THE EFFECT OF BUILDING SHAPE AND ORIENTATION ON ENERGY PERFORMANCE: AN OPTIMISATION SOLUTION FOR SCHOOL BUILDING IN SYRIA

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I certify that in my opinion the thesis submitted by Khaled ALBAIOUSH titled "THE EFFECT OF BUILDING SHAPE AND ORIENTATION ON ENERGY PERFORMANCE: AN OPTIMISATION SOLUTION FOR SCHOOL BUILDING IN SYRIA" is fully adequate in scope and quality as a thesis for the degree of Master of Science.

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Khaled ALBAIOUSH

ABSTRACT

M. Sc. Thesis

THE EFFECT OF BUILDING SHAPE AND ORIENTATION ON ENERGY PERFORMANCE: AN OPTIMISATION SOLUTION FOR SCHOOL BUILDING IN SYRIA

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Sustainable architectural design promotes using passive design principles for reducing energy consumption in buildings while conserving the indoor comfort levels of building users in terms of energy-efficient design processes. Building form and orientation have a significant impact on the behavior of building energy use. However, the study of these two parameters concerning other design parameters in the early design stages is widespread. Within the scope of the study, the Energy performance of buildings can be determined by the amount of Energy Use Intensity (EUI). This study aims to determine a clear workflow for optimizing building form and orientation in the early design stages. For that purpose, a parametric optimization workflow process had been suggested. A primary school building located in a warm and dry climate zone was selected as a case study. By using parametric energy modeling and simulation tools, various building forms (simple rectangular, L Shape, U shape, Court shape, and

Square shape) were generated, simulated to reach to results of EUI for each shape. The optimization process was performed within the same canvas of the parametric tool (Grasshopper) by using the Octopus plugin. After determining the input variables of the optimization process that represented by Orientation and glazing ratio WWR and genetic diversity of EUI value. The objective function of choosing the optimal solution for each form was determined by improving building energy performance (minimum of EUI value) with a suitable amount of daylight for classroom spaces following ASHRAE standards. The optimal solution for each suggested shape was obtained in terms of EUI value, orientation angle, and WWR and improvement in energy performance compared to the existing case. The results indicated that the optimal solution of the Square shape with a 17° orientation angle achieved the maximum development in EUI value. Up to 40 % improvement in energy performance had been achieved. The research also concluded that architects and designers should follow an optimization process for determining the most suitable building form and orientation angle concerning any other design parameters in the early design stage of their projects.

Key Words: Building Energy Performance, Building Shape, Building Orientation, Window to Wall Ratio W, Parametric Optimization, Grasshopper, Octopus.

Science Code : 80408

ÖZET

Yüksek Lisans Tezi

BİNA BİÇİMİNİ VE ORYANTASYONU ENERJİ PERFORMANSINA ETKİSİ: SURİYE'DE OKUL BİNALARI İÇİN OPTİMİZASYON ÇÖZÜMÜ

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Sürdürülebilir mimari tasarımı, binalarda enerji tüketimini azaltmak için pasif tasarım ilkelerinin kullanılmasını teşvik ederken, enerji verimliliği açısından bina kullanıcılarının konfor Beklentilerini de sağlar. Bina şekli ve yönelimi, binanın enerji kullanım davranışı üzerinde önemli bir etkiye sahiptir. Ancak, erken tasarım aşamalarında bu iki parametrenin diğer tasarım parametreleriyle ilgili olarak incelenmesi açık değildir. Çalışma kapsamında binaların Enerji performansı, Enerji Kullanım Yoğunluğu (EUI) miktarı ile belirlenebilmektedir. Bu Çalışmada, erken tasarım aşamalarında bina şeklini ve oryantasyonunu optimize etmek için net bir iş akışı belirlemeyi amaçlıyor. Bunun için, parametrik bir optimizasyon iş akışı süreci önerildi. Örnek olarak sıcak ve kuru iklim kuşağında bulunan bir ilkokul binası seçilmiştir. Parametrik enerji modelleme ve simülasyon aracı kullanılarak, her bir şekil için EUI sonuçlarına ulaşmak için çeşitli bina şekilleri (basit dikdörtgen, L formu, U formu, Avlu formu ve Kare formu) oluşturulmuş, simüle edilmiştir. Optimizasyon işlemi parametrik aracın (Grasshopper) aynı çevre içerisinde Octopus eklentisini kullanılarak gerçekleştirilmiştir. Oryantasyon ve pencere duvar oranı (WWR) ve EUI değerinin genetik çeşitliliği ile temsil edilen optimizasyon işleminin girdi değişkenleri belirlendikten sonra her form için en uygun çözümü seçmenin amaç fonksiyonu, ASHRAE standartlarına uygun olarak sınıf alanları için uygun miktarda gün ışığı ile bina enerji performansının (minimum EUI değeri) iyileştirilmesiyle belirlenmiştir. Önerilen her bir şekil için en uygun çözüm, EUI değeri, oryantasyon açısı ve WWR ve mevcut duruma kıyasla enerji performansındaki iyileşme açısından elde edilmiştir. Sonuçlar, 17° oryantasyon açısına sahip kare şeklin optimal çözümünün EUI değerinde maksimum gelişmeyi sağladığını göstermiştir. Enerji performansında %40'a varan iyileşme sağlanmıştır. Araştırma ayrıca, mimarların ve tasarımcıların, projelerinin erken tasarım aşamasında diğer tasarım parametrelerine göre en uygun bina şeklini ve yönlendirme açısını belirlemek için bir optimizasyon süreci izlemeleri gerektiği sonucuna varmıştır.

Anahtar Kelimeler : Bina enerji performansı, EUI, bina şekli, Bina Yönü, Pencereden Duvara Oranı, Parametrik Optimizasyon, Grasshopper, Octopus.

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SYMBOLS

γ	: Thermal Conductivity coefficient
%	: Percentage
°	: Orientation Degree
m^2	: Meter square

ABBREVITIONS

EUI	: Energy Use Intensity
WWR	: Window to Wall Ratio
WO	: Window Orientation
WG	: Window Geometry
RC	: Relative Compactness
PFM	: Pareto Front Method
m	: Meter
kW	: Kilo Watt
kWh	: Kilo Watt-hour
DSF	: Double Skin Facade
V	: Volume
A	: Area
DV	: Dependent Variable
IV	: Independent Variable
N	: North
E	: East
S	: South
W	: West
C	: Classroom

PART 1

INTRODUCTION

1.1. BACKGROUND

Today, the problem of energy resources has a significant interest in research studies. Buildings consume more than 40% of the total global energy consumption. This will produce several amounts of problems in buildings as a result of the limitans of energy resources in the future. In the last decade, the term sustainable architecture design has been raised. This trend promotes the directions toward energy efficiency in high-performance buildings. Therefore, buildings performances should be evaluated to save energy use and achieve indoor comfort.

Predicting energy use in buildings is a very effective factor in reducing the energy use in buildings and maintaining the comfort measures at the same time. For this reason, architects and designers have to predict the energy of their projects in the early design stages rather than the operation phases of buildings. Within this context, several design parameters must be studied in the design stages that have a significant effect on building energy performance. Building design parameters such as building geometry, shape, zoning, construction materials, façade type, glazing type, window construction, glazing ratio, and much more alongside with building condition and location, building type and occupancy levels, and HVAC system type should be evaluated in the design stage to reduce energy consumption while conserving the same level of the required comfort metrics.

In literature, it was found that building shape and orientation parameters have a significant effect on building energy performance. Many studies in the literature have attempted to study these two important parameters alongside building envelope characteristics, however, most of these studies depended on assumptions and their

The workflow works in the selected study area. Even though some of these studies adopted the optimization process in finding the optimal solutions their methods depended on the complex workflow of numerical energy simulation that needs manipulation of final results to reach the optimum solutions.

School buildings have special design and planning requirements. Classroom spaces can be considered as the most important function in school buildings due to the high occupancy and operational works hours during the educational day. Providing sufficient lighting levels to classroom spaces is one of the basic requirements. On the other hand, reducing energy consumption must be taken into consideration especially in high occupancy levels of school buildings. Within this context, school buildings' shape and orientation play an important role in determining energy consumption concerning design requirements. Architects and designers of school buildings should have sufficient knowledge of the required energy use in the early design stage. Depending on these hypotheses, the current research aims to provide a parametric optimization workflow of school buildings' shape and orientation solutions in the early design stages.

1.2. PROBLEM STATEMENT

Recently, many researchers studied the effect of architectural volumetric design solutions on the demand for energy in buildings (Parasonis et al, 2012; Al Anzi et al, 2008). The form and shape of the buildings can affect energy performance through their aspect ratios (Koranteng and Abaitey, 2010). Moreover, building orientation is one of the most important factors that affect energy consumption (Ashmawy and Azmy, 2019).

Most of the current research studies are simulation-based. However, the vast majority of them are depending on assumptions and use numerical energy simulation to investigate the effect of this assumption. The workflow of determining the suitable shape and orientation is still not obvious. Within this context, the main problem of the current study can be determined by finding a clear workflow that can help in understanding the impact of the main problem. Figure 1.1 illustrates the general scheme of the study process diagram.

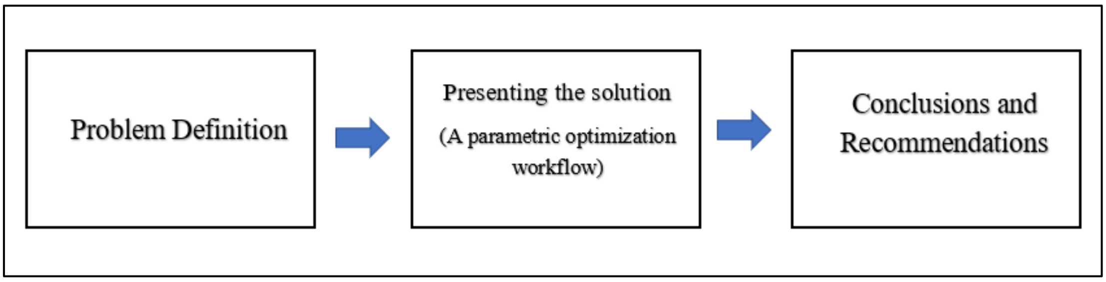


Figure 1.1. The general scheme of the study diagram.

1.3. RESEARCH PURPOSE

Providing a clear workflow of optimizing building shape and orientation in school buildings with a minimum value of Energy use and sufficient amount of natural daylighting of classroom spaces are the basis of the study. The workflow to be suggested combines the ability to put assumption of any building shape with optimizing the orientation and any other design parameter- WWR is taken in the study- that may help architects and designers in the early design stages of school buildings in any climate region.

1.4. RESEARCH QUESTIONS

The research aims to answer the following questions:

- Is it possible to apply the suggested workflow of optimizing shape and orientation parameters with other design parameters such as glazing ratio WWR, construction materials, glazing type, etc.?

- What is the difference between the assumption of the shape and orientation approach and the optimization approach of building shape and orientation in the early design stage in the current studies?

- What is the effect of building shape and orientation on the annual energy use of school buildings?

- How we can reach the optimal solution regarding shape and orientation in school buildings?

- Which school building shape and orientation degree are most suitable for the selected study area?

- To what extent can the optimal solution of shape and orientation improve building energy performance in the selected study area?

1.5. RESEARCH METHODOLOGY AND DESIGN

For the study, the methodology is divided into four main stages. These stages are represented by the shape generation stage, energy modeling stage, energy simulation stage, and optimization process stage. A case study of the primary school building is selected in a dry-warm climate region in the city of Aleppo- Syria. Five main shape geometry had been suggested to complete the scope of the study. However, the parametric workflow of the study allows the user to suggest any shape concerning his design preferences. Rectangular shape, L-shape, U-shape, Court shape, and Square shape had been suggested. The suggested shapes are modeled with the same design inputs in the base case but by changing glass type. Construction materials, occupancy levels, and zone programs are determined and fixed for all suggested shapes in the Grasshopper tool. Only glass ratio and orientation parameters are allowed to vary in the optimization process. A parametric energy simulation is run to get the value of Energy Use Intensity EUI for each suggested shape. This value is used as an indicator of building energy performance. In the final stage, the optimization process is performed on the same canvas of grasshopper by using the Octopus plugin- an optimization tool. The variables of the optimization process are determined to be orientation and glazing ratio- WWR with the value of EUI. As a result, the optimal solutions for each shape are obtained using Pareto Front Method PFM in the Octopus plugin.

The obtained results are analyzed depending on an assumed objective function of minimizing EUI value with sufficient WWR value of classroom spaces. The optimal solution for each shape is determined and discussed. The conclusions are drawn to help architects and designers to optimize the shape and orientation of school buildings in the study area. Figure 1.2 illustrates the research design and method stages.

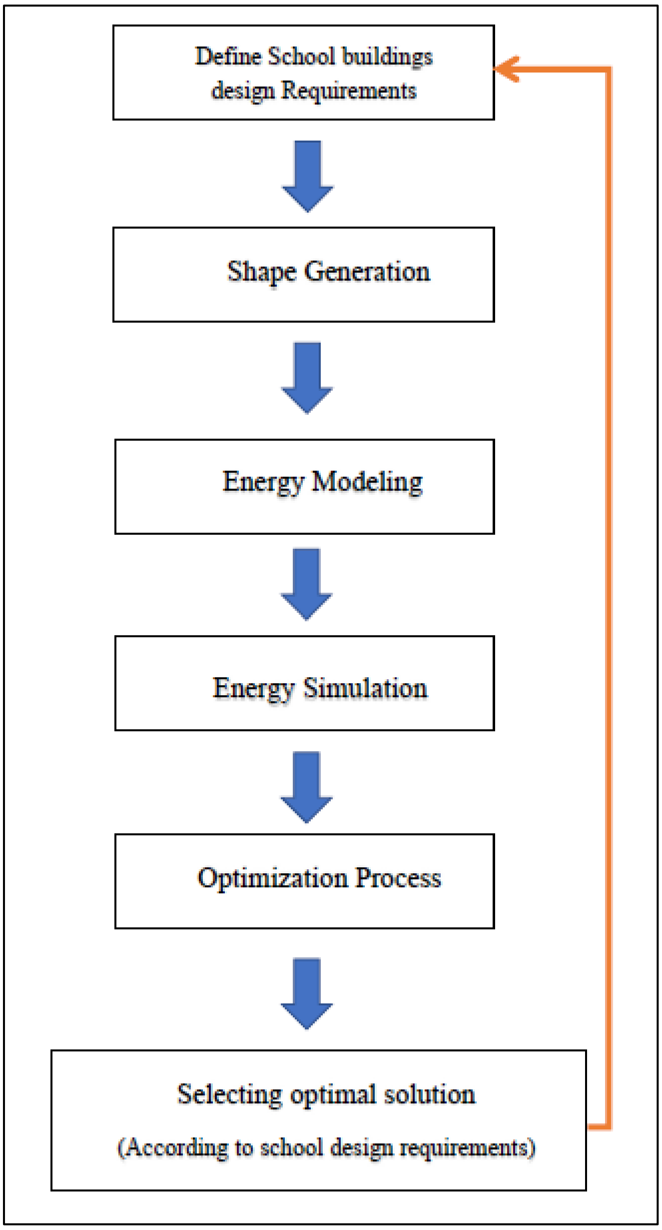


Figure 1.2. The general research design and stages.

1.6. RESEARCH OUTLINE

In **Part One**, a summarization of the research background, problem, aim, and scope, questions as well as methods to be used, and the expected outcome are presented. This Part gives the big picture of the general output and clarifies the research design.

In **Part Two**, a theoretical approach will be presented for the related literature of building energy performance, design parameters, building shape and orientation as well as the school buildings' design requirements. The output of this Part helped in determining the main problems in the literature studies and the school building design process.

Part Three of the study describes the research methodology in general, the material and methods, and the tools used to perform the study scope. It describes the selected case study, its location, structure, function, existing shape, and orientation. This Part also includes the method stages description (shape generation, energy modeling and simulation, and the optimization process) with the used tools for each stage. The chapter describes the integration between Rhino, Grasshopper, Ladybug, Honeybee, and Octopus optimization plugin to perform the parametric optimization workflow.

Part Four presents the obtained results of possible optimal solutions for each suggested shape. The outputs after 4 generations of optimization process represented by Pareto Front graphs are presented. This Part also includes the analysis and the discussion of the results depending on proposed criteria to reach the optimal solution of each building shape that is also obtained.

The final part of the study represents **Part Five** where conclusions and recommendations are drawn to help designers of school buildings to optimize building shape and orientation concerning other design parameters in the early design phases of the project.

PART 2

BUILDING ENERGY PERFORMANCE

In this chapter, the various literature related to the current research title was reviewed. To connect the study with the current state of knowledge, this chapter will be divided into titles to facilitate an understanding of the literature related to the current research topic. The literature reviews building energy performance topics, building shape, building orientation, and the design requirements of a school building.

Energy performance in buildings measures the "relative energy efficiency of a building, building equipment, or building components as measured by the amount of energy required to provide building services" (Baird, 2018).). In other words, energy performance describes the condition of energy savings due to renovation measures. For example, if a renovation of the façade is done. The heating energy losses of the current façade are the status. The savings are then set into relation with the total heating energy losses (Carlander et al., 2020).

Many factors affect the energy performance of the building such as ambient weather conditions, building structure, and characteristics (shape, orientation, building envelope materials, transparency, façade properties, occupancy, activities, etc.). Therefore, predicting energy use in buildings is important for evaluating energy performance (Zhao and Magoules, 2012).

The fact indicates that buildings consume 40% of global energy production. According to Masyali and El-Gohary (2018) predicting energy consumption in buildings is essential for planning, managing, and conserving energy. Predicting
energy consumption depends on several numbers of factors such as the physical characteristics of the building, installed equipment, external weather conditions, and the energy use behavior of building occupants. (Masyali and El-Gohary, 2018).

In bioclimatic buildings, the application of renewable material and energy sources is promoted (Widera, 2015; Sheliavovich, 2011). Using local materials and techniques such as the use of court spaces as a buffering element in difficult climates, the use of air captures within court spaces, and the use of walled gardens in a desert climate can enhance building energy performance (Manzano-Agugliaro, 2015).

Pacheco et al. (2012) concluded that building orientation, shape, and the ratio between the building context and its size are vital factors that have a significant impact on the final energy demand of the building (Pacheco et al., 2012). Accordingly, using passive design strategies in the early design phases can achieve the energy balance by obtaining the best performance with the least energy use which is called energy efficiency (Pathirana et al., 2019).

2.1. BUILDING SHAPE

The shape of the building plays an important role in building heat balance. Several geometric shapes were used in this field to obtain the appropriate shape in study research. Along with aesthetic concerns, building form and shape can contribute to an extreme degree to determine energy building performance. Building mass that is related directly to the building shape has a great influence on the direct solar radiation reflectance or absorption (Brzezicki, 2012). For example, curved facades can scatter our focus light beams more than flat façade in several random ways (Tumbaş, 2019).

Architects usually consider the aesthetic and functional issues before considering any environmental impact of building shape on its performance. Once the project is developed, it will be difficult for building simulation experts and designers to retrieve back and suggest more shapes options with more performance efficiency at advanced stages of the design process. Figure 2.5 shows an example of the most popular shapes used by architects and designers in the architectural design process of school projects.

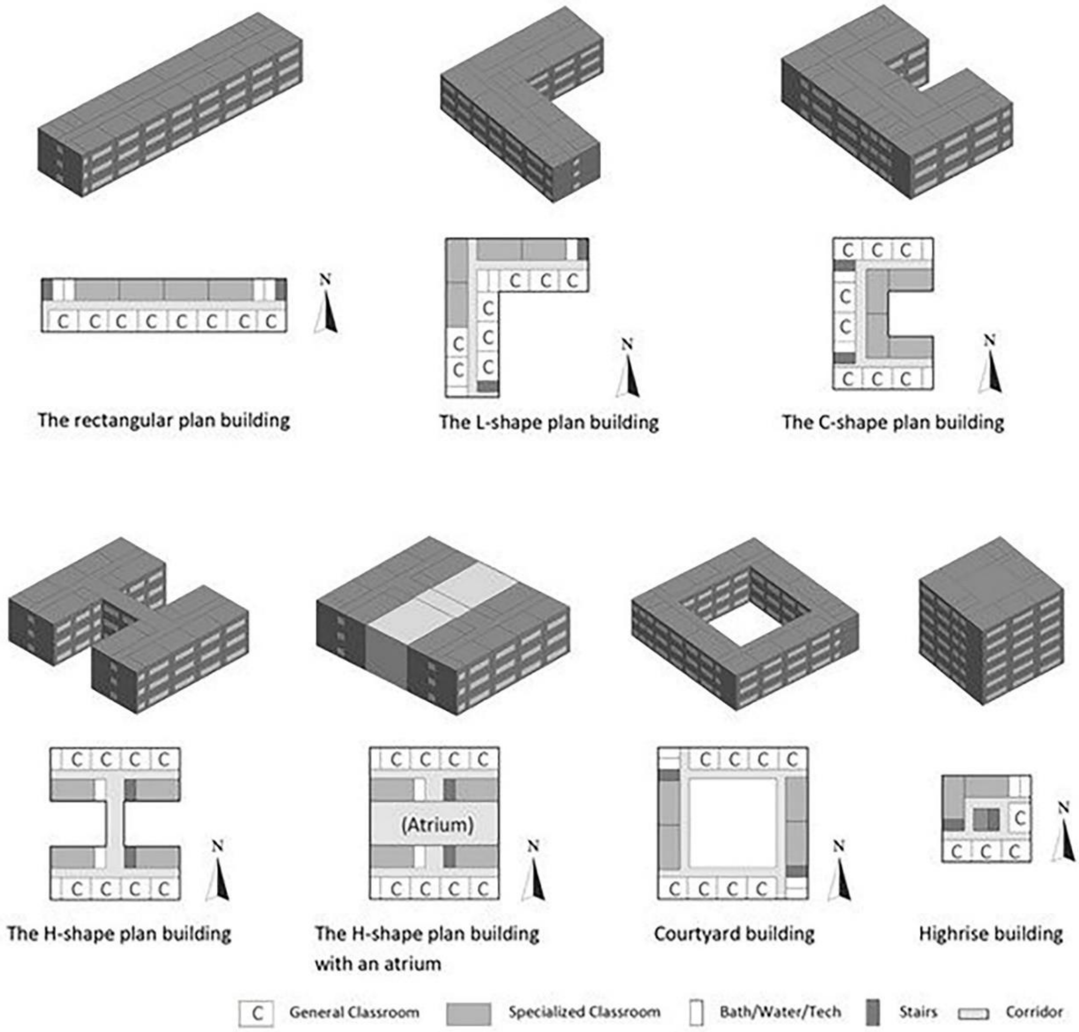


Figure 2.1. Most popular building form shapes used in school projects building design (Zhang et al., 2017).

Wang et al (2006) claimed that building shape is a very important factor in green building design due to its significant impact on energy performance and construction costs. In their study, they used the genetic algorithm method to optimize a shape with a multi-side polygon. Through the trial and error method, they tried to optimize the geometrical properties (dimensions, angles, and several sides) of the simple polygon as well as determine some future works areas (Wang et al, 2006). Al- Anzi et al (2008) examined several building shapes and their impact on the thermal performance of office buildings. The research analyzed rectangular, L-shape, U-shape, and H-shape through comprehensive building energy simulation. The results concluded that the effect of building shape on total building energy use depends on primarily three factors: Relative compactness (RC), the window to wall ratio (WWR), and glazing type. The major finding of the study indicated that total energy use of building with low WWR is inversely proportional to RC (AL-Anzi et al, 2008). Granadeiro et al. (2013) examined the building envelope shape influence on energy performance. In their study titled “Building envelope shape design in early stages of the design process: Integrating architectural design systems and energy simulation”, they were able to create a parametric design system through which architects can evaluate alternative envelope shape designs and calculate the energy demand of each design. They claimed that this method will save time in the design and energy simulation integration process (Granadeiro et al., 2013).

Premrov et al. (2018) studied the impact of timber glass buildings’ shape on energy performance. They claimed in their research that the optimal proportion and appropriate orientation of glazing surfaces in timber-glass buildings play an important role in energy efficiency and solar heat gains in warm climate regions. According to that assumption, they analyzed 216 timber box house samples that parametrically varied in building shape (Aspect ratio, horizontal and vertical extension). The results emphasized that building shape has an important influence on the energy behavior of timbered-framed buildings located in warm European climate conditions. Aspect ratio, glazing size, its orientation, horizontal and vertical extension of the building also played as important factors (Premrov et al, 2018).

2.2. BUILDING ORIENTATION

Building orientation is “the positioning of a building about seasonal variations in the sun's path as well as prevailing wind patterns” (URL 1). The orientation is a key factor in the solar thermal gain of buildings as shown in Figure 2.6, which can reduce the energy used in heating and cooling systems and the energy consumed by any building varies according to the design of the outer envelope which also contributes to the heat gain from the surrounding environment.

