YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

AN INVESTIGATION INTO FENESTRATION STRATEGIES ON BUILDING PERFORMANCE: CASE OF RESIDENTIAL BUILDINGS IN TURKEY

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PRESENTATION DATE: 27-AUGUST-2018

BORNOVA / İZMİR
JULY 2018

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science

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ABSTRACT

AN INVESTIGATION INTO FENESTRATION STRATEGIES ON BUILDING PERFORMANCE:
CASE OF RESIDENTIAL BUILDINGS IN TURKEY

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July 2018

The reduction of energy consumption is a major challenge around the world. Using natural daylight is one of the basic energy saving criteria which promotes usage of natural sources as well as decreases energy demand dramatically in residential buildings. However, the insufficient study of fenestration strategies through building design significantly limits the impact on daylight such building performance. To this end, the current study aims to investigate the impact of optimum fenestration strategies on building performance in the context of residential buildings in Turkey. Two performance metrics, namely energy use intensity (EUI) and useful daylight illuminance (UDI), were employed through analysis. In the first part of the study, a hypothetical test box model was considered to determine optimum fenestration strategies in four different climate zones of Turkey. In this context, fenestration ratios at each elevation formed the decision variables while HyPE optimization algorithm attempted to find solutions that minimize EUI and maximizes UDI. In the second part, the results obtained from the first section were validated by implementing these results in real residential projects, located in the very climate zones. This allows the current work to study comparatively the effect of so-called optimum fenestration values on building performance of the real cases. The comparative results suggest optimum fenestration values obtained from a test box model causes no significant improvements in building performance metrics of the real residential projects. As a conclusion, the current work discussed the uniqueness of each architectural design and therefore, the necessity of conducting such performance analysis for each unique case.

Keywords: performance-based architecture, computational design, multi-objective optimization, daylighting-energy optimization, fenestration, residential

ÖZ

PENCERE AÇIKLIĞI STRATEJİLERİNİN BİNA PERFORMANSINA ETKİSİ ÜZERİNE BİR İNCELEME: TÜRKİYE KONUT PROJELERİ VAKASI

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Temmuz 2018

Günümüzde, enerji tüketiminin giderek artması, dünya çapında büyük bir sorun haline gelmiştir. Doğal gün ışığını kullanmak hem doğal kaynakları hem de konut binalarında enerji taleplerini önemli ölçüde azaltan temel enerji tasarrufu kriterlerinden biridir. Bununla birlikte, bina tasarımlarında pencere sistemlerinin uygun olmayan ve yetersiz bir şekilde kullanılması, gün ışığının bina performansı üzerindeki etkisini önemli ölçüde sınırlandırmaktadır. Bu amaçla, mevcut çalışma Türkiye'de konut binaları bağlamında optimum pencere açıklıklarının bina performansına olan etkisini araştırmayı amaçlamaktadır. Enerji performans yoğunluğu (EUI) ve kullanışlı gün ışığı aydınlatması (UDI) olmak üzere iki performans ölçütü analizlerde kullanılmıştır. Çalışmanın ilk bölümünde, Türkiye'nin dört farklı iklim bölgesinde optimum pencere sistemlerini belirlemek için varsayımsal bir test modeli oluşturulmuştur. Bu bağlamda, her bir duvar-pencere oranı karar değişkenlerini oluştururken, HyPE optimizasyon algoritması ile EUI'yı minimize eden ve UDI'yı maksimize eden çözümler bulmaya çalışılmıştır. Çalışmanın ikinci bölümünde, ilk bölümden elde edilen sonuçlar, bu sonuçların iklim bölgelerinde bulunan gerçek konut projelerine uygulanmasıyla doğrulanmıştır. Bu, çalışma ile optimum duvar-pencere oranlarının gerçek konut projelerindeki bina performansına olan etkisi karşılaştırmalı olarak incelenmiştir. Karşılaştırmalı sonuçlar, test modelinden elde edilen optimum değerlerin, gerçek konut projelerine uygulandığında bina performanslarında önemli bir etkiye neden olmadığını göstermektedir. Sonuç olarak, bu çalışma her bir mimari tasarımın kendi özgü olması gerektiğini ve dolayısıyla her bina için böyle bir performans analizinin projenin tasarım aşamasındayken yapılması gerektiğini ortaya koymaktadır.

