaluation of their environmental impacts (Caldas and Norford, 2002). The real life performance of buildings in a cost-effective way can be estimated by using computer simulations. A more controlled platform is also provided by simulation techniques which means that the user can interfere and iterate each data (Cho, 1995; Architecture, 2001; Ochoa and Capeluto, 2008; Kim Et Al., 2009). Based on these issues, in order to find proper shading device types or design optimal shading devices as building components, it is possible to use the simulation modeling. In literature, there are a lot of studies done about shading devices integrated to buildings so far. Since 1996 researchers have started to aware of using shading devices in their scientific studies. According to year, author(s), studied location, simulation type, used simulation tool, shading device type, glazing type, climate type, building type and study type, there are some important studies which are in Appendix A. We have taken into account several parameters in different studies. So that, the variation of the total number of studies can be seen for each comparison in the figures.

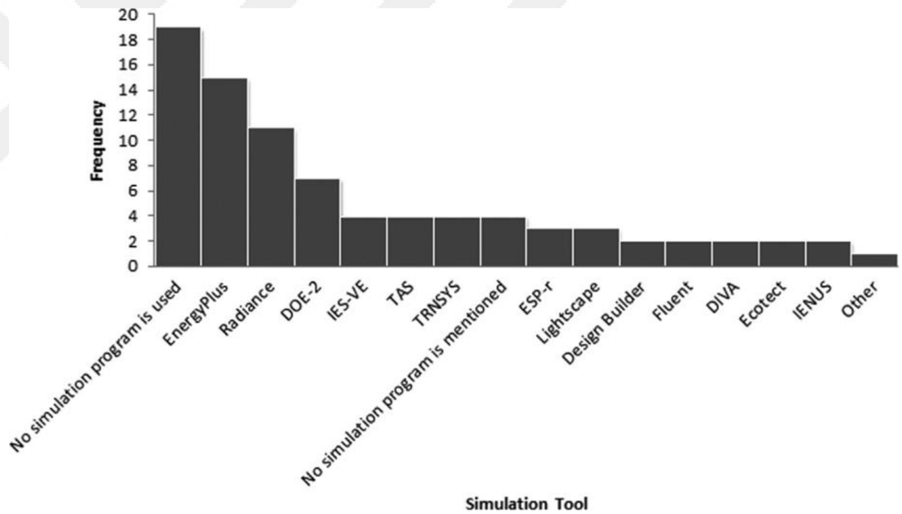

Figure 2.17. Simulation Tools Used in the Studies (Kirimtat Et. Al., 2016)

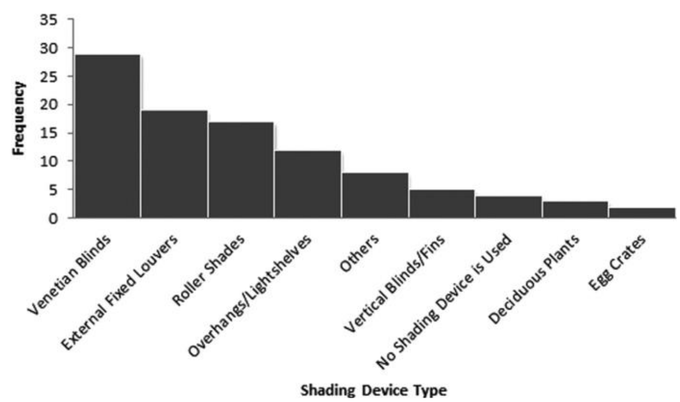

Figure 2.18. Distribution of Shading Device Types into Studies (Kirimtat Et. Al., 2016)

Researchers have used different simulation tools like Radiance, DOE-2, Daysim, ENER-LUX, MIDAS, COMFORT, TRNSYS, ADELINE, IENUS, ESP-r, WIS, LIGHTSCAPE, Phoenix, TAS, Simulink, IDRBlock, Energy Plus, Ecotect, AutodeskVIZ, VE for Revit, Matlab, EES, IES–VE, iD-build, WINDOW, DIVA for Rhino, DesignBuilder, Sun-Shade, Radlink in Adeline, Fluent, Fener, Evalglare and Bsim for performance analysis in the studies in literature. According to Figure 2.17, because of the reason that EnergyPlus is the oldest simulation software among others, it has a frequency of 15 usage rate in the scientific researches which means it is the most widely-used simulation tool. Radiance, daylight simulation program, has the frequency of 11 and DOE-2, building energy analysis program, has the frequency 7. According to Table1, Ecotect, DesignBuilder and DIVA for Rhino are the least used programs. Because, they are new and have started to be used recently.

According to Figure 2.18, different types of shading devices have been studied in literature so far. The most commonly studied shading devices among other types are venetian blinds, mainly used in office buildings. External fixed louvers chase after, roller shades, and overhangs. No shading devices is used in some studies. External mobile screen, window shutter, dynamic solar shading, external shutter, and switchable liquid shading types are other categories. Egg crates and deciduous plants are the least studied shading device types.

2.3 Conclusion

In this chapter, studies about simulation modeling on shading devices in buildings were deeply reviewed. It can be summarized from those studies that most of the studies about simulation modeling on shading devices in buildings are getting important year by year. Researchers have used various simulation tools to analyze performance of shading devices in buldings both for cooling and heating periods. Since performance analysis of the building is necessary, different digital tools have been developing for making these analyses. To conclude, developing a scheme to find the most appropriate shading device for a building by using simulation tools is necessary.

Secondly, shading device types in buildings were clearly defined. They were categorized in a table as fixed shading device types and movable shading device types. Moreover, examples from all over the world were shown according to their categories. Fixed shading devices can be categorized as external and internal types which means they can be integrated both exterior and interior part of buildings. On the other hand, movable shading devices are separated into three parts. Also, they can be integrated both exterior and interior parts of the building, they can be intermediate which is a part of window itself.

Lastly, a discussion on previous studies about simulation modeling on shading devices in buildings from 1996 to 2015 was conducted. Graphs were created according to simulation tools and shading device types used in the studies. It was shown that in order to predict the energy performance of buildings in the last few decades, simulation tools are quite important. Moreover, what kind of shading devices used in the studies between the year 1996-2015 was shown in the graph. It was concluded that the most commonly studied shading devices among other types are venetian blinds, mainly used in office buildings.

As a result of all of these, in order to provide energy efficiency in both existing and the new buildings, precautions should be taken in the early stage of a design process. Using shading devices is one of these precautions, because protecting the building from overheating in cooling period is very important. Furthermore, estimation of the performance of any shading device can be made by using simulation tools. As can be seen in the paper (Kirimtat Et. Al., 2016), some researchers have been using these simulation tools in recent years. These simulation tools are very effective to solve the complex relationships between climate, occupancy requirements, mechanical and electrical systems energy-efficiency issues and design characteristics.

CHAPTER 3

METHODOLOGY

In this part, how four different generative models are developed and tested with simulation based computational optimization is explained. Shading devices in buildings and simulation modeling for shading devices are deeply reviewed as a literature survey in the previous chapters. According to this literature survey, it is stated that performance criteria has a significant role in shading device designs in buildings. In accordance with these, it is important to state that shading devices are one of the most complex architectural designs since they contain many design variables in order to reach many design goals in the early stage of design process.

Furthermore, in order to evaluate the performance of shading devices and their impact on building's overall energy performance during its lifecycle, different simulation tools such as EnergyPlus, Radiance etc. have widely been used since early years. Many engineers and architects have been using these simulation programs in scientific researches. They are used for analyzing, designating and evaluating the daylight value, energy performance, indoor thermal and visual comfort etc. Different simulation software both for evaluating the energy performance of buildings and for helping the designers predict the real life performance have been being developed. So, in this section, simulation models both for daylight and energy performances of shading device models are created for selected case study building.

Complex design is defined as "optimization problem" by Bittermann (2009). He stated that it can be understood by establishing a model to assess the performance of design solutions. In order to reach satisfied design solutions with the highest performance score, computational optimization methods should be implemented in the model. Moreover, by referring Deb (2001), Bittermann (2009) defines the optimization as *"...a procedure of finding and comparing feasible solutions until no better solution can be found*".

Simulation based optimization processes of four different shading device models have two conflicted objectives. Objectives can be mentioned as maximization of useful daylight illuminance and minimization of total energy consumption which includes heating and cooling energy consumptions. At this point, the optimization problem of the model can be stated as multi-objective optimization problem. There is a well-known concept which is called Pareto-optimality and it generates non-dominated solutions. According to Chatzikonstantinou (2011) non-dominated solution is defined as *"…evolves a population based on multiple fitness values until it reaches a set of solutions, each of which are good at some particular aspect, expressed by and objective function*". Moreover, Bittermann (2009) explains the main logic of this solution as "*A solution is non-dominated if there exists no other solution that performs better in every respect*". In accordance with these statements Pareto-optimal method in the evolutionary algorithm has an important role in order to discover design solutions for complex shading device problem.

In this study, the main aim of the shading device problem is to investigate optimal design options which should have more advantages rather than disadvantages according to two objectives which are useful daylight illuminance and total energy consumption that includes heating and cooling energy consumptions. Results of Non-Dominated Sorting Genetic Algorithm II (NSGA-II) were extensively applied. This algorithm depends on evolutionary search methodology.

3.1 Non-Dominated Sorting Genetic Algorithm II (NSGA-II)

NSGA-II namely Non-Dominated Sorting Genetic Algorithm II is a Multi-Objective Evolutionary Algorithm and it was developed by Deb Et Al. (2002) at Kanpur Genetic Algorithms Laboratory. This algorithm can handle constraints for multi-objective problems and also it is an elitist algorithm. Regarding to this, expression of the main loop of NSGA-II is as follows:

• First of all, a parent population is randomly created.

• According to nondomination, the population is sorted.

• Nomination of each solution is done as a fitness that resembles to its nondomination level

• A "Crowding Distance" value, which is a measure of how unique this particular solution stands within the solution space, is assigned for each population member.

• In order to create an offspring population, the usual binary tournament selection, recombination, and mutation operators are used.

• After that current population is compared with previously found best non-dominated solutions, elitism is introduced, but the process changes after the initial generation.

The t th generation of NSGA-II is described by Deb Et Al. as follows (Figure 3.1):

When we put them in an order, initially, parent and offspring population which belong to a combined population are formed. After that, based on nondomination, combined population, which can be defined as a mating pool, is sorted. In the event of that combined population contains all previous and current population members, elitism is provided.

Solutions in the best non-dominated set (F1) should weight more than any other solution in the combined population. If the size of offspring population is not bigger than best non-dominated set, then for the new population, which is used for selection, crossover, and mutation to create a new population, best non-dominated sets are chosen.

Selection step initializes by making “Tournament Selection” with individuals which are going through a pairwise comparison. In this process, there are three step comparisons. Before two random individuals are first compared regarding their violation of a constraint, if one is set, they are picked from the population. Suppose that both of them have a violation on the constraint, the one with less violation is selected. When the other one is selected, it means just one has a violation. If none of them has a violation, then the following step is carried out the ranking step. It means comparison between ranking values of each of them is done. This time, the one with best ranking is selected. Suppose that the ranking values of both of them are the same, then the final step comes into play. This time, it is comparison between crowding distance values. The one with the largest value is selected (Chatzikonstantinou, 2011).

Ekici and Kutucu (2014) by referring Chatzikonstantinou (2011) explained main loop of NSGA-II and as it is shown in Figure 3.2 the relations among function evaluation, pareto ranking, crowding distance, population reduction, tournament selection, crossover and mutation steps can be seen.

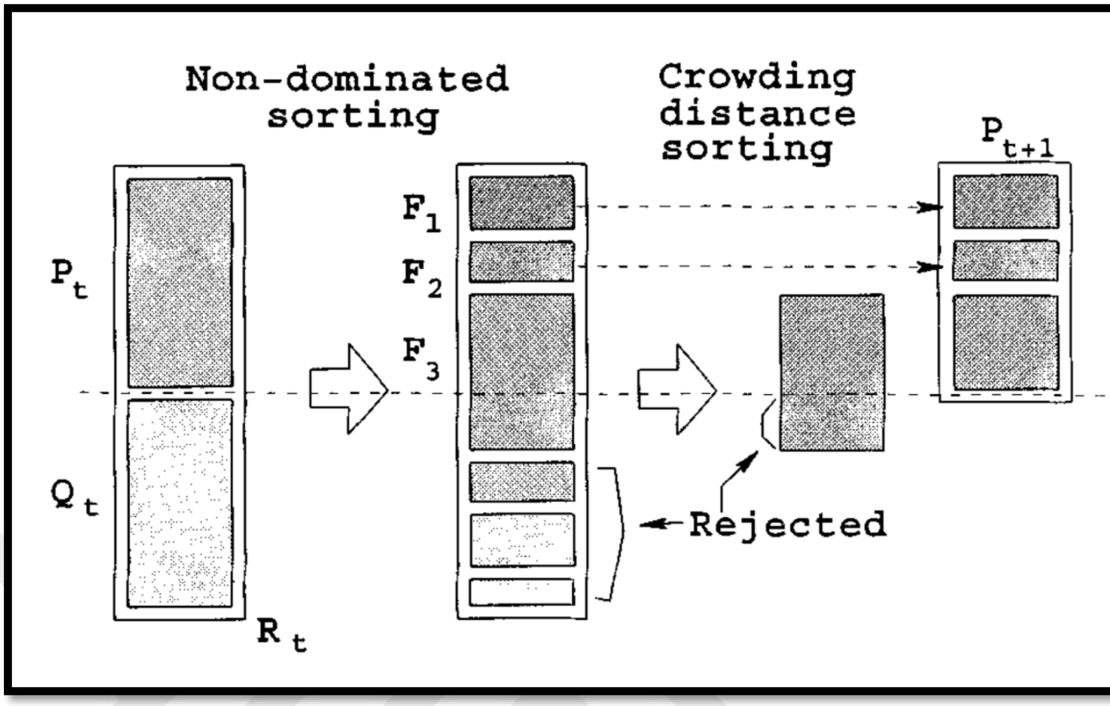

Figure 3.1. NSGA-II Procedure (Deb Et Al., 2002)

Figure 3.2. NSGA-II Loop (Ekici and Kutucu, 2014; Chatzikonstantinou, 2011)

Lotus-NSGA-II version was developed in C-sharp programming language by using Rhinoceros and Grasshopper Environment. In the Lotus, solutions of the optimization process are shown in 2D graph. When chosen solution is clicked, then it is possible to see the results in Grasshopper environment right away. Moreover, it is possible to see objective, variable and crowding distance values of each solution in the chart and this chart is consolidated to Lotus.

3.2 Useful Daylight Illuminance (UDI) and Radiance

According to Nabil and Mardalijevic (2005), UDI is a daylighting metric. The percentage of hours is taken into account by UDI annually, and illuminance conditions are reasonable. Here [300-2000] lux is a certain domain which reasonable illuminance values fall within, since that the values outside of this range are considered not convenient and not sufficient for proper illumination. UDI establish this domain in order to provide adequate illumination without significant glare. In shading device models in this research, the calculation of UDI values is made by using illuminance values which come from the Radiance simulation software. In the model, DIVA uses Radiance's infrastructure as an interface. DIVA is a plugin which was developed for Grasshopper Algorithmic Modeling Platform. It is also used for the Rhinoceros CAD program. The calculation of UDI is as below:

$$\mathrm{UDI}\ (\mathrm{Pt_i}) = \frac{1}{n}\sum_{j=1}^{n} \mathrm{H}\left(\mathrm{L}(\mathrm{Pt_i}, \mathrm{j})\right)\mathrm{X}100 \tag{1}$$

L (a, b) means the simulation result. This result comes from the simulation for sampling point i and time (within a year) j. H(x) is given as an illuminance value which is a function. When the input value is within the specified limits, it outputs one, otherwise it outputs zero.

$$H(x) = \begin{Bmatrix} 1, if\ 300 \leq x \leq 2000 \\ 0, otherwise \end{Bmatrix} \tag{2}$$

The Building Technologies Program, which is in the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory in Berkeley, California, developed the Radiance. Lighting simulations can be made and images for lighting design can be presented. In order to estimate accurate illumination levels and design spaces via artificial and natural lighting technologies, architects and engineers use Radiance. The software presents interfaces for modeling and translating space geometry, luminaire data and material characteristics to make simulations (RADSITE). DIVA-for-Rhino Grasshopper uses Radiance's platform as an interface. According to Ward, Radiance is a physically-based rendering system which fulfills the demands of lighting design and architecture. In order to solve the rendering equation under most conditions, the simulation uses a light-backwards ray-tracing method with extensions. By combining any level in any environment such as complicated and curved geometries, it makes specular, diffuse and directional diffuse reflection and transmission. Moreover, in order to succeed the best balance between speed and accuracy in its local and global illumination methods, the simulation uses deterministic and stochastic ray-tracing methods.

3.3 Total Energy Consumption and EnergyPlus

In our model, total energy consumption includes heating and cooling energy consumptions. Ladybug+Honeybee plugin was used as an interface for calculation of the total energy consumption. This plugin uses EnergyPlus'infrastructure as an interface. It was again developed for Grasshopper Algorithmic Modeling Platform and part of the Rhinoceros CAD program.

Ladybug+Honeybee for Rhino Grasshopper uses EnergyPlus's platform as an interface. EnergyPlus is new and simulates energy. It builds on the power of both BLAST and DOE-2. Moreover, EnergyPlus includes a new code which was written in Fortran 90. EnergyPlus has many simulation capabilities. For instance, it makes heat balance and load calculations, system and plant calculations in same time step. Besides, it is user-configurable. It is a modular structure for other users to add new simulation modules (Crawley Et Al., 2000).

EnergyPlus is self-directive simulation program, whose graphical interface is not user-friendly. Inputs and outputs are created in the text files format. Energy analyses and thermal load simulations are made in this program. Heating and cooling loads are also calculated in order to carry thermal comfort setpoints. There are some key capabilities in this software for instance; it can build into infinite solutions incontinently, daylight can be manipulated, it can create thermal comfort models, it can integrate heat and mass transfer, and it can calculate different window layouts (EnergyPlus Energy Simulation Software).

3.4 Conclusion

In the light of the previous chapters, daylight simulation model was formed by using DIVA. Then, energy simulation model was created by the help of Ladybug+Honeybee. DIVA uses Radiance's platform as an interface, while Ladybug+Honeybee uses EnergyPlus' infrastructure as an interface as it can be seen in Figure 3.3. At the same time simulation is processing, optimization also occurs by using NSGA-II.

UDI was used as a daylight metric in this research. Illuminance values between [300-2000] lux which are reasonable were taken into account for the case study building. For UDI calculation, DIVA component which is integrated to Grasshopper Environment was used. DIVA made this calculation by getting values from Radiance.

Total energy consumption which includes heating and cooling energy consumptions was calculated by the help of Ladybug+Honeybee component which is also integrated to Grashopper Environment. Calculation was made hourly for one whole year. Since EnergyPlus does not have graphical interface, energy values were taken by using Ladybug+Honeybee component.

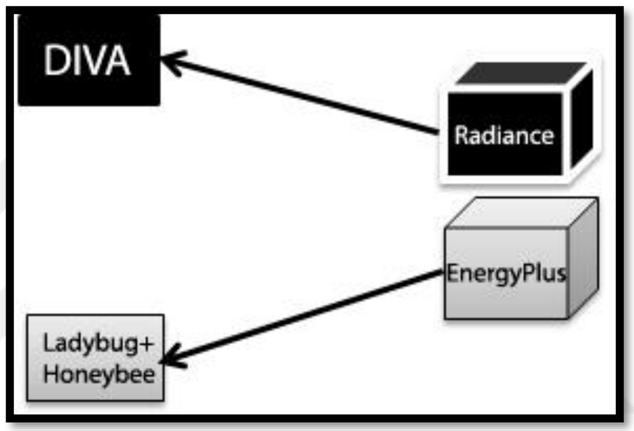

Figure 3.3. DIVA and Ladybug+Honeybee Simulation Process

CHAPTER 4

CASE STUDIES

In this study, four different scenarios are created in a case study building located in Yaşar University, Izmir. In this selected building, four different shading models which are horizontal louvers, vertical louvers, overhang and proposed shading device are integrated on the south façade of a classroom. This part of the case study building was created in Rhino platform. It consists of classrooms, offices and corridors. The test room's characteristics can be seen in Table 2.

Room Description	Basecase
Orientation	South
Shape	Rectangular (7.50 m X 10.34 m)
Floor Height	2.50 m height
Volume	193.875 m^3
External Wall Area	7.5 m^2
Shading Device	Venetian Blinds
Ceiling Area	78 m^2
Floor Area	78 m^2
Windows Area	11.25 m^2
Window Wall Ratio	60%
Glazing Type	Double Pane Clear

Table 2. Description of Test Room

Figure 4.1. Case Study Building: Yaşar University New Building, İzmir, Turkey

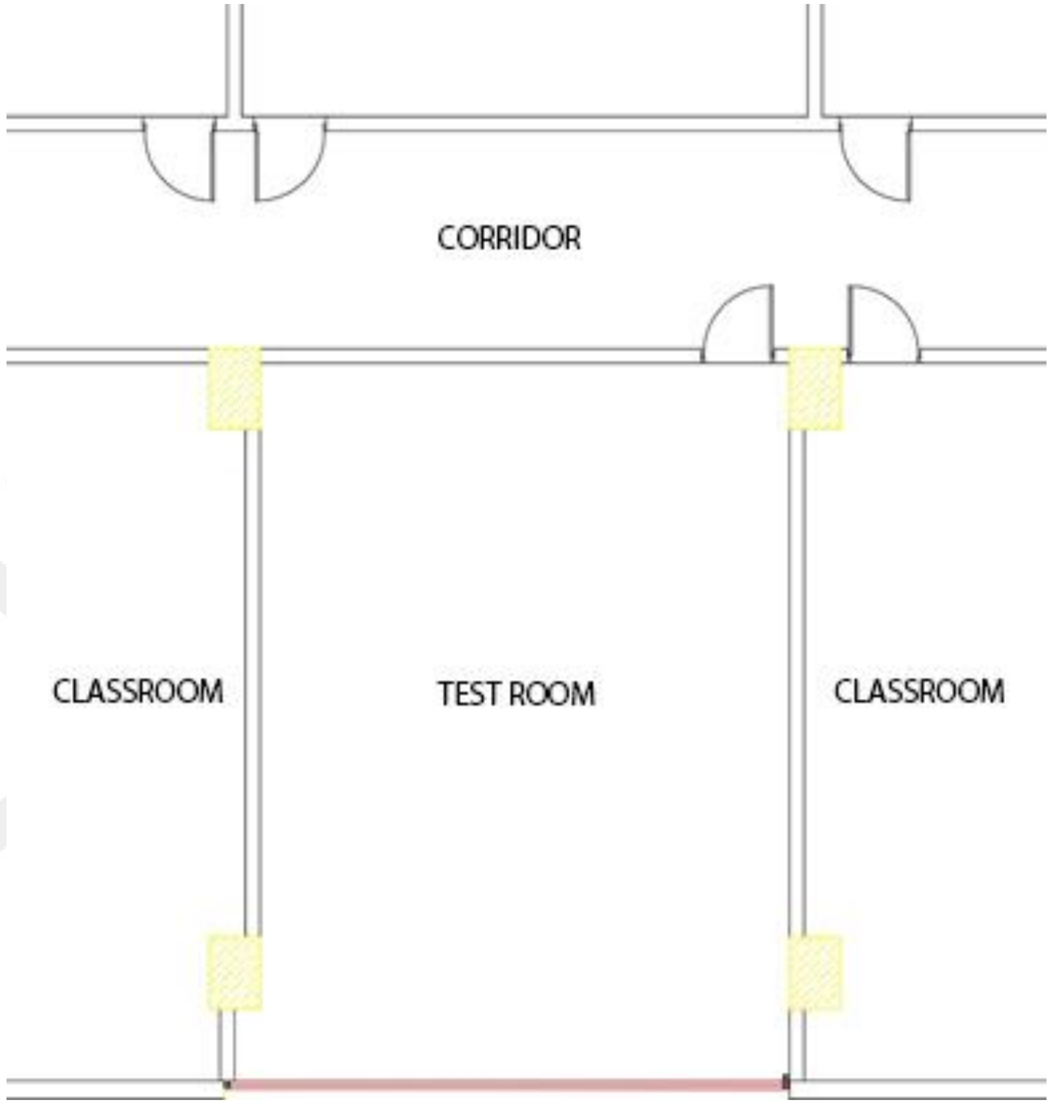

Figure 4.2. Test Room Plan: Yaşar University New Building, İzmir, Turkey

4.1 Problem Definition

In this research, the aim is to apply Evolutionary Computation to design of proposed shading device by using parametric modeling techniques in combination with Intelligent Decision Support tools and simulation techniques. The aim is to find optimal widths and rotation angles for each louver integrated on the exterior of the south façade of the test room. For the other case studies which are horizontal louvers, vertical louvers and overhang, problem is to find optimal width, density and rotation angle. Therefore, it is being tried to minimize total energy consumption which includes heating and cooling energy consumptions and maximize useful daylight illuminance by integrating proposed shading device into a building in a multi-objective manner.

4.2 Objective Functions

In the problem for each case study, there are two objectives which are total energy consumption which includes heating and cooling energy consumptions and useful daylight illuminance. They are conflictive and they are defined separately in the problem. It is being tried to maximize *UDI (Useful Daylight Illuminance)* and minimize *TEC (Total Energy Consumption).*

4.3 Generative Models

The generative models have been created in the Grasshopper Environment (Grasshopper, Algorithmic Modeling for Rhino). Complete Grasshopper models of case study 1: horizontal louvers, case study 2: vertical louvers, case study 3: overhang and case study 4: proposed shading device problems exist in Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6. Moreover, DIVA and Ladybug+Honeybee plugins were used to run daylight and energy simulations.