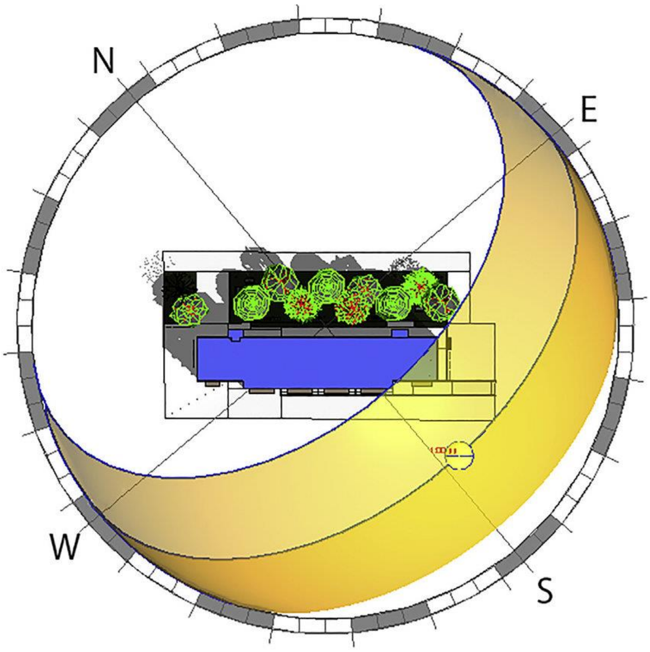


Figure 2.2. Example of solar path and orientation of building (Mytafides et al, 2017).

Abanda and Byers (2016) investigated the impact of building orientation on energy consumption in a domestic building by using BIM technology (Building Information Modeling). Their results showed that many factors influence a building's energy needs including the building envelope, building components, occupant behavior, building orientation, building size, and shape. The way the building is directed at the site determines its interaction with the sun and thus determines to a large extent the internal solar gain. Reducing requirements for heating and lighting units will reduce energy use and improve efficiency. Their investigation succeeded in establishing that the orientation of the building affects energy use (Abanda and Byers, 2016).

In the literature, many studies dealt with building shape and orientation and their effect on energy performance. A study tried to determine the effect of building geometric shape and orientation on its energy performance in various climate regions conducted by Lapsia (2018). The study was carried out by extensive numerical simulations using a coupling of TRNSYS (parametric simulation tool) and CONTAM energy simulation tools. The results showed that appropriate building shape and orientation can reduce the building energy consumption for heating and cooling systems up to 81% (Lapsia, 2018). Another study titled “Analyzing Optimum Building Form about Lower Cooling

Load" tried to manipulate the shapes of buildings that significantly affect the cooling load (Rashid et al.,2016).

2.3. BUILDING ENVELOPE

The building envelope is the most crucial factor in improving building energy performance due to its direct contact with the ambient environment. Many types of research have been conducted using design strategies to improve the building performance through the building envelope (Aksamija, 2015). Passive design principles such as using appropriate thermal insulation, glazing type, and shading devices in building envelopes can save up to 40% of heating and cooling loads (Sozer, 2010). Another important factor in building envelope topic is Window to Wall Ratio WWR and its direction that represents the glazing ratio of the building which plays an important role in gaining natural daylight access inside buildings and controlling the energy use of a building (Harmati and Magyar, 2015).

2.3.1. Construction Materials and Window Construction

Building envelope materials with their thermal and physical properties are the most common factors that are used to improve or evaluate energy performance in buildings. The properties of used materials in walls, roofs, and basements of buildings play an important role in determining the flow of heat from inside to outside the building and vice versa. Within this field, many researchers studied the effect of construction and structural materials on building performance.

Filate (2014) conducted a building energy simulation study in an office building using nanogel insulation plaster and new windows. The results showed that using 5 cm thick nanogel insulation boards could improve heat loss through external walls up to 71% while the same results can be obtained by using 11.5 cm and 7.6 cm thick mineral wool and rigid PUR / PIR insulation boards respectively (Filate,2014). Beccali et al (2018) compared using traditional stone walls and adobe wall material and its effect on indoor thermal comfort at different separated zone in the same building. The study concluded that the application of traditional material in walls allows good comfort conditions in Naturally Ventilated Buildings in hot humid climate zone (Beccali et al., 2018).

The type of glass material and window construction is also affecting the building envelope performance. Single, double, or triple glass with filled materials or gasses can be used. Granqvist et al. 2018 introduced a critical review of new material technology called "Electrochromic Materials EC" in construction that can be integrated into thin-film devices and used for modulating optical transmittance as shown in Figure 2.4. The research described EC technology as technology that has recently been implemented in large-area glazing (window and glass façade) to create buildings that, combine energy efficiency with good indoor comfort (Granqvist et al., 2018).

Figure 2.3. Electrochromic glazing type (Granqvist et al., 2018).

2.3.2. Shading Devices and Façade Systems

Passive solar design principles promote maximizing heat solar gain that may reduce the energy amount needed for heating in cold climates. However, it may lead to overheating in summer periods especially in hot and warm climate regions. For that reason, it is essential to design an ideal shading device that functions all over the year. Installing fixed vertical or horizontal shading devices on a building façade could function for not only providing occupants with an appropriate daylight status but also reducing the energy consumption of buildings (Kim et al., 2015) as shown in Figure 2.2. The same logic can be used in cold regions to allow sunbeams to enter the building in winter and natural ventilation in summer periods (Palermo& Olivera, 2010).

Figure 2.4. a) Horizontal louvers b) vertical louvers (Kirimtat et al., 2016).

Building skin design that is represented by the term "façade system" influences the amount of the passive solar heat gain and the opportunity to modify the effect of prevailing wind surrounding the building. In that field, it is important to consider the various climate levels of the building including the general climate, the meso climate, and the microclimate (Manzano-Agugliaro et al., 2015). Some studies in the field tried to deal with buildings as microclimate modifiers to achieve the thermal balance in buildings (Iyendo et al., 2016; Hosseini et al., 2019) by suggesting façade techniques as design or retrofitting strategies to improve building energy performance.

Ventilated façade, Double Skin Façade DSF, and kinetic façade (dynamic louvers) systems are used nowadays in building skin to improve building energy performance. These systems proved their ability to achieve thermal comfort with maximum daylight efficiency, especially in hot and warm climate zones. Figure 2.3 shows an example of the effect of a Greenhouse in the Double skin façade technique (Gratia and De Herde, 2007; Joe et al., 2014).

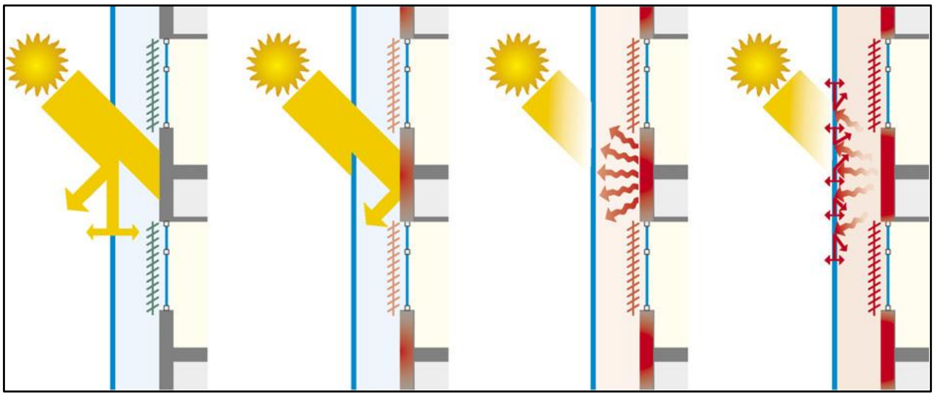


Figure 2.5. The effect of Greenhouse in double skin façade system (Gratia and De Herde, 2007).

2.3.3. Window to Wall Ratio WWR

The WWR can be defined as “the ratio of the area of clear glass to the area of the opaque wall from floor to floor outside” (Alsehail and Almhafdy, 2020). In other words, WWR represents the percentage of glass or window areas in an exterior wall. This percent can significantly affect the building performance as a whole and building envelope in particular (Troup et al., 2019). Both terms thermal comfort and energy consumption are affected by WWR directly. So, it is essential to find an ideal design that combines window size, orientation, and shading system. According to Alsehail and Almhafdy 2020, visual transmittance (Tv) and thermal conductance (U -value) as well as climatic conditions are the most aspects of windows design that must be taken into consideration while studying the ideal WWR of building envelope (Alsehail and Almhafdy, 2020). Moreover, besides (WWR), window geometry (WG) and glazing properties have a significant influence on building envelope performance (Harmati and Magyar, 2015).

Window Orientation WO is also an important factor in determining building performance. A study by (Gasparella et al., 2011) has confirmed that WWR is not the only influential upon the buildings but WO is also of high importance. Alshayeb et al. (2015) confirmed that the direction of construction has a significant influence on the degree of solar radiation received on the building's facade and the solar radiation, which is a major factor affecting the cooling loads in buildings (Alshayeb et al., 2015). It is worth mentioning here that WWR is a design variable that deals with window design, while the WO is an environmental variable that deals with building orientation (Troup et al., 2019; Kim et al., 2016). Figure 2.4 illustrates an example of WWR and the percentage to the wall. WWR most likely ranges between 10% to 90%.

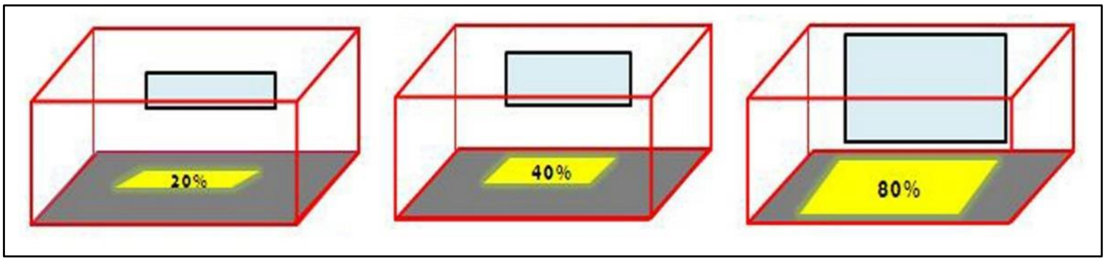


Figure 2.6. Graphical representation of Window to Wall Ratio (Khan, 2018).

Fallahtafi and Mahdavinjad (2015) optimized the building shape and orientation for better energy performance by determining the impact of building shape, relative compactness (RC) as well as glazing percentage on its optimized orientation. Their study was conducted in Tehran- Iran and concluded that the worst degree of orientation is between 171 and 177 degrees. They also found that the less amount of glazing in buildings, the more a building should be oriented to the south, and the more amount of glazing the more it needs to be oriented to the southwest. As a result, and compared to the worst oriented degrees, they were able to save up to 105% of building annual energy by optimizing its orientation (Fallahtafi and Mahdavinjad, 2015).

Mokrzecka 2018 studied the influence of building shape and orientation on heating demand by using computer energy simulations for student dormitories in temperate climate conditions. The results showed that the shape affects heating energy consumption. According to the research, the most suitable design in terms of heating demand is the square shape, where the difference between the minimum and the maximum heating request in the selected area was 50%. The results also showed that the least desirable form is the U-shape as it generates not only problems with heating demand but also limits access to natural light even though it allows the designer to increase the number of rooms in the building. (Mokrzecka, 2018).

Pathirana et al. 2019 investigated the effect of building shape, orientation, window to wall ratios WWR on energy efficiency and thermal comfort of naturally ventilated houses in a tropical climate. The results indicated that the zone sizes and the zone locations affected the thermal comfort and lighting electricity. Window to Wall Ratio WWR increased thermal comfort by 20-50%. Lower WWR provides less thermal comfort and higher light electricity at the same time. The percentage change in lighting electricity due to WWR is 1.5-9.5%. The results indicated that the rectangular shape with the staircase in the middle will provide a higher thermal comfort. While square-shaped houses with stairs in the middle have the highest electricity for lighting, L-shaped homes have the lowest electricity for lighting (Pathirana et al, 2019).

Patios or middle courtyards are used in hot and dry climate zones because of their effective role in passive cooling strategies. A study was carried out by Soflaei et al. (2020) used Rhino and Grasshopper tools to enhance the design efficiency of courtyards. Many scenarios were examined the impact on thermal comfort. These alternatives are related to courtyard geometry and the building orientation, used materials, window sizes, and courtyard eccentricity. The study concluded that parametric simulation can significantly examine a huge number of design alternatives resulting in enhancing the design of the courtyard geometry and design variables to achieve the maximum level of thermal comfort in hot and dry climates (Soflaei et al., 2020).

The previously mentioned studies are valuable and have significant findings. However, some of these studies adopted an optimization approach using numerical energy simulation and then manipulating the results to reach the findings while other studies depended on assumptions using the parametric energy simulation approach to reach the results. This research aims to introduce a parametric optimization workflow that can facilitate reaching the optimum results of shape and orientation of school buildings regarding energy performance. This approach is expected to help architects and designers to optimize the school building shape, orientation, and glazing ratio parameters in the early design stages.

2.4. DESIGN REQUIREMENTS OF A SCHOOL BUILDING

2.4.1. Thermal and Visual Comfort Standards

The Indoor Environment Quality IEQ is a very important factor that must be taken into consideration in school design buildings. Indoor Environment Quality IEQ is included thermal quality, lighting quality, acoustic quality, and air quality parameters. Therefore, the student's indoor comfort can be divided into Four main sub-systems that include: Thermal Comfort, Visual Comfort, Acoustic Comfort, and Indoor air comfort. These are extensively related to energy use in school buildings.

ASHRAE standard 55 and ISO 07730 use PMV-PPD models or the adaptive comfort model to evaluate thermal comfort conditions in buildings. In school buildings, the thermal comfort of students can be achieved when the operative temperature of the indoor spaces of the classroom ranges between 17-24 C° in hot and arid climate zones (ASHRAE 55, 2013).

The visual comfort of students in the classroom is one o of the important factors to be considered in the early design stages of school buildings. ASHRAE 90.1 standards ensure that the amount of daylighting should be less than 300 lux. However, higher values should be evaluated to prevent uniformity and glare or color rendering issues. According to that, opening size in a classroom space should range between 18-22% of its gross floor area (ASHRAE 90.1, 2010).

2.4.2. Site Location

Minimum or maximum needs for a school building and the percentage of utilization of the site for construction or various services can be determined by the site location in the city town or rural areas. The followings represent the general requirements in school site locations:

- **Orientation**
  - Orientation of Classrooms

The general orientation of the classrooms is the northern direction. A deviation of 25 degrees to the east or west from the north is possible

- It is preferred to orient the classrooms to the north
- In the case that it is not possible to orient classrooms to the north, it is possible to direct the western or southern direction by using sun shadings and louvers on the windows.
- It is not preferred to orient the classrooms directly to the east (ASHRAE 90.1, 2010).

  - Orientation of Playgrounds

- It is preferred to orient the playgrounds to the north-south direction

❖ **Surroundings**

- The site must be far away from the noise, vibration, and distortion sources.
- The site must be free of environmental pollutants such as factories and others.
- The site must be surrounded by a public street 6 meters minimum wide with a previous study for the occupants in rush hours.

❖ **Site location needs**

- Accessibility for security, health, and fire protection services.
- Availability for maintenance services.

❖ **Site Plan organization**

After choosing the site that meets the previous requirements, it must be planned according to several design criteria, the most important of which are:

- Take advantage of the site's space so that the schematic design of the site includes all the elements needed by the project program, as well as taking into account the project's relationships with each other as much as possible.

- The planning of traffic and vehicle systems should be integrated to provide the general safety of children by separating each category and excluding or minimizing the intersection between pedestrians and vehicles.
- Protecting the movement of vehicles within the site by providing an appropriate system for parking vehicles as shown in Figure 2.7 (Moore & Lackney, 1993).

Figure 2.7. Example of vehicles Movement in school site (Moore & Lackney, 1993).

2.4.3. Planning Requirements for a School Building

- **Entrances**

- The entrances should be clear and within visible places that welcome the arrival. In addition, an entrance should be allocated to serve the parking lots of vehicles.
- Avoiding entrances on the main streets to ensure the general safety of children.
- Doors must be open from the inside at any time, even after the school is closed.
- It is preferable to have a separate entrance for teachers and another one for students. In some design cases, it may be better to have one entrance for teachers, students, and visitors.

- Signs should be placed for emergency exit doors to secure the exit of children in the least possible time to avoid loss of life in case of danger.

The maximum height (ground + 4 floors) is 18 meters, taking into account building laws, and the first floors are allocated to young first-year students as shown in Figure 2.8 (Neufert, 2012).

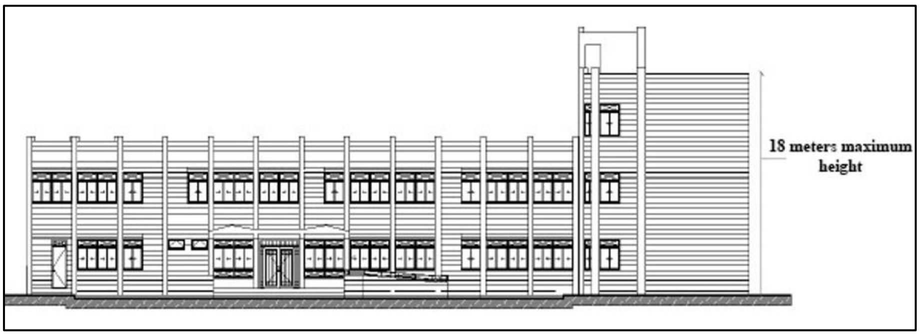


Figure 2.8. Maximum height of school buildings (Neufert, 2012).

Services are placed so that they are close to the various elements of the building to achieve their purpose and ease of use as shown in Figure 2.9.

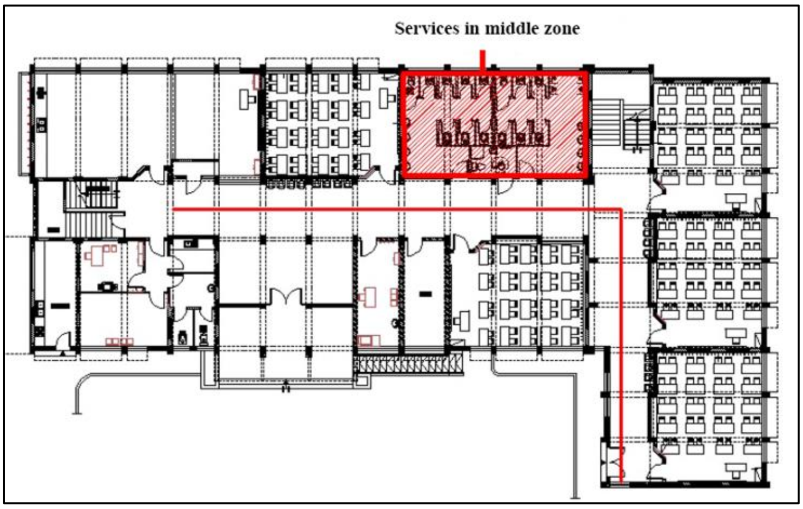


Figure 2.9. Services are located on the floor (Neufert, 2012).

2.4.4. Functional Design Requirements for a School Building

The design of a school building consists mainly of classroom spaces, administration spaces, educational activities spaces (libraries, laboratories, galleries, etc.), and Bathrooms spaces. Other functions can be added according to the school building design program such as Spore activities spaces, Food courts spaces, and Religious activities spaces.

❖ **Classrooms spaces**

The classroom spaces must meet the following requirements:

- The height of the classroom should be at least half of its width and not less than 3.2 m as shown in Figure 2.10.
- Providing 1.2 m^2 for each student, with an increase in the width of the classroom of 6 m, and the area of the classroom should not be less than 45 m^2 as shown in Figure 2.11.
- The height of the windows sitting is higher than the level of the students' eyesight while they are sitting in the classroom to prevent them from looking outside as shown in Figure 2.12.
- The colors of the interior walls should be of light colors, and it is recommended that they be painted from the bottom with oil paint at the height of the doors for easy cleaning.
- Windows should not be placed at the back of the classroom.
- The natural lighting should be sufficient, as well as the presence of continuous ventilation to provide a healthy atmosphere inside the classroom space.
- The natural daylighting should be to the left of the student so as not to form a shadow that prevents clarity of vision as shown in Figure 2.13 (Neufert, 2012).

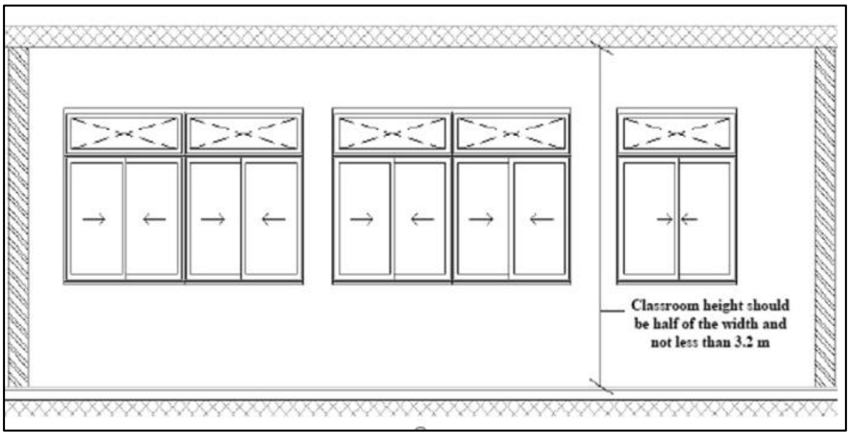


Figure 2.10. Classroom space height (Neufert, 2012).

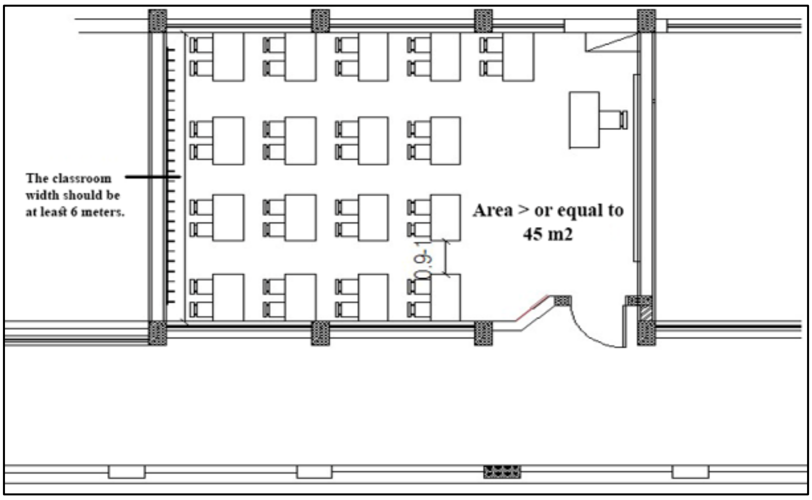


Figure 2.11. Classroom space area and width (Neufert, 2012).

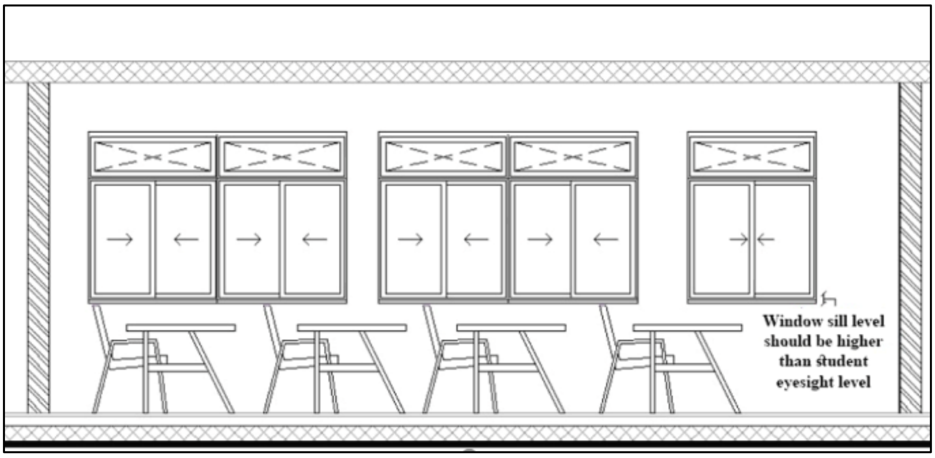


Figure 2.12. Windows sill height (Neufert, 2012).

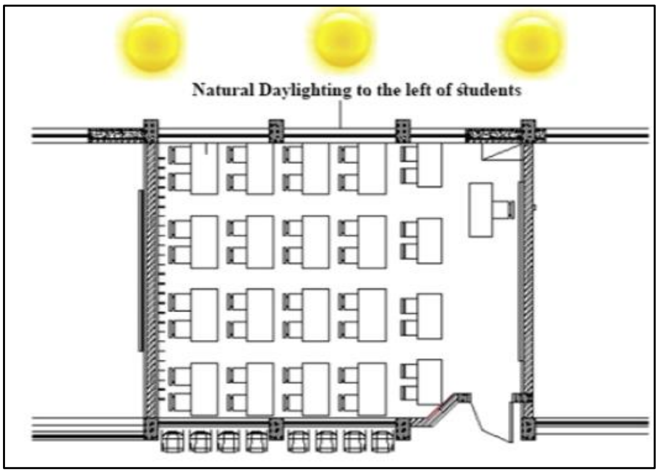


Figure 2.13. Location of natural lighting and students (ASHRAE 90.1, 2010).

- The front door of the classroom should be next to the teacher for easy control of the classroom as shown in Figure 2.14.

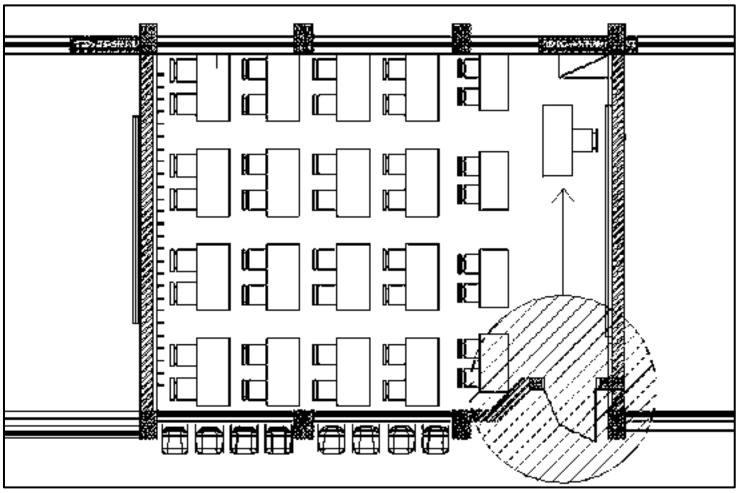


Figure 2.14. Location of classroom space door (Neufert, 2012).

- The area of the window openings ranges between 18-22% of the classroom space to ensure good ventilation and lighting (ASHRAE 90.1, 2010), as shown in Figure 2.15.
- The maximum number of students per class is 35 students.
- Choose flooring from a durable and abrasion-resistant material.

- The classrooms are provided with sound-insulating material to ensure clarity of sound.
- **Orientation of classroom spaces:** The longitudinal direction of the classroom should be in the north, northeast, northwest direction to obtain an adequate amount of natural lighting.
- The classroom spaces should be far enough from sources of noise and pollution.

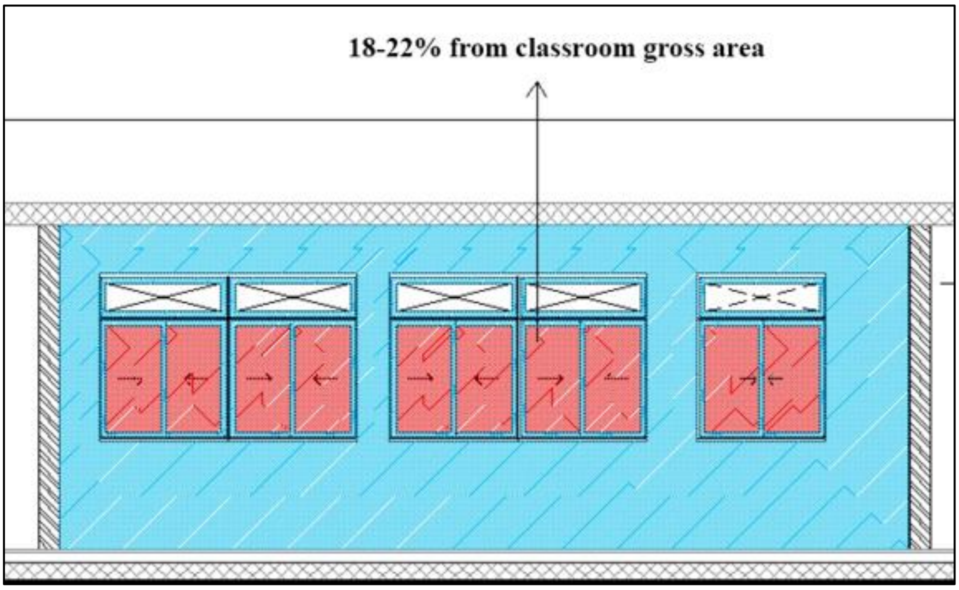


Figure 2.15. Window openings Location and ratio (ASHRAE 90.1, 2010).

❖ **Administration spaces**

Several criteria are taken into account when designing the administration space as followings:

- Allocating the manager's office and student affairs offices in the middle location of the floor to facilitate parents' accessibility.
- Accessibility to classrooms and education staff room.

Administration space elements contain manager room with the area between 20-30 m² and secretary room as shown in Figure 2.16, and the teachers and education members' room.

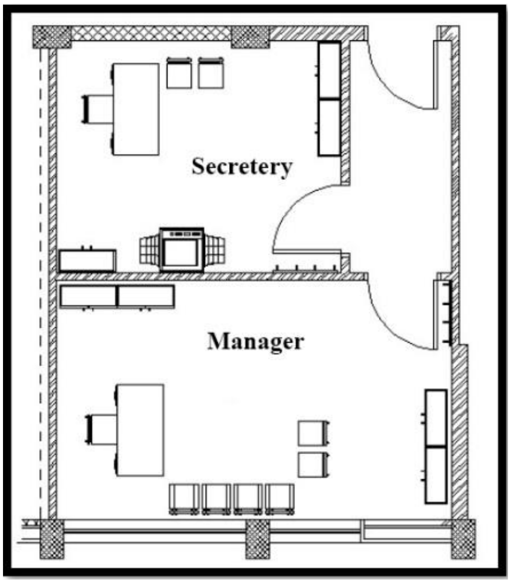


Figure 2.16. Administration Unit with furniture organization (Neufert, 2012).

- **Educational activities spaces**

  - Library

- It must be in a central location so that it is easily accessible.
- It should be with sufficient lighting to provide a suitable atmosphere for reading.
- It is advisable to place the library on the ground or first floor.
- The library spaces should be suitable for most of the age groups of students.
- The furniture consists of (examining tables, comfortable seats for students, cupboards to place books, the supervisor's desk with a special seat for him) as shown in Figure 2.17.
- It is taken into account to paint the walls with a sound-insulating material to provide calm.
- It is taken into account to paint the walls in colors that help attention and concentration.

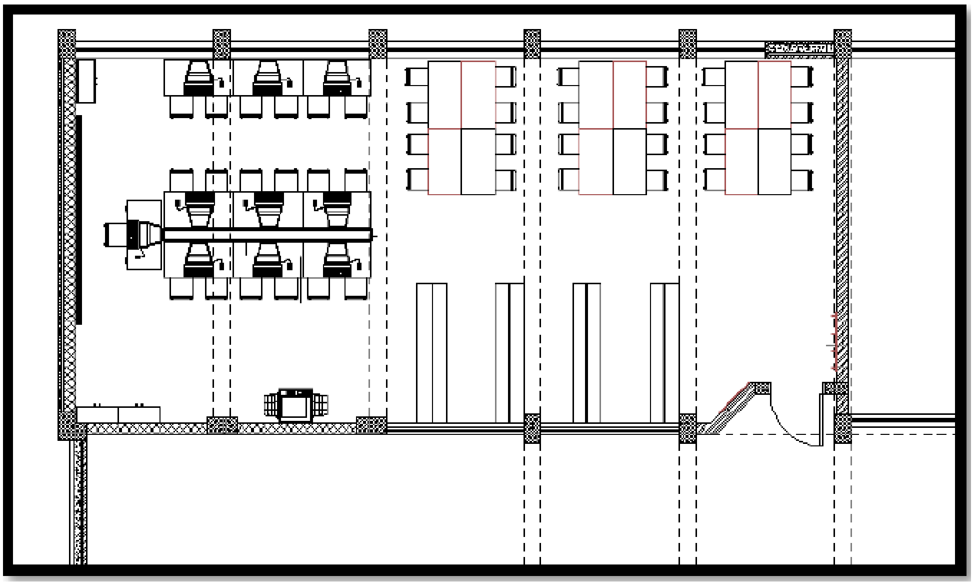


Figure 2.17. Library Unit with furniture organization (Neufert, 2012).

- Laboratory

- It is placed on the first floor and equipped with south or southwest windows.
- It is equipped with a door that opens onto the courtyard so that students can study outside the building without going through the building.
- The front wall is equipped with a blackboard for an explanation.
- Contours are installed on both sides of the lab.
- Its area ranges between 50-60 m² in basic education schools.
- It can be equipped with several seats to sit.
- The furniture consists of tables for displaying experiments, cupboards for storage, scientific devices necessary for conducting experiments, and the supervisor's office as shown in Figure 2.18.
- Take into account the insurance of the laboratory against accidents, such as fires, by placing fire extinguishers and alarm devices.

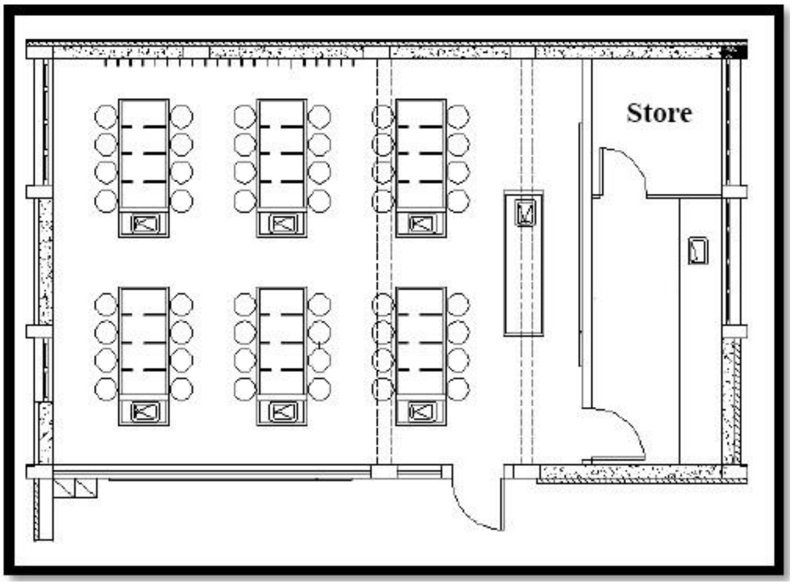


Figure 2.18. Laboratory Unit with furniture organization (Neufert, 2012).

❖ **Bathrooms Spaces**

The following should be noted in designing bathrooms:

- Correct orientation to not blow unpleasant odors on the school by placing bathrooms in the east or south direction.
- The number of bathrooms in each school depends on the number of classrooms, the ratio is one bathroom for each class.
- Every two bathrooms has one sink.
- In male schools, urinals are added.
- The sanitary unit must contain a bathroom for people with special needs (handicapped), taking into account the standards for distributing bathroom furniture.
- The dimensions of a single bathroom space (WC) are 1 m * 1.5 m (Neufert, 2012).
- The need for continuous and sufficient ventilation in the bathroom units.
- The necessity of having at least one unit on each floor if the school has several floors.
- Drinking taps and fountains are separated from the toilets.

- Providing a bathroom for people with special needs as shown in Figure 2.19.

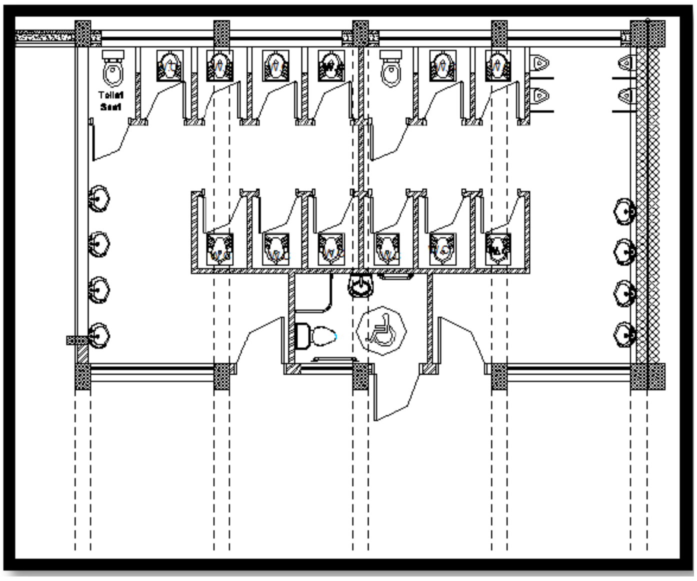


Figure 2.19. Bathroom Unit with sanitary fixtures organization (Neufert, 2012).

❖ **Corridors**

The width of the corridors varies according to the type of school system, if the school is double band, the width of the corridor will be 3.2 meters as shown in Figure 2.20 (a) but if the school is single band, the width of the corridor will be 2.3 meters as shown in Figure 2.20 (b).

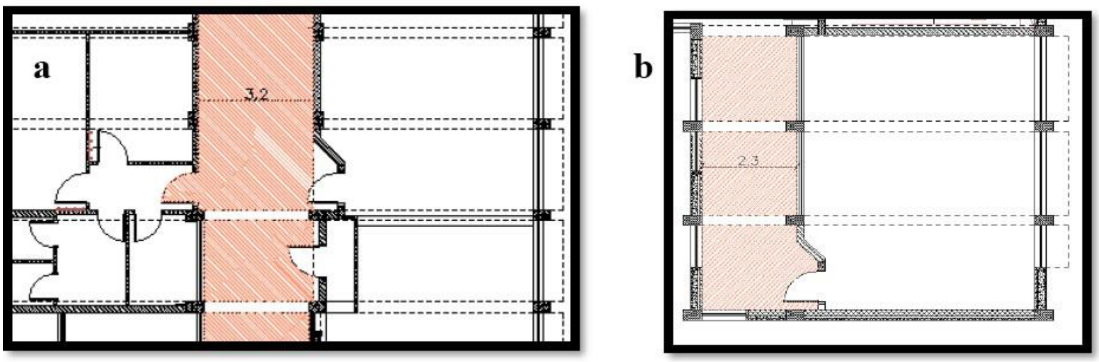


Figure 2.20. a) Width of corridors in double band systems b) Width of corridors single-band systems (Neufert, 2012).

PART 3

MATERIAL AND METHOD

The current research methodology depends mainly on the quantitative approach of the single-objective optimization process. The optimization process was held by using a parametric framework. This framework aims mainly to investigate the impact of building shape and orientation on building energy performance. For that purpose, a case study of the educational structure (primary school) in Aleppo, Syria was selected. Various types of building geometry were proposed in the study, building geometry has a significant effect on energy performance, thus, rectangular shape, L-shape, U-shape, Court shape, and square shape were supposed to complete the scope of the study. Alongside building shape, design variables were considered to be glazing type, building orientation, and glazing ratio or Wall to Window Ratio WWR. For each shape, these variables were considered to be independent variables (IV) alongside the dependent variable (DV) that represents Energy Use Intensity EUI. In this case, EUI was used as an indicator for building performance and will be discussed in the following sections.

The study framework was implemented in a comparative approach to determine the impact of glazing type, building shape, orientation, and WWR on building energy performance. For energy modeling and simulation purpose, the building shapes were modeled and prepared separately using Rhinoceros software (3D modeling tool). Under the umbrella of the Grasshopper tool, a unique parametric algorithm was developed. Ladybug and Honeybee tools were used to conduct the energy modeling of the selected case. Energy plus tool was used to perform the energy simulation. As a result, the selected case was simulated. The value of EUI was obtained to start the optimization process. For the optimization purpose, the Octopus plugin was used to complete the computational process of optimal solutions for each shape. Last but not

At least, Pareto Front Method PFM was used to collect the optimal solutions after 4 generations of the optimization process. Finally, the results of optimal solutions for each shape were analyzed and compared to obtain the recommendations and conclusions that may help architects and designers in the conceptual stage of school design in warm and dry climate regions.

3.1. MATERIAL

This part will explore the used materials in the study. The selected case study that will be used to achieve the scope of this research will be introduced. The climate properties and location of the existing building as well as its construction properties, building shape, and orientation will be explained. Besides, a general description of the used tools will be reviewed.

3.1.1. Case Study

A Primary school building located in Aleppo City- Syria was selected as a case study to apply the scope of the research. The case study represents an existing educational structure in a warm and dry climate. The building is located in the southwestern part of the city of Aleppo- Figure 3.1 (a). The project is built in 2005 and consists of 3 main floors (Ground, First, and second). The school has a rectangular shape floor plan with a length and width is approximately 43.60 and 11.10 meters with a floor area equal to 484 m^2. The height for each level is 3 meters. Figure 3.1(b) shows the main facade of the school that is oriented in the western direction.

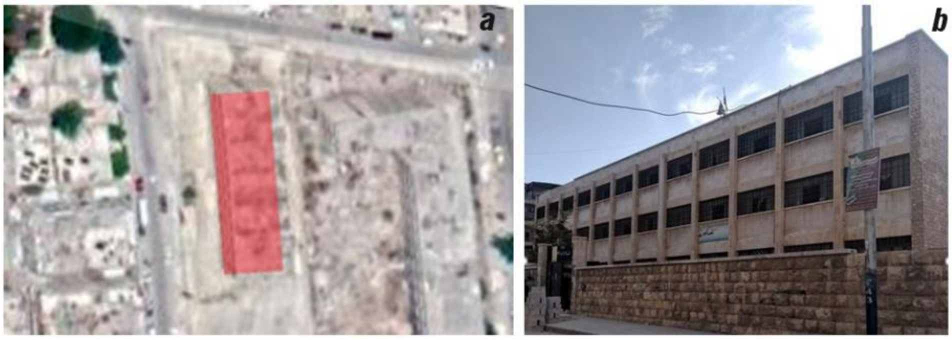


Figure 3.1. a) Aerial photo of the selected case b) Front elevation of the case.

3.1.1.1. Climate and Location

Aleppo is found in the Mediterranean at the 36-degree latitude and 37-degree longitude under a broad range of moisture and thermal conditions. It can be considered the coldest region in Syria in the winter period (URL 2). The average maximum temperature is about 24 C°. Figure 3.2 provides the hours of sunshine per day, the rainy days per month, the precipitation in millimeters per day, and the relative humidity through the months of the year.

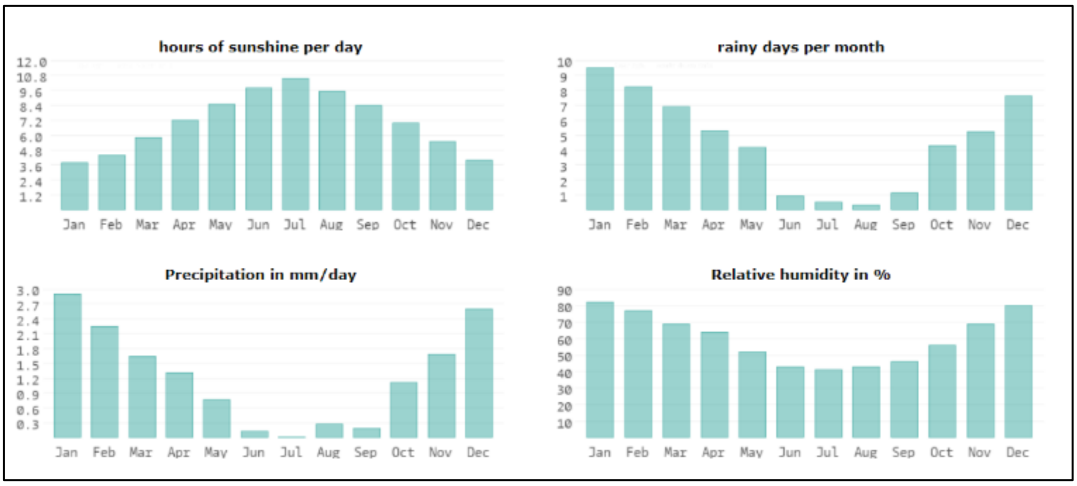


Figure 3.2. Aleppo climate data (URL 2, 2021)

Aleppo is the “largest governorate in terms of area, extension and number of populations with an about two million and three hundred thousand people” (URL 2). Aleppo is the economic capital in Syria, the climate in city of Aleppo is hot and dry in summer and cold in winter. Figure 3.3 represents the dry bulb temperature, the dew point temperature, and the relative humidity in Aleppo climate for the whole year period.

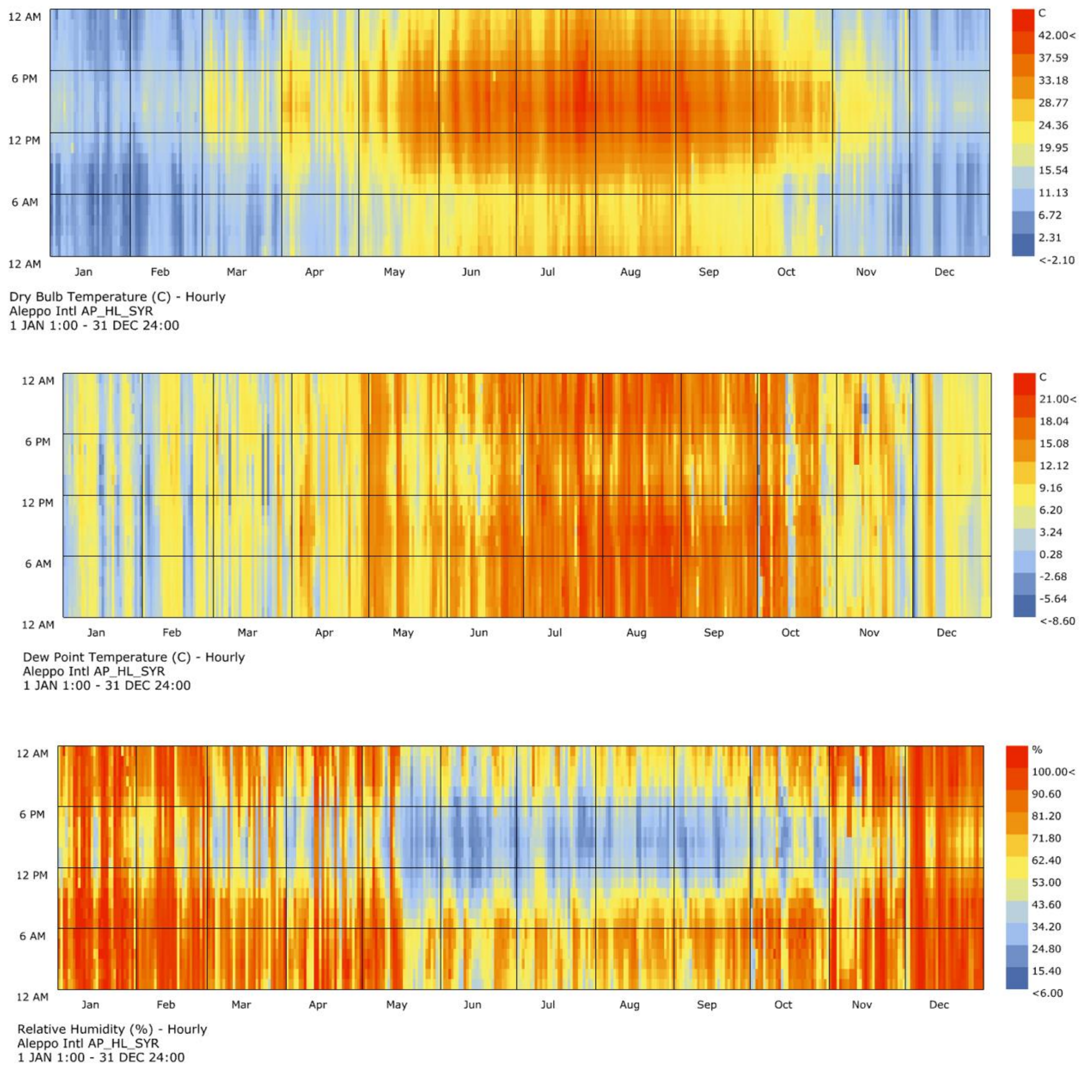


Figure 3.3. a) Representation of the dry bulb temperature b) Representation of the dew point temperature c) Representation of the relative humidity of Aleppo climate.

3.1.1.2. Construction and Glazing Ratio WWR

The building contains three main floors with a floor area equal to 484 m². The ground floor contains the main entrance and classroom spaces while the first and second floor contains multipurpose hall space and classroom spaces located in the east direction and organized in linear form with a single band corridor type with two main staircases at both sides. Figure 3.4 shows the typical plan of the existing building.