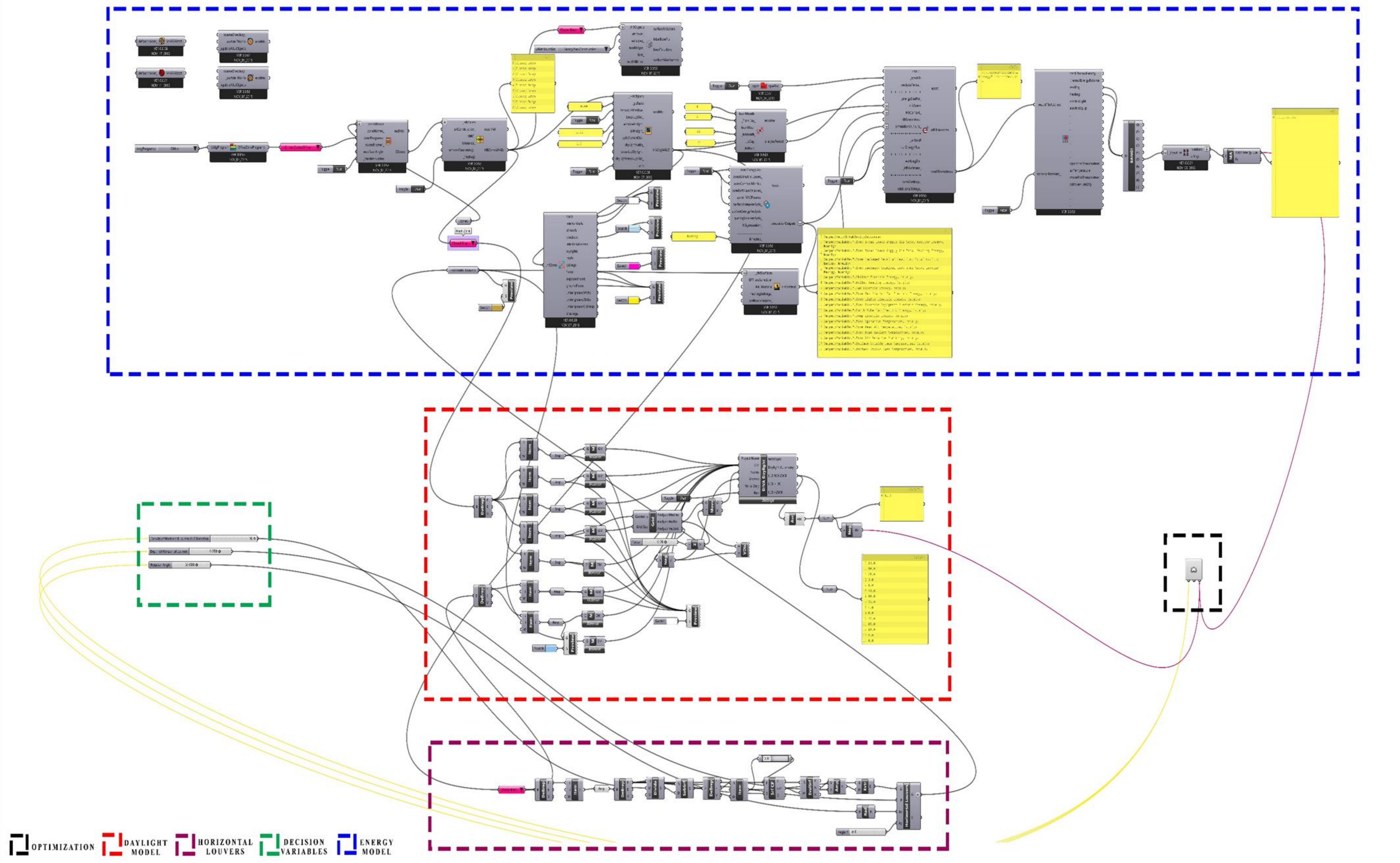

Figure 4.3 Complete Grasshopper Model of Case Study 1: Horizontal Louvers

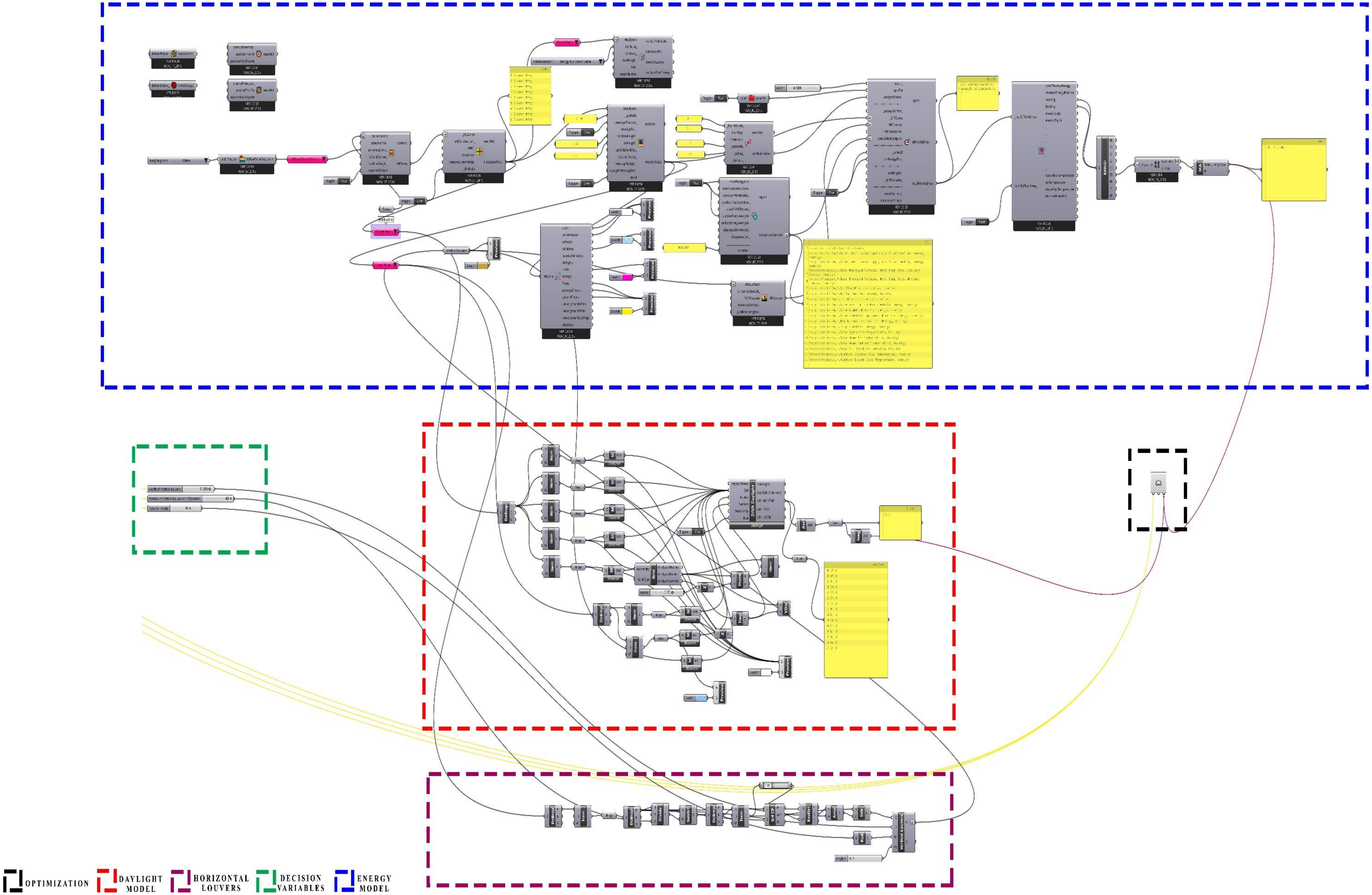

Figure 4.4. Complete Grasshopper Model of Case Study 2: Vertical Louvers

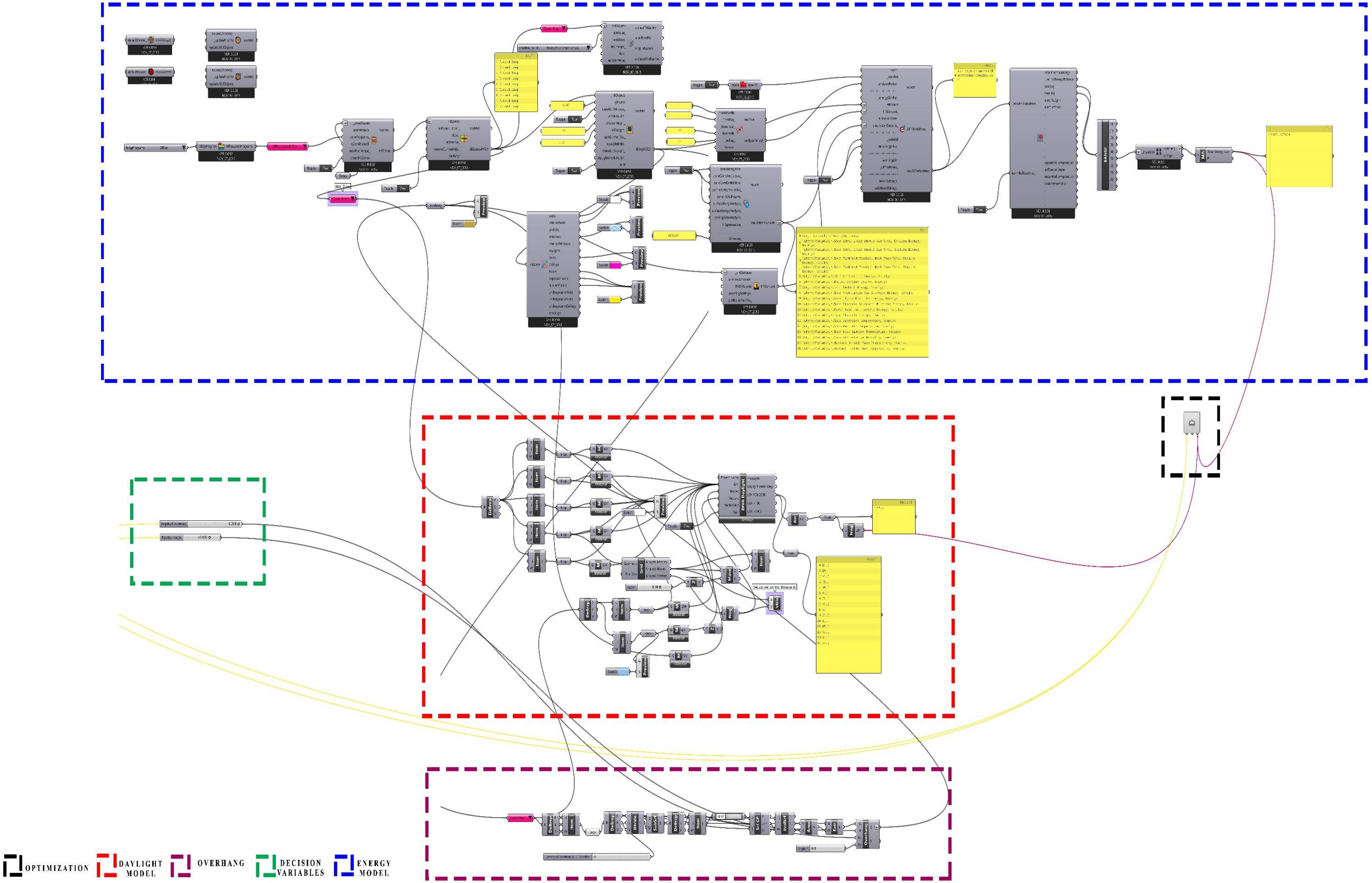

Figure 4.5. Complete Grasshopper Model of Case Study 3: Overhang

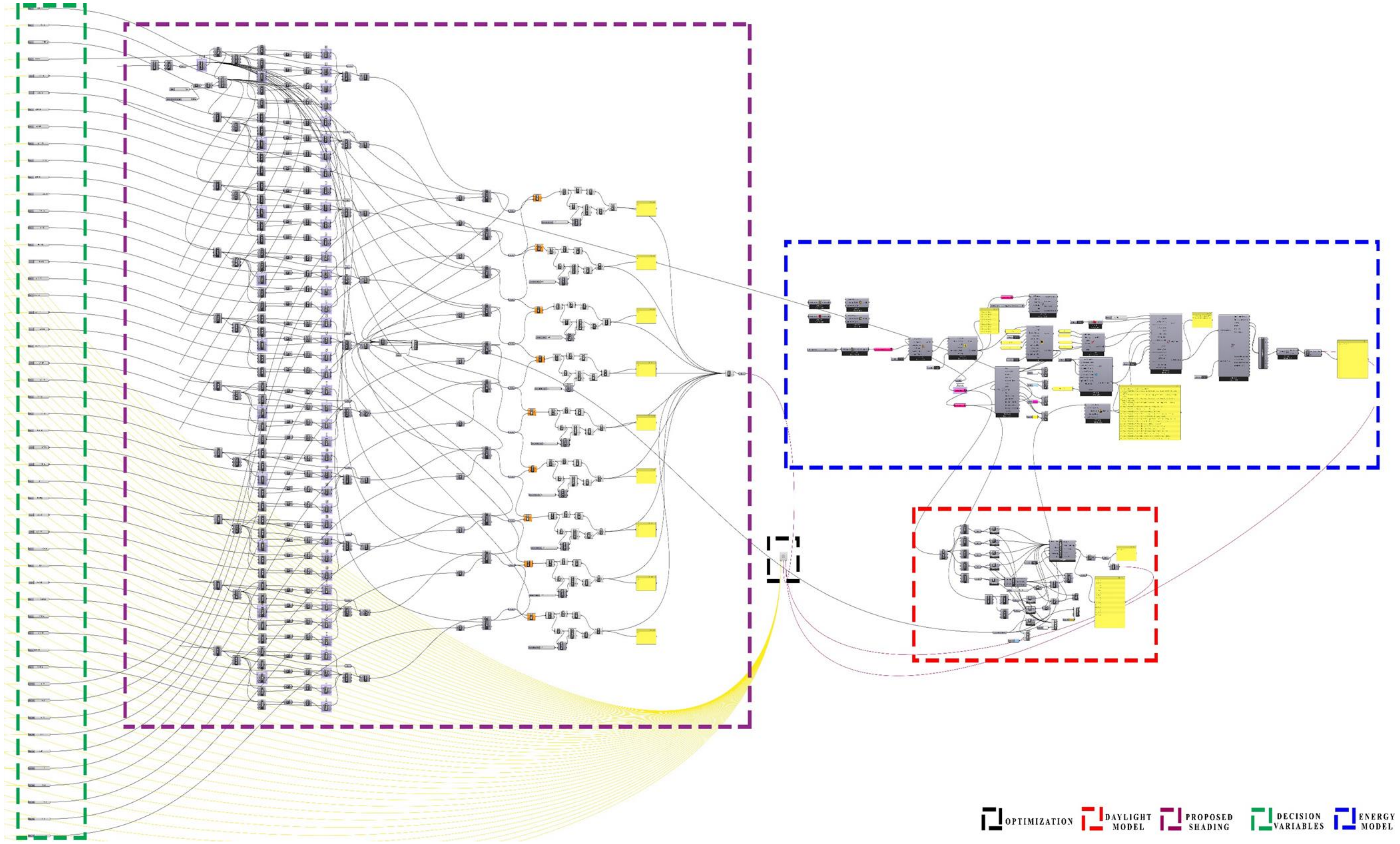

Figure 4.6. Complete Grasshopper Model of Case Study 4: Proposed Shading Device

4.4 Case Study 1: Horizontal Louvers

4.4.1 Decision Variables

In the first case study, the decision variables are available in d_h, w_h, r_h (Figure 4.7). Density of horizontal louvers in z direction is represented by d_h. According to two objectives which are useful daylight illuminance and total energy consumption, d_h changes in between 1 and 10. For instance, if the value is 10, horizontal louvers close up in z direction. The width of horizontal louvers is represented by w_h. It varies in between 0.1m and 0.3m as a real number. The rotation angle of horizontal louvers around the x axis is represented by r_h, and it varies in between -90° and 90° as an integer number.

Decision Variables	*Explanation*	*Range*	*Type*
d_h	Density of horizontal louvers in z direction	[1,10]	integer
w_h	Width of horizontal louvers	[0.1,0.3m]	real
r_h	Rotation angle of horizontal louvers	[-90°,90°]	integer

Table 3. Decision Variables of Horizontal Louvers

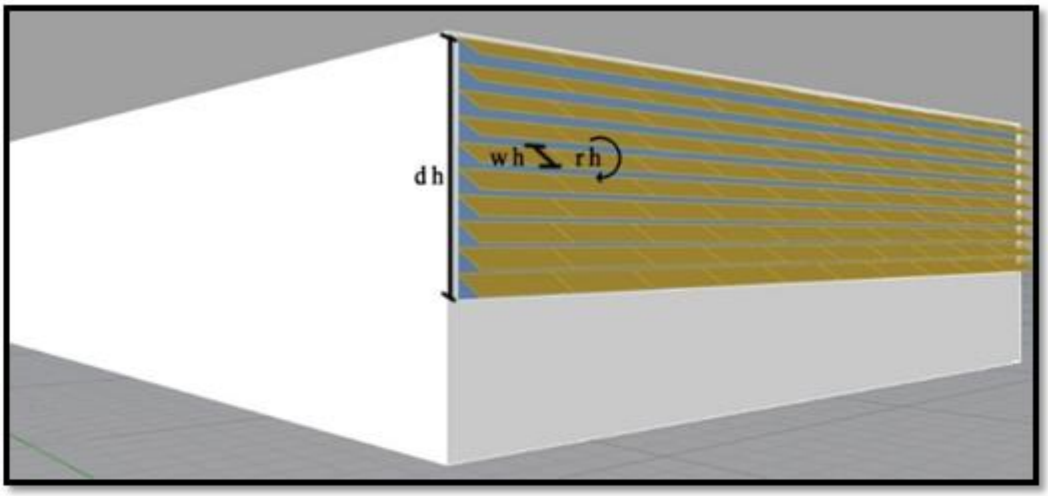

Figure 4.7. Decision Variables of Horizontal Louvers

4.4.2 Parametric Definition of Horizontal Louvers

Before creating the parametric model, first, a part of the reference building was created in Rhino platform. This part consists of classrooms, offices and corridors. The dimensions of main classroom are 7.50m width and 10.34m length. The height of the classroom is 2.50m. Glazing ratio is 60%. It means that the window has 1.50m height and 1.00m sill height. Secondly, the parametric definiton of the horizontal louvers was created according to width, rotation angle and density which are also decision variables. In Figure 4.8 the detailed parametric definition of horizontal louvers which was created in the Grasshopper Environment can be seen.

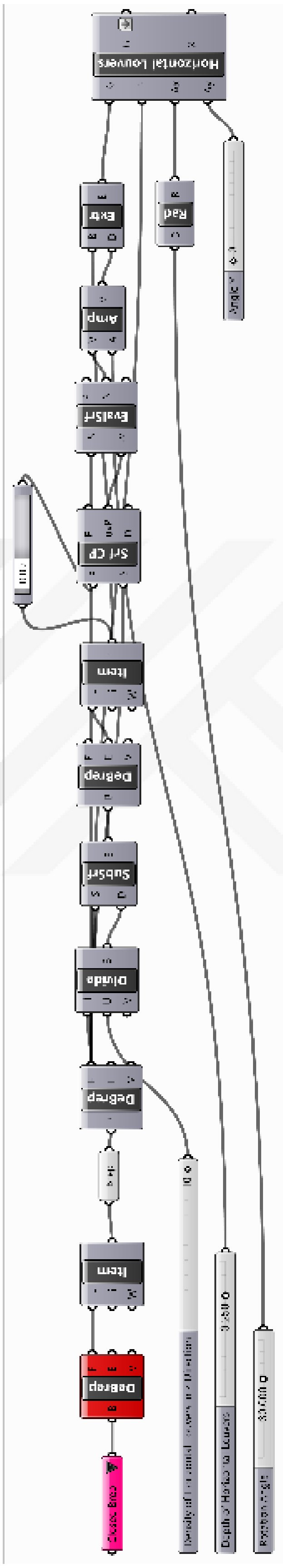

Figure 4.8. Detailed Parametric Definition of Horizontal Louvers

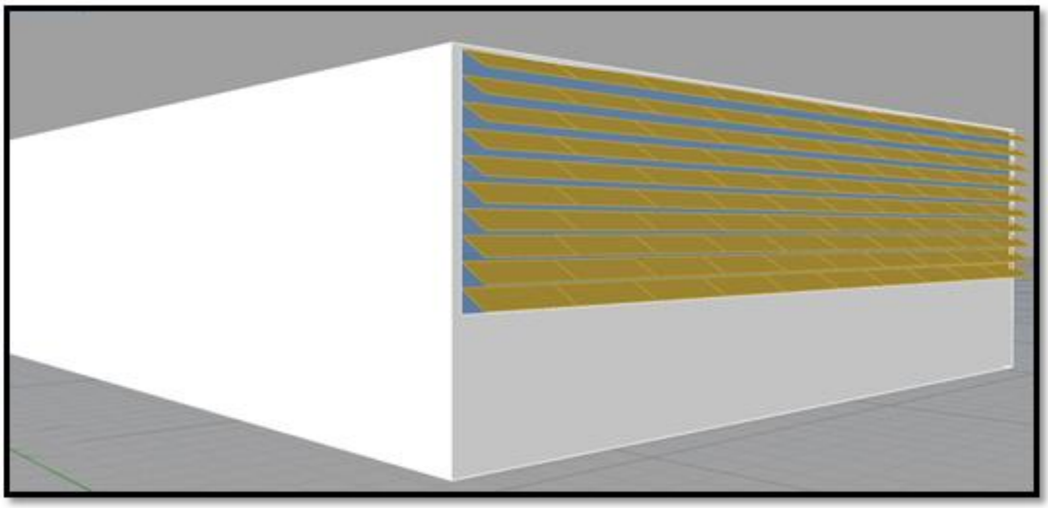

Figure 4.9. Horizontal Louvers Integrated to the South Façade of the Main Classroom (Perspective View)

4.5 Case Study 2: Vertical Louvers

4.5.1 Decision Variables

In the second case study, the decision variables are d_v, w_v, r_v (Figure 4.10). Density of vertical louvers in y direction is represented by d_v. According to two objectives which are useful daylight illuminance and total energy consumption, d_v changes in between 1 and 42. The width of vertical louvers is represented by w_v . It varies in between 0.1m and 0.3m as a real number. The rotation angle of vertical louvers around the z axis is represented by r_v, and it is varying between -90° and 90° as an integer number.

Decision Variables	*Explanation*	*Range*	*Type*
d_v	Density of vertical louvers in z direction	[1,42]	integer
w_v	Width of vertical louvers	[0.1,0.3m]	real
r_v	Rotation angle of vertical louvers	[-90°,90°]	integer

Table 4. Decision Variables of Vertical Louvers

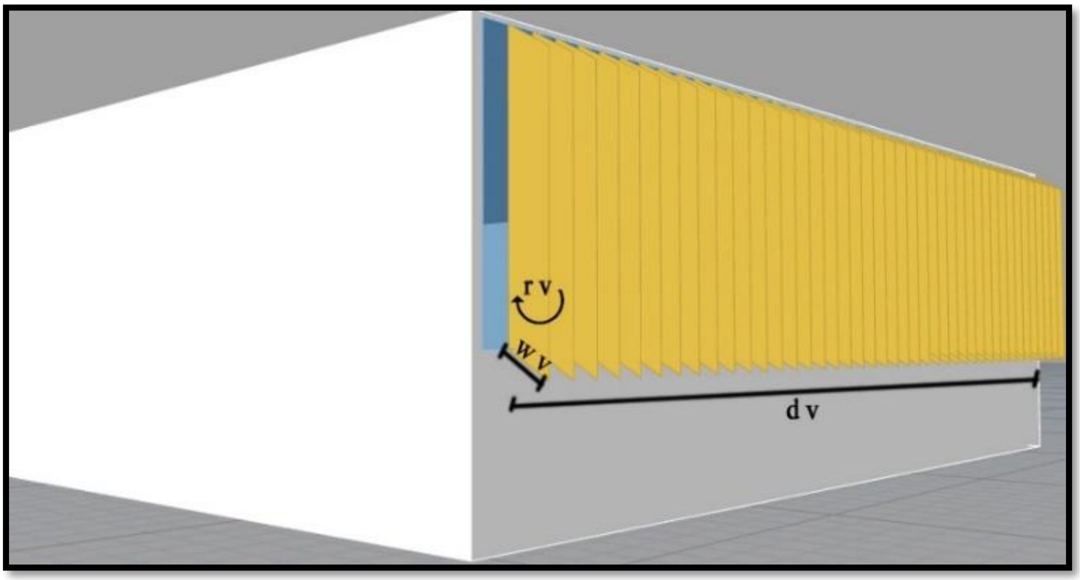

Figure 4.10. Decision Variables of Vertical Louvers

4.5.2 Parametric Definition of Vertical Louvers

Before creating the parametric model, first, a part of the reference building was created in Rhino platform. Secondly, the parametric definiton of the vertical louvers was created according to width, rotation angle and density which are also decision variables. In Figure 4.11 the detailed parametric definition of vertical louvers which was created in the Grasshopper environment can be seen.

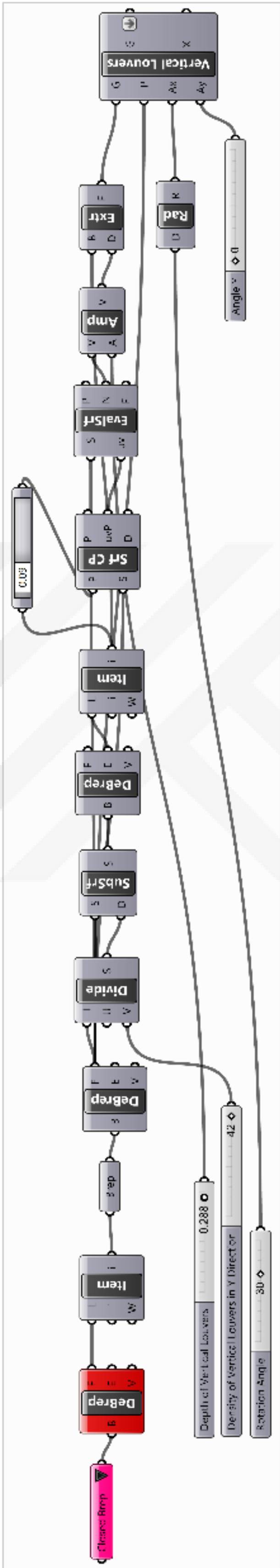

Figure 4.11. Detailed Parametric Definition of Vertical Louvers

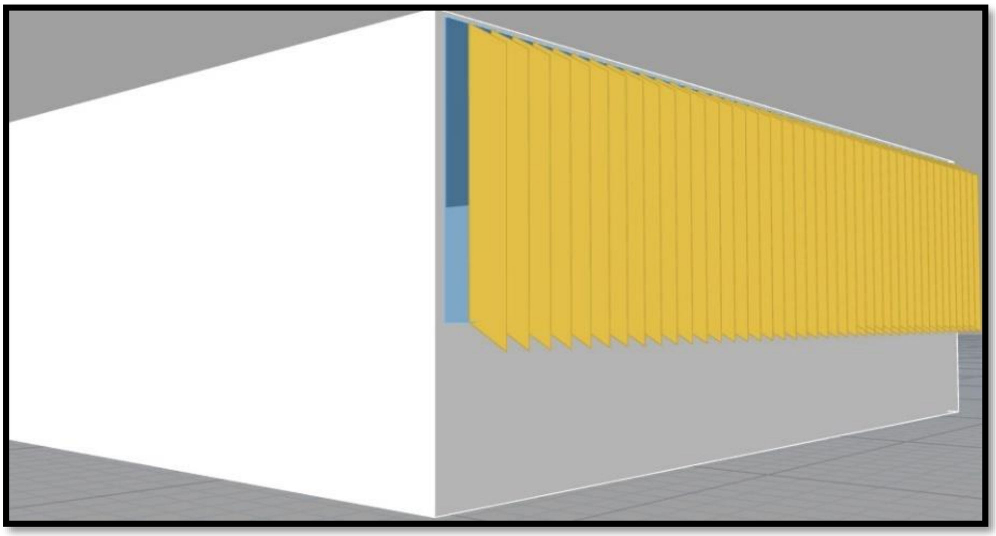

Figure 4.12. Vertical Louvers Integrated to the South Façade of the Main Classroom (Perspective View)

4.6 Case Study 3: Overhang

4.6.1 Decision Variables

In the third case study, the decision variables are w_o , r_o (Figure 4.13).

Decision Variables	*Explanation*	*Range*	*Type*
w_o	Width of overhang	[0.1,0.3m]	Real number
r_o	Rotation angle of overhang	[-90°,90°]	integer

Table 5. Decision Variables of Overhang

The width of overhang is represented by w_o. It varies in between 0.1m and 0.3m as a real number. The rotation angle of overhang around the x axis is represented by r_o, and varies in between -90° and 90° as an integer number.

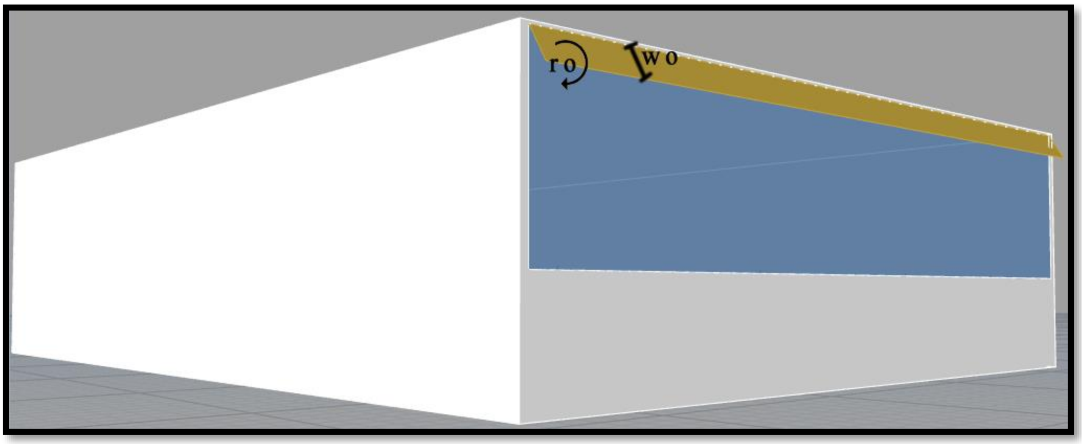

Figure 4.13. Decision Variables of Overhang

4.6.2 Parametric Definition of Overhang

Before creating the parametric model, first, a part of the reference building was created in Rhino platform. Secondly, the parametric definiton of the overhang was created according to width and rotation angle which are also decision variables. In Figure 4.14 the detailed parametric definition of overhang which was created in the Grasshopper environment can be seen.

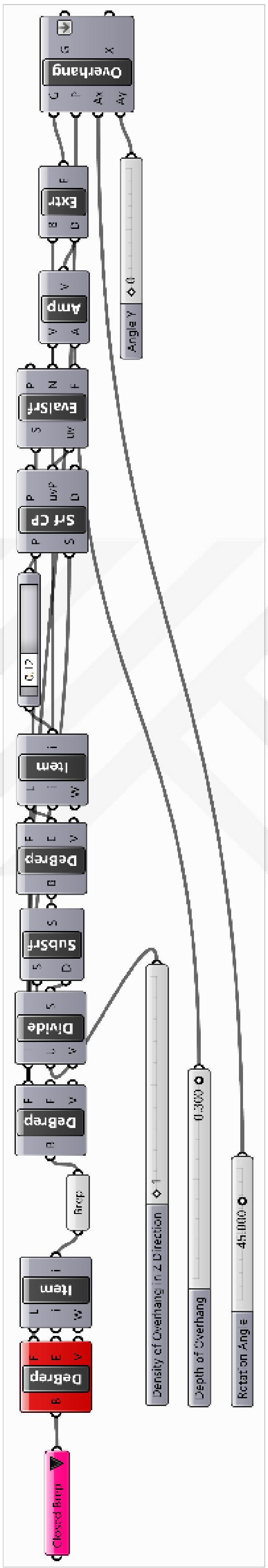

Figure 4.14. Detailed Parametric Definition of Overhang

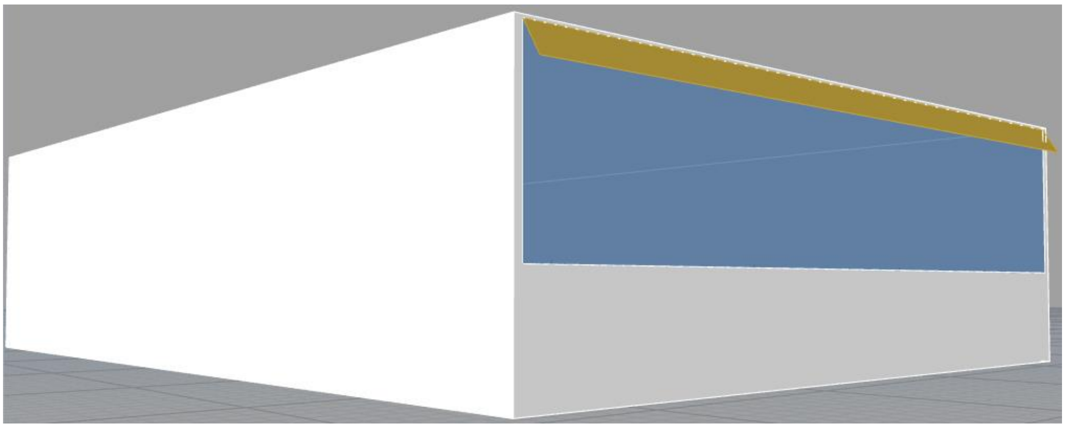

Figure 4.15. Overhang Integrated to the South Façade of the Main Classroom (Perspective View)

4.7 Case Study 4: Proposed Shading Device

4.7.1 Decision Variables

In this case study, the decision variables are w_{L1} , w_{L2} , ... w_{L40} in Figure 4.16 and $ra_{L1}, ra_{L2}, ra_{L3}, ra_{L4}, ra_{L5}, ra_{L6}, ra_{L7}, ra_{L8}, ra_{L9}, ra_{L10}$ in Figure 4.17. There are four widths for each louver by $w_{L1}, \dots w_{L40}$. According to two objectives which are useful daylight illuminance and total energy consumption, $w_{L1}, \dots w_{L40}$ change in between 0.1 m and 0.3 m as a real number. The rotation angle for each louver around the x axis is represented by $ra_{L1}, \dots ra_{L10}$, and it vary in between -90° and 90° as an integer number.

Decision Variables	*Explanation*	*Range*	*Type*
$w_{L1}, \dots w_{L40}$	Widths for each louver	[0.1,0.3m]	Real number
$ra_{L1}, \dots ra_{L10}$	Rotation angle for each louver	[-90°,90°]	integer

Table 6. Decision Variables of Proposed Shading Device

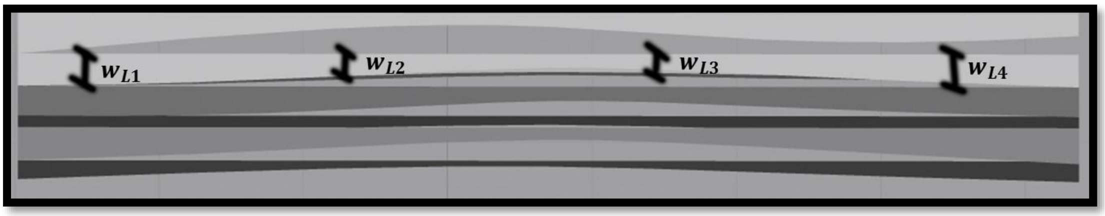

Figure 4.16. Decision Variables of Proposed Shading Device (Top View)

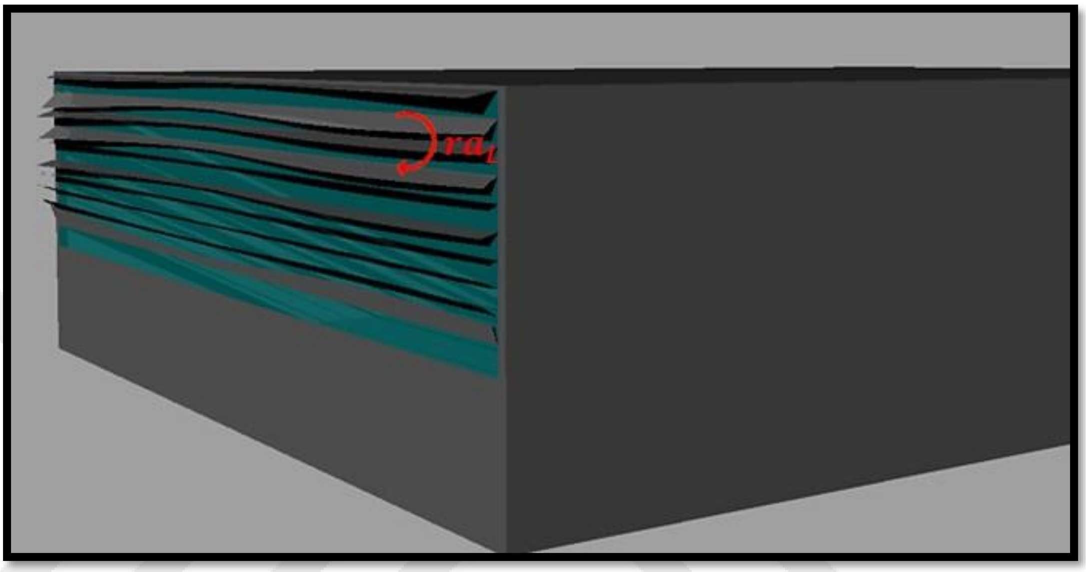

Figure 4.17. Decision Variables of Proposed Shading Device (Perspective)

4.7.2 Constraints

In this problem, we have 9 **"constraints"** which are all about relationship between louvers. It means, there should not be any intersection for each 2 louvers in order to have a logical order on the façade. For instance, first louver and the second louver should not be intersected from any solid region while the algorithm is trying to find optimal rotation angle. So, constraints are as follows:

$$N\ (A_{i}\ \cap\ A_{i+1}) = 0 \qquad (3)$$

$$A_1, A_2, \dots A_{10} \qquad (4)$$

$$i = 1, \dots, 9 \qquad (5)$$

4.7.3 Parametric Definition of Proposed Shading Device

Before creating the parametric model, first, a part of the reference building was created in Rhino platform. Secondly, the parametric definiton of proposed shading device was created according to widths and rotation angles which are also decision variables. In Figure 4.21 the detailed parametric definition of proposed shading device which was created in the Grasshopper environment can be seen.

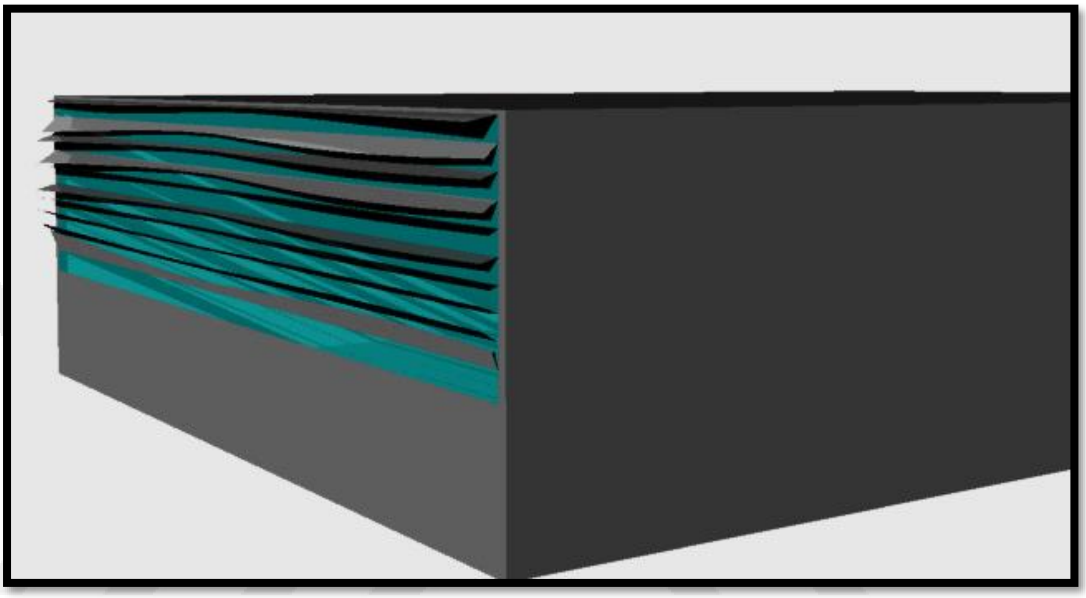

Figure 4.18. Proposed Shading Device Integrated to the South Façade of the Main Classroom (Perspective)

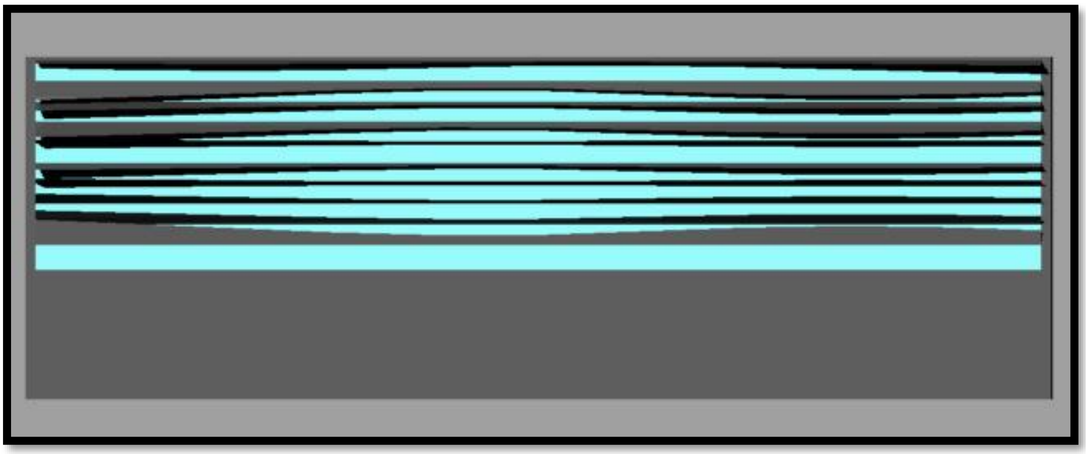

Figure 4.19. Proposed Shading Device Integrated to the South Façade of the Main Classroom (South Elevation)

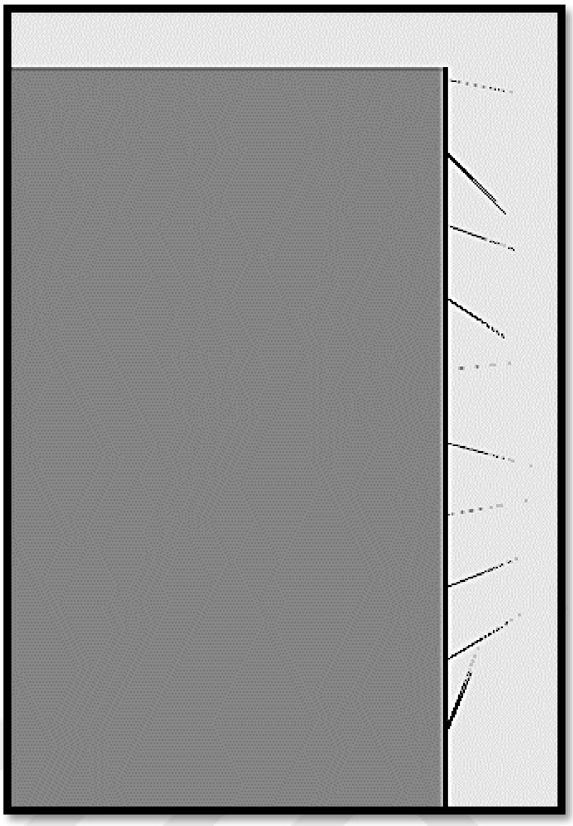

Figure 4.20. Proposed Shading Device Integrated to the South Façade of the Main Classroom (West Elevation)

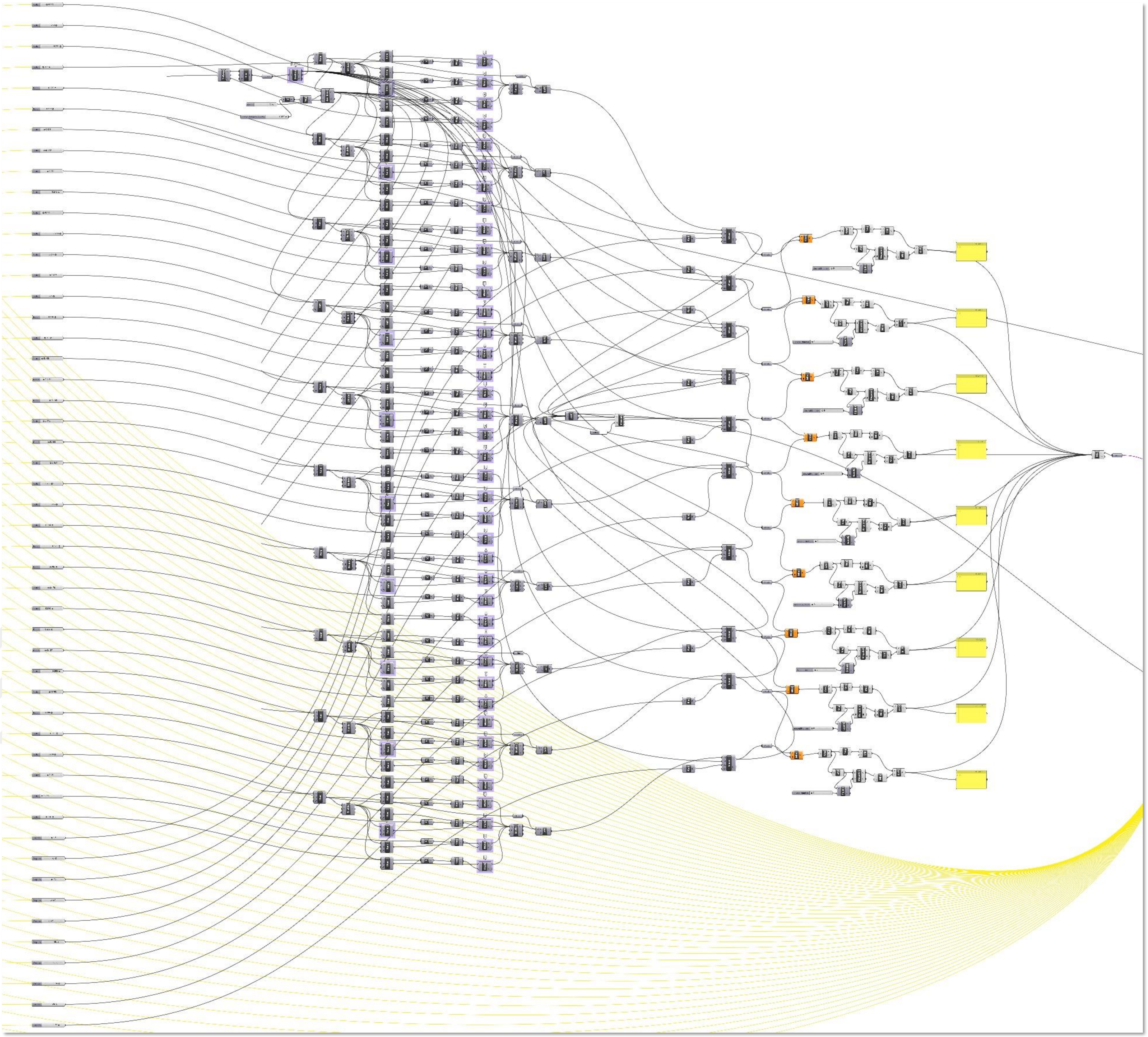

Figure 4.21. Detailed Parametric Definition of Proposed Shading Device

4.8 Conclusion

This chapter clearly defined four different scenarios which belong to four different shading device types integrated to the case study building. Generated models were shown and explained according to decision variables which are related to important parameters of mentioned shading devices. Mentioned shading devices are horizontal louves, vertical louvers, overhang and proposed shading device. While for the horizontal louvers and vertical louvers decision variables are width of louvers, rotation angle and density of louvers, for the overhang type density of louvers were not mentioned as a decision variable. For the proposed shading device type, there are totally 50 **“decision variables”** which are related to **“widths for each louver”** and **“rotation angle for each louver”**. In case study 4, there is an aspect different than other case studies. It is constraints. Constraints are included in this problem, since each louver has various rotation angle. In order to prevent any intersection between each two louvers, constraints were defined in the parametric generative model. All the models were developed in the Grasshopper Environment by implementing parametric modeling and simulation techniques and optimization method.

CHAPTER 5

RESULTS AND DISCUSSION

In this research NSGA-II was used to get optimization results for each scenario. After tests were held in the computer environment, scatterplots for each scenario were created according to optimization results. For each case study, population size of 100 and generation number of 50 were taken. Since they took too much time to run the simulation based optimization, only 50 generations were run. Four different problems were formulated as a two-objective by taking into account maximizing useful daylight illuminance and minimizing total energy consumption. Performance of NSGA-II is shown by graphs for each case study.

5.1 Results of Case Study 1: Horizontal Louvers

In Case Study 1, horizontal louvers were tested when they were integrated to south façade of the test room. The graph of UDI and total energy consumption were created according to simulation based optimization for horizontal louvers. The scatterplot of total energy consumption and UDI can be seen in Figure 5.1.