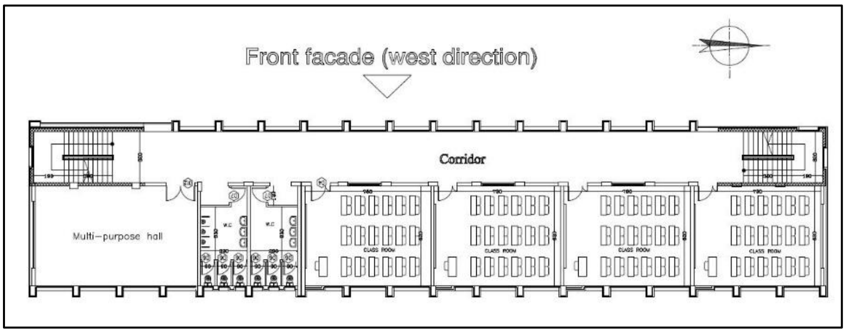


Figure 3.4. A typical plan of the existing school building.

Construction materials

The construction system of the building depends on a skeleton structure of reinforced concrete that contains the main structural material of the columns, beams, and slabs. Natural stone is used as a cladding material for the building façade. The window construction and glazing type used are Aluminum framed Generic PYR B Clear glass "Double glass" with 13 mm middle space. Table 3.1 shows the detailed construction materials used in the building envelope with their thermal properties.

Table 3.1. Construction materials properties of the selected case.

		Layer	**Thickness (m)**	**Thermal conductivity ɣ W/(m.K)**	**U- Value (W/m^2K)**
Walls	**Exterior**	Stone	0.1	0.840	0.350
		XPS Extruded polystyrene	0.795	0.034	
		Concrete block	0.100	0.510	
		Gypsum plastering	0.013	0.400	
		Total thickness	**0.2925**		
Floors		Tile ceramic	0.030	1.30	0.262
		Screed	0.070	0.410	
		cast concrete	0.100	1.130	
		UF Foam	0.1327	0.040	
		Total thickness	**0.3327**		
Roof		Asphalt	0.010	0.700	0.197
		MW Glass wool	0.1445	0.040	
		Aerated Concrete slab	0.200	0.160	
		Gypsum plastering	0.013	0.400	
		Total thickness	**0.3675**		
Glazing Type		Aluminum framed Generic PYR B Clear glass "Double glass" with 13 mm middle space.	**Description:** The glazing type used is an aluminum frame with Generic PYR B Clear glass 3-12-3 double glass with a U value of the middle space: 13 mm- U= 1.987		

Glazing Ratio

The glazing ratio is represented by Wall to Window Ratio WWR in the study. The building's west and east direction have WWR=0.6 while the north and south directions have WWR=0.1 as shown in Table 3.2.

Table 3.2. Glazing ratio for the existing building facades.

	South facade	North facade	West facade	East façade
WWR	0.1	0.1	0.6	0.6

3.1.1.3. Building Shape and Orientation

The shape of the building floors is rectangular and the building is oriented in straight axis with the south-north axis with 0 degrees. The main façade of the building is facing the west direction and is close to the adjacent street where the entrance gate exists. While the shortest dimension of the rectangular shape is facing the south and north direction as shown in Figure 3.5.

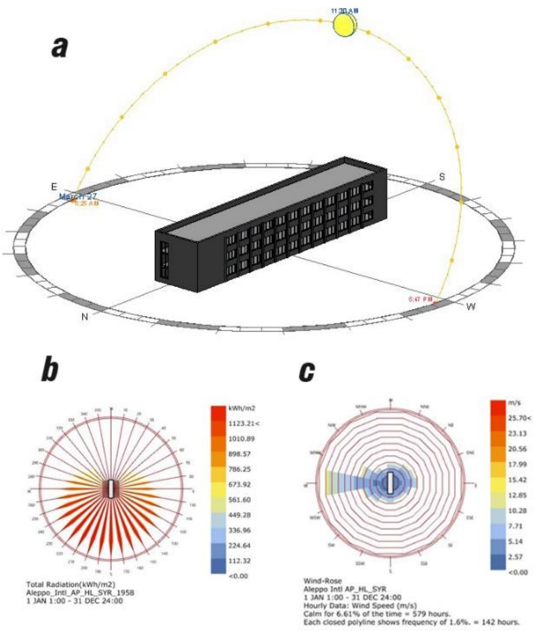


Figure 3.5. a) Orientation and solar direction for the selected case b) Total radiation representation of the selected case c) Wind rose representation of the selected case.

3.1.2. Energy Modeling, Simulation, and Optimization Tools

The study aims to optimize the shape and orientation of school buildings in a warm and dry climate. For that reason, parametric energy modeling and simulation tools were chosen to perform the process and answer the research questions. Using a parametric optimization approach for finding the optimal solutions of shape and orientation in the study area can accelerate the design workflow in the conceptual design stage. Therefore, the study adopted the parametric design approach for Energy modeling, simulation as well as and optimization process. The following explains the used tools in the study in general:

3.1.2.1 Grasshopper

Grasshopper can be considered as one of the visual programming languages VPL tools that run with Rhinoceros 3D software (URL 3). The application allows the user to create algorithms that use numerical values to compute design parameters. The VPL method enables designers to change the design parameters of a certain project or product to select choices and/ or optimize components according to the user target (Zani et al., 2016). Currently, Grasshopper with Rhino is a famous example of a visual programming environment that is based on parametric design basics (Kensek, 2015) and extend to parametric energy modeling using some plugins such as Ladybug, Honeybee for energy modeling (Toutou et al., 2018) and include components for single and multi-objective optimization process such as Galapagos and Octopus using generative algorithms (Zani et al., 2016).

3.1.2.2. Energy plus

Energy Plus™ is a “whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings” (URL 4). Energy plus can read file inputs and output text files. Therefore, Energy plus in the Grasshopper environment is responsible to read the inputs from Ladybug and

Honeybee plugins and run the simulation to output the desired results for the user. Figure 3.6 illustrates a sample simulation workflow in Rhino-Grasshopper.

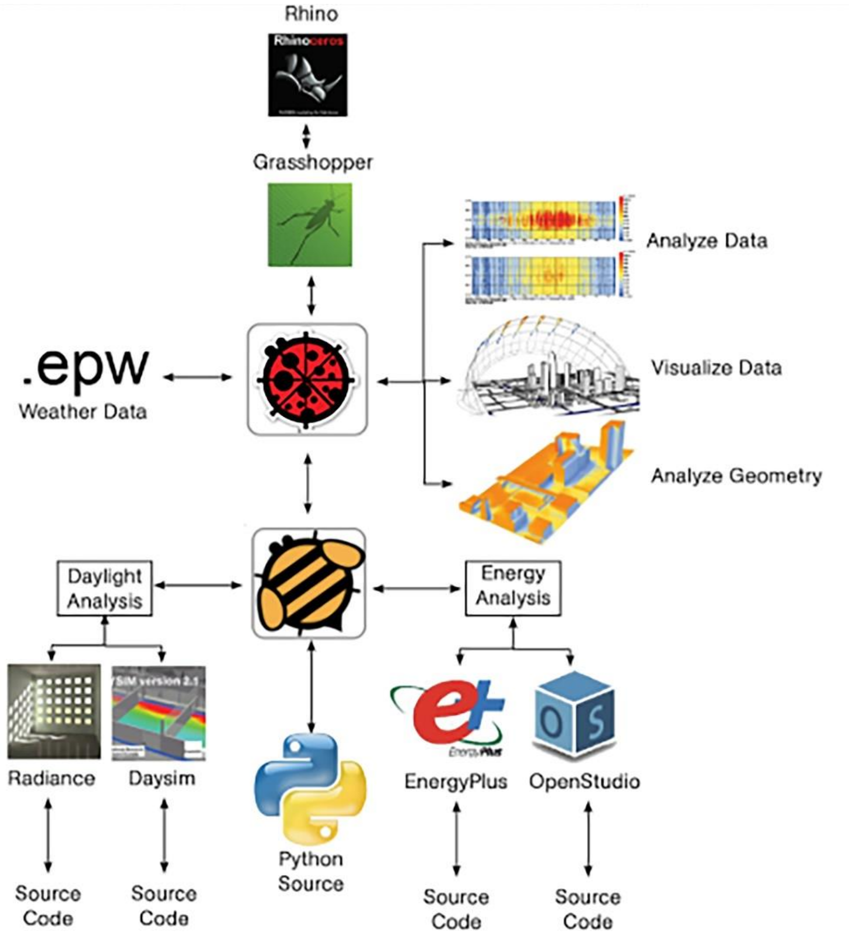


Figure 3.6. Sample simulation workflow in Rhino-Grasshopper (URL 5).

3.2. METHOD

The methodology used in the study depends on creating a unique parametric algorithm using parametric energy modeling and simulation tools. For the optimization purpose, the design parameters (fixed and variables) had been determined. Accordingly, the methodology had been divided into 4 main stages. The first stage represented the shape generation phase that included the assumptions of shape geometry to be used in the study. Five main shape geometry had been suggested. Rectangular shape, L-shape, U-shape, Court shape, and square shape had been suggested as shown in Figure 3.7. The rectangular shape represented in the base case will also enter the optimization process. At the end of this phase, the 3D geometries of the shapes were prepared **with the same**

area of the base case. The second stage of the study represented the energy modeling of the geometry. For that purpose, the Grasshopper tool in with conjunction by Ladybug and Honeybee plugins was used to create the analytical zones for each shape in the same canvas in Rhinoceros software. The zone program, occupancy, heating, and cooling setpoints, and construction materials were determined. Finally, the analytical zones were prepared to be simulated. The third stage represented energy simulation. For this purpose, Energy plus tool was used to simulate the prepared zones. The Energy Use parameter was assigned to the simulation outputs. At the end of this stage, the Energy Use Intensity EUI was calculated for each shape using the energy simulation outputs component. The final stage of the study represented the optimization process. In this phase, the independent design variables represented the orientation and the glazing ratio WWR while the dependent variable represented the EUI for each shape. In the end, the optimal possible solutions for each shape were determined with the optimal WWR and orientation angle from the North-South direction. The results were collected and analyzed in a comparative approach. The objective function to select the optimal solution was determined to minimize EUI and maximize North WWR as much as possible. Recommendations and conclusions were drawn to help architects and designers of school buildings in warm and dry climate regions.

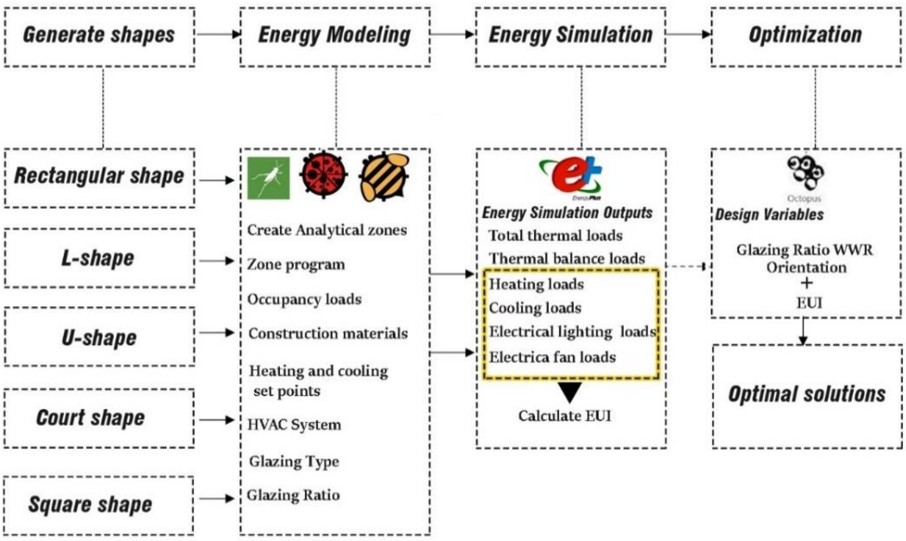


Figure 3.7. Method stages.

3.2.1. Shape Generation and Scenarios

The school building form has a significant effect on its energy performance. Architects and designers at this stage are restricted by many factors. Some of these factors are related to the functional design requirements while others are related to the built environment. Many shapes and forms can be suggested in school buildings as mentioned in Chapter 2. However, for the study, five main building forms had been suggested. These shapes are assumed to maintain the **same floor area** with the same main spaces (Corridor and classrooms). In the study, simple rectangular shape, L-shape, U-shape, court shape, and square shape were assumed and modeled in Rhinoceros software as shown in Figure 3.8. It is worth mentioning here that the glazing ratio and orientation for each base case of suggested shapes were assumed to be the same as the base case of the existing buildings as mentioned in section 3.1.1 and shown in Figure 3.8 and Table 3.3 respectively. According to the previous mentioned, the scenarios of the study will be as the followings:

Scenario 1: Changing shape geometry

This scenario includes changing the existing case shape **(rectangular shape)** with 44m length and 10 m width and height of 12 m that represents the three floors of the school to L-shape, U-shape, Court shape, and square shape. The dimensions of the suggested shapes were determined to **save the same area in the existing case** as shown in Figure 3.8.

Scenario 2: Changing glass type

This scenario includes changing the existing glass type from double Generic PYR B Clear glass with U-value= 1.987 W/m²K to double low-E glass with U-value= 0.27 and the same thicknesses for the existing and the suggested shapes.

Scenario 3: Changing Glazing Ratio and building orientation

This scenario includes changing the glazing ratio WWR from the existing ratios in each direction. The new suggested values range between 0.1-0.9 with an increment of 0.01 for the existing and suggested shapes. Moreover, this scenario includes changing the building orientation from the existing orientation degree. The new suggested values range between 0-180° for the existing and suggested shapes. For that reason, this scenario will enter an optimization process.

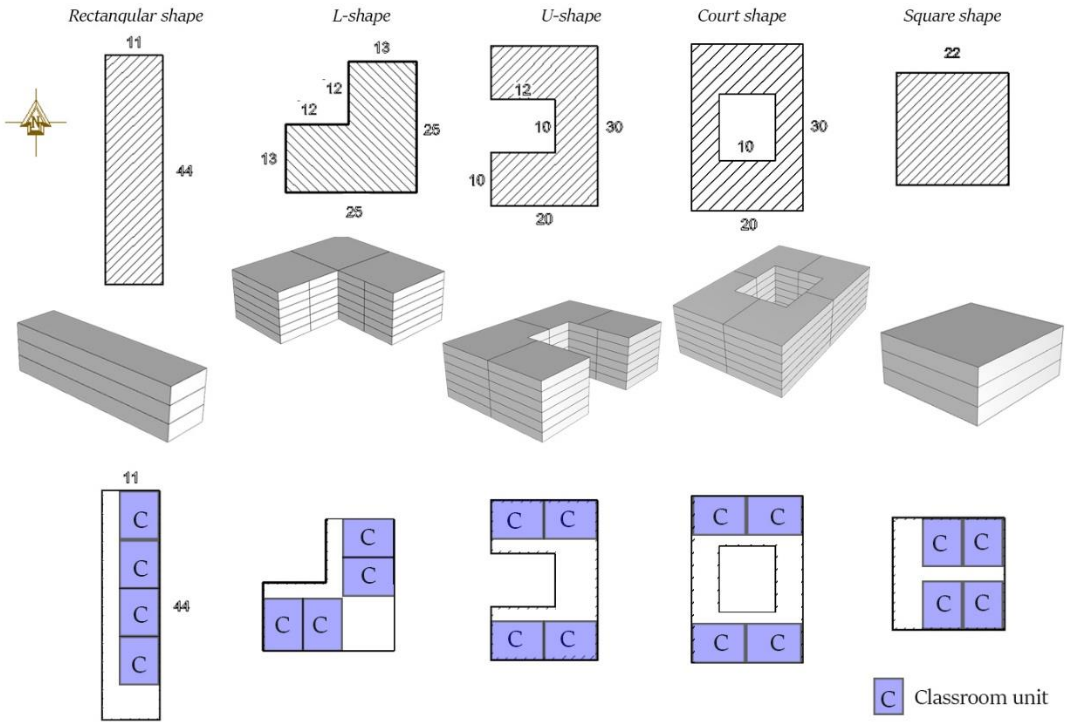
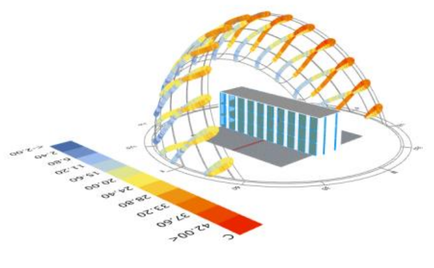


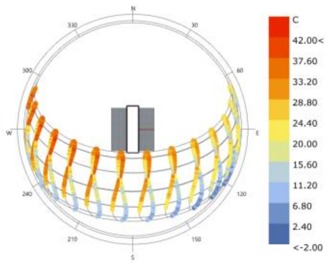
Figure 3.8. Typical shapes were used in the study.

Table 3.3. Base cases of suggested shapes.

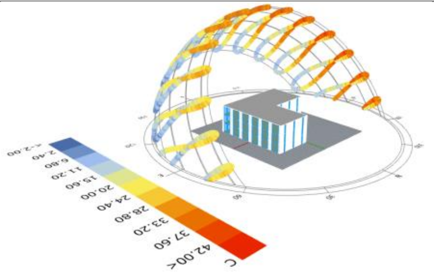
South WWR	North WWR	West WWR	East WWR	Orientation
0.1	0.1	0.6	0.6	0°

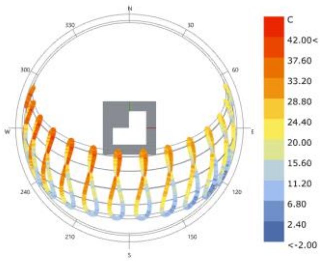
Base Case of Rectangular shape (Existing building)



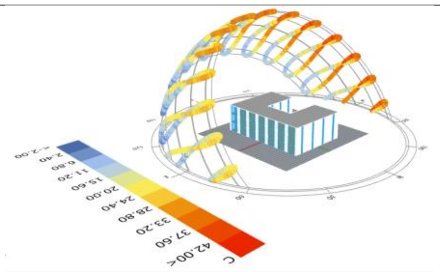


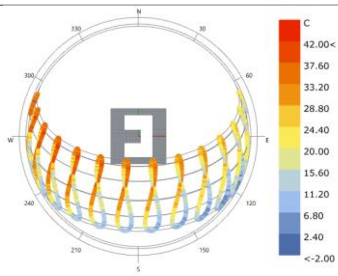
Base Case of L-shape



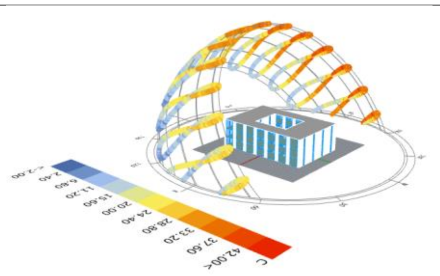


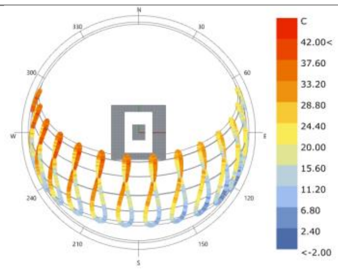
Base Case of U-shape



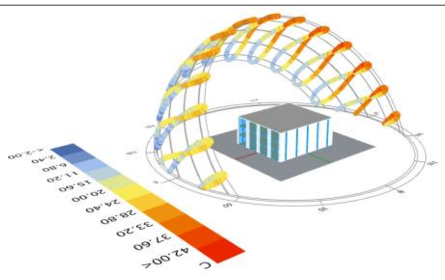


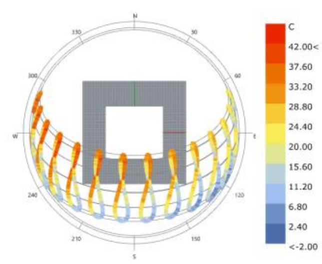
Base Case of Court shape





Base Case of Square shape





3.2.2. Energy Modelling

The energy modeling process started by creating the analytical zones of the three main floors of the school buildings. In the study, two main zones were assumed to have a significant effect on energy performance. These two zones are represented by classroom spaces and corridors. Accordingly, the analytical zones for each generated shape were prepared using Ladybug and Honeybee plugins under the umbrella of the Grasshopper tool. In this stage, a zone program is assigned to each zone with a primary school zone program- See Appendix A. The adjacent surfaces between these zones were solved and the glazing ratio (WWR) parameters were created for each façade as in the base case- See section 3.1.1.2. The construction materials and properties and glazing type parameter were assigned to the analytical zones (walls, floors, roofs) with the same properties in the base case of the existing building as mentioned. The heating and cooling temperature set points were determined as 18 and 24 respectively for classroom spaces and 12 and 20 for corridor spaces. These setpoints affect the indoor temperature once the heating and cooling systems are turned on according to ASHRAE standards. In the end, the analytical zones were modeled and ready to be simulated. It is worth mentioning here that Construction materials and other zone properties will be fixed in the energy simulation and optimization process. Only three design parameters will vary in the optimization process. These variables are the glazing type, orientation, and WWR for each shape and will be discussed in the following sections. In addition, Classrooms and corridor spaces are assumed to be in the same direction as the existing building as shown in Figure 3.4 where classroom spaces are facing the east direction and corridors are facing the west direction.

3.2.3. Energy Simulation

The analytical zones for each shape were prepared using the Honeybee plugin. The weather data file of Aleppo city was imported using the Ladybug plugin. The analysis period was assigned through Ladybug- Analysis period component from January to December. The zones are ready to be simulated in the climate of Aleppo. The simulation outputs were determined using the Honeybee-Generate EP Output component as zone energy use. The simulation process was run and the output represented total thermal loads, thermal load balance, heating loads, cooling loads, electric lighting, and fan electric loads. Thus, the energy simulation process has ended and the next step is optimization. It is worth mentioning here that the study is using EUI as an indicator of building energy performance. Hence, the sum value for heating, cooling, electrical lighting, and fan electric loads are summed and EUI was calculated for each shape to be used as a dependent variable number in the optimization process in the analytical period.

3.2.4. Optimization Process

In the optimization process of building shape, there are many conflicting parameters. For this reason, design variables were considered to be building orientation and glazing ratio. Other design parameters were fixed in the suggested shapes of the building.

In any optimization process, there will be independent variables and dependent variables to optimize accordingly (Khan, 2018). In the study, the main variables of the optimization process have been determined as the followings:

- Building Orientation: Independent Variable
- Glazing Ratio or Wall-to-window Ratio WWR: Independent Variable.
- Energy Use Intensity EUI: Dependent Variable

Energy Use Intensity *(EUI)* expresses "the total energy use of building comparative to its gross floor area". Hence, EUI can be an indicator of building energy performance. It is usually calculated by dividing the total energy that a building consumes in a year by its floor area measured in kWh/m²/year (Khan, 2018). In the study, EUI is considered as the dependent variable in the optimization process. Octopus plugin which helps in optimizing design parameters in the Grasshopper tool was used to find the logical balance between EUI, WWR, and building orientation angles as shown in Figure 3.9. WWR parameter ranges between 0.1-0.9 while Building orientation angle parameter ranges between 0-180° from the north-south direction. EUI is a dependent variable that varies according to the energy simulation process outputs of Energy plus engine- See Appendix A.

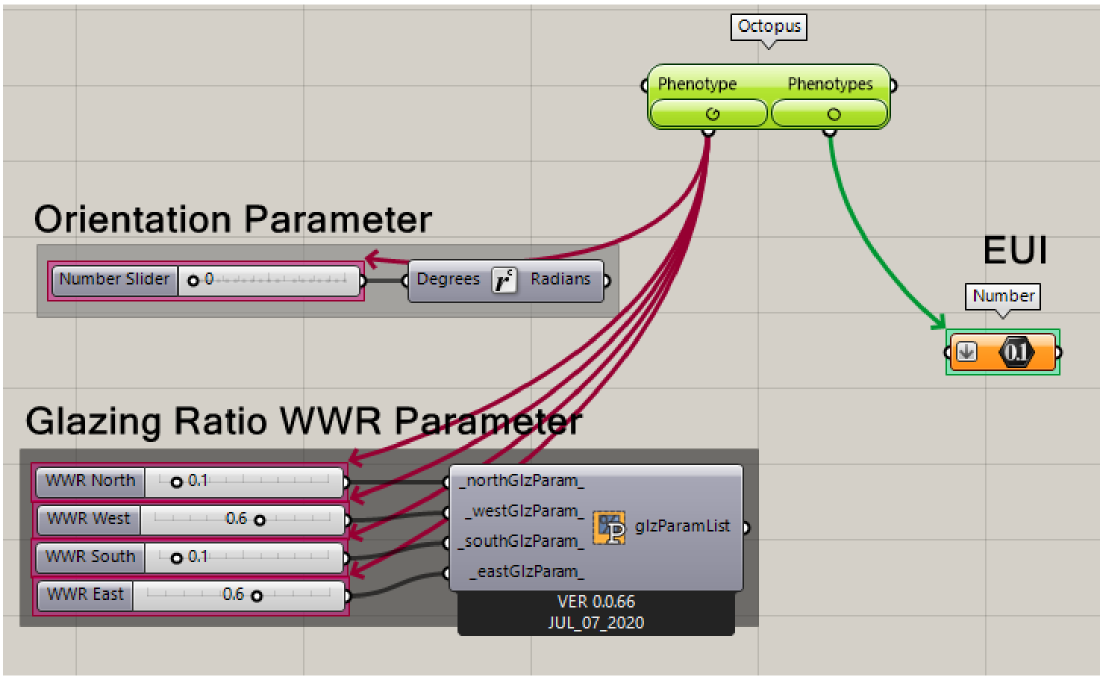


Figure 3.9 Octopus plugin inputs.

PART 4

RESULTS AND DISCUSSION

In this chapter, the results of the method adopted in Chapter 3 will be introduced. First, the optimization procedure will be introduced by exploring the generation of optimal solutions. Then, the results of optimal solutions will be presented to have a big picture which from we can analyze the obtained data to reach conclusions and recommendations.

4.1. GLAZING TYPE SCENARIO RESULTS

The scenario of changing glass type was conducted to the existing case as well as the suggested shapes. Energy simulation of the suggested shapes was held using Energy plus in Grasshopper. The results of the energy simulation showed that by changing glass type from double Generic PYR B Clear glass with U-value= 1.987 W/m²K to double low-E glass with U-value= 0.27, the EUI of rectangular shape decreased from 436.28 kWh/m² to 326.25 kWh/m². For L-shape, U shape, Court shape, and Square shape, the values of EUI were decreased from 346.89, 370.48, 400.52, 315.48 kWh/m² to 293.12, 306.07, 315.64, and 271.74 respectively as shown in Table 4.1 and Figure 4.1. Low-e glass type has a considerable effect in decreasing energy consumption in school buildings.

Table 4.1. Results of EUI by changing glass type of suggested shapes

Glass type	**EUI value for existing and suggested shapes kWh/m²/year**				
	Rectangular	L-shape	U-shape	Court shape	Square shape
Existing glass type	436.28	346.89	370.48	400.52	315.48
Double low e glass	326.25	293.12	306.07	315.64	271.74

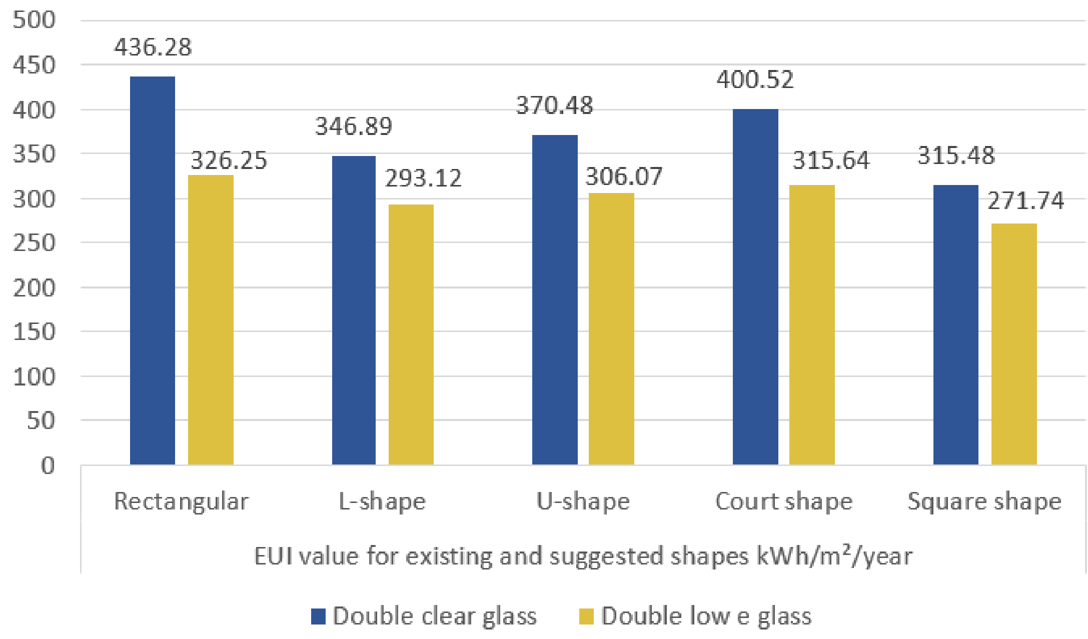


Figure 4.1. Results of changing Glass type.

4.2. ORIENTATION AND WWR SCENARIOS RESULTS

After changing the glass type to the existing and the suggested shapes. The new values of EUI for each building shape were considered to enter the optimization process of orientation and WWR scenarios. The main aim of this successive procedure is to determine the difference in EUI value for the optimal solutions for each shape compared to the existing case results. The following sections explore the results of the optimization process.

4.2.1. Generation of Optimal Solutions

As mentioned in Chapter Three, the optimization process variables (dependent and independent) were determined. The optimization process in its parametric framework depended on using the Octopus plugin in the Grasshopper tool. In the optimization process, Octopus is trying to find the logical balance between these input variables. After the energy simulation is ended for each shape, the total thermal loads were obtained. This total included **heating loads, cooling loads, electrical lighting, and electric fan loads**. Before thinking about the optimization process, EUI was calculated for each base case of the suggested shapes using equations in the Grasshopper environment by summing the annual thermal loads that the building consumes and dividing them on the floor area for each shape that is fixed for all. Accordingly, the input variables of the Octopus plugin were prepared and ready to start the optimization process.

Octopus plugin was running for 24 hours within the analysis period from January to December. During this period, many solutions were generated. About 4 generations were produced with more than 180 solutions for each shape. The optimal solutions were also allowed to be **genetic diversity** mode that gives octopus the authority to discard an optimal solution if the more fitted solution was found and achieved the balance between the input variables in the next generation. The generations of optimal solutions were represented by the **Pareto front*** graph as shown in Figure 4.2 for the rectangular shape and **Appendix B** for the L-shape, U-shape, Court shape, and square shape respectively.

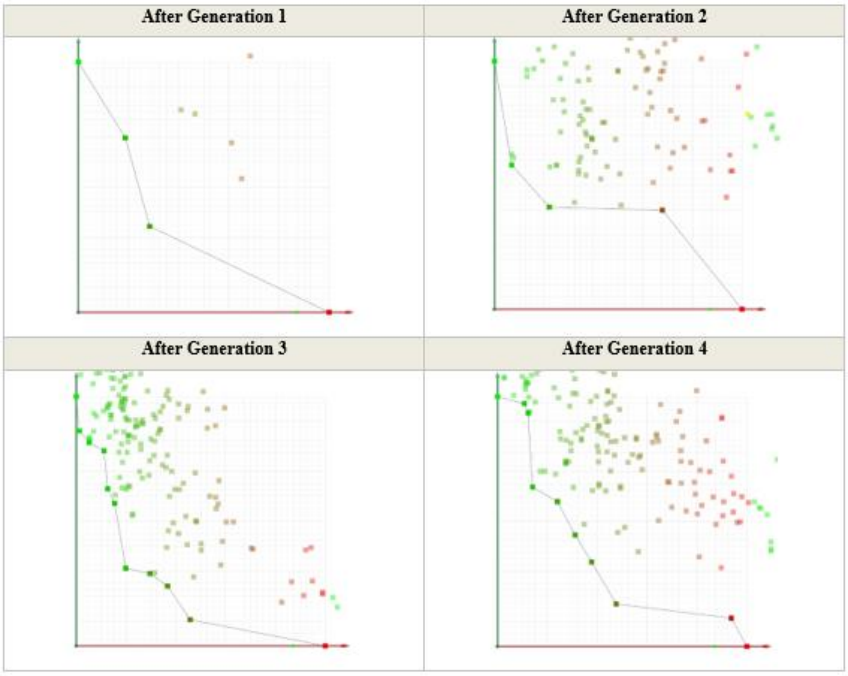


Figure 4.2. Generations of optimal solutions for the rectangular shape.

*** Pareto front** is a "set of nondominated solutions, being chosen as optimal if no objective can be improved without sacrificing at least one other objective. On the other hand, a solution x* is referred to as dominated by another solution x if, and only if, x is equally good or better than x* concerning all objectives" (URL 6).

While the generations were produced, some of them have optimal solutions that are fitter than the previous one. These solutions are represented as Pareto Front graph which contains two main axes in the single-optimization process as shown in Figure 4.3. The X-axis represents the EUI while the Y-axis represents the genetic diversity for choosing the fitter optimal solution in the next generation. In the Pareto front optimal graph, the fittest solution should be located on and near the Pareto Front 2D line that represents the fittest optimal solutions that achieve the balance between the input variables. Figure 4.3 shows examples of Pareto Front optimal solutions for the suggested shapes after the same generation phase.

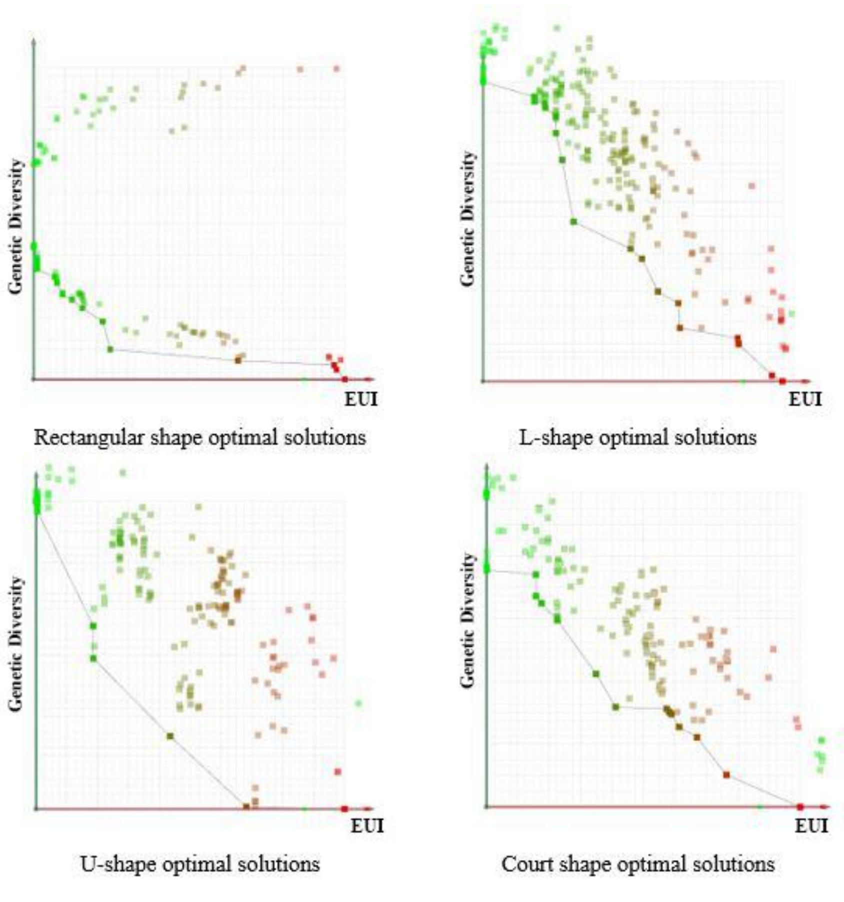


Figure 4.3. Pareto Front optimal line for the suggested shapes.

4.2.2. Optimal Solutions of Suggested Shapes

After 4 generations of the optimal solution for each building shape. More than 180 solutions were produced in each shape. These solutions are filtered by Pareto Front Graph. As mentioned, the fittest solutions are near or on the Pareto front line. Accordingly, Random points (optimal solutions) located on this line were selected for each shape. These points achieve the balance between orientation parameter, Glazing Ratio (WWR), as well as EUI value. The following introduced the results of the optimal solutions for each suggested shape separately.

4.2.2.1. Rectangular Shape Results

The results of energy simulation of the base case of rectangular shape (existing case with Low-E glass type) indicated that the Energy Use Intensity EUI is **336.25 kWh/m²/year**. As shown in Figure 4.4, the lowest value of EUI that achieved rectangular shape optimal solutions is 302.32 kWh/m²/year while the highest value is 318.15 kWh/m²/year as shown in Figure 4.3. 11 optimal solutions located on Pareto Front optimal line- **See Appendix C.** Table 4.2 shows the results of the EUI, WWR, Angle of orientation and graphical representation for the selected optimal solutions.

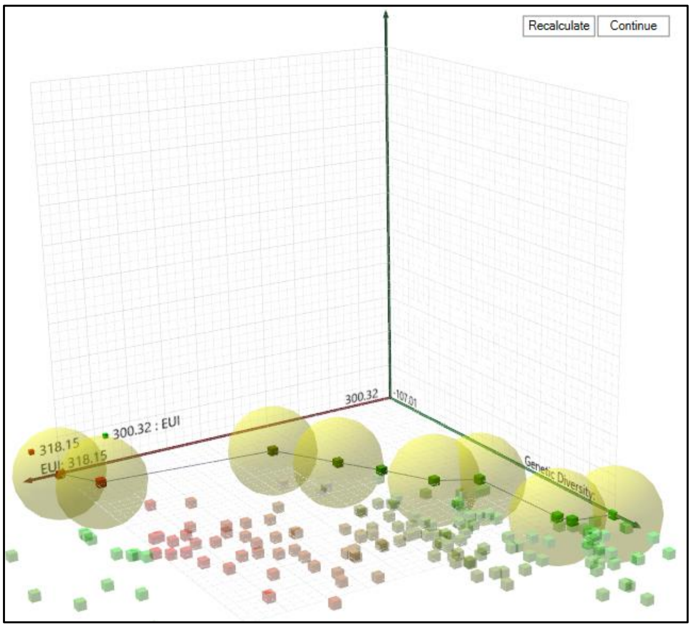


Figure 4.4. Selected optimal solutions of rectangular shape.

* X-axis: EUI, Y-axis: genetic diversity, green cubes: Orientation> WWR, red cubes: WWR> Orientation, brown cubes: Balance between WWR and Orientation.

Table 4.2. Rectangular shape base case and selected optimal solution results.

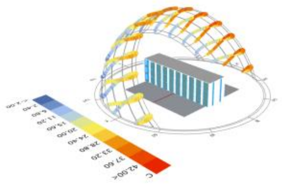
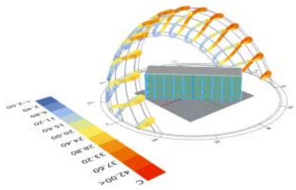
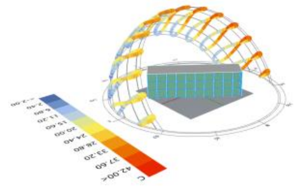
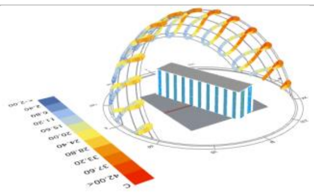
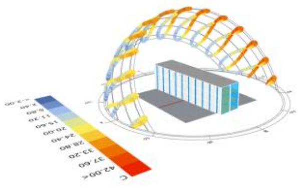
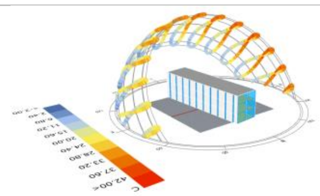
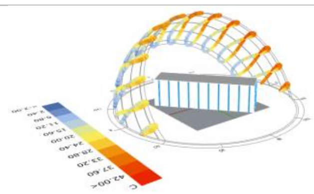
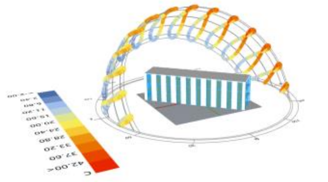
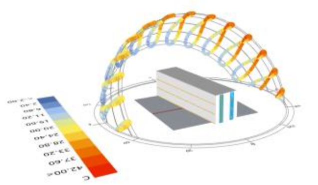
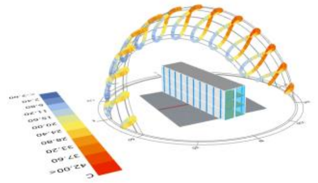
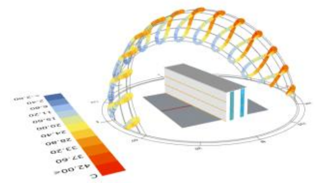
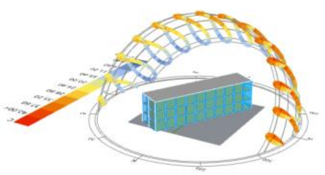
	EUI	North WWR	West WWR	South WWR	East WWR	Orientation	Representation
Base Case	**326.25**	**0.10**	**0.60**	**0.10**	**0.60**	**0°**	
1	**305.87**	0.10	0.50	0.10	0.90	44°	
2	**318.14**	0.90	0.25	0.85	0.1	52°	
3	**303.69**	0.46	0.63	0.10	0.36	18°	
4	**303.36**	0.42	0.90	0.09	0.12	5°	
5	**307.04**	0.90	0.90	0.3	0.10	6°	
6	**302.63**	0.38	0.70	0.10	0.10	41°	

Table 4.2. (continues)

7	**317.02**	0.90	0.4	0.85	0.14	45°	
8	**302.23**	0.30	0.94	0.10	0.0	8°	
9	**308.80**	0.8	0.10	0.92	0.11	9°	
10	**300.31**	0.30	0.85	0.04	0.0	0.5°	
11	**304.59**	0.67	0.93	0.85	0.10	6°	

4.2.2.2. L Shape Results

The results of the energy simulation of the base case of L shape indicated that the Energy Use Intensity EUI is **293.12 kWh/m²/year.** As shown in Figure 4.5, the lowest value of EUI achieved in the L shape optimal solutions is 283.11 kWh/m²/year while the highest value is 305.49 kWh/m²/year. 7 optimal solutions located on Pareto Front optimal line- **See Appendix C.** Table 4.4 shows the results of the EUI, WWR, Angle of orientation, and graphical representation for the selected optimal solutions of L shape.

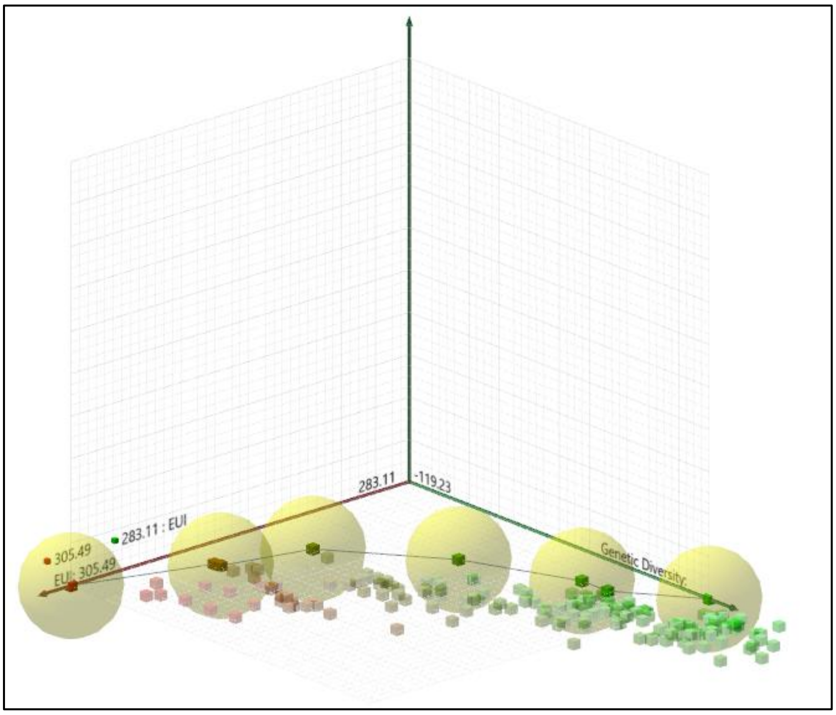


Figure 4.5. Selected optimal solutions of L shape.

Table 4.3. L shape base case and selected optimal solution results.

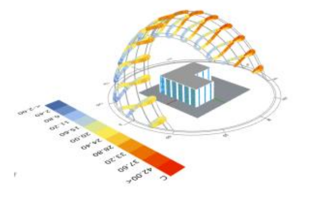
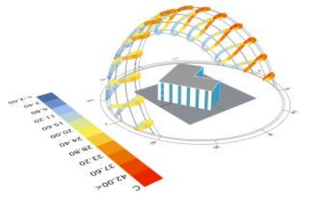
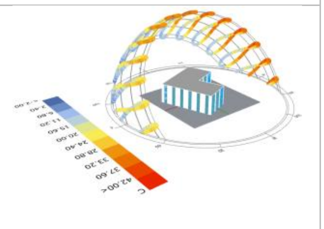
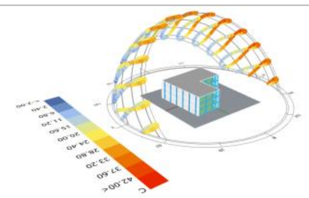
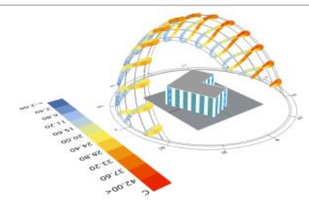
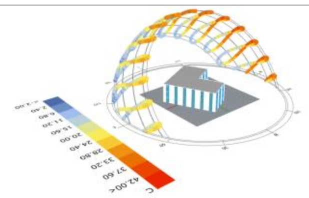
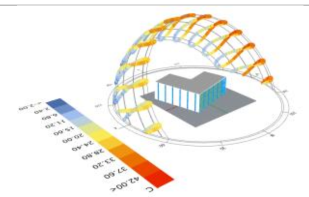
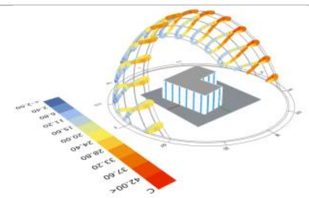
	EUI	North WWR	West WWR	South WWR	East WWR	Orientation	Representation
Base Case	**293.12**	**0.10**	**0.60**	**0.10**	**0.60**	**0°**	
1	**293.05**	0.92	0.87	0.10	0.30	28°	
2	**286.11**	0.62	0.92	0.10	0.25	21°	

Table 4.3. (continues)

3	**298.038**	0.94	0.10	0.23	0.10	3°	
4	**305.48**	0.44	0.12	0.13	0.54	53°	
5	**288.65**	0.38	0.46	0.62	0.30	26°	
6	**283.10**	0.94	0.95	0.94	0.13	105°	
7	**298.12**	0.18	0.04	0.10	0.14	8°	

4.2.2.3. U Shape Results

The results of the energy simulation of the base case of U shape indicated that the Energy Use Intensity EUI is **306.07 kWh/m²/year**. As shown in Figure 4.6, the lowest value of EUI achieved in the U shape optimal solutions is 293.71 kWh/m²/year while the highest value is 322.03 kWh/m²/year. 10 optimal solutions located on Pareto Front optimal line- **See Appendix C.** Table 4.4 shows the results of the EUI, WWR, Angle of orientation, and graphical representation for the selected optimal solutions of U shape.

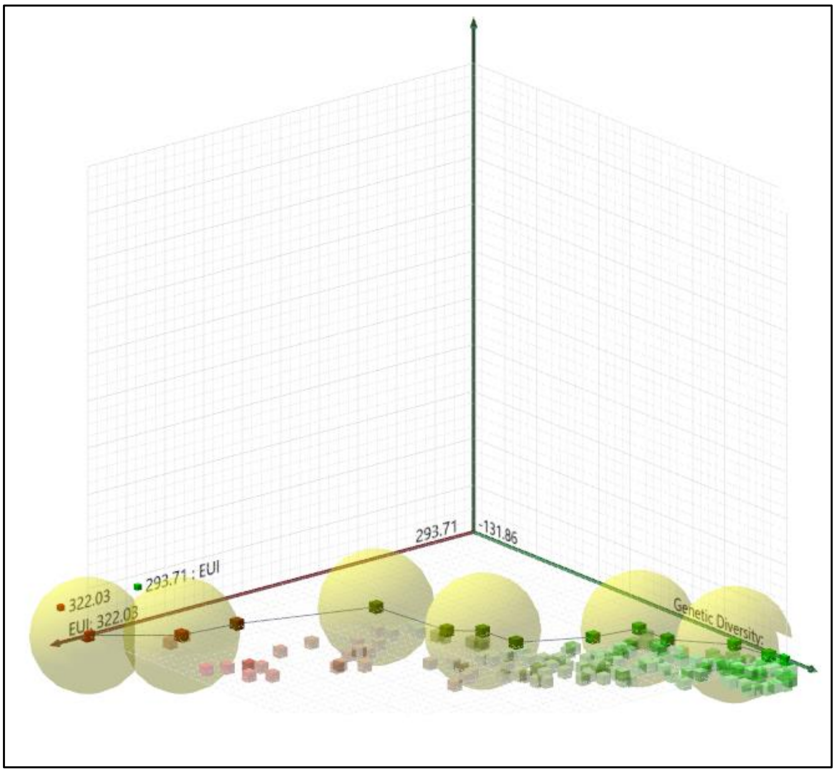


Figure 4.6. Selected optimal solutions of U shape.

Table 4.4. U shape base case and selected optimal solution results.