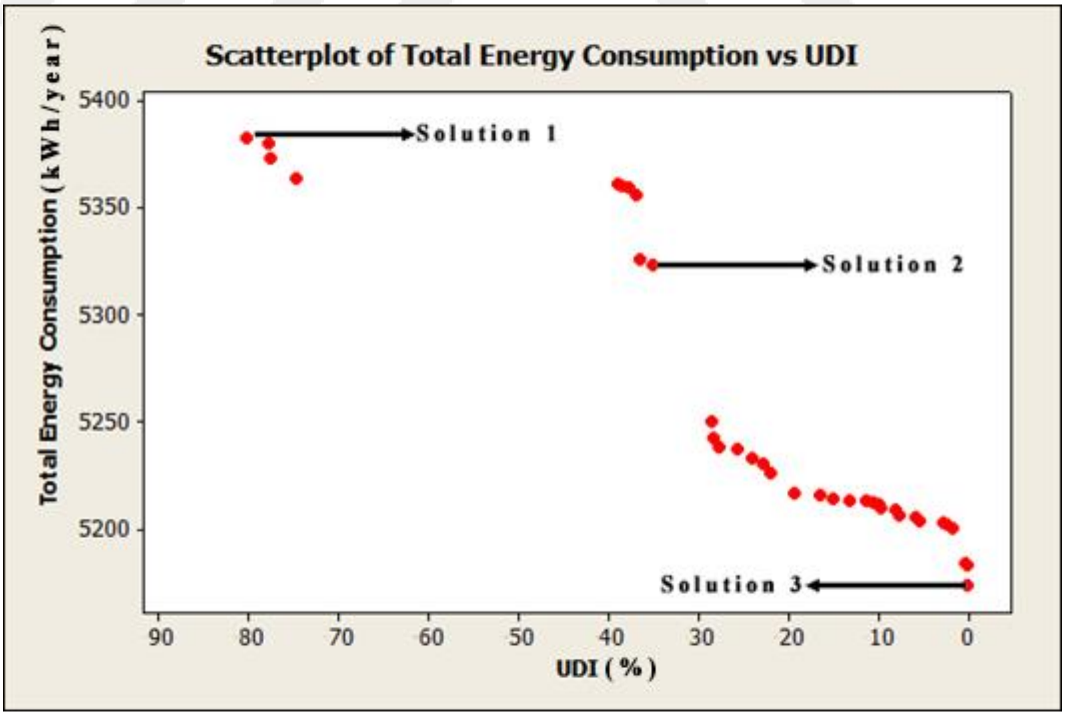

Figure 5.1. Scatterplot of NSGA-II in 50 Generations for Horizontal Louvers

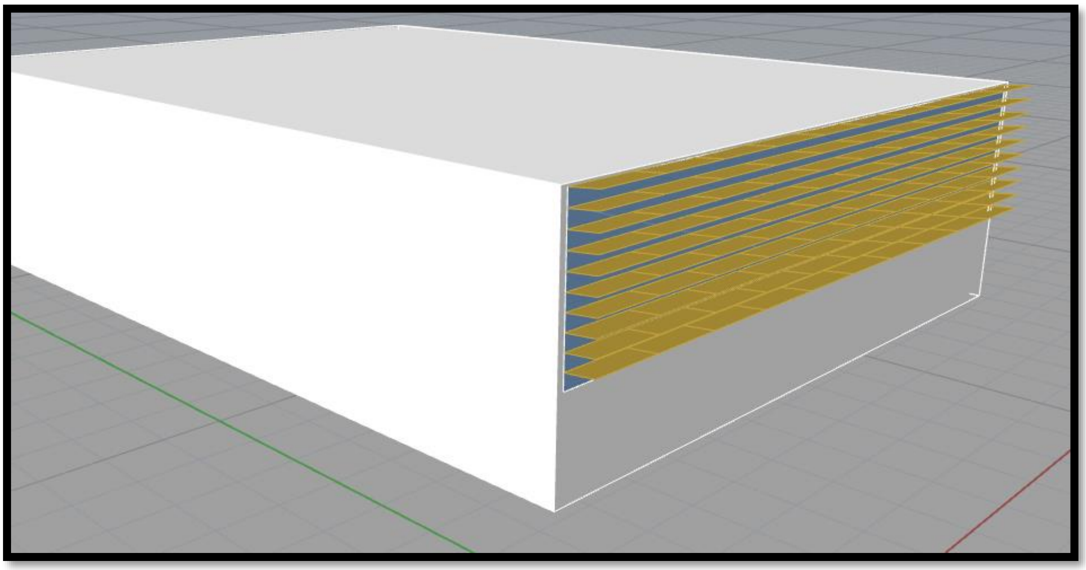

Figure 5.2. Solution 1 in NSGA-II for Horizontal Louvers (Perspective)

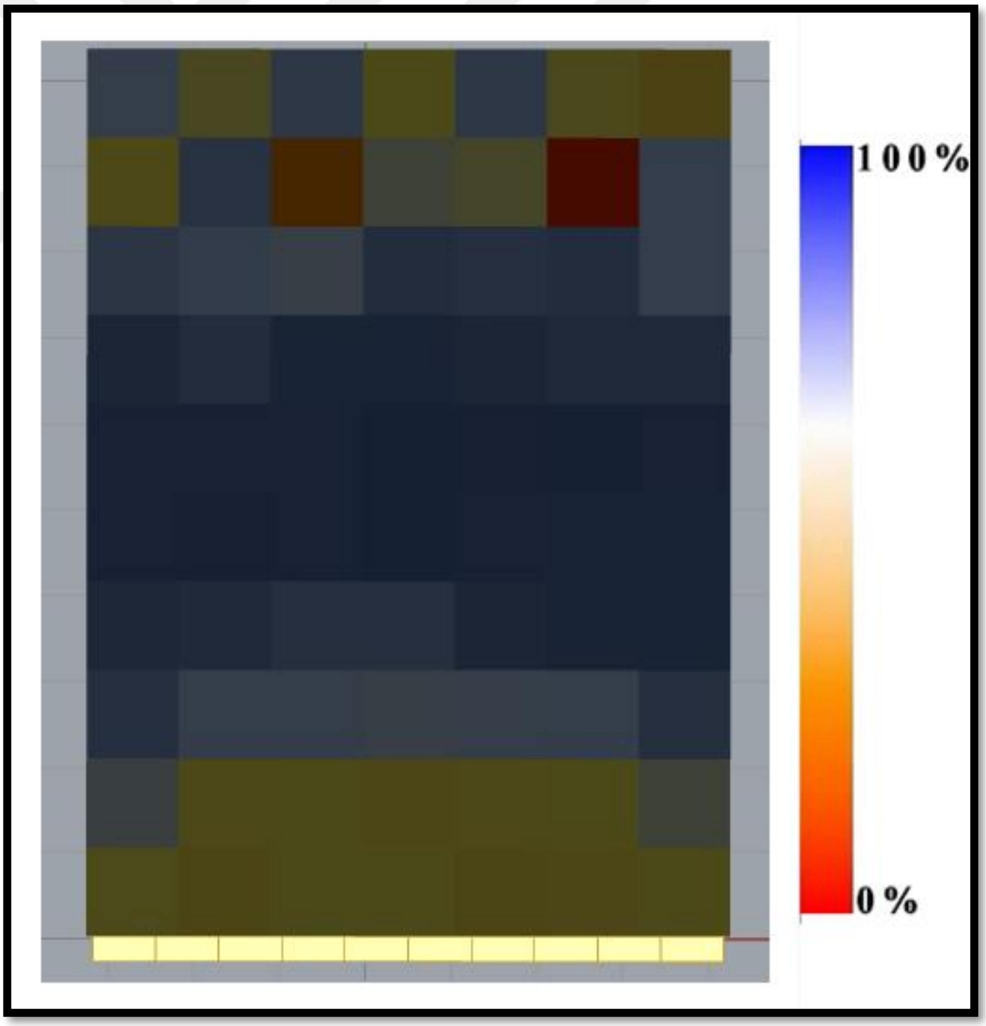

Figure 5.3. UDI in Solution 1 in NSGA-II for Horizontal Louvers (Plan)

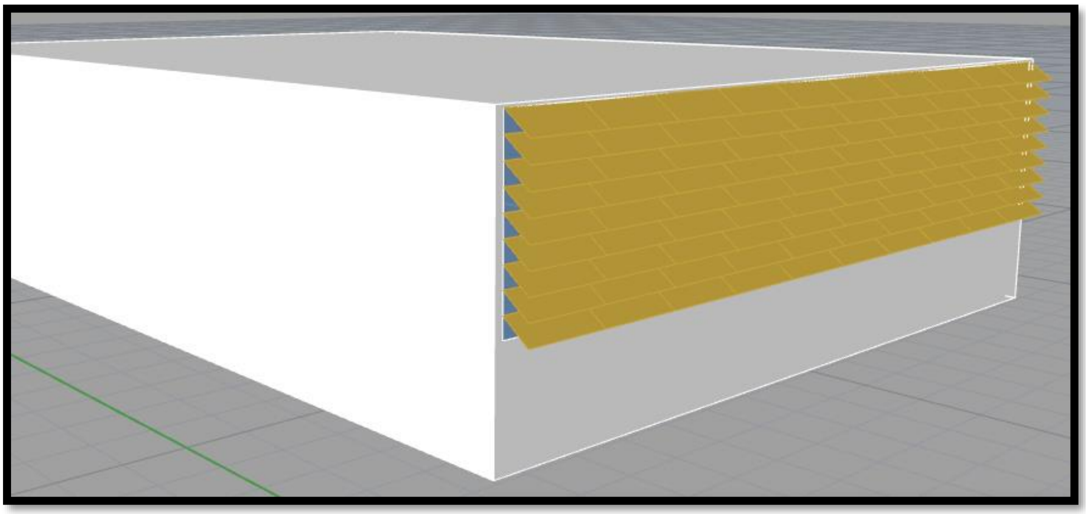

Figure 5.4. Solution 2 in NSGA-II for Horizontal Louvers (Perspective)

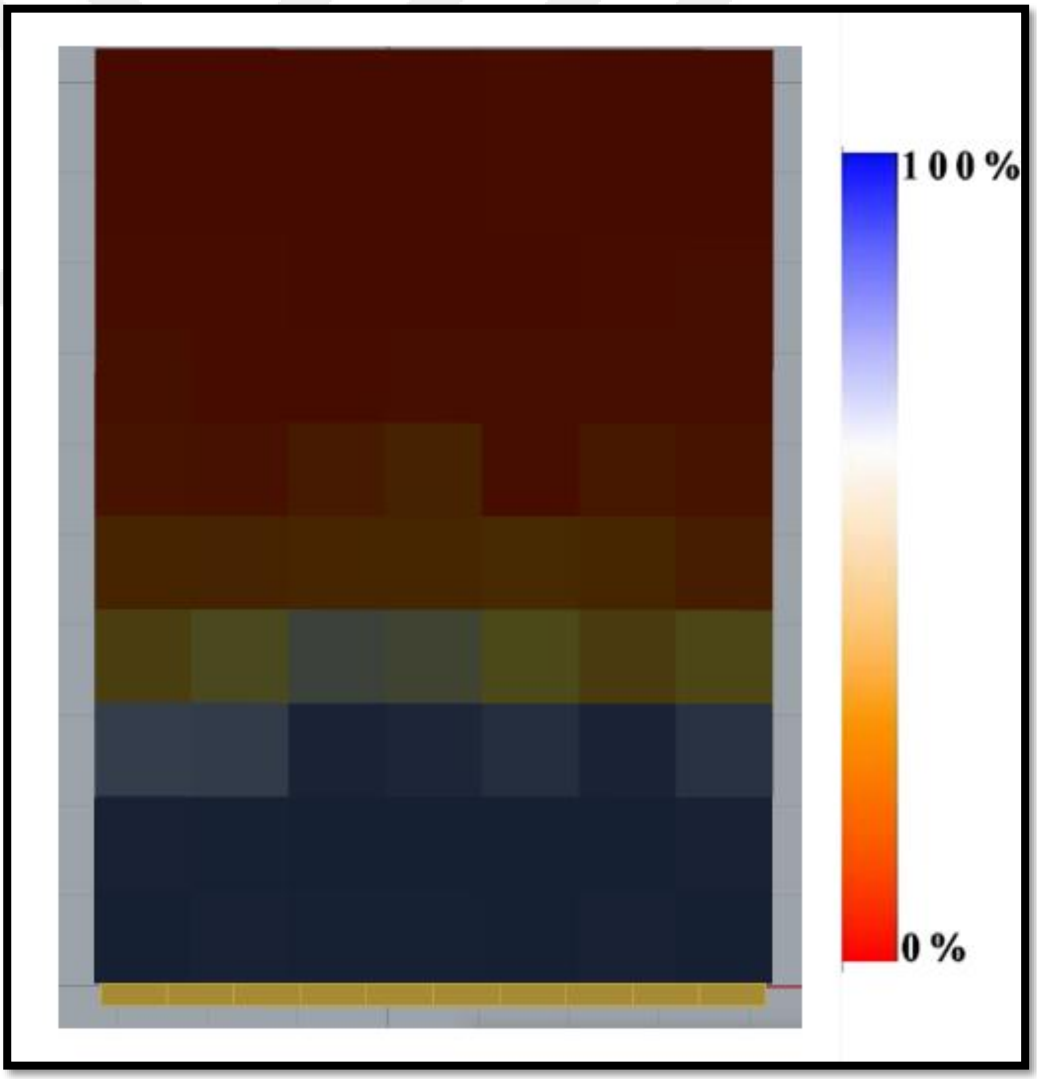

Figure 5.5. UDI in Solution 2 in NSGA-II for Horizontal Louvers (Plan)

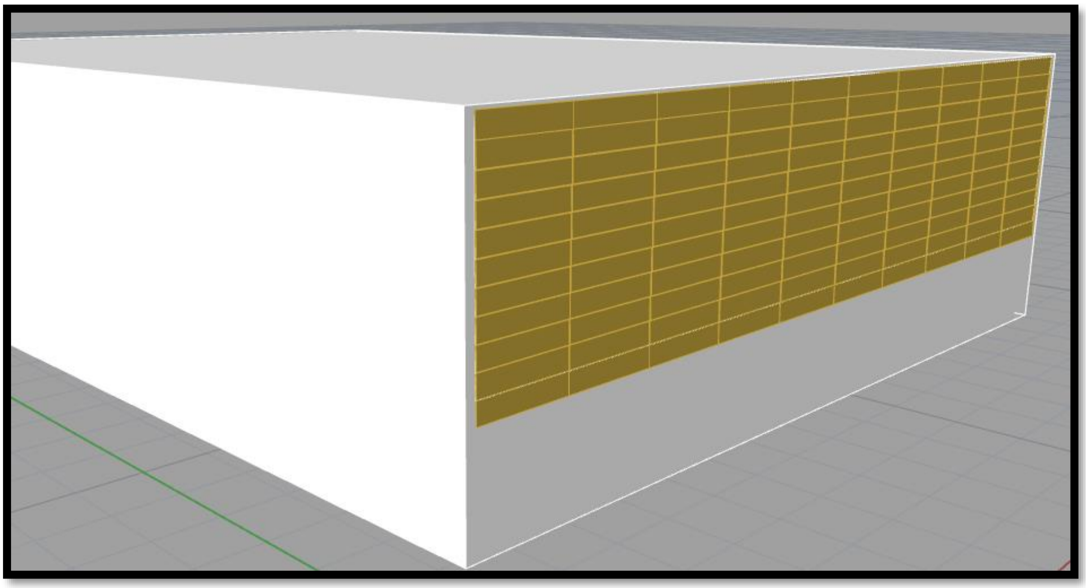

Figure 5.6. Solution 3 in NSGA-II for Horizontal Louvers (Perspective)

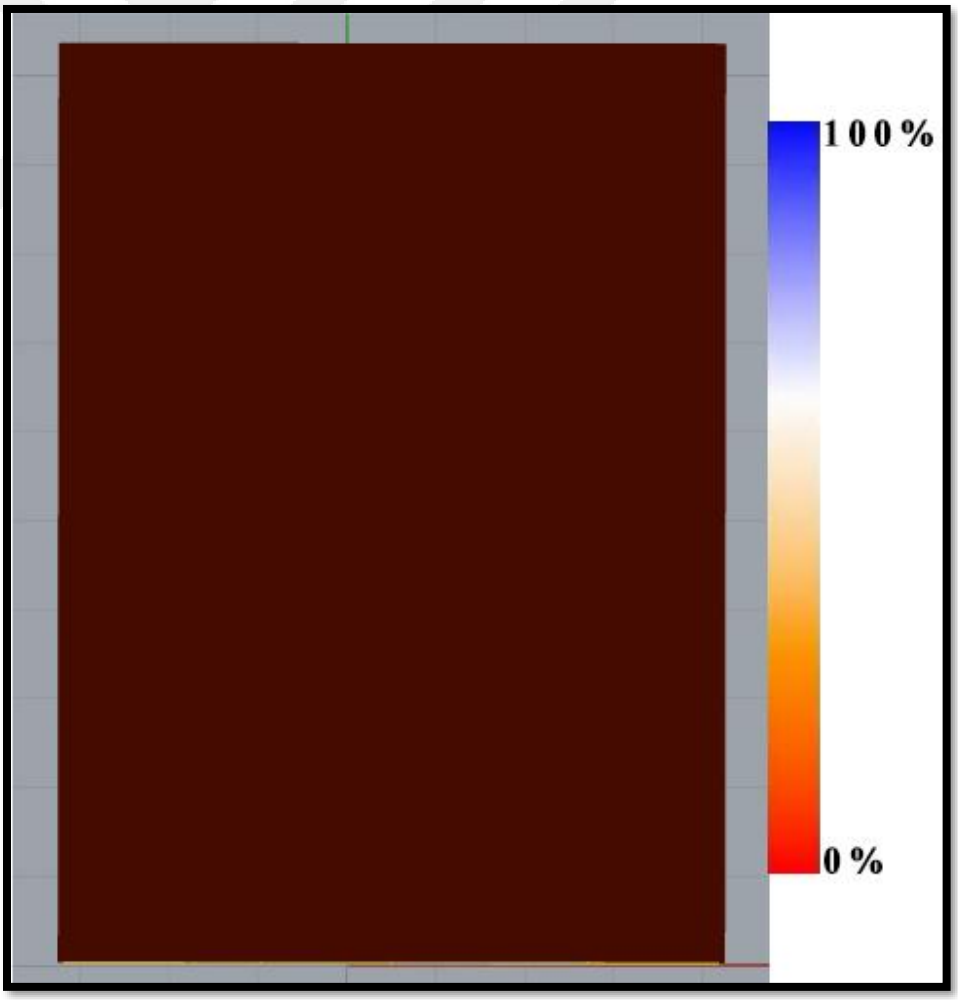

Figure 5.7. UDI in Solution 3 in NSGA-II for Horizontal Louvers (Plan)

Solutions in Case Study 1	*Depth of Horizontal Louvers*	*Rotation Angle*	*Density of Horizontal Louvers*	*Yearly Total Energy Consumption*	*UDI*
Solution 1	0.298 meter	-5°	10	5382.29 kWh/year	%77
Solution 2	0.298 meter	35°	9	5323.46 kWh/year	%33
Solution 3	0.300 meter	88°	10	5173.10 kWh/year	%0

Table 7. Solutions in Case Study 1

Solution 1 in Figure 5.1 demonstrates a solution which has an energy consumption of 5382.29 kWh/year and %77 UDI interior space of the classroom. It means more daylight comes into interios space according to graph. While this is happening much more energy use is seen in heating and cooling energy consumptions. In this solution density of horizontal louvers in Z direction is 10. It means there are totally 10 louvers integrated to the façade. Also, depth of each louver is 0.298 meter. Moreover, rotation angle of each louver is -5° since it changes in between -90° and 90° which is reasonable. Secondly, solution 2 in Figure 5.1 represents a solution that consumes 5323.46 kWh/year total energy while it allows %33 UDI interior space of the classroom. That means horizontal louvers close up more and they consume less total energy than solution 1 while it allows less daylight comes into interior space of the classroom. In this solution density of horizontal louvers in Z direction is 9 which means there are 9 horizontal louvers integrated to the façade. Besides, depth of each louver is again 0.298 meter and rotation angle of each louver is 35 degrees. Thirdly, in solution 3 in Figure 5.1 there is a total energy use of 5173.10 kWh/year and %0 UDI interior space of the classroom. That solution shows that since horizontal louvers closes up almost totally, no daylight comes into interior space. Moreover, in this solution density of horizontal louvers in Z direction is 10. The depth of each louver is 0.300 meter while rotation angle of each louver is 88°.

From the viewpoint of UDI and total energy consumption objectives, we can clearly observe that decision variables (dimensions) of horizontal louvers have an impact on the performance criterias which UDI and total energy consumption. However, based on our observation, it seems that the decision variable, which is rotation angle of each louver is much more important for UDI and total energy consumption objectives since there is a big change especially in UDI when rotation angle of each louver changes. Furthermore, from the point of NSGA-II UDI values in Pareto Front are observed in between %0 and %90 which means there are some solutions that do not allow any daylight comes into interior space of the chosen classroom.

5.2 Results of Case Study 2: Vertical Louvers

In Case Study 2, vertical louvers were tested when each louver was integrated to south façade of the test room. The graph of UDI and total energy consumption was created according to simulation based optimization for vertical louvers. The scatterplot of total energy consumption and UDI can be seen in Figure 5.8.

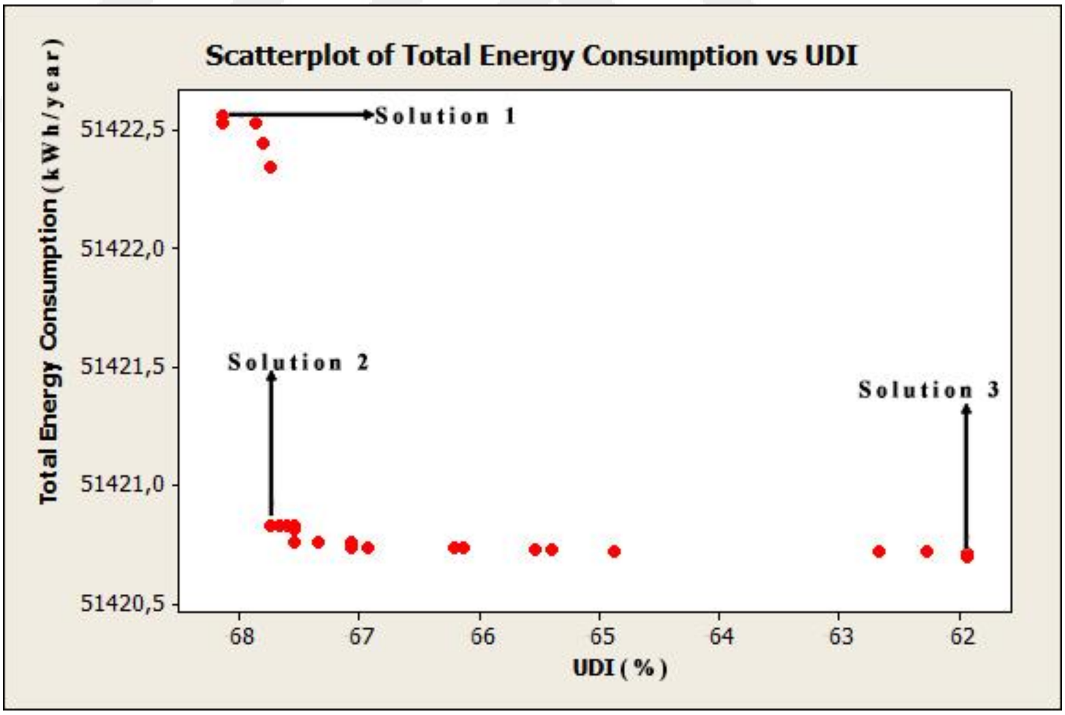

Figure 5.8. Scatterplot of NSGA-II in 50 Generations for Vertical Louvers

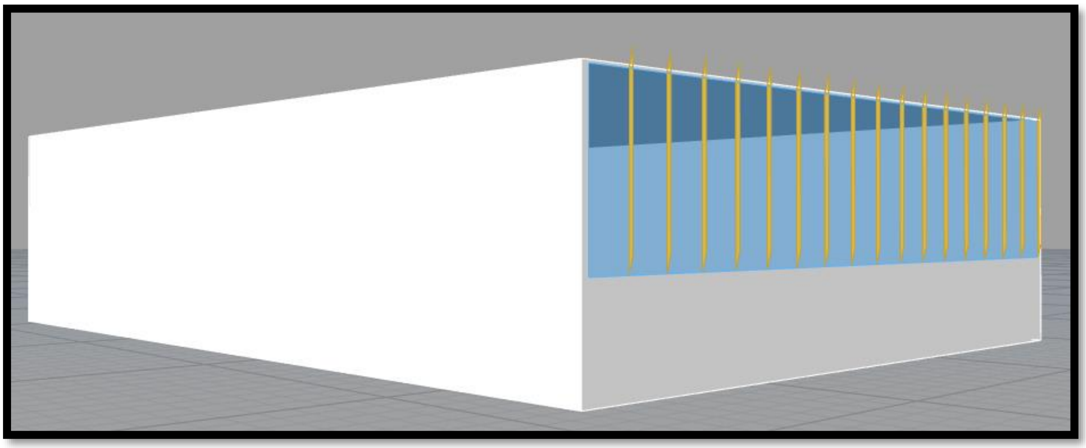

Figure 5.9. Solution 1 in NSGA-II for Vertical Louvers (Perspective)

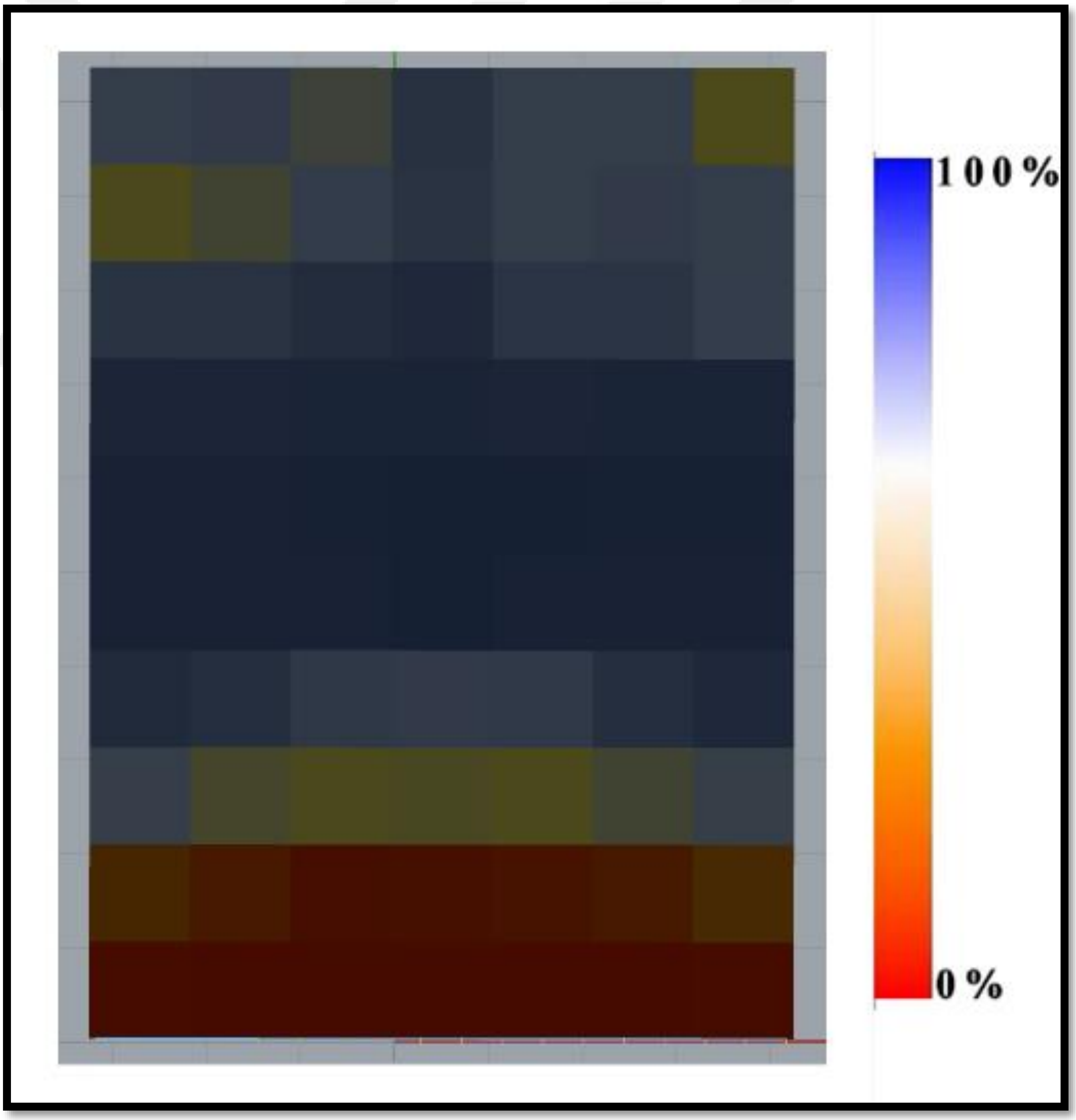

Figure 5.10. UDI in Solution 1 in NSGA-II for Vertical Louvers (Plan)

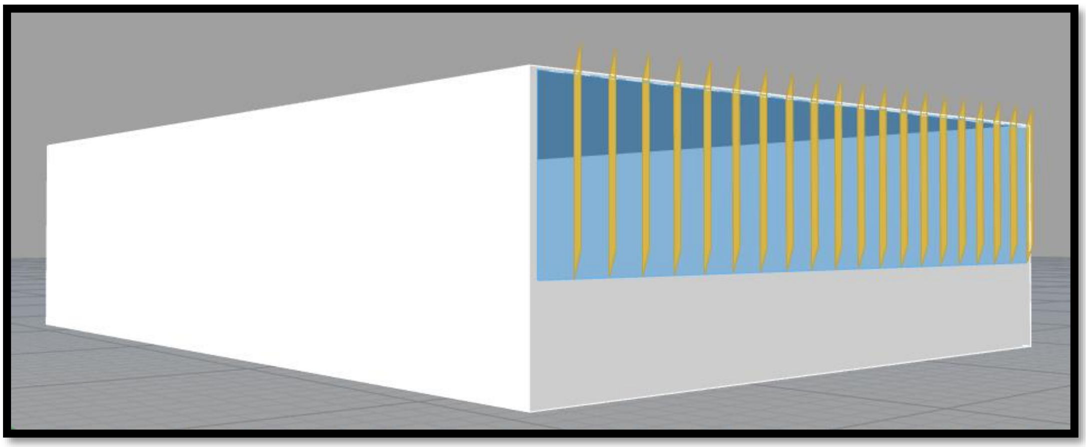

Figure 5.11. Solution 2 in NSGA-II for Vertical Louvers (Perspective)

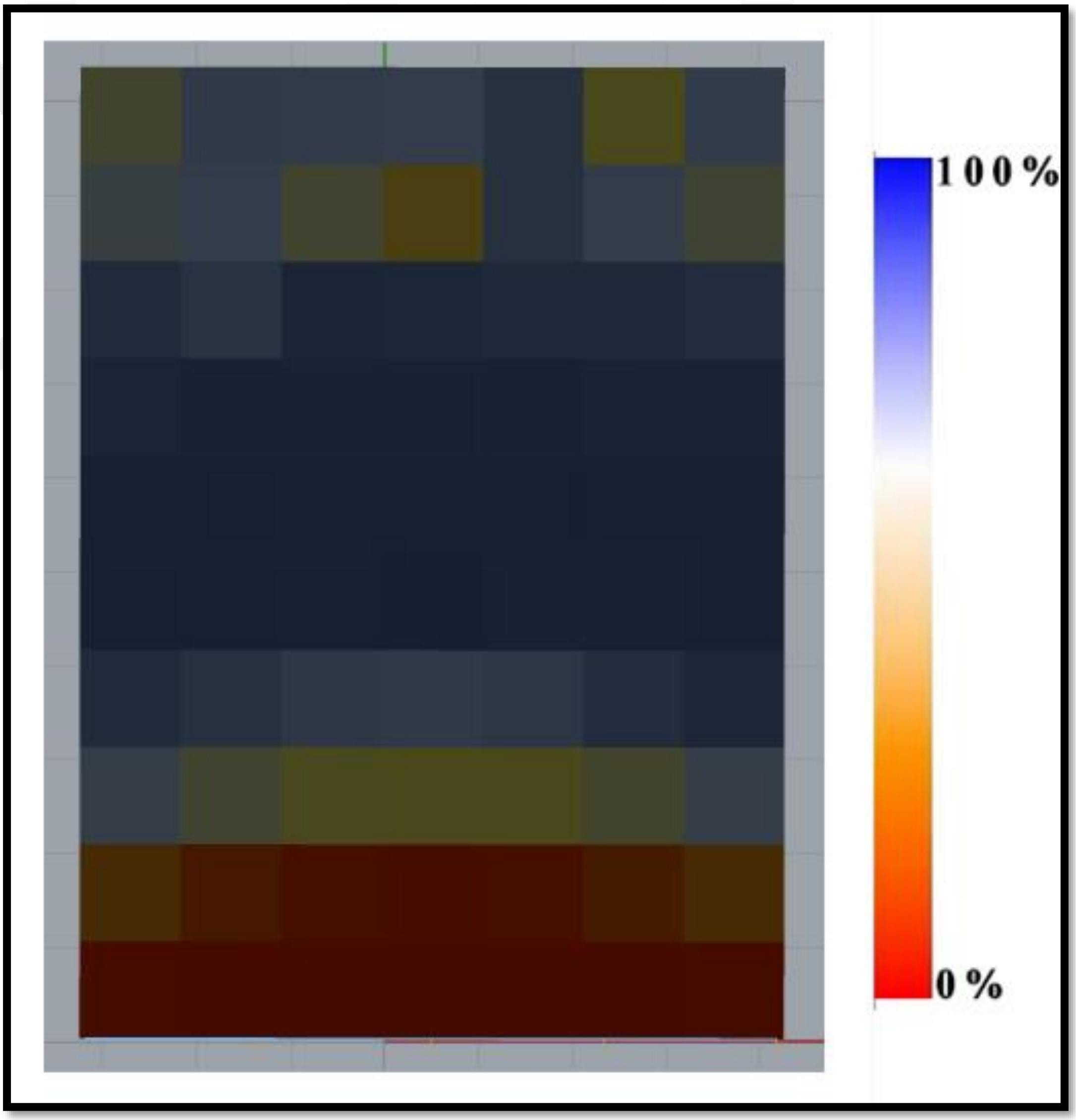

Figure 5.12. UDI in Solution 2 in NSGA-II for Vertical Louvers (Plan)

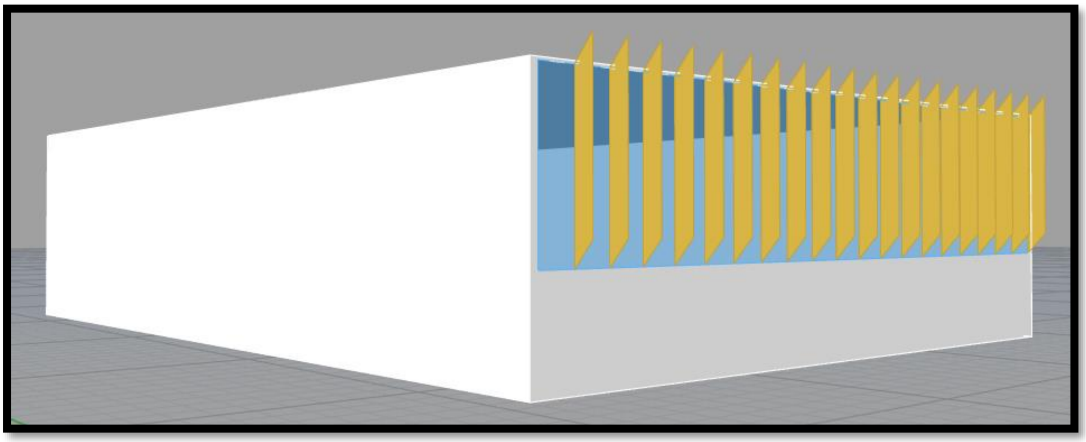

Figure 5.13. Solution 3 in NSGA-II for Vertical Louvers (Perspective)

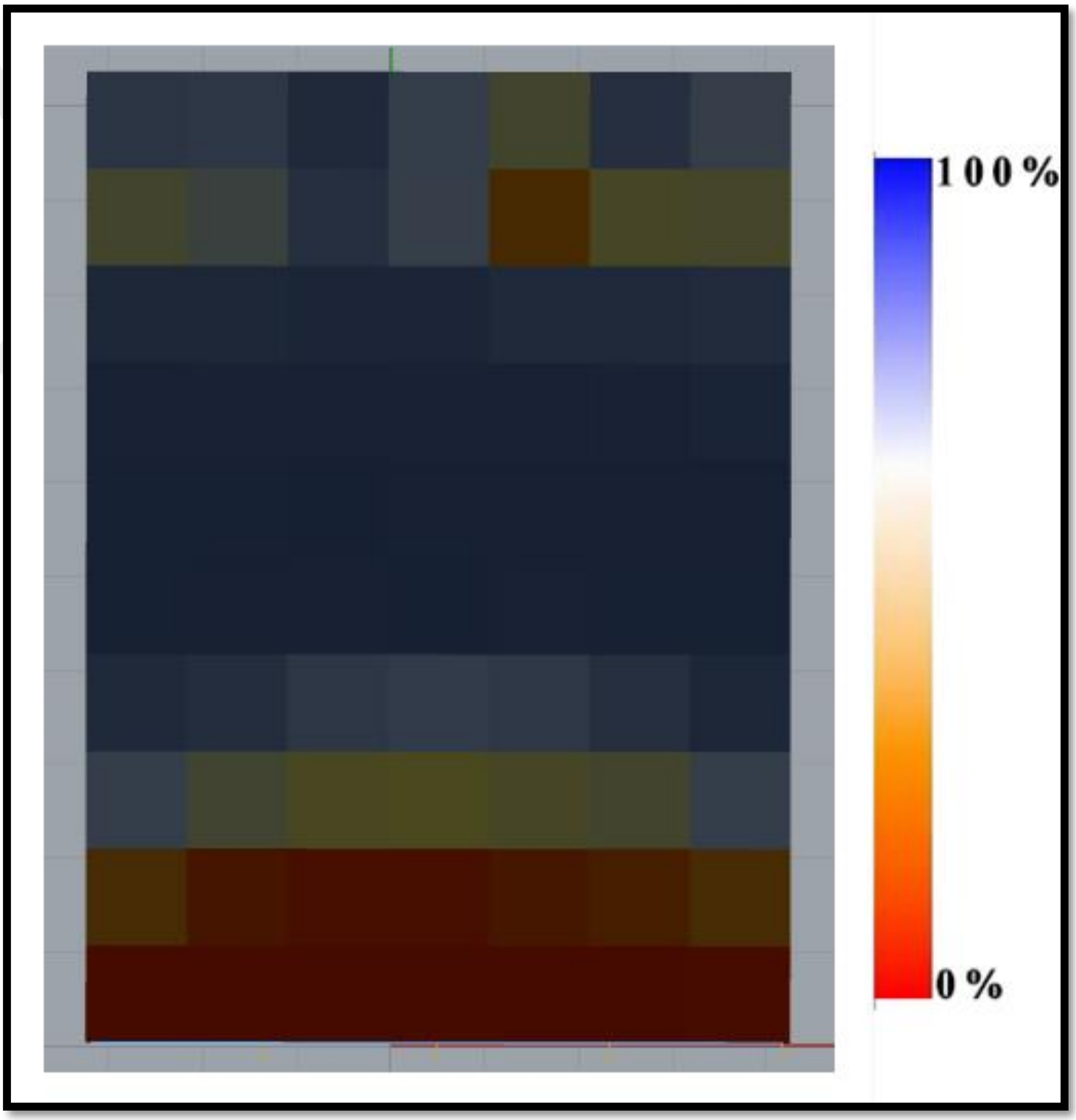

Figure 5.14. UDI in Solution 3 in NSGA-II for Vertical Louvers (Plan)

Solutions in Case Study 2	*Depth of Vertical Louvers*	*Rotation Angle*	*Density of Vertical Louvers*	*Yearly Total Energy Consumption*	*UDI*
Solution 1	0.160 meter	-76°	17	51422.53 kWh/year	%68
Solution 2	0.231 meter	-72°	20	51420.83 kWh/year	%67
Solution 3	0.299 meter	-45°	20	51420.69 kWh/year	%62

Table 8. Solutions in Case Study 2

As it is also seen in Table 8 solution 1 in Figure 5.8 represents a solution which has an energy use of 51422.53 kWh/year and %68 UDI interior space of the classroom. While total energy consumption, which includes heating and cooling energy consumptions, is very high according to graph, UDI value is also high. In this solution density of horizontal louvers in X direction is 17. It means there are totally 17 louvers integrated to the façade. Also, depth of each louver is 0.160 meter. Moreover, rotation angle of each louver is -76° since it is changing between -90° and 90° which is reasonable. Secondly, in solution 2 in Figure 5.8 there is a total energy use of 51420.83 kWh/year and %67 UDI interior space of the classroom. That means vertical louvers close up more but they consume almost same total energy as solution 1 while it allows almost same daylight comes into interior space of the classroom. In this solution density of horizontal louvers in X direction is 20 which means there are 20 vertical louvers integrated to the façade. Besides, depth of each louver is again 0.231 meter and rotation angle of each louver is -72°. Thirdly, solution 3 in Figure 5.8 represents a solution that consumes 5173.10 kWh/year while it allows %62 UDI interior space of the classroom. That solution shows that since vertical louvers close up more than solution 2, less daylight which is %62 UDI comes into interior space of the classroom. Moreover, in this solution density of vertical louvers in X direction is again 20. The depth of each louver is 0.299 meter while rotation angle of each louver is -45°.

According to UDI and total energy consumption objectives, it can be clearly observed that dimensions of vertical louvers have an impact on the performance criterias which UDI and total energy consumption. However, regrading to our observation, it seems that the decision variables, which are rotation angle and depth of each louver are much more important for UDI and total energy consumption objectives since there is not a small change especially in UDI when rotation angle and depth of each louver change. However, from the point of NSGA-II total energy consumption values in the graph are observed in between 51420.69 kWh/year and 51422.53 kWh/year which means there is not a big change in range of total energy consumption values according to graph.

5.3 Results of Case Study 3: Overhang

In Case Study 3, overhang was tested when it was integrated to south façade of the test room. The graph of UDI and total energy consumption was created according to simulation based optimization for overhang. The scatterplot of total energy consumption and UDI can be seen in Figure 5.15.

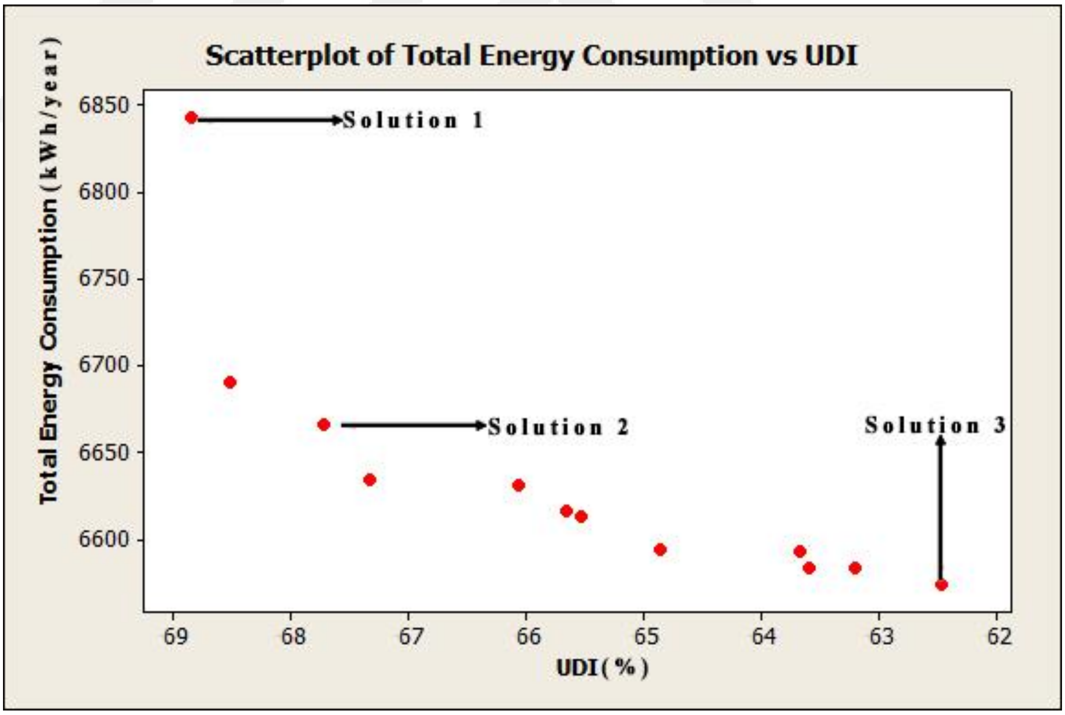

Figure 5.15. Scatterplot of NSGA-II in 50 Generations for Overhang

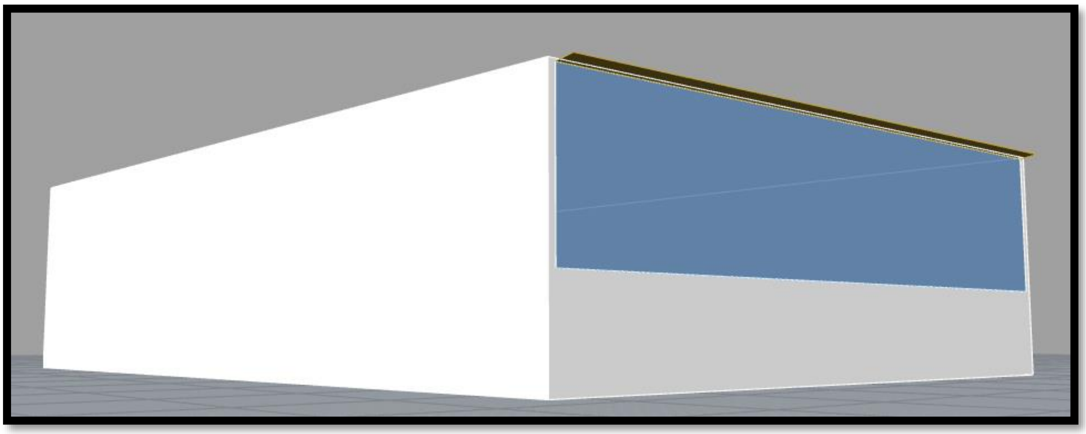

Figure 5.16. Solution 1 in NSGA-II for Overhang (Perspective)

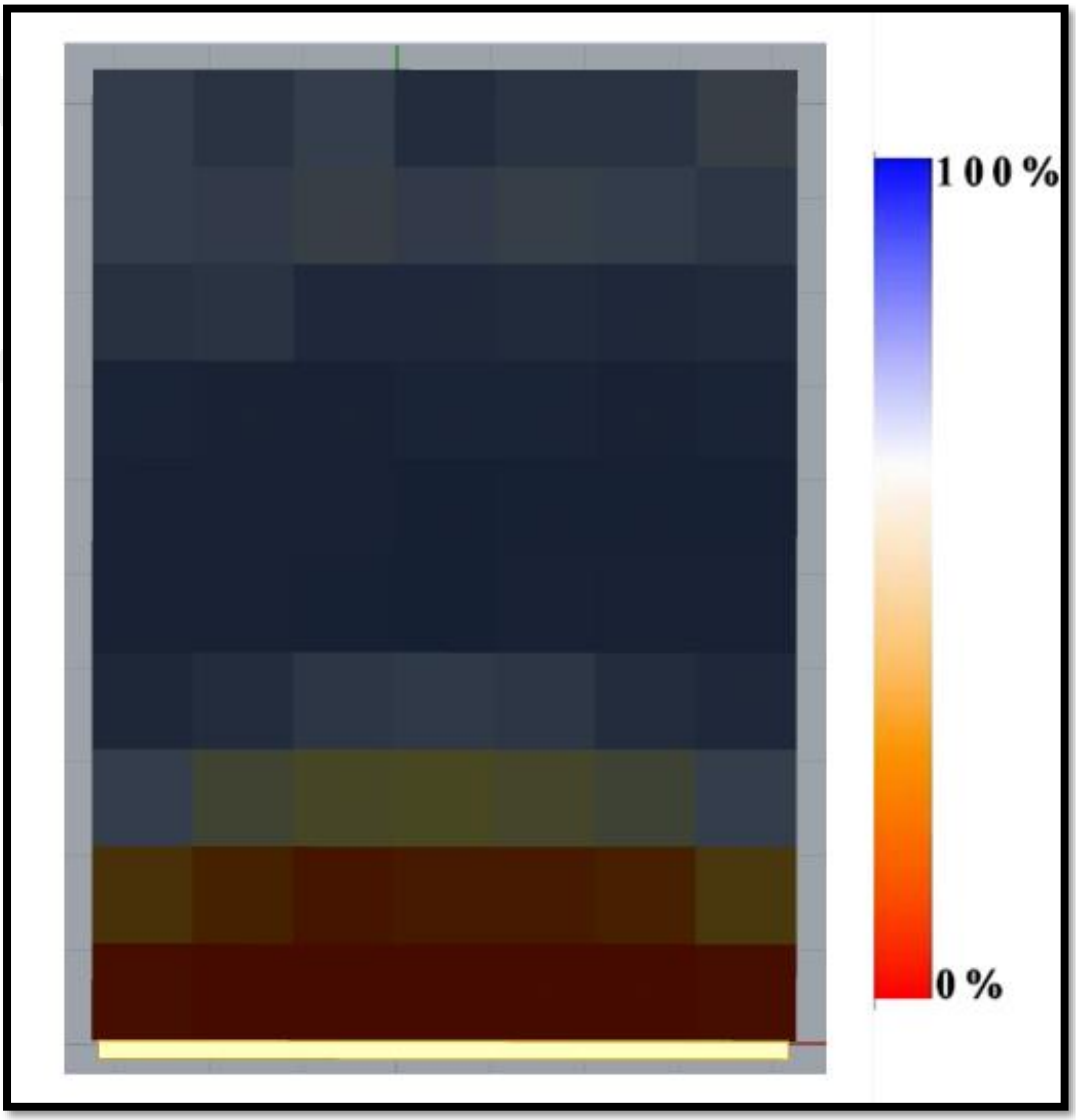

Figure 5.17. UDI in Solution 1 in NSGA-II for Overhang (Plan)

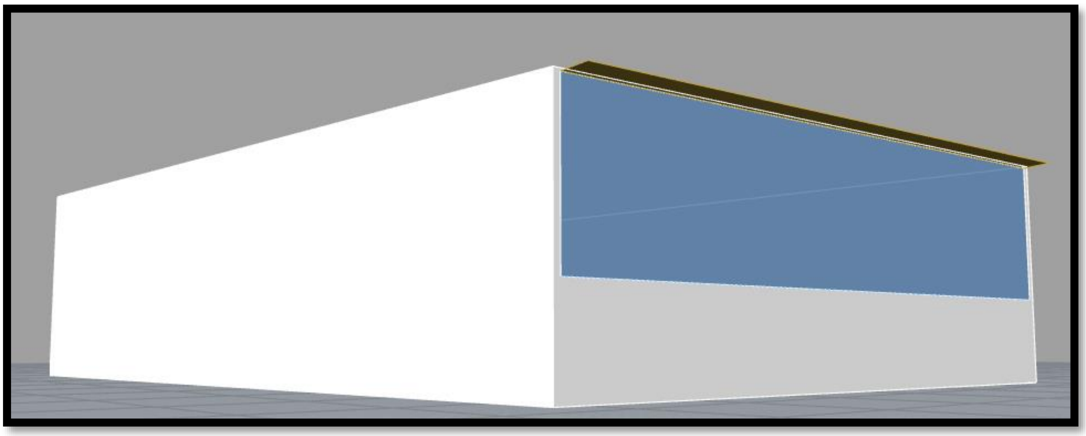

Figure 5.18. Solution 2 in NSGA-II for Overhang (Perspective)