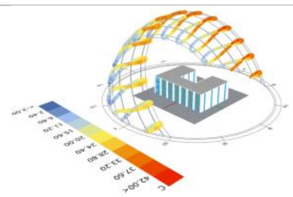
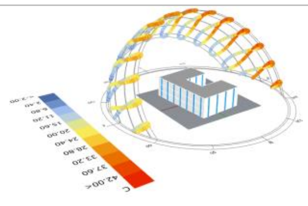
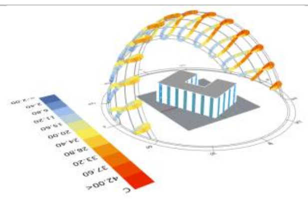
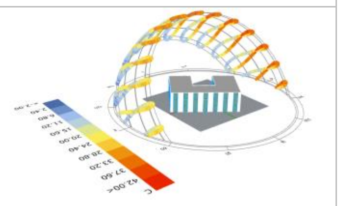
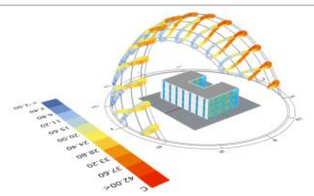
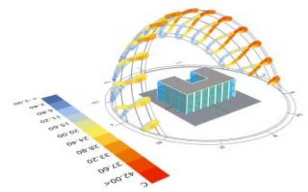
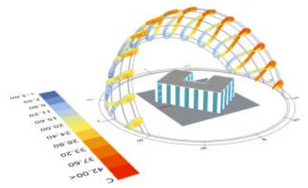
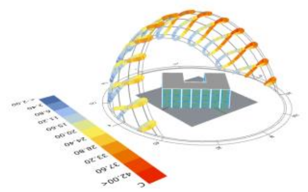
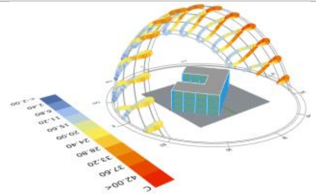
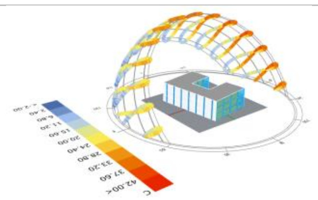
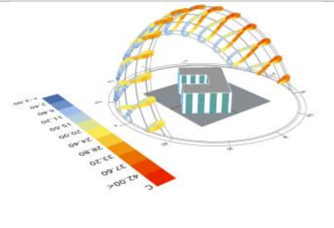
	EUI	North WWR	West WWR	South WWR	East WWR	Orientation	Representation
Base Case	**306.07**	**0.10**	**0.60**	**0.10**	**0.60**	**0°**	
1	**296.88**	0.10	0.13	0.92	0.08	5°	
2	**293.70**	0.20	0.10	0.11	0.30	22°	

Table 4.4. (continues)

3	**314.16**	0.44	0.06	0.20	0.91	54°	
4	**317.08**	0.94	0.93	0.70	0.20	4°	
5	**304.86**	0.67	0. 20	0.92	0.88	91°	
6	**294.41**	0.41	0.37	0.25	0.35	34°	
7	**306.17**	0.83	0.5	0.09	0.12	52°	
8	**322.02**	0.84	0.44	0.94	0.91	128°	
9	**303.85**	0.93	0.94	0.85	0.19	9°	

10	**305.60**	0.57	0.87	0.21	0.1	145°	

4.2.2.4. Court Shape Results

The results of the energy simulation of the base case of Court shape indicated that the Energy Use Intensity EUI is **315.64 kWh/m²/year**. As shown in Figure 4.7, the lowest value of EUI that achieved in the Court shape optimal solutions is 296.45 kWh/m²/year while the highest value is 312.50 kWh/m²/year. 7 optimal solutions located on Pareto Front optimal line- **See Appendix C.** Table 4.5 shows the results of the EUI, WWR, Angle of orientation, and graphical representation for the selected optimal solutions of Court shape.

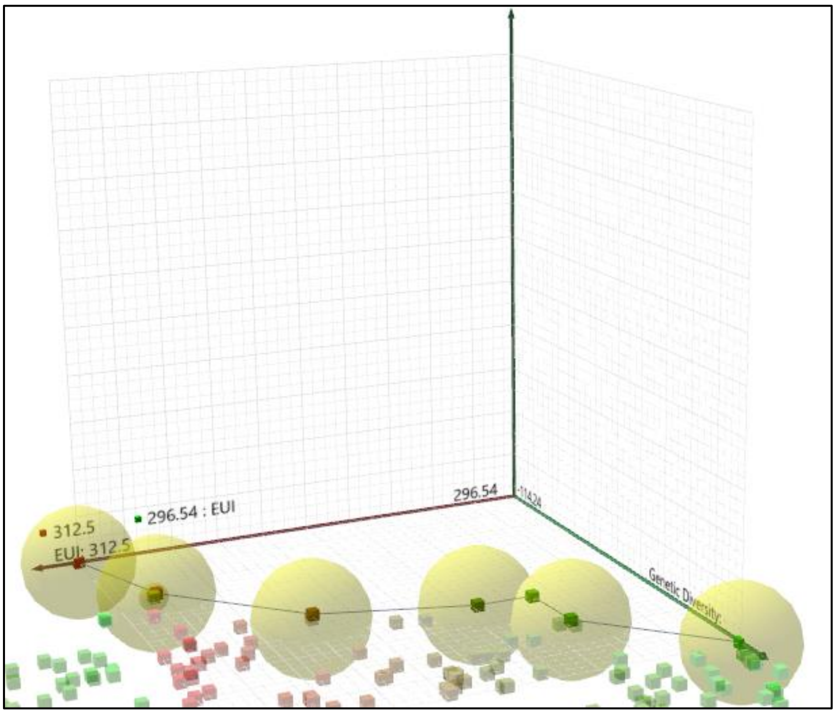


Figure 4.7. Selected optimal solutions of Court shape.

Table 4.5. Court shape base case and selected optimal solution results.

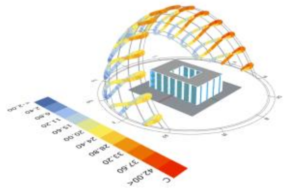
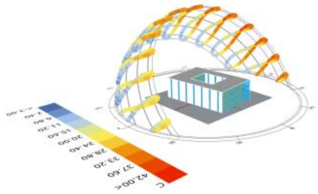
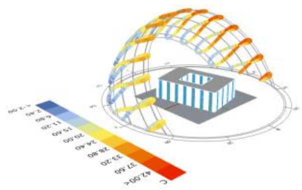
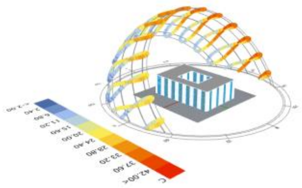
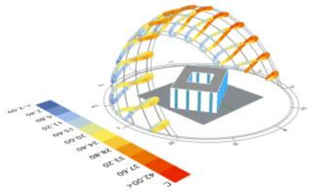
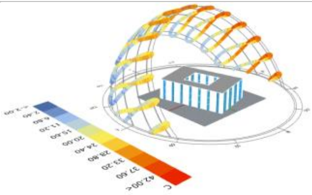
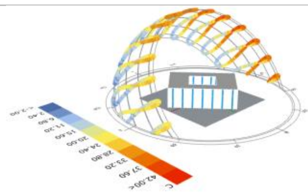
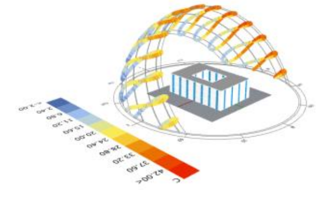
	EUI	North WWR	West WWR	South WWR	East WWR	Orientation	Representation
Base Case	**315.64**	**0.10**	**0.60**	**0.10**	**0.60**	**0°**	
1	**307.23**	0.1	0.93	0.94	0.12	7°	
2	**302.32**	0.1	0.98	0.84	0.3	13°	
3	**300.43**	0.18	0.93	0.9	0.4	3°	
4	**312.50**	0.35	0.99	0.85	0.14	121°	
5	**300.26**	0.39	0.49	0.31	0.15	14°	
6	**311.04**	0.3	0.9	0.8	0.1	43°	

Table 4.5. (continues)							
7	**296.53**	0.05	0.93	0.13	0.16	2°	

4.2.2.5. Square Shape Results

The results of the energy simulation of the base case of square shape indicated that the Energy Use Intensity EUI is **271.74 kWh/m²/year**. As shown in Figure 4.8, the lowest value of EUI achieved in the Square shape optimal solutions is 262.96 kWh/m²/year while the highest value is 278.67 kWh/m²/year. 8 optimal solutions located on Pareto Front optimal line- **See Appendix C.** Table 4.6 shows the results of the EUI, WWR, Angle of orientation, and graphical representation for the selected optimal solutions of square shape.

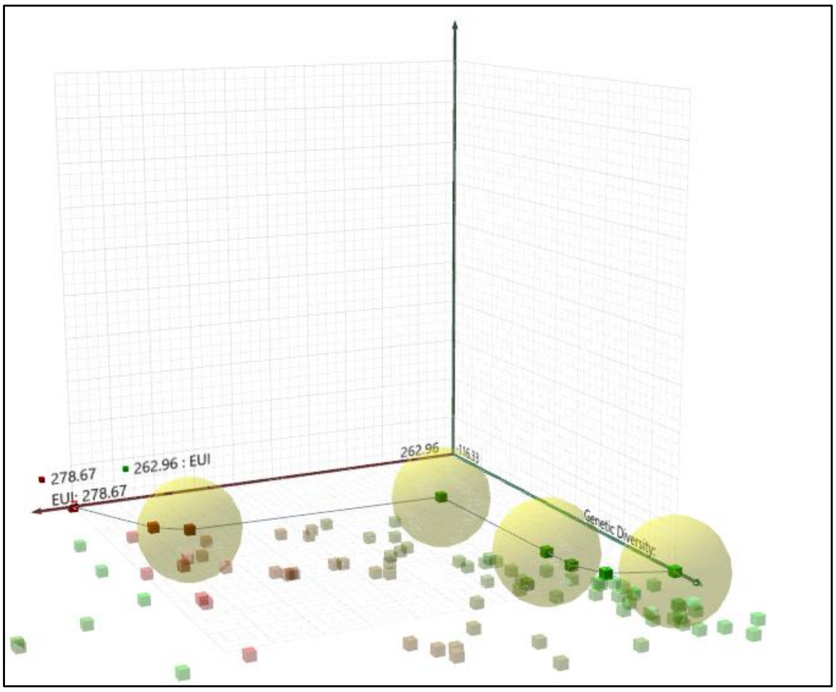


Figure 4.8. Selected optimal solutions of Square shape.

Table 4.6. Square shape base case and selected optimal solution results.

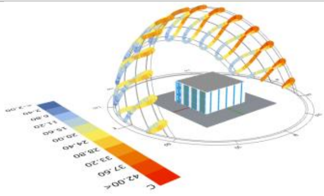
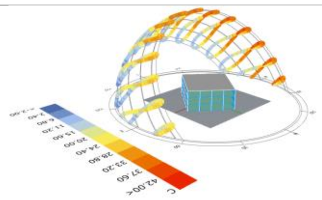
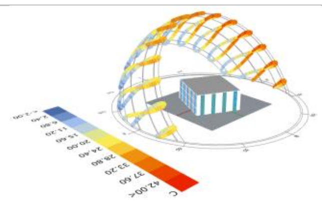
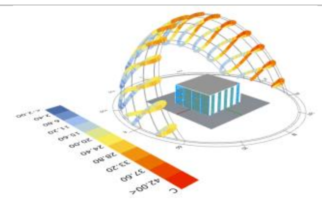
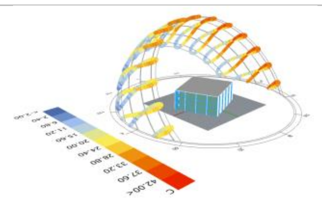
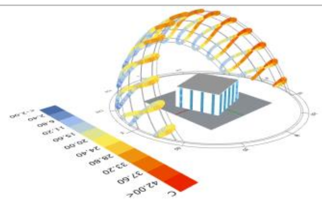
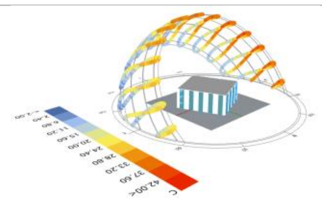
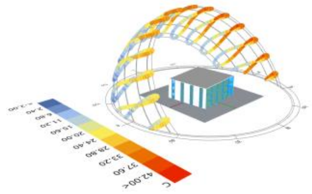
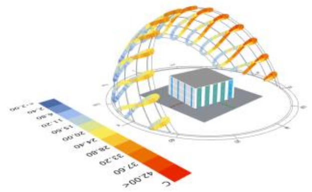
	EUI	North WWR	West WWR	South WWR	East WWR	Orientation	Representation
Base Case	**271.74**	**0.1**	**0.6**	**0.1**	**0.6**	**0°**	
1	**265.09**	0.86	0.96	0.14	0.05	52°	
2	**264.32**	0.22	0.87	0.14	0.01	65°	
3	**332.65**	0.36	0.42	0.84	0.86	2°	
4	**354.43**	0.17	0.14	0.46	0.90	22°	
5	**264.16**	0.38	0.47	0.25	0.15	17°	
6	**269.64**	0.50	0.62	0.13	0.38	114°	

Table 4.6. (continues)							
7	**262.95**	0.88	0.92	0.1	0.25	7°	
8	**275.67**	0.54	0.3	0.25	0.1	170°	

4.3. DISCUSSION AND ANALYSIS OF THE RESULTS

The study established a parametric framework for optimizing the most important design parameters that affect energy use in school buildings. The study of energy efficiency in buildings requires an extensive amount of data. Buildings require energy for heating, cooling, lighting, refrigeration, ventilation, and other services (Khan, 2018). However, this amount of energy is determined by the type of building and its operation and occupancy work hours. In that case, energy simulation can help in determining the energy use of buildings. The current research explored the school buildings' energy use. The suggested parametric workflow helped in optimizing the shape, orientation, and glazing ratio parameters in the early design phases that can have a significant effect on building energy performance in the operation phases of school buildings.

This section discusses the results obtained in the previous section starting by exploring the results of the base case for each shape as well as the results of the optimization process for each suggested shape.

As shown in Figure 4.1, changing the shape geometry from a rectangular shape to L-shape with the same construction and functional properties achieved up to 20.4% improvement in energy performance while U-shape, Court shape, and Square shape achieved up to 15.0%, 8%, and 27.65% respectively. On the other side, after changing glass type to **Low-E glass in all shapes the improvement in energy performance reached up to** 31.40% in a rectangular shape, 32.80% in L-shape, 29.80% in U-shape, 27.60% in Court shape, and 37.70% in Square shape

It can be concluded that changing glass type of school buildings window construction to **low e** in warm and dry climates have a significant effect on improving building energy performance. Figure 4.9 illustrates the improvement percentage for each shape in energy performance after changing glass type compared to the existing case result.

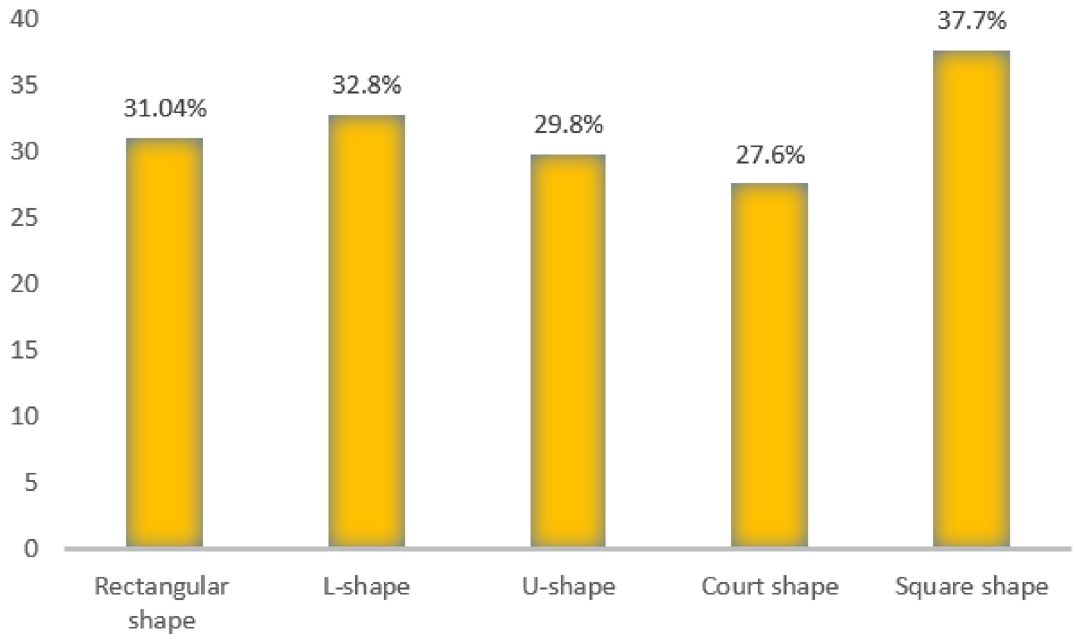


Figure 4.9. Percent of energy performance improvement for shapes base case compared to the existing case

It can be seen from Figure 4.9 that the square shape achieved the highest percentage of improvement in energy performance after changing glass type. However, it is not enough to say that the Square shape is the most suitable shape for school buildings in the suggested study area. For that reason, design parameters alongside building shape must be optimized to achieve the balance between these parameters and the value of EUI. In addition, there are much more aspects that must be taken into account in the conceptual design stage of school buildings. Providing sufficient daylighting and ventilation for classroom spaces is from these aspects as mentioned in Chapter 2. The classroom spaces are also preferred to be located in the **north direction** to achieve sufficient daylighting and avoid the risk of overheating in the summer period of the year. For these reasons, architects and designers can follow the suggested parametric workflow to choose the optimum solution regarding their design parameters focuses.

Selecting the optimal solution

Depending on the previously mentioned factors and especially the location of classroom spaces in the north direction, an attempt of choosing the optimal solution from the obtained results -that achieve the balance between the input variables with as much less value of EUI- was performed. Considering the location of classroom spaces, the selection process of optimal solution will depend on the followings criteria:

- ASHRAE 90.1 Standards of daylighting in school buildings projects
- The solution is preferred to achieve the minimum value of EUI
- The optimal solution is preferred to have a minimum value of WWR in the south direction.

ASHRAE 90.1 standards ensure that the **area of the window openings ranges between 18-22% of the classroom space** to ensure good ventilation and lighting in hot-dry climate regions. Accordingly, the WWR of classroom sides must range between 0.375- 0.458. By depending on these values and the other supposed criteria, the optimal solution for each suggested shape including the rectangular shape was selected and compared as shown in Table 4.7.

Table 4.7 shows the optimal solution for each suggested shape. North WWR, Northwest, and northeast directions were investigated to get the optimal solution that achieves the purpose of providing sufficient daylight and preventing glare according to ASHRAE 90.1 standards. The selected solutions in each shape compared depended on also minimizing WWR south. The final selected optimal solution achieved the minimum value of EUI which means having a higher energy performance.

Table 4.7. The selected optimum solution for each shape compared to the existing case and its base case

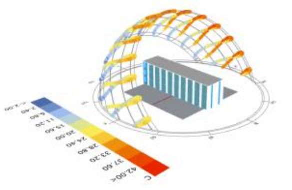
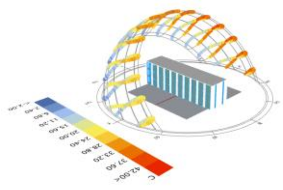
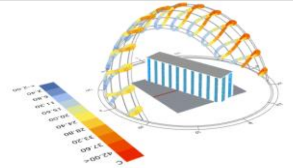
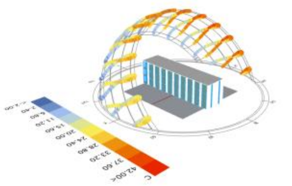
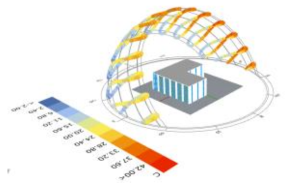
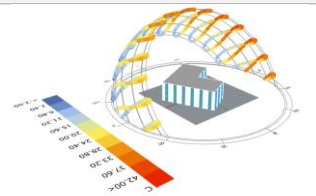
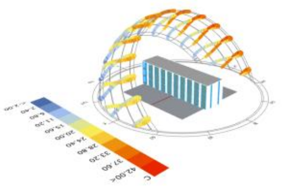
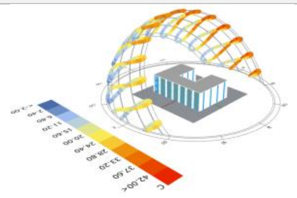
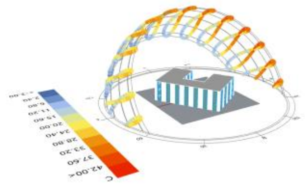
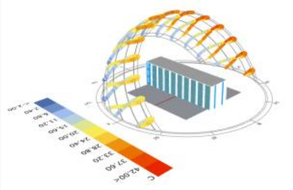
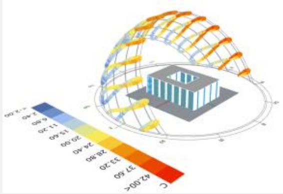
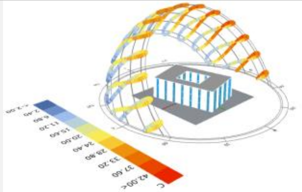
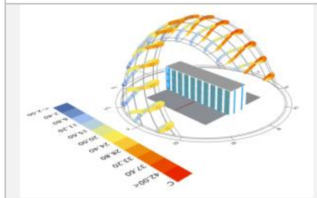
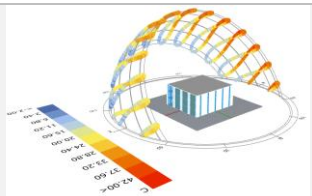
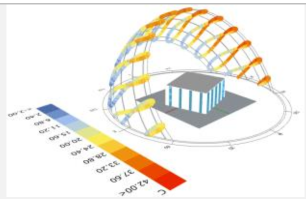
The optimal solution of Rectangular shape								
Existing Case EUI	**Base Case (low e glass) EUI**	**Optimal Solution**	**WWR North**	**WWR West**	**WWR South**	**WWR East**	**Orientation**	**% improvement**
			0.46	0.63	0.10	0.36	18°	**30.3%**
EUI (kWh/m²/y) 436.28	**EUI (kWh/m²/y)** 326.25	**EUI (kWh/m²/y)** 303.69						
The optimal solution of L shape								
Existing Case EUI	**Base Case (low e glass) EUI**	**Optimal Solution**	**WWR North**	**WWR West**	**WWR South**	**WWR East**	**Orientation**	**% improvement**
			0.38	0.46	0.62	0.30	26°	**33.8%**
EUI (kWh/m²/y) 436.28	**EUI (kWh/m²/y)** 293.12	**EUI (kWh/m²/y)** 288.65						
The optimal solution of U shape								
Existing Case EUI	**Base Case (low e glass) EUI**	**Optimal Solution**	**WWR North**	**WWR West**	**WWR South**	**WWR East**	**Orientation**	**% improvement**
			0.41	0.37	0.25	0.35	34°	**32.5%**

Table 4.7 (continues)											
EUI (kWh/m²/y)	436.28	**EUI (kWh/m²/y)**	306.07	**EUI (kWh/m²/y)**	294.41						
The optimal solution of Court shape											
Existing Case EUI		**Base Case (low e glass) EUI**		**Optimal Solution**		**WWR North**	**WWR West**	**WWR South**	**WWR East**	**Orientation**	**% improvement**
						0.39	0.49	0.31	0.15	14°	**31.1%**
EUI (kWh/m²/y)	436.28	**EUI (kWh/m²/y)**	315.64	**EUI (kWh/m²/y)**	300.26						
The optimal solution of Square shape											
Existing Case EUI		**Base Case (low e glass) EUI**		**Optimal Solution**		**WWR North**	**WWR West**	**WWR South**	**WWR East**	**Orientation**	**% improvement**
						0.38	0.47	0.25	0.15	17°	**39.45%**
EUI (kWh/m²/y)	436.28	**EUI (kWh/m²/y)**	271.74	**EUI (kWh/m²/y)**	264.16						

PART 5

CONCLUSIONS

The study presented a parametric optimization workflow to investigate the effect of shape and orientation on energy performance in school buildings. The study was conducted in dry and warm-climate regions. The suggested parametric workflow can help architects and designers in the early design stages of buildings generally and in school buildings design in the climate region of the study area. An existing case study of a primary school building in Aleppo city was chosen to implement the workflow. Using parametric modeling and energy simulation tools, the thermal loads were obtained to calculate the Energy Use Intensity EUI which is used as an indicator of building energy performance. To achieve the research goals, five main building geometry were suggested. Simple rectangular shape, L-shape, U-shape, Court shape, and Square shape were suggested to be the base cases of the study. A unique parametric algorithm was developed using Grasshopper and Ladybug tools to obtain the EUI for each shape case. First of all, the glazing type was changed to low e glass type to see the effect of this kind of glass on the value of EUI in the study area. The optimization process was held using the Octopus plugin after determining the input variables that contain EUI (dependent variable) and orientation and Glazing ratio WWR (independent variables).