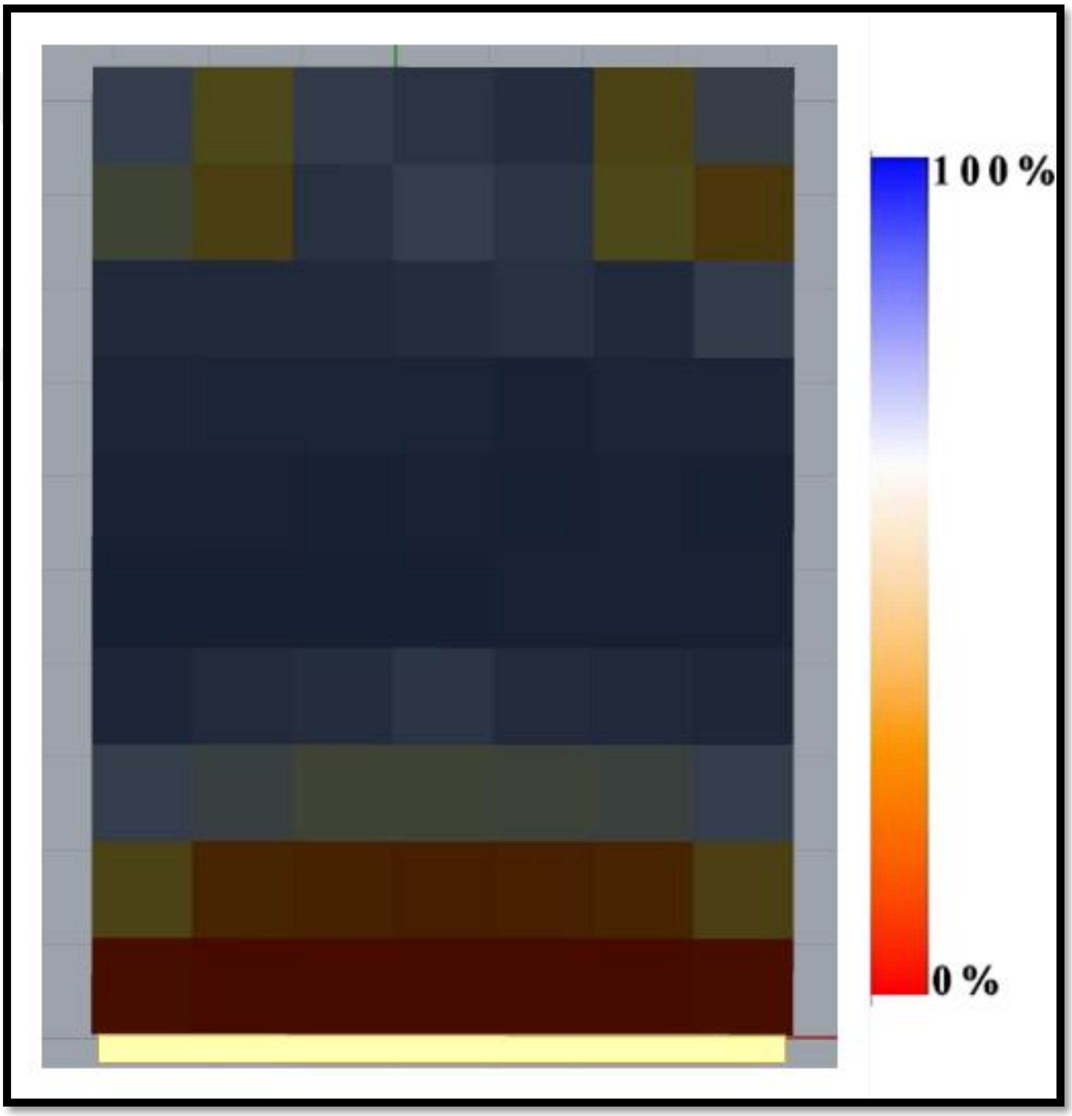

Figure 5.19. UDI in Solution 2 in NSGA-II for Overhang (Plan)

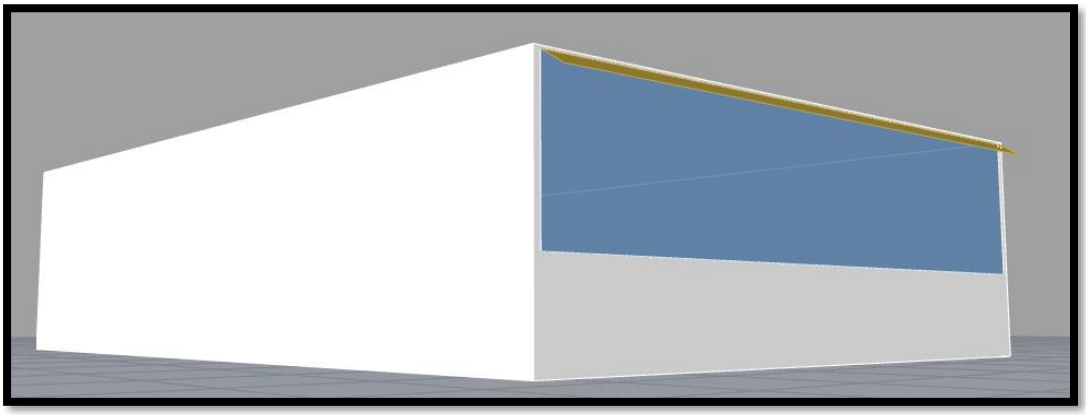

Figure 5.20. Solution 3 in NSGA-II for Overhang (Perspective)

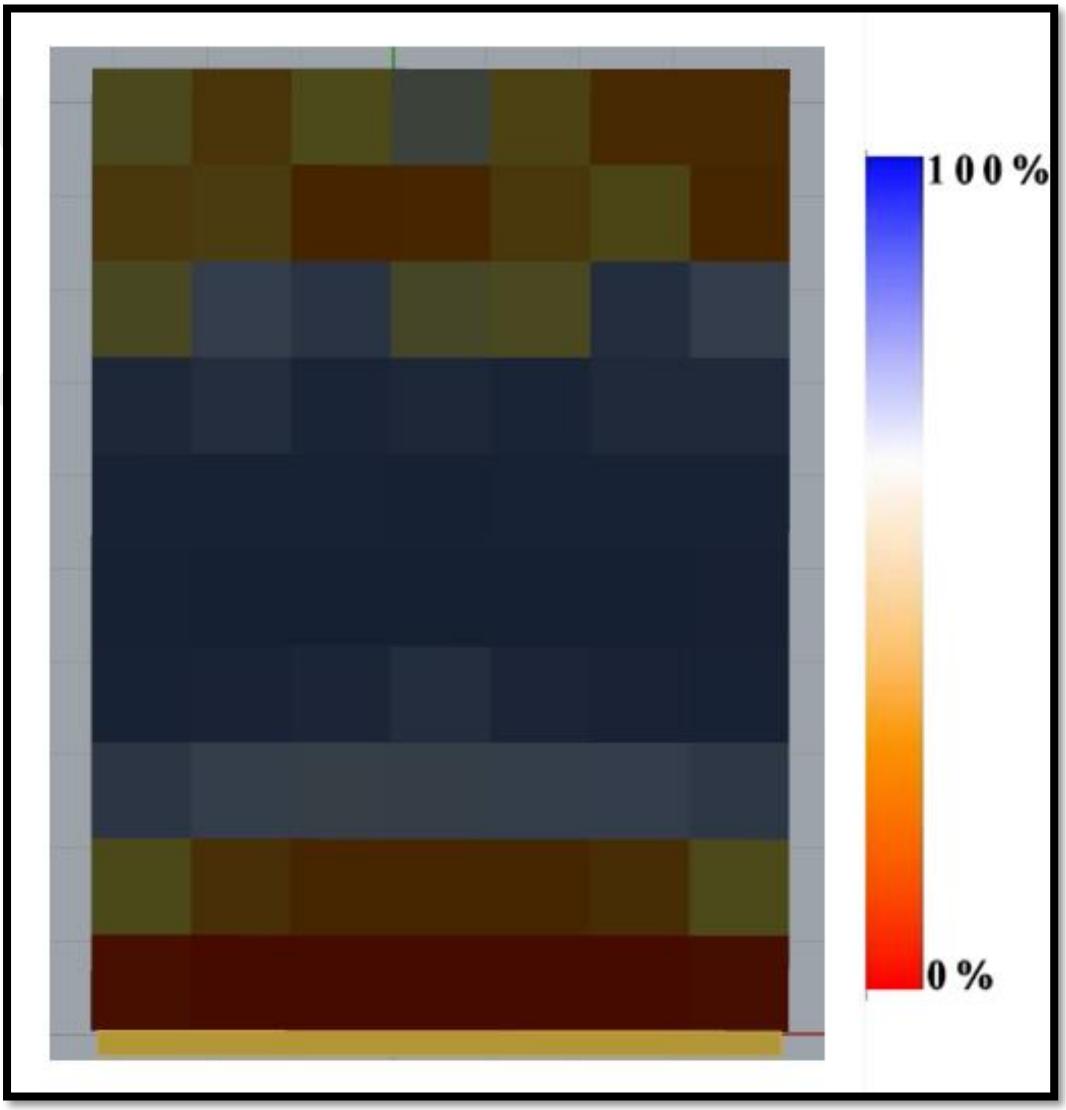

Figure 5.21. UDI in Solution 3 in NSGA-II for Overhang (Plan)

Solutions in Case Study 3	*Depth of Overhang*	*Rotation Angle*	*Yearly Total EnergyConsumption*	*UDI*
Solution 1	0.199 meter	-19°	6842.71 kWh/year	%68
Solution 2	0.298 meter	-18°	6666.02 kWh/year	%67
Solution 3	0.3 meter	-12°	6574.11 kWh/year	%62

Table 9. Solutions in Case Study 3

In case study 3, solution 1 in Figure 5.15 shows a solution which has an energy use of 6842.71 kWh/year and %68 UDI interior space of the classroom. While much more energy use is seen in heating and cooling energy consumptions according to graph, more daylight comes into interior space of the classroom. In this solution, the depth of overhang is 0.199 meter. Moreover, rotation angle of overhang is -19° since it is changing between -90° and 90° which is reasonable. Secondly, solution 2 in Figure 5.15 demonstrates a solution that consumes 6666.02 kWh/year total energy while it allows %67 UDI interior space of the classroom. That means overhang consumes less total energy than solution 1 while it allows almost same daylight comes into interior space of the classroom. The depth of overhang is 0.298 meter and rotation angle of overhang is -18°. Thirdly, in solution 3 in Figure 5.15 there is a total energy use of 6574.11 kWh/year and %62 UDI interior space of the classroom. That solution shows that while less energy is consumed rather than solution 1 and 2, less daylight comes into interior space of the classroom. The depth of overhang is 0.300 meter while rotation angle of overhang is -12°.

According to UDI and total energy consumption objectives, we can clearly observe that decision variables (dimensions) of overhang have an impact on the performance criterias which UDI and total energy consumption. However, based on our observation, it seems that the decision variable, which is depth of overhang is much more important for UDI and total energy consumption objectives since there is change in UDI and total energy consumption when depth of overhang changes. Furthermore, from the point of NSGA-II UDI values in Pareto Front are observed in between %62 and %67 which means there are not any solutions that do not allow any daylight comes into interior space of the chosen classroom. Moreover, solutions show that there is not a big change in UDI values.

5.4 Results of Case Study 4: Proposed Shading Device

In Case Study 4, proposed shading device was tested when each louver was integrated to south façade of the test room. The Pareto front graph of UDI and total energy consumption was created according to simulation based optimization for proposed shading device. The scatterplot of total energy consumption and UDI can be seen in Figure 5.22.

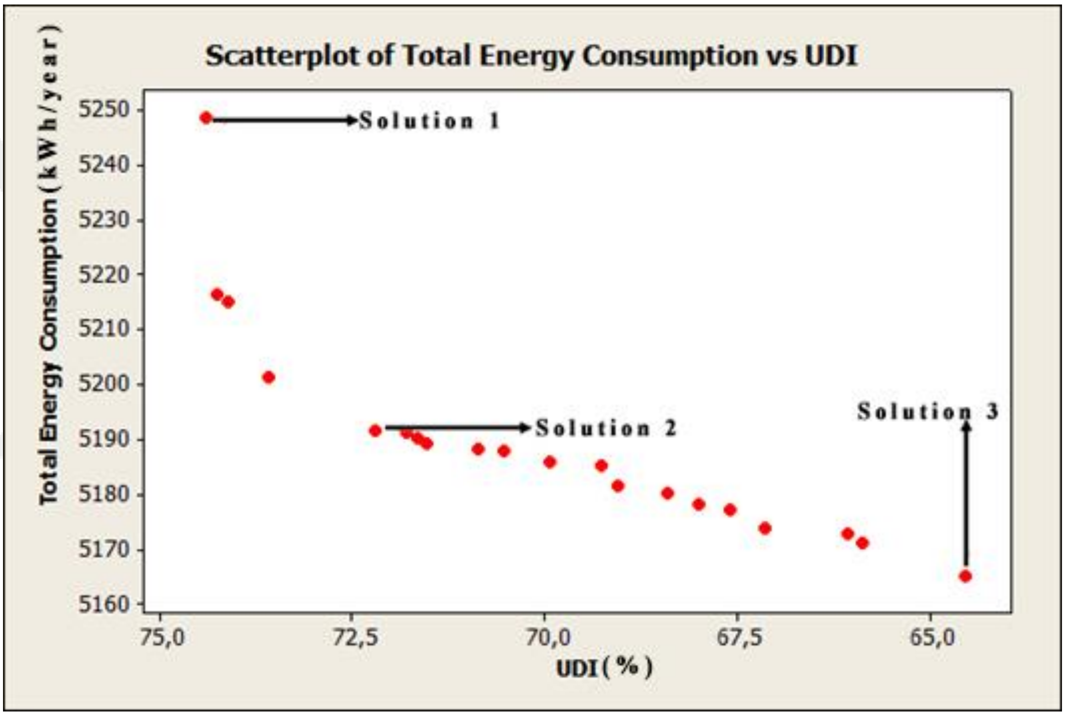

Figure 5.22. Pareto Front Rank of NSGA-II for Proposed Shading Device

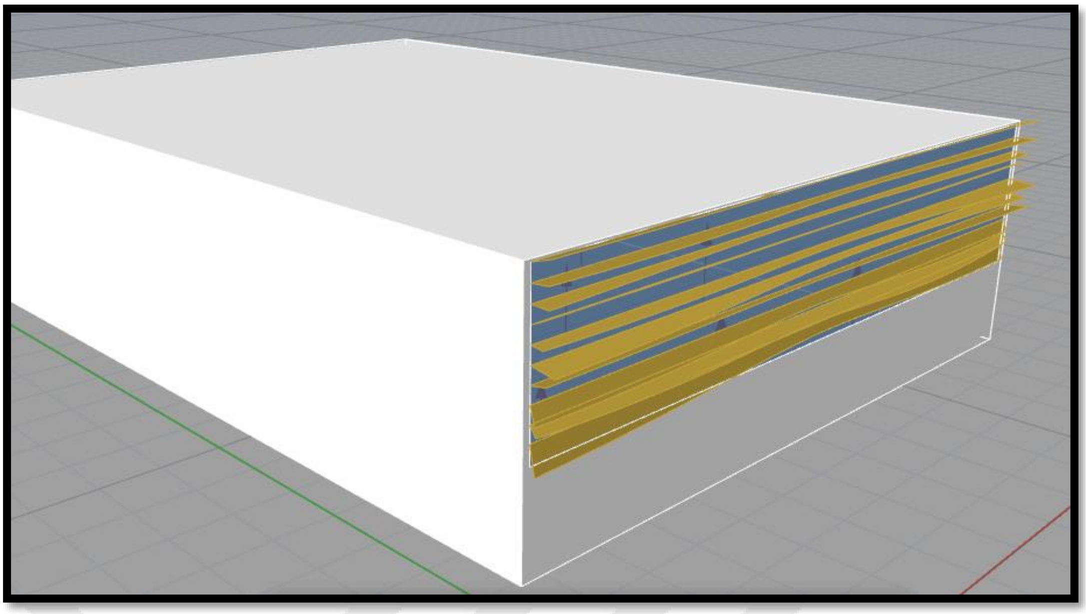

Figure 5.23. Solution 1 in NSGA-II for Proposed Shading Device (Perspective)

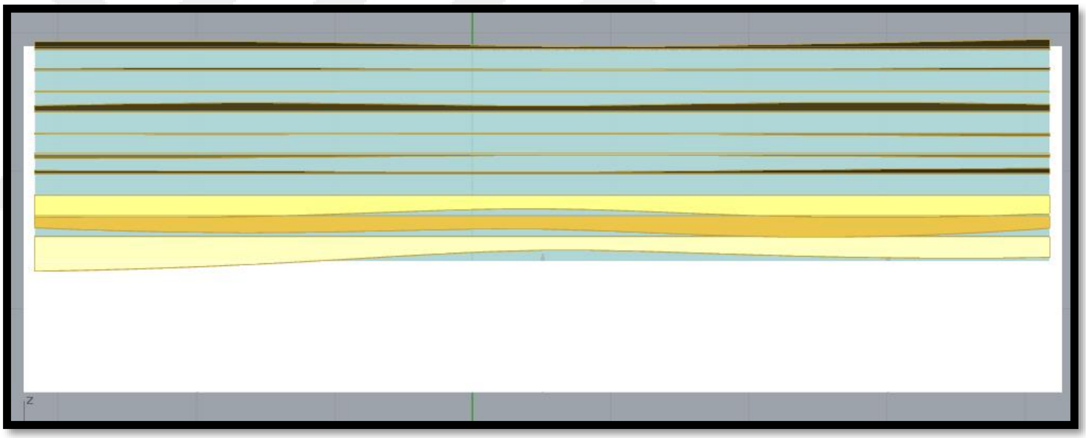

Figure 5.24. Solution 1 in NSGA-II for Proposed Shading Device (South Elevation)

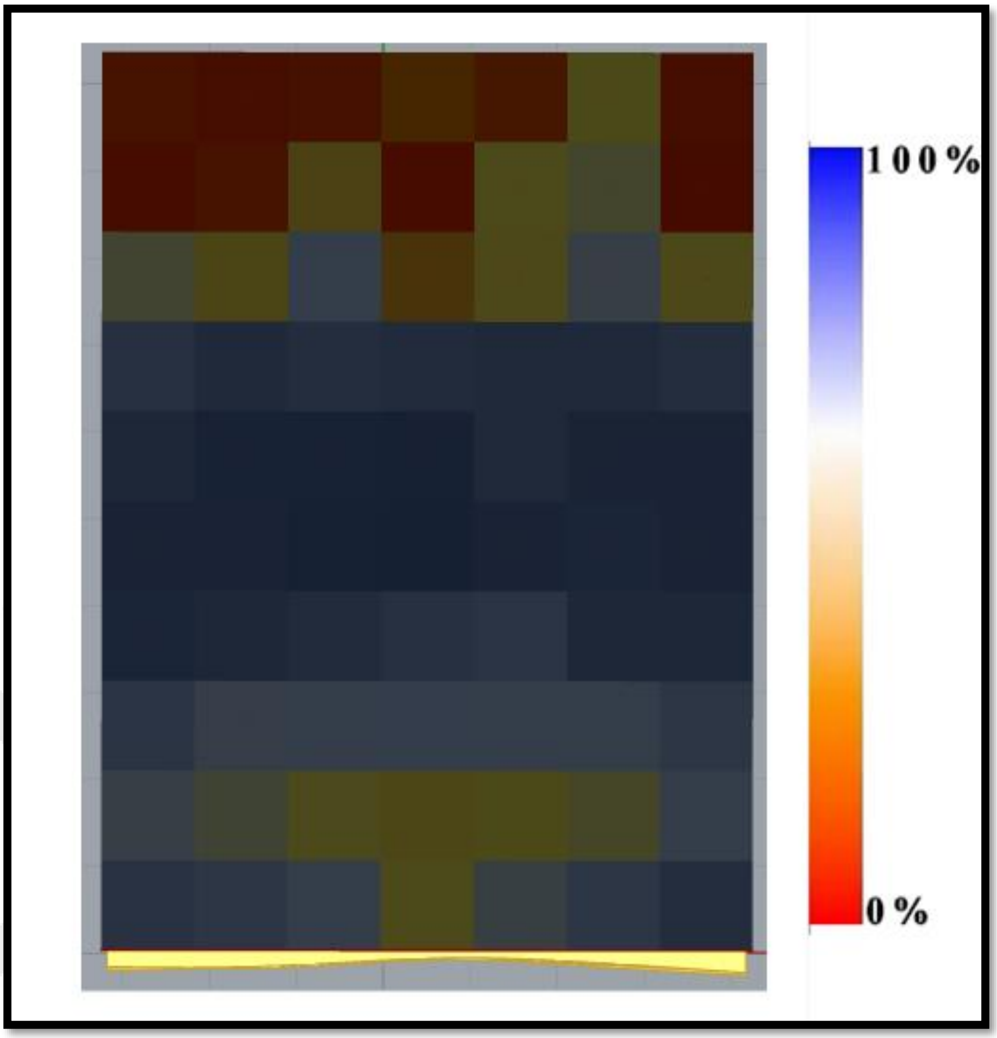

Figure 5.25. UDI in Solution 1 in NSGA-II for Proposed Shading Device (Plan)

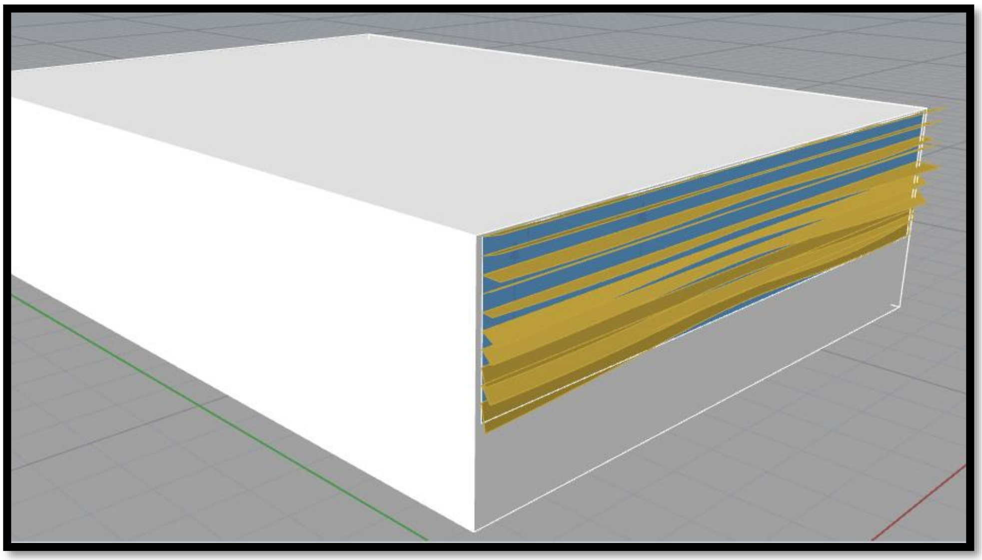

Figure 5.26. Solution 2 in NSGA-II for Proposed Shading Device (Perspective)

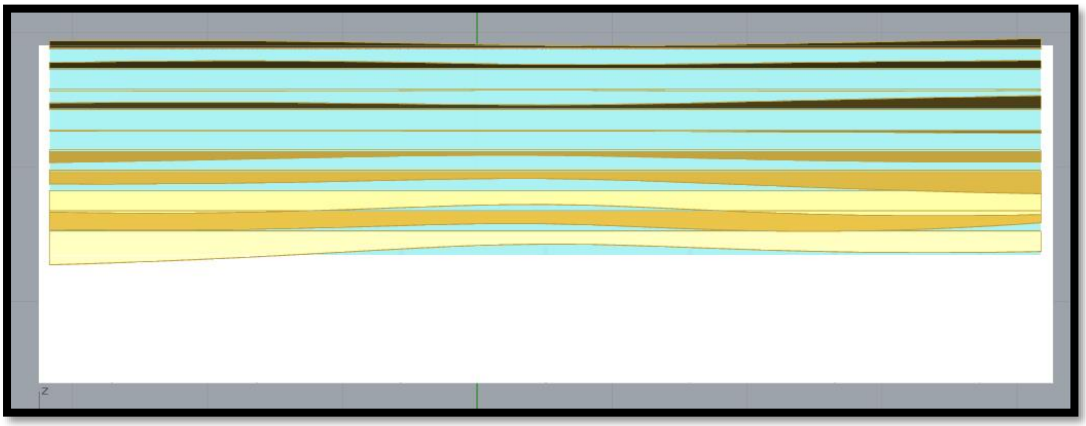

Figure 5.27. Solution 2 in NSGA-II for Proposed Shading Device (South Elevation)