To find the optimal solution, the optimization plugin (Octopus) was running for 24 hours resulting in more than 180 solutions after 4 generations of optimal solutions for each suggested shape. These solutions were assumed to achieve the balance between the input parameters. Using the Pareto Front line, optimal solutions were selected for each shape. The optimal solutions were analyzed and compared depending on certain criteria that include ASHRAE 90.1 standards (related to WWR) as well as the minimum value of EUI and WWR in the south direction.

As a result, the optimal solution for each shape was chosen concerning the proposed criteria. The obtained results can conclude the followings:

- Low e glass type has a significant effect on improving school building energy performance in warm and dry climate regions.
- The optimal solution of rectangular shape achieved up to 30.3% development in EUI value compared to the existing case with 18° orientation angle.
- The optimal solution of L-shape achieved up to 33.8% development in EUI value compared to the existing case with 26° orientation angle.
- The optimal solution of the U-shape achieved up to 32.5% development in EUI value compared to the existing case with a 34° orientation angle.
- The optimal solution of Court-shape achieved up to 30.10% development in EUI value compared to the existing case with a 14° orientation angle.
- The optimal solution of Square shape achieved up to 39.45% development in EUI value compared to the existing case with 17° orientation angle.

It can be concluded that the optimal orientation angle of school buildings ranges between 14-34° in the climate of Aleppo (warm-dry climate). Moreover, the Square shape achieved a potential decrease in EUI value concerning the design criteria in classroom spaces. Thus, providing the same daylighting amount for classroom spaces. On the other hand, architects can choose shape geometry depending on their design preferences and the required EUI reference value of the project by following the produced workflow in the study.

Furthermore, it can be concluded that architects and designers of school buildings should avoid the assumptions of shape and orientation parameters in the early design stages as much as possible. The optimization process should be held to investigate the optimum shape and orientation angle concerning the most important parameters that affect building energy performance. In addition, parametric energy modeling and simulation can accelerate the optimization process in the early design stages.

Within that content the research recommends the following for future investigations:

- Considering more design parameters such as shading devices in the optimization process of school buildings’ shape and orientation could improve energy performance in the warm and dry climate regions.
- Multi-objective optimization process that includes energy performance and daylight performance alongside more design parameters could be performed in future studies to get more investigation and optimal solutions as concluded by Aksin and Arslan Selçuk 2021.

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APPENDIX A.

GRASSHOPPER ALGORITHIM

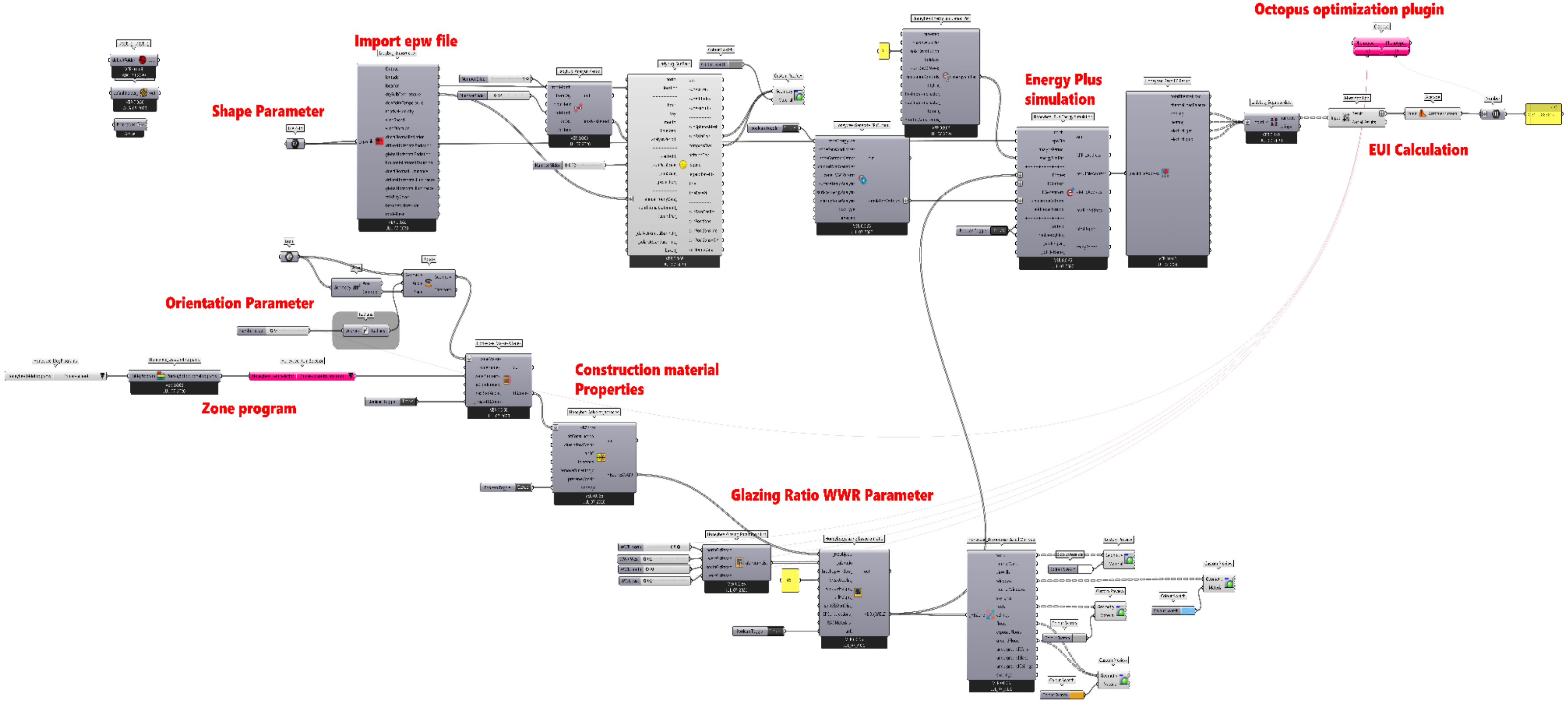


Figure Appendix A.1. Grasshopper Algorithm.

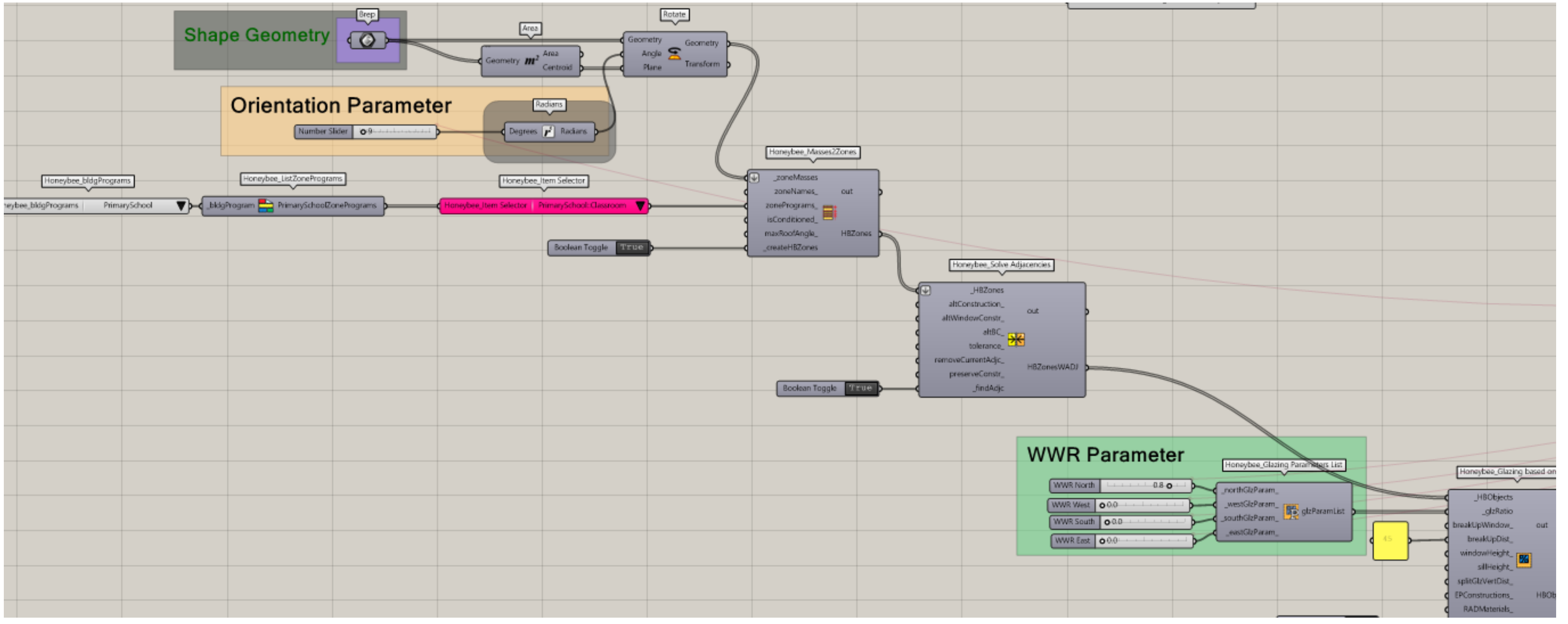


Figure Appendix A.2. Orientation and WWR parameters and shape geometry in Grasshopper.

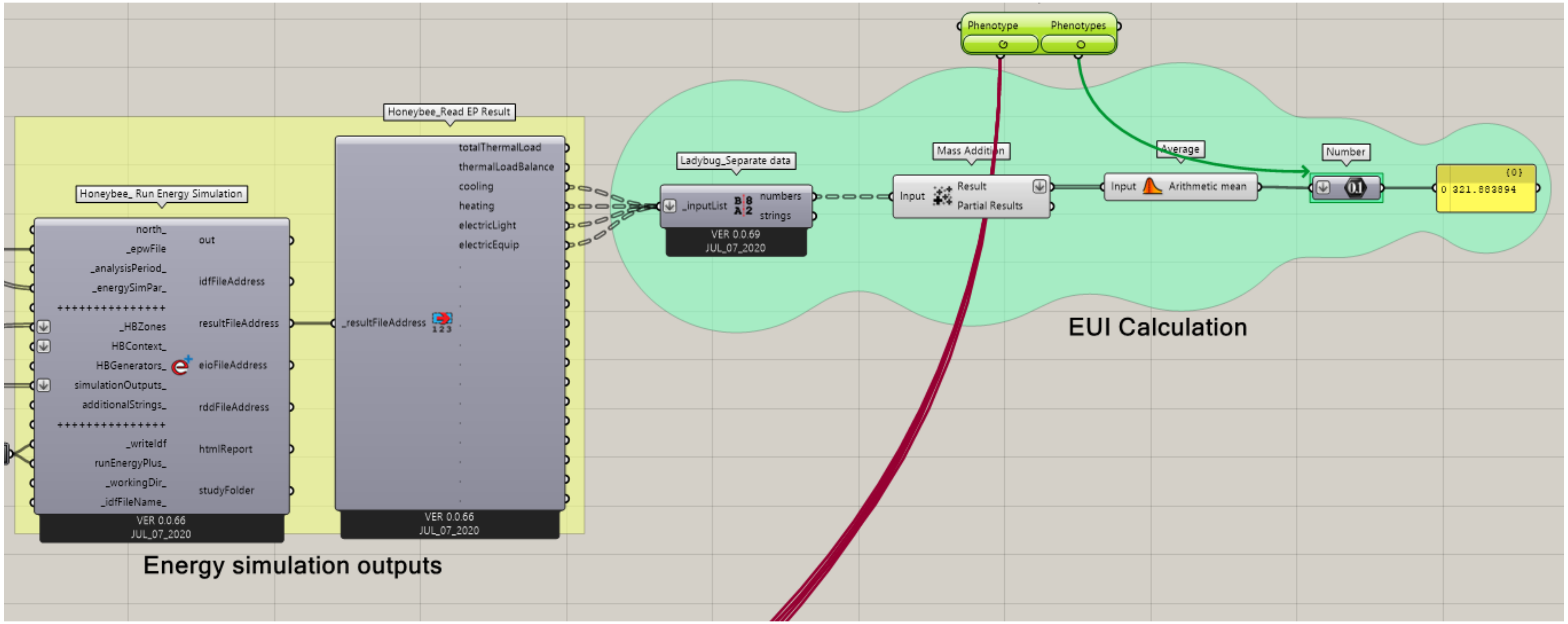


Figure Appendix A.3. EUI calculation process in Grasshopper.

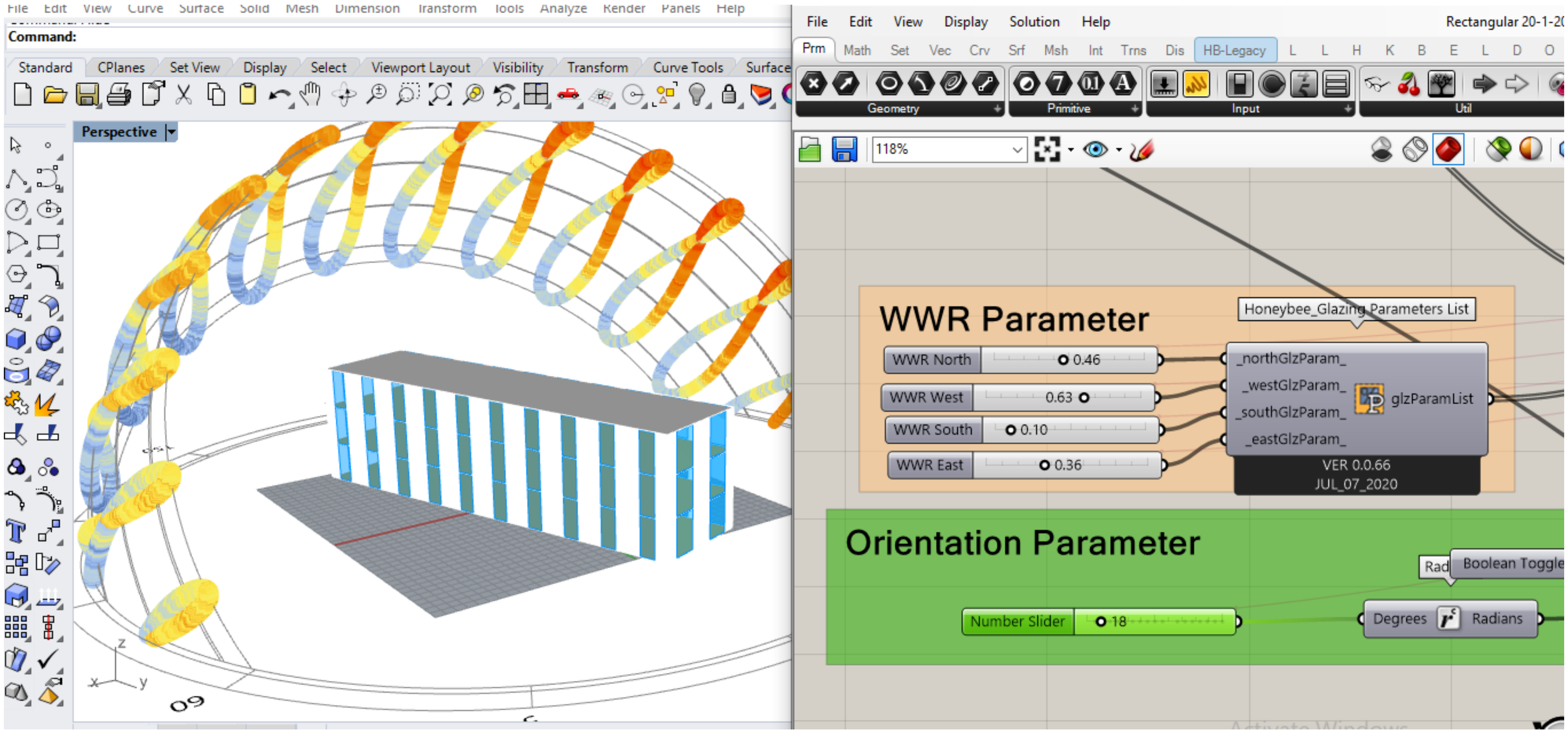


Figure Appendix A.4. Optimal solution of Rectangular shape in Grasshopper

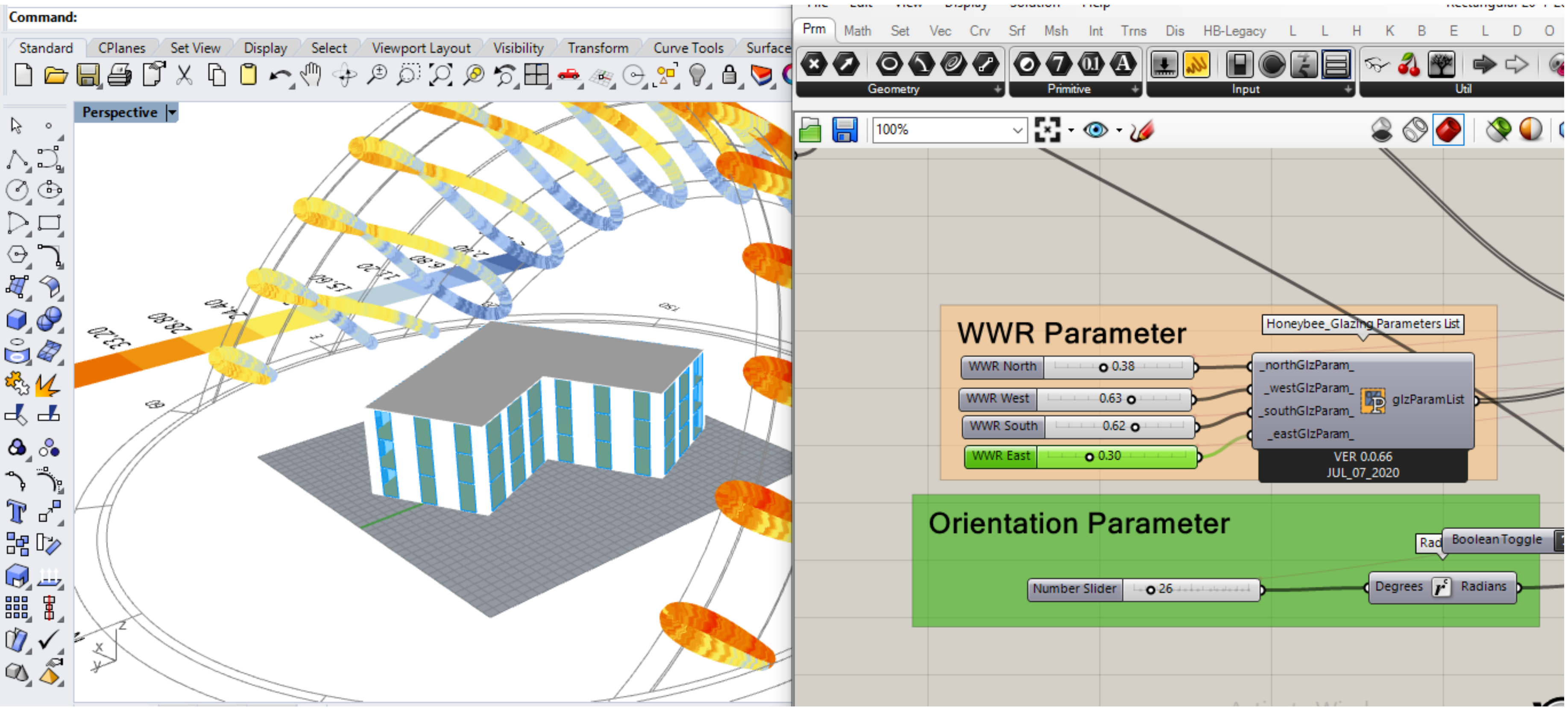


Figure Appendix A.5. Optimal solution of L- shape in Grasshopper

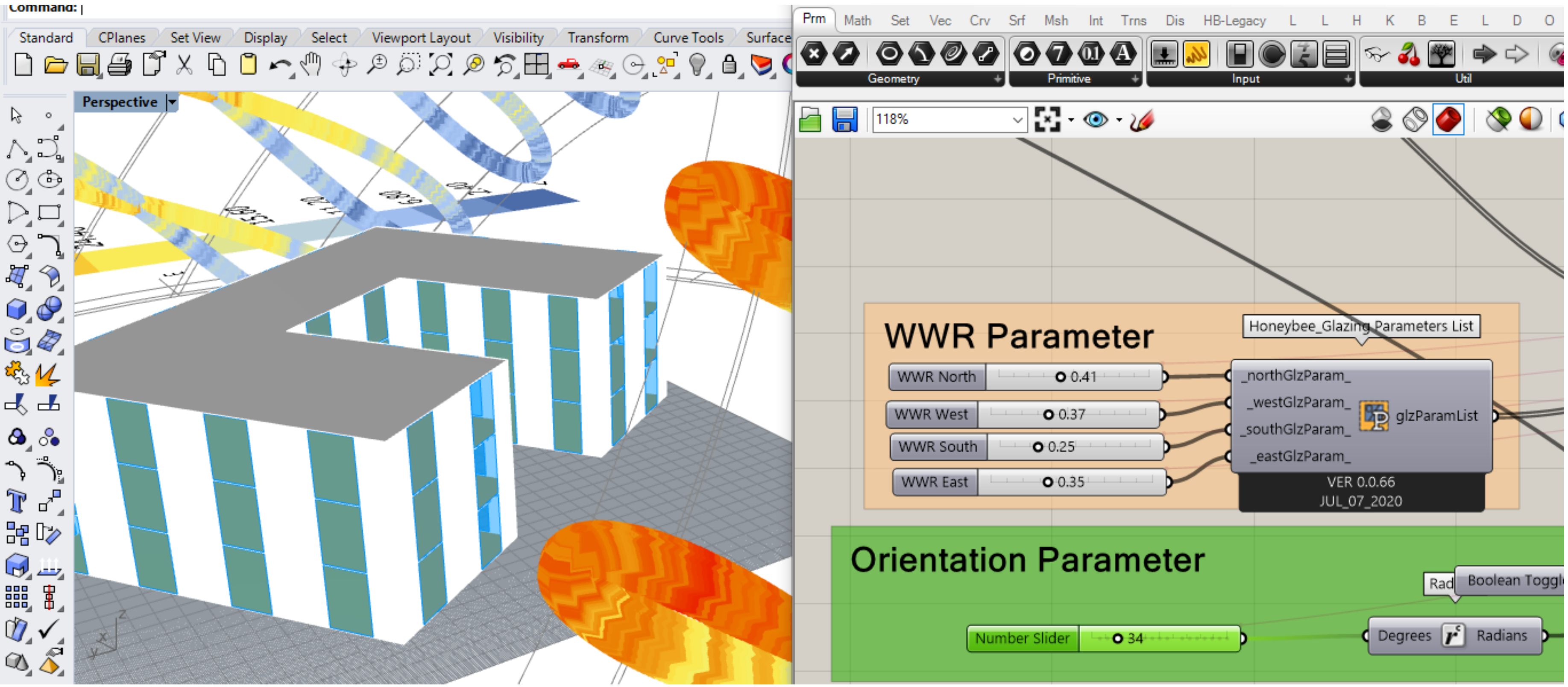


Figure Appendix A.6. Optimal solution of U- shape in Grasshopper

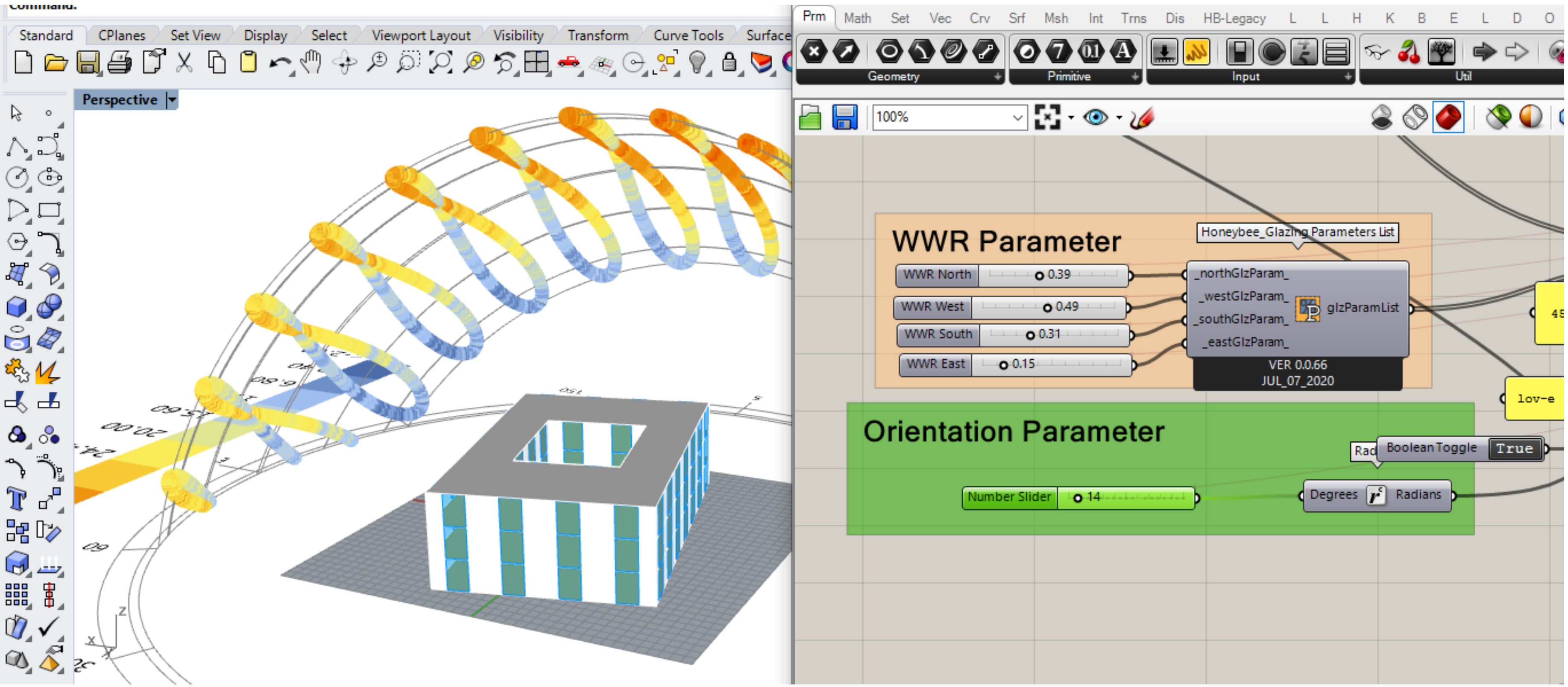


Figure Appendix A.7. Optimal solution of Court shape in Grasshopper

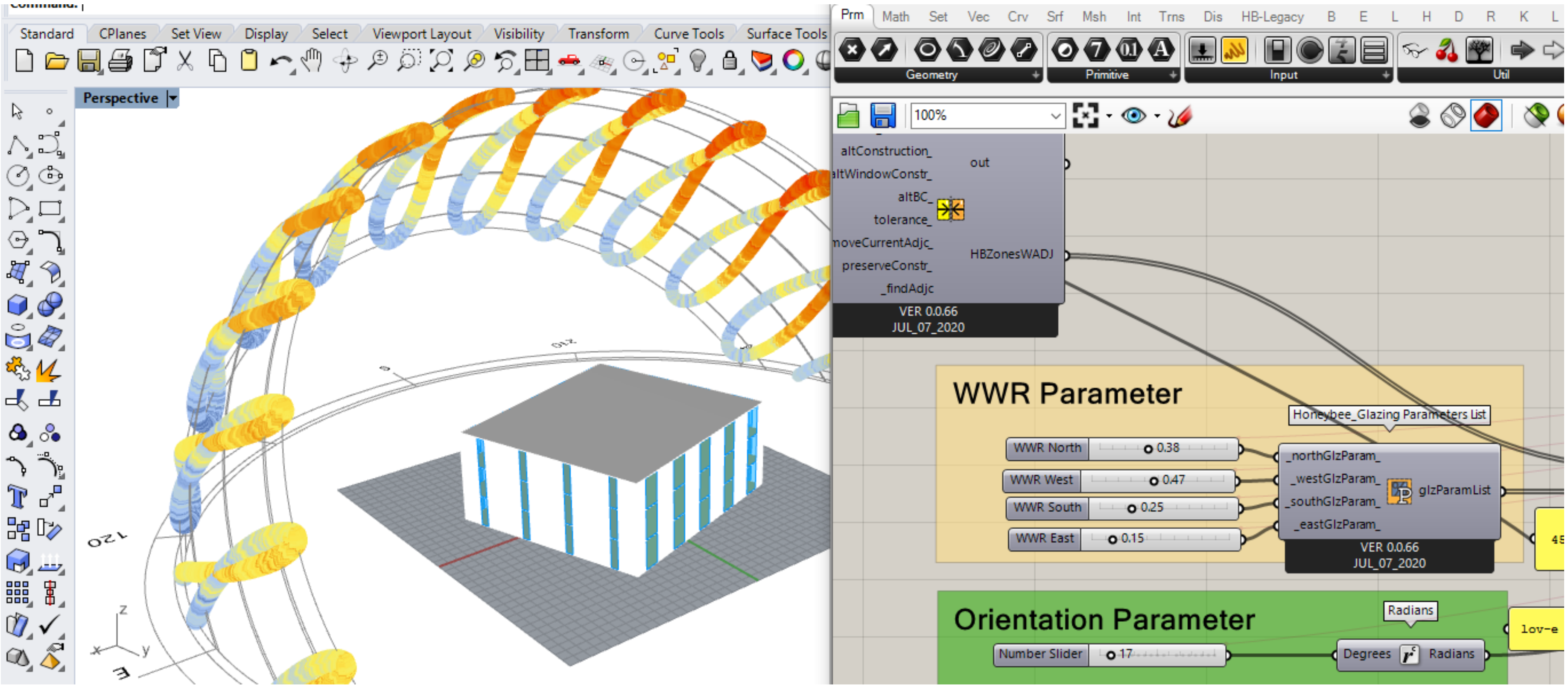


Figure Appendix A.8. Optimal solution of Square shape in Grasshopper

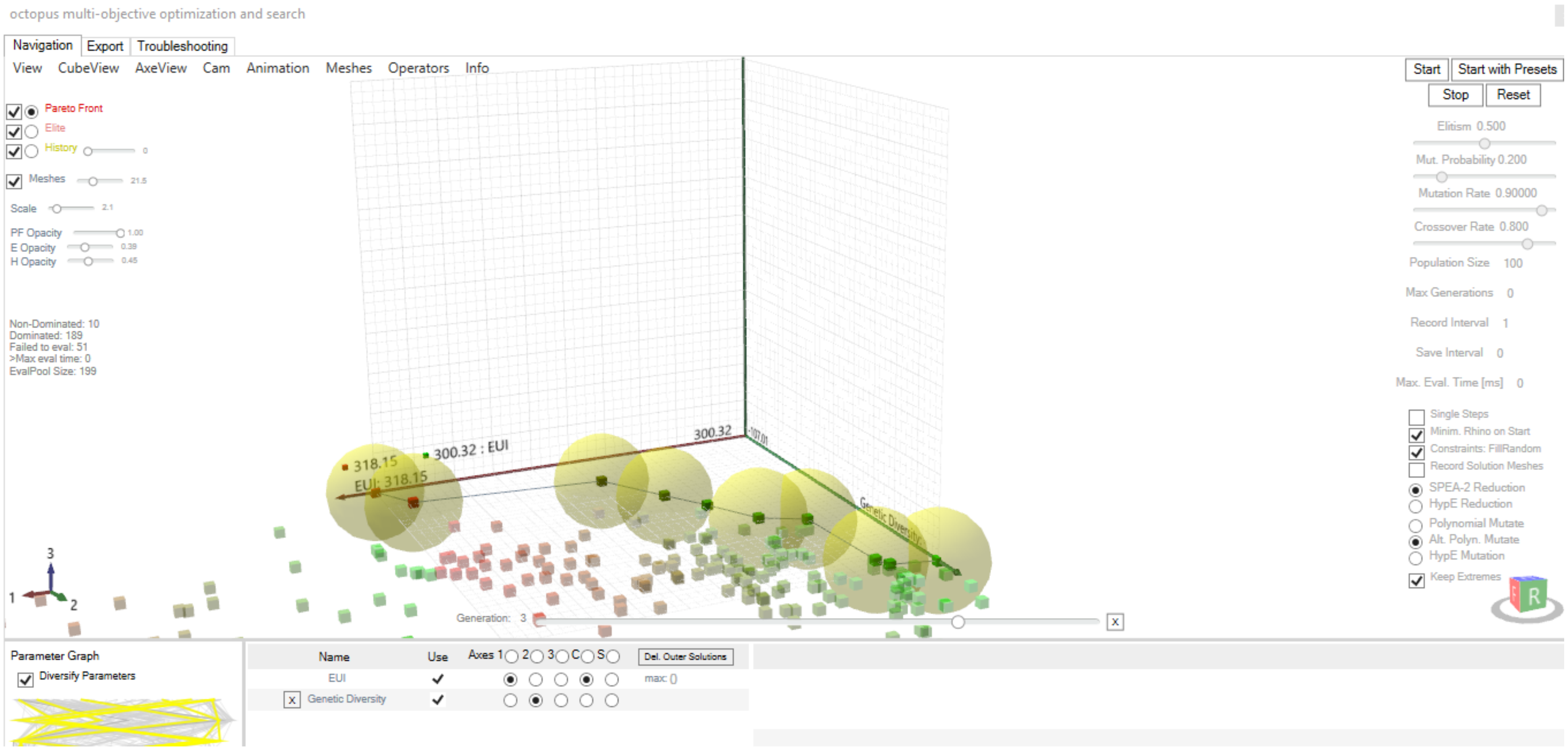
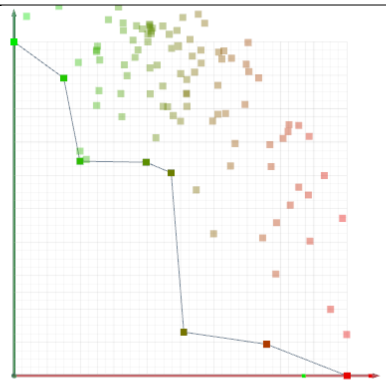
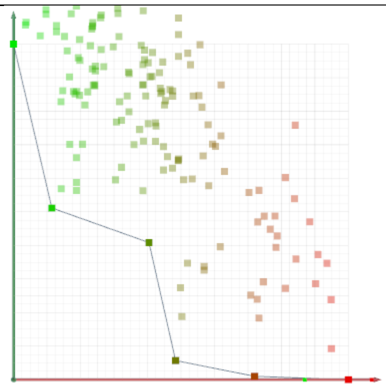


Figure Appendix A.8. Octopus Plugin interface.

APPENDIX B.

GENERATIONS OF THE OPTIMAL SOLUTIONS

Table Appendix B.1. Optimal solutions generation of L-shape.

After Generation 1	After Generation 2
	
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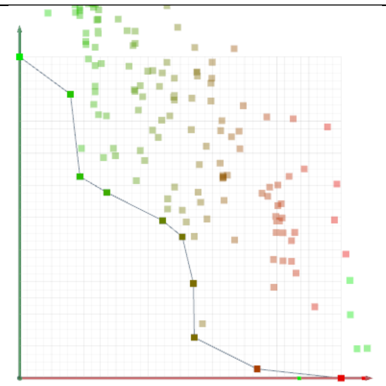
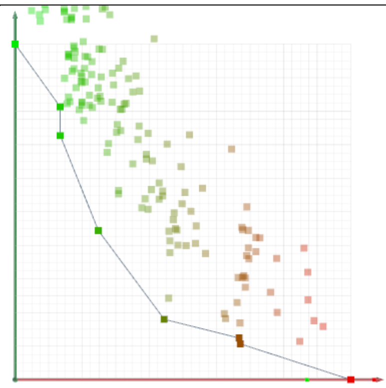
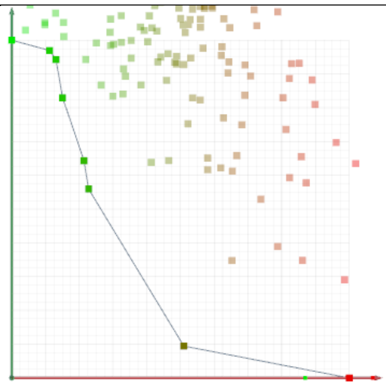
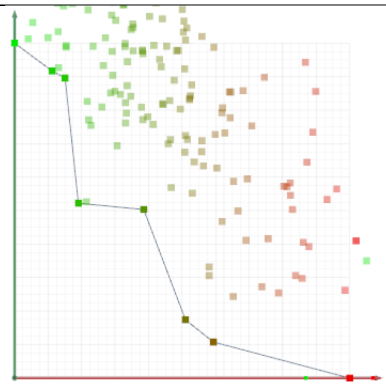
	

Table Appendix B.2. Optimal solutions generation of U-shape.

After Generation 1	**After Generation 2**
	
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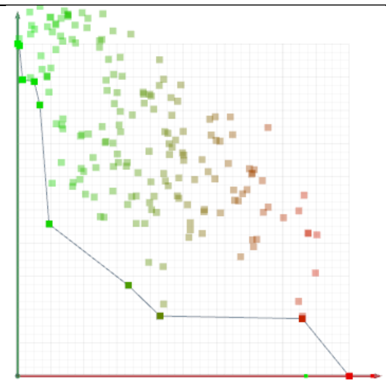	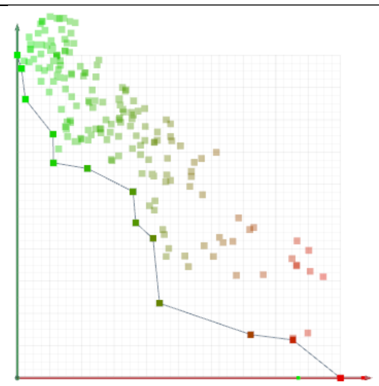

Table Appendix B.3. Optimal solutions generation of Court shape.

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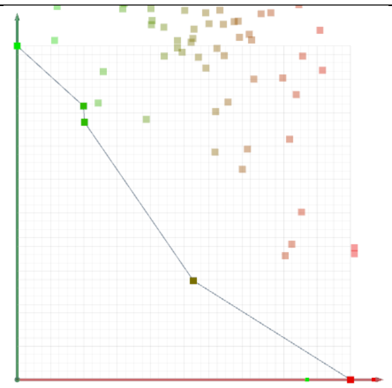	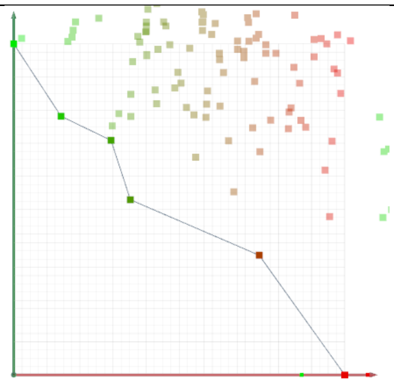
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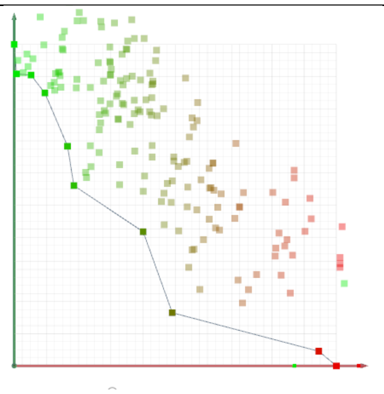	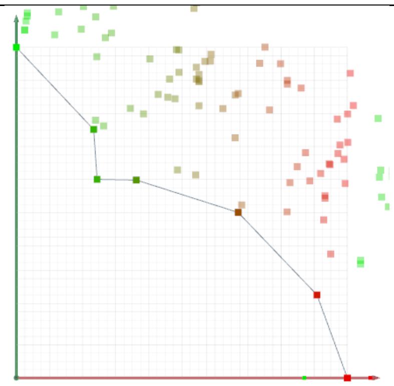

Table Appendix B.4. Optimal solutions generation of Square shape.

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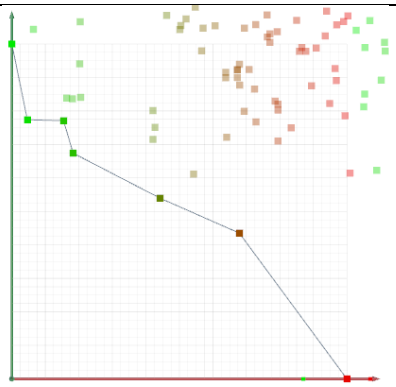
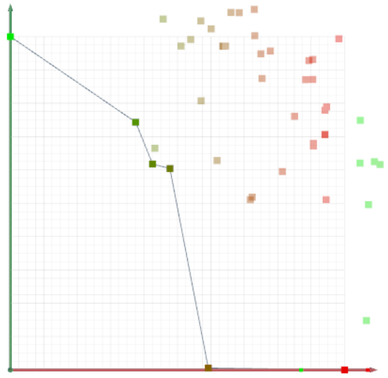
<tr><td></td><td></td></tr>
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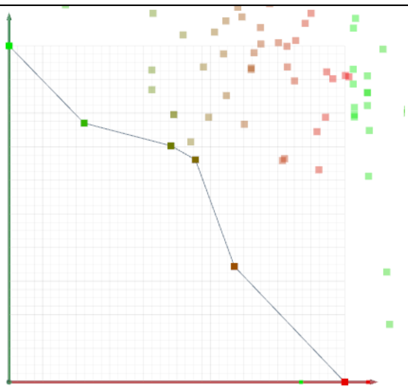
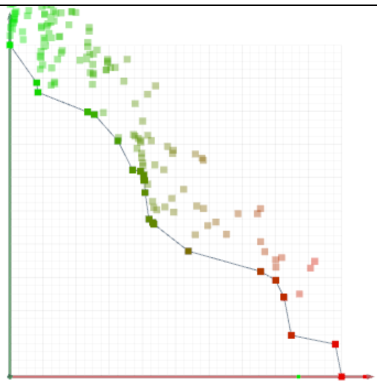
<tr><td></td><td></td></tr>
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APPENDIX C.

OPTIMAL SOLUTIONS RESULTS ON PARETO FRONT LINE

Table Appendix C.1. Optimal solutions results of rectangular shape.

	1	**2**	**3**	**4**
WWR North	0.10194463	0.92685631	0.467071242	0.425329976
WWR West	0.502493774	0.254866881	0.633135716	0.909868891
WWR South	0.108224636	0.859301379	0.108586446	0.090260767
WWR East	0.900491205	0.106436138	0.36274007	0.126931343
Orientation (Radian)	0.940792515	0.890439627	0.949740247	0.928427078
EUI (kWh/m²/year	305.8707963	318.1416999	303.699519	303..364989
Genetic diversity	-205.0720692	-194.3953454	-189.1156201	-183.8651344
	5	**6**	**7**	**8**
WWR North	0.901230904	0.389326286	0.907168511	0.326243791
WWR West	0.905473707	0.716229304	0.406746265	0.94663088
WWR South	0.36900480	0.13130259	0.857193504	0.105575873
WWR East	0.143414683	0.179126311	0.145290388	0.002193783
Orientation (Radian)	0.873339896	0.884963682	0.019599791	0.925395942
EUI (kWh/m²/year	307.0462644	302.6398585	317.0236535	302.0378072
Genetic diversity	-170.0473995	-138.8319651	-124.4261961	-113.826381
	9	**10**	**11**	
WWR North	0.810727501	0.303709436	0.67094164	
WWR West	0.102645391	0.853578668	0.930962681	
WWR South	0.920200786	0.040376368	0.849402025	
WWR East	0.110663234	0.001175376	0.104058749	
Orientation (Radian)	0.010408262	0.006027765	0.104956785	
EUI (kWh/m²/year	308.8088157	300.3135534	304.5975255	
Genetic diversity	-108.0310706	-94.93115575	-88.53496209	

.

Table Appendix C.2. Optimal solutions results of L- shape.

	1	**2**	**3**	**4**
WWR North	0.926491802	0.628200222	0.943568485	0.44592425
WWR West	0.878560014	0.922131856	0.106340988	0.12478103
WWR South	0.103321444	0.105494928	0.237334710	0.13319900
WWR East	0.30314062	0.254257687	0.109739936	0.547891941
Orientation (Radian)	0.928537509	0.847268636	0.942466042	0.851537348
EUI (kWh/m²/year	293.0547051	286.0190686	298.038.9013	305.4837946
Genetic diversity	-191.72425	-190.3498101	-181.6446837	-179.2830352
	5	**6**	**7**	
WWR North	0.387815358	0.947606711	0.180815975	
WWR West	0. 465417110	0.953620499	0.040248305	
WWR South	0.619551805	0.940111926	0.105580786	
WWR East	0.309603336	0.127891941	0.141673252	
Orientation (Radian)	0.858086083	0.851537348	0.067359371	
EUI (kWh/m²/year	288.6528106	283.1005816	298.1259936	
Genetic diversity	-173.5059744	-170.7465859	-163.1127342	

Table Appendix C.3. Optimal solutions results of U- shape.

	1	**2**	**3**	**4**
WWR North	0.100069782	0.203367105	0.447575944	0.941027435
WWR West	0.137049095	0.105947484	0.065962095	0.935699829
WWR South	0.920853584	0.116774269	0.206010793	0.71276881
WWR East	0.080017619	0.307297922	0.917297922	0.20186897
Orientation (Radian)	0.949219467	0.011122474	0.01575443	0.004727809
EUI (kWh/m²/year	296.8772089	293.7055551	314.058364	317.0865909
Genetic diversity	-167.5119646	-127.8711122	-126.3690499	-115.7347416
	5	**6**	**7**	**8**
WWR North	0.675795771	0.411072483	0.834156217	0.845810903
WWR West	0.207284773	0.370465845	0.503363311	0.446343295
WWR South	0.926774269	0.254712292	0.092225552	0.943597792
WWR East	0.881011649	0.359631584	0.121374048	0.91815176
Orientation (Radian)	0.004570693	0.018168703	0.003966162	0.929924156
EUI (kWh/m²/year	304.8627937	294.411061	306.1766	322.0212
Genetic diversity	-117.4376084	-96.89267324	-106.769	-112.301
	9	**10**		
WWR North	0.938200222	0.579326286		
WWR West	0.942131856	0.876229304		
WWR South	0.855494928	0.211302590		
WWR East	0.194257687	0.109126311		
Orientation (Radian)	0.847268636	0.884963682		
EUI (kWh/m²/year	303.8590686	305.6098585		
Genetic diversity	-190.3498101	-138.8319651		

Table Appendix C.4. Optimal solutions results of Court shape.

	1	**2**	**3**	**4**
WWR North	0.117071242	0.103426612	0.184862635	0.355290613
WWR West	0. 93135716	0.980969892	0.939010645	0.993363311
WWR South	0.948586446	0.847005211	0.901696557	0.858784231
WWR East	0.12740070	0.304982114	0.404819886	0.141525638
Orientation (Radian)	0.949740247	0.91277584	0.935348381	0.920341089
EUI (kWh/m²/year	307.239519	302.32.9649	300.4363	312.5840
Genetic diversity	-189.1156201	-152.972	-148.501	-145.265
	5	**6**	**7**	
WWR North	0.392993124	0.306313355	0.055810903	
WWR West	0.497217032	0.908515812	0.936343295	
WWR South	0.311696557	0.810394282	0.133597792	
WWR East	0.157554560	0.108467611	0.16815176	
Orientation (Radian)	0.91868215	0.004257134	0.929924156	
EUI (kWh/m²/year	300.2646	375.6861	311.0412	
Genetic diversity	-122.254	-119.291	-112.301	

Table Appendix C.4. Optimal solutions results of Square shape.

	1	2	3	4
WWR North	0.867071242	0.223426612	0.364862635	0.175290613
WWR West	0. 96135716	0.870969892	0.429010645	0.143363311
WWR South	0.148586446	0.147005211	0.841696557	0.468784231
WWR East	0.005740070	0.009982114	0.864819886	0.901525638
Orientation (Radian)	0.949740247	0.91277584	0.935348381	0.920341089
EUI (kWh/m²/year	265.099515	264.32.9649	332.6563	354.4340
Genetic diversity	-189.1156201	-152.972	-148.501	-145.265
	5	**6**	**7**	**8**
WWR North	0.382993124	0.506313355	0.885810903	0.548200222
WWR West	0.4797217032	0.628515812	0.926343295	0.302131856
WWR South	0.251696557	0.130394282	0.103597792	0.255494928
WWR East	0.157554560	0.388467611	0.258151760	0.104257687
Orientation (Radian)	0.91868215	0.004257134	0.929924156	0.847268636
EUI (kWh/m²/year	264.1646	269.6461	262.9512	257.6790686
Genetic diversity	-122.254	-119.291	-112.301	-190.3498101

RESUME

Khaled ALBAIOUSH was born in Idlib- Syria and he graduated first and elementary education in this city. He completed high school education in The-Qar High School, after that, he started undergraduate program at Ebla Private University in Aleppo City Department of Architecture in 2011 and graduated in 2016. After 2016 he started working in the field of architecture in designing projects. He moved to Karabük University in 2018 to complete his master's degree in Architecture.