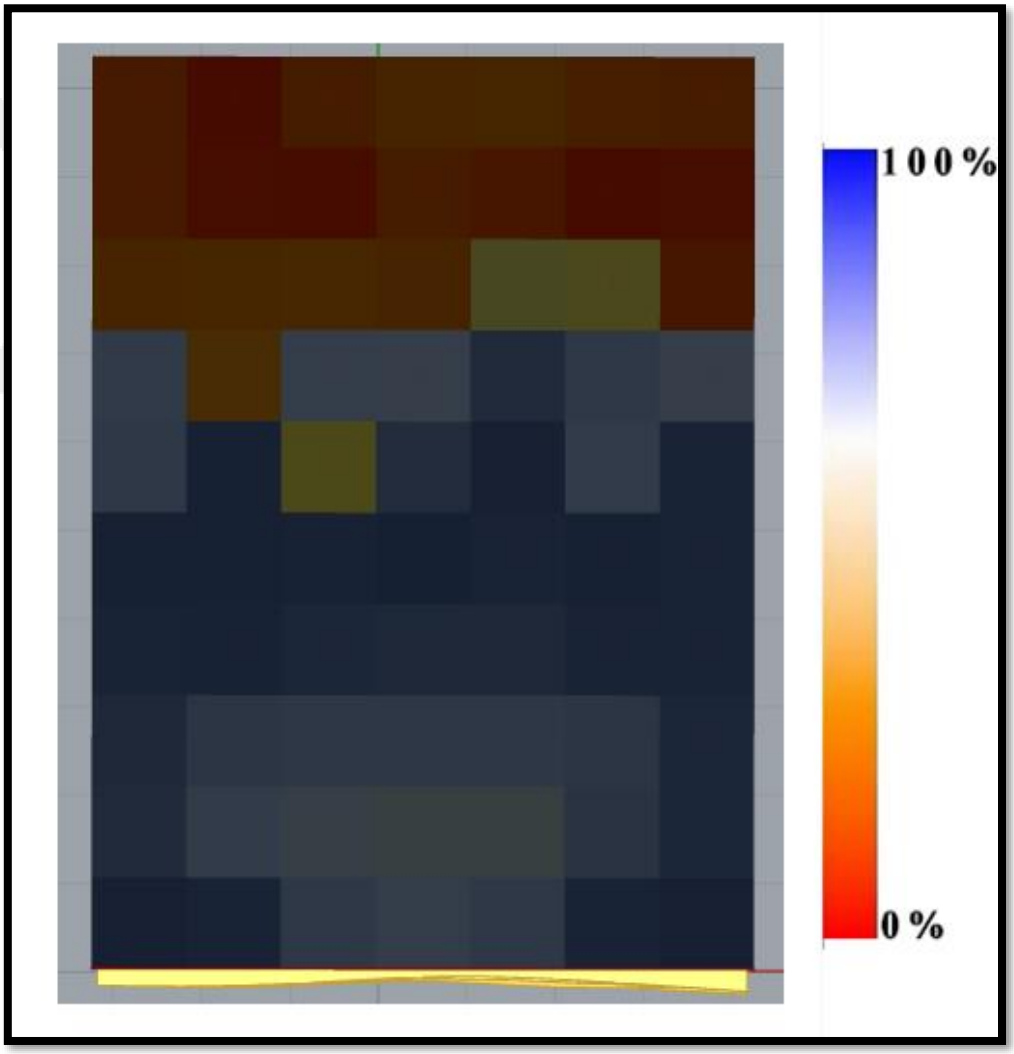

Figure 5.28. UDI in Solution 2 in NSGA-II for Proposed Shading Device (Plan)

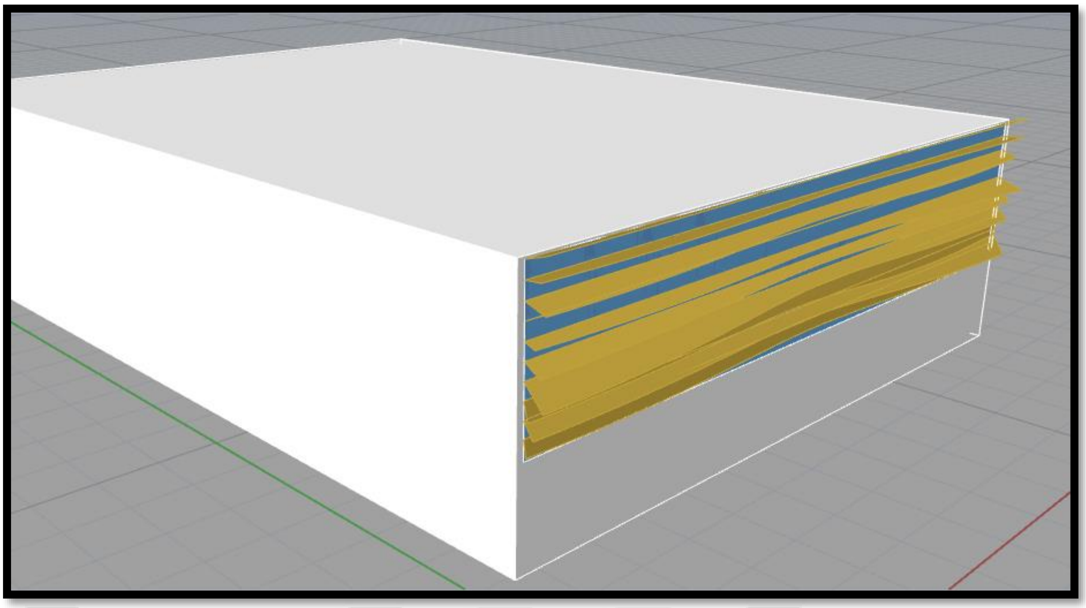

Figure 5.29. Solution 3 in NSGA-II for Proposed Shading Device (Perspective)

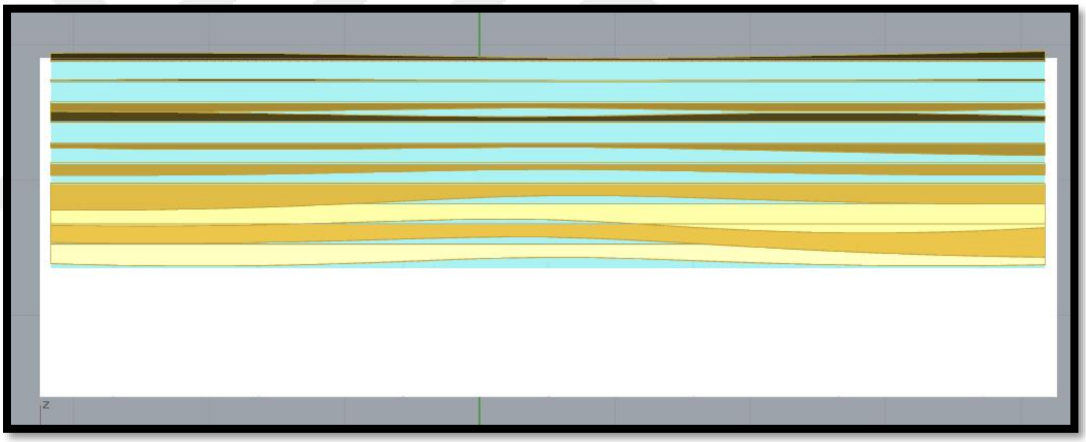

Figure 5.30. Solution 3 in NSGA-II for Proposed Shading Device (South Elevation)

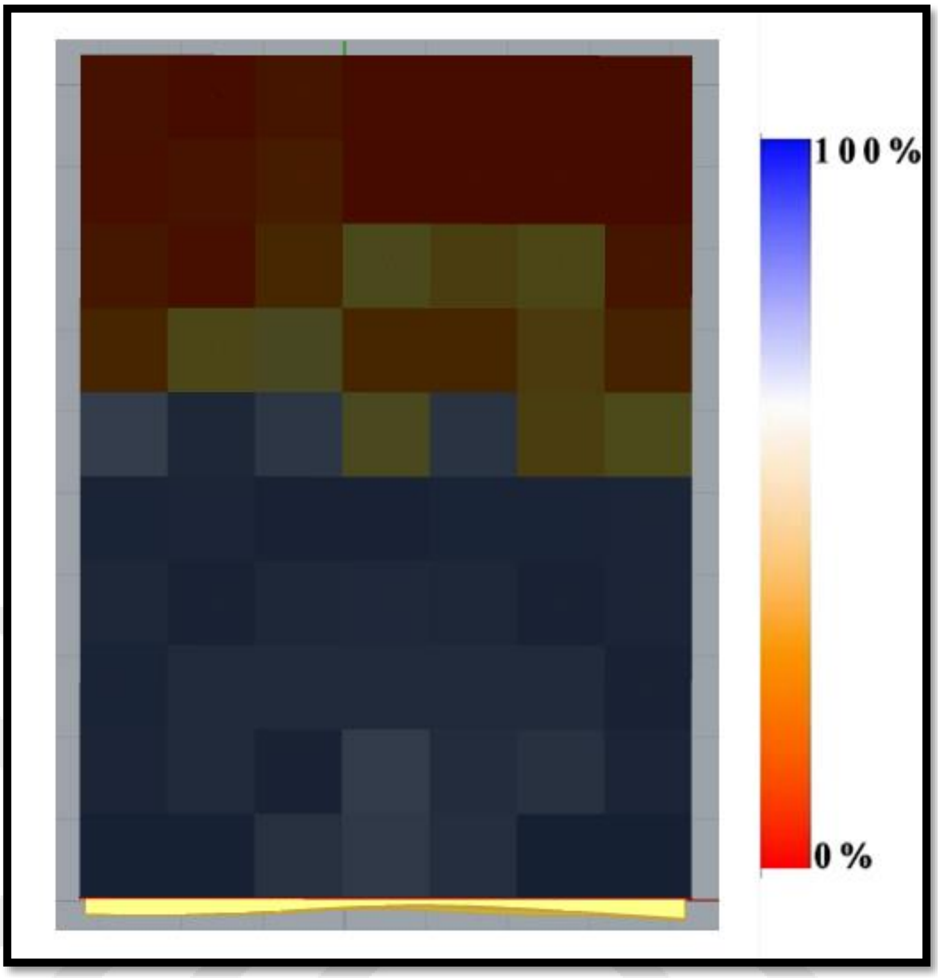

Figure 5.31. UDI in Solution 3 in NSGA-II for Proposed Shading Device (Plan)

Solutions in Case Study 4	***Yearly Total Energy Consumption***	***UDI***
Solution 1	5248.62 kWh/year	%74
Solution 2	5191.40 kWh/year	%72
Solution 3	5164.99 kWh/year	%64

Table 10. Solutions in Case Study 4

Solution 1 in Figure 5.22 represents a solution which has an energy use of 5248.62 kWh/year and %74 UDI interior space of the classroom. It means more daylight comes into interios space according to graph. While this is happening much more energy use is seen in heating and cooling energy consumptions. Secondly, solution 2 in Figure 5.22 demonstrates a solution that consumes 5191.40 kWh/year total energy while it allows %72 UDI interior space of the classroom. That means louvers close up more and they consume less total energy than solution 1 while it allows less daylight comes into interior space of the classroom. Thirdly, in solution 3 in Figure 5.22 there is a total energy use of 5164.99 kWh/year and %64 UDI interior space of the classroom. That solution shows that since louvers close up more than solution 2, and less daylight comes into interior space when it is compared to solution 1 and 2.

From the viewpoint of UDI and total energy consumption objectives, it can be clearly observed that decision variables (dimensions) of proposed louvers have an impact on the performance criterias which UDI and total energy consumption. However, based on our observation, it seems that the decision variable, which is rotation angle of each louver is much more important for UDI and total energy consumption objectives since there is a big change especially in UDI when rotation angle of each louver changes. Furthermore, from the point of NSGA-II, UDI values in Pareto Front are observed in between %65 and %75 which means there is no solution that does not allow any daylight comes into interior space of the chosen classroom as it is in case study 1. Average of UDI and total energy consumption values of all solutions is more than the average of UDI and total energy consumption values of all solutions in case study 1, 2 and 3.

5.5 Conclusion

In this chapter, results of four different scenarios which belong to horizontal louvers, vertical louvers, overhang and proposed shading device have been clearly discussed. According to graphs of four different case studies, average of UDI and total energy consumption values is highest in case study 4 which is proposed shading device. Thus, proposed shading device shows more energy efficient solutions when it is integrated to the south façade of the reference room which is in case study building. Moreover, since results of case study 1 which is horizontal louvers represented more energy efficient solutions than case study 2 and 3, which are vertical louvers and overhang, the design of case study 4: proposed shading device was considered as horizontal section. As a result of this, the solutions in case study 4: proposed shading device consumed less energy than others and captured more UDI inside of the reference room which is in case study building.

CHAPTER 6

CONCLUSION

This thesis provides an overview of the research developments concerning the use of shading devices integrated to buildings. Moreover, it presents a new shading design concept by comparing with traditional shading device types. First of all, in order to underline the importance of simulation modeling for different types of shading devices in buildings, a wide variety of existing studies done between the years 1996 and 2015 have been investigated. According to this deep investigation, it is found that many simulation tools have been developed since 1990s and they have been used in different scientific researches. Secondly, the turning point of this thesis is to find or to design proper shading element which has an optimal form in order to increase energy efficiency of the building, reduce running costs and reduce environmental effects. So, simulation modeling is easiest and fastest way to achieve these tasks. And also, using evolutionary algorithms to deal with complex tasks is one method that can be used to reach optimality.

6.1 Research Findings

1) In order to formulate the whole problem in a parametric computational environment, both energy and daylight model has been developed in Grasshopper's useful platform and this will lead researchers in the field of architectural design.

2) The most important parameters of both traditional shading devices and proposed shading device are width, rotation angle and density.

3) In order to find proper shading device design, Computational Intelligence Methods were used as one of the strongest way to cope with this kind of architectural problem.

4) Since the integration of the vertical louvers to the case study building consumed much more energy than the integration of horizontal louvers, the proposed shading device design resulted with horizontal section.

5) As a result of simulation based optimization of four different scenarios, total energy consumption range is lowest in case study 4: proposed shading device and UDI range is highest again in case study 4: proposed shading device.

8.2 Future Projections

1) In order to deal with more complex shading design problems, development in the shading strategies, materials used and comfort parameters inside the buildings should profoundly be taken into account.

2) The data collection for certain locations affected by the micro-climatic conditions should precisely be done for shading device design.

3) Regarding to energy consumption of buildings, integration of movable shading devices to buildings should be a priority for future designs.

4) Control mechanism of adaptive shading device types should be necessarily studied as a new future study.

5) The adaptive shading device will be developed regarding to Computational Intelligence Methods in Grasshopper Environment.

6) The adaptive shading device design will be tested with computational analysis tools.

7) In order to decrease both the cooling loads and the polluting effect of the building, the use of proper shading device type in hot, hot and dry, hot and humid or very hot climatic regions should be necessarily taken into account.

8) Other algorithms such as Differential Evolution, Harmony Search etc. can be used in this kind of shading device problem in the future.

9) As a continuation of this thesis, this project will turn into Scientific Research Project which is funded by Yasar University. It will include both design and production processes. Optimal design will be produced as a result of this project.

As a result, it can be concluded that together with the rise of popularity of net zero energy building issue, the usage of simulation tools will become widespread especially for the early stages of the shading device design process. Moreover, integration of Computational Intelligence Method tools is also quite necessary to solve this kind of complex architectural problems.

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APPENDIX

YEAR	AUTHOR(S)	PAPER NAME	STUDIED LOCATION	SIMULATION TYPE	SIMULATION TOOL	SHADING TYPE	GLAZING TYPE	CLIMATE TYPE	BUILDING TYPE	STUDY TYPE
1996	P.Pfrommer, K.J.Lomas, CHR. Kupke	Solar Radiation Transport Through Slat-Type Blinds:A New Model and Its Application for Thermal Simulation of Buildings	London	1)Detailed Blind Systems Calculations 2)Thermal Building Simulation	Radiance	Movable Venetian Blinds	Clear double glazing	Temperate oceanic	Commercial	Theoretical
1998	E.S.Lee, D.L. DiBartolomeo, S.E. Selkowitz	Thermal and Daylighting Performance of an Automated Venetian Blind and Lighting System in a Full-Scale Private Office	Oakland, California	1)Solar Energy performance 2)Daylight admission	1)DOE-2 for building energy simulation 2)Radiance	Movable Venetian Blinds	6 mm single-pane green tinted glass and electrochromic glazing	Mediterranean	Office	Experimental and Theoretical
2001	Christoph F. Reinhart, Oliver Walkenhorst	Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds	Germany	1)Daylight simulation 2)Indoor illuminance control	1)Radiance 2)Daysim	Movable External Venetian Blinds	Double glazing	Temperate and Marine	Office	Experimental and Theoretical
2001	Antonio Carbonari, Giancarlo Rossi, Piercarlo Romagnoni	Optimal Orientation and Automatic Control of External Shading Devices in Office Buildings	Italy (Rome, Venice, Trapani)	1)Thermal Balance 2)Lighting Comfort 3)Thermal Comfort	1)ENER_LUX 2)MIDAS 3)COMFORT	Automatically adjustable louvers and External fixed louvers 45° tilted	Double glazing of 0.004 m thickness with 0.006 m of air gap	Mediterranean	Office	Theoretical
2001	Gouri Datta	Effect of fixed horizontal louver shading devices on thermal perfomance of building by TRNSYS simulation	Italy (Rome, Milan, Palermo, Napoli)	Thermal performance	TRNSYS simulation	Fixed horizontal louver	Double glazing units having U-value 2.8 W m^{-2} K^{-1} g-value 0.755	1)Milan is humid subtropical 2)Palermo, Napoli and Rome are Mediterranean	Residential	Theoretical
2002	M. Bodart, A.De Herde	Global energy savings in offices buildings by the use of daylighting	Belgium	1)Daylight simulation 2)Thermal simulation	1)ADELINE (daylighting simulation tool) 2)TRNSYS (thermal simulation software)	NO Shading Device is used	9 different glazing types which visible transmittance varies from 0 to %81.	Maritime temperate	Office	Theoretical
2002	A. K. Athientis and A. Tzempelikos	A Methodology for Simulation of Daylight Room Illuminance Distribution and Light Dimming for a Room with a Controlled Shading Device	Montreal, Canada	1)Daylight simulation 2)Lighting energy consumption analysis	NO simulation programme is mentioned.	Motor-controlled Blinds	Double-glazed with a low-emissivity coating	Humid continental	Office	Experimental and Theoretical

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2002	Luisa Gama Caldas, Leslie K. Norford	A design optimization tool based on a genetic algorithm	Phoenix and Chicago	1)Thermal simulation 2)Lighting simulation	DOE2.1E for thermal and lighting simulation	NO Shading Device is used	Double pane with a layer of spectrally selective glass, with a shading coefficient of 0.34 and visual transmittance of 0.41	1)Phoenix, a cooling-dominated climate 2)Chicago, a heating-dominated climate	Office	Theoretical
2003	F. Gugliermetti, F. Bisegna	Visual and energy management of electrochromic windows in Mediterranean climate	Italy	1)Indoor illuminance control by energy saving 2)Environmental comfort	IENUS (Integrated ENergy Use Simulation)	NO Shading Device is used	Double glazed electrochromic windows	Mediterranean	Office	Theoretical
2003	Milan Janák	Whole Building Energy Simulation with Complex External Shading Devices	NO location is studied	Thermal comfort	1)ESP-r software 2)WIS programme	Fixed external shading louvre	NO glazing type is mentioned	NO climate data	Office	Theoretical
2003	Wong Nyuk Hien, Agustinus Djoko Istiadji	Effects of External Shading Devices on Daylighting and Natural Ventilation	Singapore	1)Daylight simulation 2)Natural ventilation	1)LIGHTSCAPE for daylighting 2)PHOENICS CFD for natural ventilation	Fixed External Shading Devices	NO glazing type is mentioned	Tropical rainforest	Residential	Theoretical
2004	Elisabeth Gratia, André De Herde	Natural cooling strategies efficiency in an office building with a double-skin façade	Belgium	1)Solar facade performance 2)Natural ventilation	TAS software-subtask A of the Task 27	NO Shading Device is used	Low-e double glazing: U= 1.8 W $m^{-2} K^{-1}$, direct solar transmission: 0.62, total solar transmission: 0.708	Maritime temperate	Office	Theoretical
2005	W.J. Stec, A.H.C. van Paassen, A. Maziarz	Modelling the double skin fac¸ade with plants	TUDelft, Netherlands	1)Temperature distribution 2)Energy consumption	Simulink (building simulation program integrated with MATLAB)	Deciduous Plants	Double skin facade	Laboratory conditions	Office	Experimental and Theoretical
2006	F. Gugliermetti, F. Bisegna	Daylighting with external shading devices: design and simulation algorithms	Italy	1)Energy Simulation 2)Interior Visual Comfort	IENUS (Integrated ENergy Use Simulation)	Fixed Overhang and Vertical Fin	A standard double-strength sheet glass DSA with 0.86 transmittance, 0.08 reflectance and 0.06 absorptance	Mediterranean	Office	Experimental and Theoretical

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2006	Mateja Trobec Lah, Borut Zupancˇic, Jozˇe Peternelj, Alesˇ Krainer	Daylight illuminance control with fuzzy logic	UL, Ljubljana	Inside illuminance control	IDR BLOK (Control algorithm with included fuzzy logic was designed in program package)	PVC Roller Blind	Double-glazing composed of two layers of standard clear glass and air fill	Oceanic	Any Building	Experimental and Theoretical
2006	Tilmann E. Kuhn	Solar control: Comparison of two new systems with the state of the art on the basis of a new general evaluation method for facades with venetian blinds or other solar control systems	Germany	Solar gain	NO simulation programme is used.	Movable Venetian Blinds	Heat-mirror glazing with g_{gzg}= 0.60	Temperate and Marine	NO Building	Experimental
2006	A. Tsangrassoulisa, V. Bourdakisb, V. Gerosc, M. Santamouris	A genetic algorithm solution to the design of slat-type shading system	NO location is studied.	Lighting simulation	Radiance	Movable Slat Type Shading System	NO glazing type is mentioned	Mediterranean	Any Building	Theoretical
2006	E.S. Lee , S.E. Selkowitz	The New York Times Headquarters daylighting mockup: Monitored performance of the daylighting control system	New York	1)Daylight performance 2)Lighting performance	NO simulation programme is used.	Automated Roller Shades	Clear glass window with transmittance Tv = 0.75	Humid continental	Office	Experimental
2007	E.S. Lee, A. Tavil	Energy and visual comfort performance of electrochromic windows with overhangs	Chicago, Houston	1)Energy efficiency 2)Visual comfort	DOE-2 simulation programme	Fixed Overhang	Electrochromic windows	Chicago is humid continental, Houston is humid subtropical	Office	Theoretical
2007	Geoffrey van Moeseke , Isabelle Bruye` re, Andre´ De Herde	Impact of control rules on the efficiency of shading devices and free cooling for office buildings	Belgium	1)Radiation level on the facade 2)Inside temperature 3)Natural ventilation	TRNSYS 16	Fixed External Mobile Screen	Clear double glass is 0.11.	Maritime temperate	Office	Theoretical
2007	Athanassios Tzempelikos, Andreas K. Athienitis	The impact of shading design and control on building cooling and lighting demand	Montreal, Canada	1)Thermal analysis 2)Daylighting analysis	Energy Plus	Movable Exterior Roller Shade	Double glazing	Humid continental	Office	Theoretical

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2007	Elisabeth Gratia, Andre´ De Herde	The most efficient position of shading devices in a double-skin facade	Belgium	Thermal Analysis	TAS software- subtask A of the Task 27	Roller Blind and Orientable Venetian Blinds	Single glazing	Maritime temperate	Office	Theoretical
2007	Athanassios Tzempelikos, Andreas K. Athienitis, Panagiota Karava	Simulation of facade and envelope design options for a new institutional building	Montreal, Canada	1)Daylighting simulation 2)Thermal simulation	NO simulation programme is mentioned.	Roller shades, Movable Venetian blinds, Combination of venetian blinds and roller shades	1)Double-glazed windows with low-emissivity coatings 2)Heat mirror glazing 3)High performance glazing	Humid continental	School/University	Theoretical
2007	Peter G. Loutzenhiser, Gregory M. Maxwell, Heinrich Manz	An empirical validation of the daylighting algorithms and associated interactions in building energy simulation programs using various shading devices and windows	Ankeny, Iowa USA	1)Building energy simulation 2)Daylight illuminance	1)EnergyPlus 2)DOE-2.1E	Motorized Mini-Blinds and Fixed Shading Screen, fixed mini-blinds and fixed vertical fins	6mm clear glass	Humid continental	School/University	Experimental and Theoretical
2008	Hans Simmler, Bruno Binder	Experimental and numerical determination of the total solar energy transmittance of glazing with venetian blind shading	Zurich, Switzerland	Solar heat gain	NO simulation programme is used.	Movable Venetian Blinds	Double-pane insulating glazing unit (IGU)	Oceanic	Any Building	Experimental
2008	C. Aghemo, A. Pellegrino , V.R.M. LoVerso	The approach to daylighting by scale models and sun and sky simulators : A case study for different shading systems	Daylighting Laboratory of the Politecnico di Torino	Daylighting simulation	NO simulation programme is used.	Fixed overhangs, external and internal+external light-shelves, horizontal fins	Clear 6 mm glass	Laboratory conditions	School/University	Experimental
2008	Eduardo L. Kruger, Adriano Lucio Dorigo	Daylighting analysis in a public school in Curitiba, Brazil	Curitiba, Brazil	1)Daylighting simulation 2)Thermal simulation	1)Radiance 2)Ecotect	Fixed External shading louvre	NO glazing type is mentioned	Maritime temperate	School/University	Theoretical
2008	Ming-Chin Ho, Che-Ming Chiang, Po-Cheng Chou, Kuei-Feng Chang, Chia-Yen Lee	Optimal sun-shading design for enhanced daylight illumination of subtropical classrooms	Taiwan	Lighting analysis	LIGHTSCAPE software	Fixed single shading, twin shading, double-layered shading, and double-layered shading with single vertical element	NO glazing type is mentioned	Humid subtropical	School/University	Experimental and Theoretical

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2008	Xiao-li Xu, Zhao Yang	Natural ventilation in the double skin facade with venetian blind	Beijing	CFD analysis	Energy Plus	Venetian Blinds	Glass 1 (d = 6 mm) coated with low-e film, air gap1 (d = 120 mm), metallized blind (d = 1 mm), air gap 2 (d = 60 mm), glass 2 (d = 4 mm), mixture that composed of 10% air and 90% argon (d = 18), glass 3 (d = 4 mm)	Monsoon-influenced humid continental climate	Test Room	Experimental and Theoretical
2008	Athanassios Tzempelikos	The impact of venetian blind geometry and tilt angle on view, direct light transmission and interior illuminance	NO location is studied.	1)View 2)Direct light transmission 3)Interior illuminance	NO simulation programme is used.	Venetian Blinds	NO glazing type is mentioned	NO climate data	Any Building	Theoretical
2009	G. Baldinelli	Double skin façades for warm climate regions: Analysis of a solution with an integrated movable shading system	Italy	1)CFD analysis 2)Summer and winter energy perfomance	NO simulation programme is mentioned.	Movable External Horizontal Shading Device	Laminated glass	Mediterranean	Office	Experimental and Theoretical
2009	Svetlana Olbina, Yvan Beliveau	Developing a transparent shading device as a daylighting system	Roanoke, Virginia, US	Daylight performance	Autodesk VIZ 4 software	Movable Glass Louvers	Transparent window	Moderate	Office	Theoretical
2009	Marco Manzan, Francesco Pinto	Genetic Optimization of External Shading Devices	NO location is mentioned.	1)Daylight Simulation 2)Energy Simulation	1)Energy code ESP-r 2)Radiance	Fixed flat panel positioned parallel to the window	1)Standart double glass 2)High performance glazing system	NO climate data	Office	Theoretical
2009	Jeong Tai Kim, Gon Kim	Advanced external shading device to maximize visual and view performance	Korea	1)Illumination 2)Building Energy Performance 3)View Performance	1)Virtual Environment (V.E.) worked with REVIT for energy analysis 2)Radiance	Fixed external shading device	Pair glass with a transmittance value, 78%	Hot summer continental	Residential	Experimental and Theoretical
2009	Deuk-Woo Kim, Cheol-Soo Park	Manual vs. Optimal Control of Exterior and Interior Blind Systems	Seoul, South Korea	Building simulation	1)Energy Plus 2)MATLAB	Movable interior and exterior blind systems	Double glazing (6 mm clear+12 mm air cavity+6 mm low-e)	Hot summer continental	Office	Theoretical

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2010	Kenneth Ip, Marta Lam, Andrew Miller	Shading performance of a vertical deciduous climbing plant canopy	South Coast of UK	1)Thermal performance 2)Solar radiation and shading performance	NO simulation programme is used.	Vertical deciduous climbing plant canopy	Single-glazed windows	Oceanic	Office	Experimental
2010	Hussain H. Alzoubi, Amneh H. Al-Zoubi	Assessment of building façade performance in terms of daylighting and the associated energy consumption in architectural spaces: Vertical and horizontal shading devices for southern exposure facades	Amman	Illumınance control	LIGHTSCAPE software	Fixed horizontal and vertical louvers	0.90 transmittance of window (2mX1.5 m)	Cold semi-arid	Office	Theoretical
2010	Ana I. Palmero-Marrero, Armando C. Oliveira	Effect of louver shading devices on building energy requirements	Mexico (Mexico), Cairo (Egypt), Lisbon (Portugal), Madrid (Spain) and London (UK)	1)Solar gain 2)Indoor air temperature 3)Building energy demand	1)TRNSYS software 2)EES software for the geometric study of the shading system	Fixed horizontal layout in a south façade and fixed vertical layout in east or west façades	Double glazing (with clear glass) with a U-value equal to 3.21 W m^{-2} $K^{-1}$and g-value equal to 0.72 (15% frame)	Lisbon and Madrid (Mediterranean), London(Temperate oceanic), Mexico(subtropical),Cairo(hot desert).	Any Building	Theoretical
2010	Hong Soo Lim, Gon Kim	Predicted Performance of Shading Devices for Healthy Visual Environment	Seoul, Korea	Daylight simulation	Radiance	Movable Venetian Blinds and Fixed Overhang	%78.2 glass transmittance	Hot summer continental	Residential	Theoretical
2010	Fawwaz Hammad, Bassam Abu-Hijleh	The energy savings potential of using dynamic external louvers in an office building	Abu Dhabi	Energy consumption	IES-VE (Integrated Environmental Solutions Virtual Environment software)	Fixed horizontal and vertical louvers	NO glazing type is mentioned	Hot desert	Office	Theoretical
2010	M. Bessoudo, A. Tzempelikos, A.K. Athienitis, R. Zmeureanu	Indoor thermal environmental conditions near glazed facades with shading devices e Part I: Experiments and building thermal model	Montreal, Canada	Thermal comfort	Energy Plus	Roller Shade and Movable Venetian Blinds	Double-glazed, with a lowe coating	Humid continental	Office	Experimental and Theoretical
2010	Paul Littlefair, Jose Ortiz, Claire Das Bhaumik	A simulation of solar shading control on UK office energy use	London, Manchester, and Edinburgh, UK	Thermal comfort	DOE-2	Movable Venetian Blinds and roller blinds	Low-emissivity double-glazed units	1)London is temprerate oceanic 2)Manchester and Edinburgh are temperate maritime	Office	Theoretical

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2010	A. Tzempelikos, M. Bessoudo, A.K. Athienitis, R. Zmeureanu	Indoor thermal environmental conditions near glazed facades with shading devices e Part II: Thermal comfort simulation and impact of glazing and shading properties	Montreal, Canada	Thermal comfort	Energy Plus	Roller Shade	1)Double-glazing, uncoated 2)Double-glazing with low-e coating (3 ¼ 0.1) 3)Triple glazing with low-e coating (3 ¼ 0.05)	Humid continental	Office	Theoretical
2011	Martin Vraa Nielsen, Svend Svendsen, Lotte Bjerregaard Jensen	Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight	Denmark	1)Daylighting simulation 2)Thermal simulation	iDbuild (BuildingCalc and LightCalc)	Dynamic solar shading and fixed solar shading	1)Heat transfer coefficient of glazing (U-value) 2)Light transmittance of glazing 3)Total solar energy transmittance of glazing	Temperate	Office	Theoretical
2011	Ahmed A. Y Freewan	Improving thermal performance of offices in JUST using fixed shading devices	Jordan	1)Thermal comfort 2)Inside temperature	NO simulation programme is used.	Fixed vertical fins, diagonal fins and egg crate	NO glazing type is mentioned	Subtropical	Office	Experimental
2011	Azadeh Omidfar	Design Optimization of a Contemporary High Performance Shading Screen-Integration of Form and Simulation Tools	Boston	1)Daylight Simulation 2)Energy Simulation	1)Design Builder 2)Energy Plus	Fixed Shading Screen	100 percent glazed south façade	Continental	Office	Theoretical
2011	Pasinee Sunakorn, Chanikarn Yimprayoon	Thermal performance of biofacade with natural ventilation in the tropical climate	Thailand	Thermal performance	NO simulation program is used.	Deciduous Plants	NO glazing type is mentioned	Tropical	Residential	Experimental
2011	Nedhal A. Al-Tamimia, Sharifah Fairuz Syed Fadzil	The potential of shading devices for temperature reduction in high-rise residential buildings in the tropics	Malaysia	Thermal performance	IES-VE (ModelIT, SunCast, and Apache)	Fixed Vertical, Horizontal and Egg Crate	NO glazing type is mentioned	Equatorial	Residential	Theoretical
2011	Sharifah Fairuz Syed Fadzil, S. J. Sia	Recommendations for Horizontal Shading Depths for Vertical Building Facades in the Tropic Region with	Penang, Malaysia	Design of horizontal shading depths	SUNTOOL	Fixed Horizontal Shading Device	NO glazing type is mentioned	Tropical	Any Building	Theoretical

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2011	Athanassios Tzempelikos	A Review of Optical Properties of Shading Devices	NO location is studied	Optical properties of shading devices	1)WINDOW software 2)TRNSYS simulation 3)ESP-r software 4)DOE-2	Movable venetian blinds, roller shades/screens and movable draperies	NO glazing type is mentioned	NO climate data	Any Building	Theoretical
2012	A. Carbonari, R. Fioretti, B. Naticchi, P. Principi	Experimental estimation of the solar properties of a switchable liquid shading system for glazed facades	Ancona, Italy	Solar transmittance properties are analyzed	NO simulation program is used.	Switchable liquid shading	Reference glass (6-12-6 low-e) 1.6 W m^{-2} K^{-1} Shielded triple glass (6-1.5-6-12-6) 2.4 Wm^{-2} K^{-1} Triple glass (6-1.5-6-12-6) without liquid 2.8 W m^{-2} K^{-1}	Humid subtropical	Any Building	Experimental
2012	Gon Kim, Hong Soo Lim, Tae Sub Lim, Laura Schaefer, Jeong Tai Kim	Comparative advantage of an exterior shading device in thermal performance for residential buildings	Seoul, South Korea	Thermal performance	IES-VE (ModelIT, SunCast, and Apache)	Movable Venetian Blinds and adjustable slats, Fixed overhang and light shelf	(6 mm + 6 mm)×2 layers Total shading coefficient Visible light transmittance	Hot summer continental	Residential	Theoretical
2012	Ahmed Abd El-Monteleb Mohammed Ali Ahmed	Using simulation for studying the influence of vertical shading devices on the thermal performance of residential buildings (Case study: New Assiut City)	Egypt:New Assiut City	Thermal performance	TAS programme	Fixed Vertical Louvers	NO glazing type is mentioned	Hot desert	Residential	Theoretical
2012	David Appelfelda, Andrew McNeil, Svend Svendsen	An hourly based performance comparison of an integrated micro-structural perforated shading screen with standard shading systems	Copenhagen, Denmark	1)Energy performance 2)Daylight simulation	Radiance	Movable Venetian Blind and Roller Shade	Clear glazing	Oceanic	Office	Experimental and Theoretical
2012	Yaik-Wah Lim, Mohd Zin Kandar, Mohd Hamdan Ahmad, Dilshan Remaz Ossen, Aminatuzuhariah Megat Abdullah	Building façade design for daylighting quality in typical government office building	Johor Bahru, Maleysia	1)Daylight and glare analysis 2)Visual comfort	Radiance	Fixed external overhang with vertical screen and fixed vertical blind	%37 transmittance of tinted glazing type	Tropical rainforest	Office	Experimental and Theoretical
2012	M. Mandalaki, K. Zervas, T. Tsoutsos, A. Vazakas	Assessment of fixed shading devices with integrated PV for efficient energy use	Athens and Crete	1)Thermal comfort 2)Electricity production 3)Daylight levels	1)Energy Plus v3.1. 2)Autodesk Ecotect v5.60. 3)Radiance v1.02	Fixed Horizontal Canopy types, fixed horizontal louvers types, fixed vertical louvers, fixed brise soleil, fixed	Double glazed aluminum frame window with thickness 0.006 + 0.03 + 0.006 = 0.042 m (glass, void, glass) and visible	Mediterranean	Office	Experimental and Theoretical

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2012	Gonçalo Castro Henriques, José Pinto Duarte, Vitor Leal	Strategies to control daylight in a responsive skylight system	Porto, Portugal	Daylight simulation	Radiance	Skylight system	Skylight panels (pavillion dome)	Mediterranean	Any Building	Theoretical
2012	Niccolò Aste, Junia Compostella, Manlio Mazzon	Comparative energy and economic performance analysis of an electrochromic window and automated external venetian blind	Milan, Italy	1)Energyperformance analysis 2)Economic performance analysis	EnergyPlus 7.0	External Venetian Blinds	Electrochromic glazing coupled with a clear float glass and an argon filled gap, low-emissive glass coupled with a clear float glass and an argon filled gap, and generic double glazing with argon filled gap	Humid subtropical	Office	Theoretical
2012	Zhen Zeng, Xiaofeng Li, Cheng Li, Yingxin Zhu	Modeling ventilation in naturally ventilated double-skin façade with a venetian blind	Tsinghua University, Beijing, China	CFD simulations	NO simulation program is used.	Venetian Blinds	Single and double glazing glass	Monsoon-influenced humid continental climate	Test Room	Experimental
2012	Seokyoun Kang, Taeyon Hwang, Jeong Tai Kim	Theoretical analysis of the blinds integrated photovoltaic modules	Seoul, Korea	NO simulation is done.	NO simulation program is used.	Venetian Blinds	5CL glass (clear glass with 5 mm thickness)	Hot summer continental	Field Test Model	Experimental
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 residential desert buildings	Jeddah, Saudi Arabia	1)Daylight availability 2)Visual Comfort 3)Solar Energy Transmittance	1)DIVA for Rhino	Fixed Solar Screen	Fixed perforated solar screen	Arid	Residential	Theoretical
2012	Francesco Frontini, Tilmann E. Kuhn	The influence of various internal blinds on thermal comfort: A new method for calculating the mean radiant temperature in office spaces	Paris and Nimes, France	Building simulation	ESP-r simulation programme	Movable various internal blinds	1)Single glazing, 2)Double glazing, 3)Low-emissivity glazing with coating on position	Paris (Oceanic) , Nimes(Mediterranean)	Office	Theoretical

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2013	Somsak Chaiyapinunt, Nopparat Khamporn	Shortwave thermal performance for a glass window with a curved venetian blind	Chulalongkorn University, Bangkok, Thailand	Thermal performance	NO simulation program is used.	Curved venetian blind	6 mm clear glass	Tropical monsoon	Test Room	Experimental and Theoretical
2013	Ahmad Ridzwan Othman, Aliff Aiman Mohd Khalid	Comparative Performance of Internal Venetian Blind and Roller Blind with Respects to Indoor Illumination Levels	Jalan PJU, Kota Damansara, Malaysia	Indoor illumination level	NO simulation program is used.	Venetian Blind and Roller Blind	NO glazing type is mentioned	Tropical	Office	Experimental
2013	Leyla Sanati, Michael Utzinger	The effect of window shading design on occupant use of blinds and electric lighting	University of Wisconsin-Milwaukee, U.S	Lighting energy	NO simulation programme is mentioned.	Venetian Blinds and lightshelves	Double-glazed clear glass	Humid continental	School/University	Experimental and Theoretical
2013	Abdelsalam Aldawoud	Conventional fixed shading devices in comparison to an electrochromic glazing system in hot, dry climate	Phoenix, Arizona	Solar heat gain	Design Builder	Fixed overhangs and side fins	1)Double glazing 2)Electrochromic glazing	Hot and dry climate	Office	Theoretical
2013	Omair Awadh, Prof. Bassam Abuhijleh	The Impact of External Shading and Windows' Glazing and Frame on Thermal Performance of Residential House in Abu-Dhabi	Abu Dhabi	1)Solar heat gain 2)Cooling loads 3)Energy consumption	IES VE2012 (energy analysis programme)	Fixed horizontal and vertical shading devices	Double and triple glazing	Hot desert	Residential	Theoretical
2013	Laura Bellia, Francesco De Falco, Francesco Minichiello	Effects of solar shading devices on energy requirements of standalone office buildings for Italian climates	Milan, Rome, Palermo	Energy simulation	Energy Plus	Fixed external horizontal louver and fixed overhang	$U_{glazing}$ = 2.7 W m^{-2} K^{-1}	1)Palermo and Rome are Mediterranean 2)Milan is humid subtropical	Office	Theoretical
2013	Yu-Sin Kim, Ji-Sun Lim, Seong-Kwan Hong, Joon-Bum Kwun, An-Seop Choi, Yong-Shik Kim	Luminous Characteristics of Shading Materials for Office Buildings: Perforated Panels vs. Fabric Blinds	NO location is mentioned.	Interior Daylight Quality	NO simulation program is used.	Movable Perforated Panels and Movable Fabric Blinds	NO glazing type is mentioned	Laboratory conditions	Office	Experimental

YEAR	AUTHOR(S)	PAPER NAME	STUDIED LOCATION	SIMULATION TYPE	SIMULATION TOOL	SHADING TYPE	GLAZING TYPE	CLIMATE TYPE	BUILDING TYPE	STUDY TYPE
2013	Mahmoud Gadelhak	Integrating Computational and Building Performance Simulation Techniques for Optimized Facade Designs	Cairo, Egypt	1)Optimizing the annual daylighting performance 2)Climate-based simulation	DIVA	Fixed Light shelf and fixed solar screen	6 mm double glazed window	Hot desert	Office	Theoretical
2013	Cheng-Li Cheng, Ling-Mei Liao, Chia-Peng Chou	A study of summarized correlation with shading performance for horizontal shading devices in Taiwan	Taiwan (Hengchuen (22 N), Tainan (23 N), Taichung (24 N), and Taipei (25 N)).	1)Shading performance 2)Solar radiation	Sun-Shade programme	Fixed horizontal shading device	NO glazing type is mentioned	Hengchuen(tropical monsoon), Tainan, Taipei, and Taichung(humid subtropical)	Any Building	Theoretical
2013	Ahmed AbdelMonteleb Mohammed Ali	Using simulation for studying the influence of horizontal shading device protrusion on the thermal performance of spaces in residential buildings	Egypt:New Assiut City	Thermal performance	TAS programme	Fixed Horizontal Shade	NO glazing type is mentioned	Hot desert	Residential	Theoretical
2013	Athanasios Tzempelikos, Hui Shen	Comparative control strategies for roller shades with respect to daylighting and energy performance	Philadelphia	1)Lighting simulation 2)Thermal simulation	Energy Plus	Movable Roller Shade	Double-clear glazing types	Humid subtropical	Office	Theoretical
2014	Jian Yao	An investigation into the impact of movable solar shades on energy, indoor thermal and visual comfort improvements	Ningbo city of China	1)Daylight illuminance 2)Indoor thermal comfort	Energy Plus	Movable solar shade	3 mm single-pane clear glazing	Humid subtropical	Residential	Experimental and Theoretical
2014	FanWang, Kittitach Pichatwatana, Sue Roaf, Lihuan Zhao, Zhichao Zhu, Jingyan Li	Developing a weather responsive internal shading system for atrium spaces of a commercial building in tropical climates	Guangzhou, China	1)Thermal performance 2)Cost analysis 3)Natural light provision	NO simulation program is used.		Clear transparent glazing roof	Humid subtropical	Commercial	Experimental
2014	Anna Atzeri, Francesca Cappelletti, Andrea Gasparella	Internal versus external shading devices performance in office buildings	Rome, Italy	1)Energy simulation 2)Daylighting simulation	Energy Plus	Movable Roller shades	1)Double glazing 2)Triple glazing	Mediterranean	Office	Theoretical

YEAR	AUTHOR(S)	PAPER NAME	STUDIED LOCATION	SIMULATION TYPE	SIMULATION TOOL	SHADING TYPE	GLAZING TYPE	CLIMATE TYPE	BUILDING TYPE	STUDY TYPE
2014	Bernt Meerbeek, Marije te Kulve, Tommaso Gritti, Mariëlle Aarts, Evert van Loenen, Emile Aarts	Building automation and perceived control: A field study on motorized exterior blinds in Dutch offices	Eindhoven, The Netherlands	NO sİmulation is done.	NO simulation program is used.	Exterior Venetian Blinds and Inddor Roller Shades	NO glazing type is mentioned	Mild Humid Temperate	Office	Experimental
2014	F. Stazi, S. Marinelli, C. Di Perna, P. Munafo	Comparison on solar shadings: Monitoring of the thermo-physical behaviour, assessment of the energy saving, thermal comfort, natural lighting and environmental impact	Ancona, Italy	1)Energy consumptions 2)Indoor thermal comfort 3)Daylighting	Energy Plus	Movable Aluminium horizontal louvers, movable aluminium sliding perforated panels, movable traditional aluminium and wooden persiana	Double-glazed window	Mediterranean	School/University	Experimental and Theoretical
2014	L.G. Bakker, E.C.M. Hoes-van Oeffelen, R.C.G.M. Loonen, J.L.M. Hensen	User satisfaction and interaction with automated dynamic facades: A pilot study	Eindhoven, The Netherlands	NO sİmulation is done.	NO simulation program is used.	Movable roller shades	Fully glazed	Mild Humid Temperate	Test Room	Experimental
2014	Cheng Tian, Tingyao Chen, Tse-ming Chung	Experimental and simulating examination of computer tools, Radlink and DOE2, for daylighting and energy simulation with venetian blinds	Hong Kong Polytechnic University	1)Daylight simulation 2)Indoor Illuminance	1)Radlink in Adeline 2)DOE2	Venetian Blinds	Clear glass whose measured optical transmittance is 0.78	Monsoon-influenced humid subtropical climate	School/University	Experimental and Theoretical
2014	Draco Iyi, Reaz Hasan, Roger Penlington, Chris Underwood	Double skin façade: Modelling technique and influence of venetian blinds on the airflow and heat transfer	NO location is mentioned.	CFD	FLUENT 14.0	Venetian Blinds	Single 12 mm thick clear glass pane	NO climate data	Any Building	Theoretical
2015	Xiaoqiang Hong, Wei He, Zhongting Hu, Chenchen Wang, Jie Ji	Three-dimensional simulation on the thermal performance of a novelTrombe wall with venetian blind structure	Hefei, China	CFD	Fluent 6.3	Venetian Blinds	NO glazing type is mentioned	Warm humid temperate	Prototype system	Experimental and Theoretical
2015	Bruno Bueno, Jan Wienold, Angelina Katsifaraki, Tilmann E. Kuhn	Fener: a Radiance-based modelling approach to assess the thermal and daylighting performance of complex fenestration systems	Frankfurt, Germany	1)Cooling and heating energy demand 2)Solar irradiance 3)Indoor illuminance	1)Fener 2)Energy Plus 3)Radiance	External Venetian Blinds	Double-pane insulating glazing	Continental	Office	Theoretical

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2015	Tiago Silva, Romeu Vicente, Fernanda Rodrigues, António Samagaio, Claudino Cardoso	Development of a window shutter with phase change materials: Full scale outdoor experimental approach	Aveiro, Portugal	Energy performance of building components	NO simulation program is used.	Window shutter	Double-glazing	Mediterranean	Test Cell	Experimental
2015	Iason Konstantzos, Athanasios Tzempelikos, Ying-Chieh Chan	Experimental and simulation analysis of daylight glare probability in offices with dynamic window shades	Architectural Engineering laboratories of Purdue University in West Lafayette, Indiana	Daylight glare probability (DGP) evaluation	Evalglare software	Roller Shades	A SB70XL-clear high performance glazing unit with a selective lowemissivity coating (visible transmittance: tv ¼ 65% at normal incidence), and a double clear glass unit (tv ¼ 78.6% at normal incidence)	Temperate	Office	Experimental and Theoretical
2015	Mingzhe Liu, Kim Bjarne Wittchen, Per Kvols Heiselberg	Control strategies for intelligent glazed façade and their influence on energy and comfort performance of office buildings in Denmark	Denmark	Energy and comfort performance	Danish dynamic building simulation tool Bsim	External Shutter	Double glazing unit with a 15 mm argon-filled cavity and low-E coating on the internal pane	Temperate	Office	Experimental and Theoretical

CURRICULUM VITEA

Ayça Kırımtat is an architect. She was born on 21st of October 1990 in İzmir, Turkey. After she completed high school in Atakent Anatolian High School, she got into Yaşar University with a scholarship in 2008. Then, she carried this success to the third year and she went to Alghero, Sardegna, Italy as an Erasmus student. She learned to look from different perspectives to architecture and her aim was always to generate creative designs. At the end 2013, she graduated from Yaşar University. After her graduation, she became a research assistant in the same university and continued her works on computational design and shading devices in buildings. At the same time, she was doing his Master of Science in Architecture. She began to publish journals and join conferences related to her field of interest.

List of Publications:

International Journal Papers

A.Kirimtat, B. K. Koyunbaba I. Constantinou, I. S. Sariyildiz, "Review of simulation modeling for shading devices in buildings", Renewable and Sustainable Energy Reviews, Vol.53, pp.23-49, 2016 (Impact Factor: 5.901).

A.Kirimtat, C. Ugurlu, B.Ekici, I. Chatzikonstantinou, S. Sariyildiz, and M.F. Tasgetiren, "A Multi-Objective Constrained Real Parameter Optimization with Differential Evolution for a Floating Underwater Hotel Room Design", Applied Soft Computing (Under Revision) (Impact Factor: 2.810).

International Conference Proceedings

A.Kirimtat, B.K. Koyunbaba, I. Chatzikonstantinou, S. Sariyildiz, and P.N. Suganthan, "Multi Objective Optimization for Shading Devices in Buildings by Using Evolutionary Algorithms" 2016 IEEE World Congress on Computational Intelligence, Vancouver, Canada.

C.Cubukcuoglu, A.Kirimtat, M.F. Tasgetiren, P.N. Suganthan, and Q.K. Pan, “: Multi-Objective Harmony Search Algorithm for Layout Design in Theatre Hall Acoustics” 2016 IEEE World Congress on Computational Intelligence, Vancouver, Canada.

A.Kirimtat, E.Paykoc, “Walkability Assessment of Mavişehir- Alaybey Coast Region in İzmir, Turkey: Building, Green Area and Path Analyses”, in International Congress: Energy and Environment Engineering and Management, Paris, France, 2015.

A. Kirimtat, I. Constantinou, I. S. Sariyildiz, and A. Tartar, “Designing Self-Sufficient Floating Neighborhoods Using Computational Decision Support”, in IEEE Congress on Evolutionary Computation, Sendai, Japan, 2015.

B. K. Koyunbaba, S. Sariyildiz, A. Kirimtat, C. Ugurlu, “Removing Market Barriers for Energy-Efficient Building Renovation”, ECSEE 2015, Brighton, United Kingdom.

E.Paykoc, A.Kirimtat “Walkability Assessment of Karşıyaka, İzmir Neighborhood: The Pedestrian Flow Analysis Through Coastline ”, in EURAU2014 Composite Cities, İstanbul, Turkey, 2014.

National Conference Proceedings

A.Kirimtat, I. Constantinou, I. S. Sariyildiz, and A. Tartar, “Bilişimsel Karar Verme Desteği Kullanarak Kendi Kendine Yetebilen Yüzen Mahalleler Tasarımı”, Yöneylem Araştırması ve Endüstri Mühendisliği (YAEM) 35. Ulusal Kongresi, ODTÜ, Ankara, Türkiye, 2015.