Anahtar Kelimeler: performansa dayalı mimari, bilişimsel tasarım, çok hedefli optimizasyon, günışığı ve enerji optimizasyonu, pencere acikliklari, konut yapıları.

ACKNOWLEDGEMENTS

First, I would like to thank my supervisor Dr.-Ing. Onur Dursun for his guidance, support, and patience during this study.

I also would like to express my deepest gratitude to my family for their unconditional love

Nezahat Püren Ünlü

Izmir, 2018

TEXT OF OATH

I declare and honestly confirm that my study, titled “AN INVESTIGATION INTO FENESTRATION STRATIGIES ON BUILDING PERFORMANCE: CASE OF RESIDENTIAL BUILDINGS IN TURKEY” presented as a Master of Science Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Ünlü, Nezahat Püren
Signature

October 1, 2018

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

UDI	Useful Daylight Illuminance
EUI	Energy Use Intensity
kWh	Kilo Watt Hour
W	Watt
m	Meter
K	Kelvin
s	Second
ppl	People
EPW	EnergyPlus Weather Data
X_n	Glazing Ratio Parameters
Y_n	Performance Objectives (Response Variables)
lx	Lux
°C	Celsius degree
T	Temperature Objective
L	Illuminance Objectives
ID	Identification Number
approx.	Approximately
i	sampling point

SYMBOLS:

%	Percentage
$\sum$	Mass Summation
σ	Interaction between parameters
^{0}C	Centigrade Degree

CHAPTER ONE

INTRODUCTION

1.1. BACKGROUND

Research studies about energy consumption and energy use in the buildings are significant owing to rising energy demand and deficiency of natural sources (Esiyok, 2006). Because of rising population and enhanced quality of life, one of the largest energy consumption sectors is residential buildings that consume approximately 35% of the overall energy on average. Accordingly, they are responsible for carbon emissions in worldwide (Figure 1.1) The pie charts of Figure 1.2 show that the estimated energy use of the residential sector that is firstly for space heating, cooling, lighting (Kapsalaki, Leal, & Santamouris, 2012). Unless any precaution is taken against expanding energy consumption in the buildings sector, energy demand is estimated to go up to 50% by 2050 (Agency, 2013)

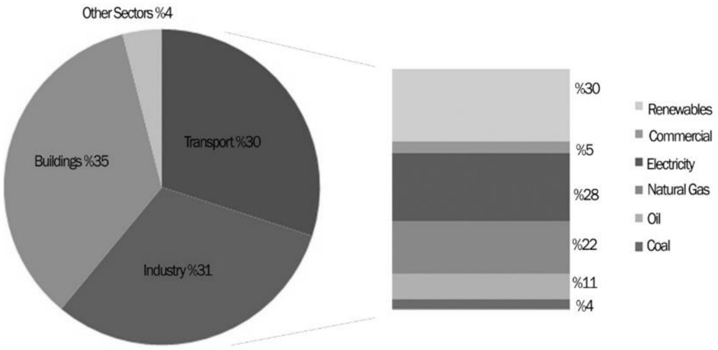


Figure 1.1 Total Energy Usage by final sector (Agency, 2013)

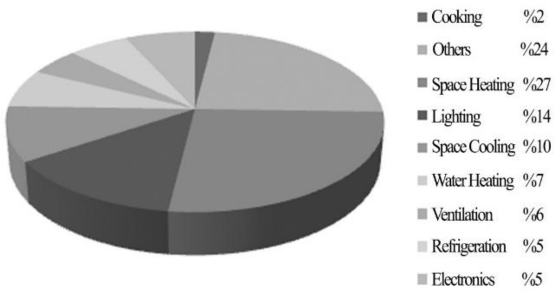
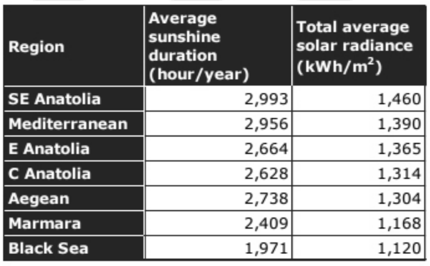


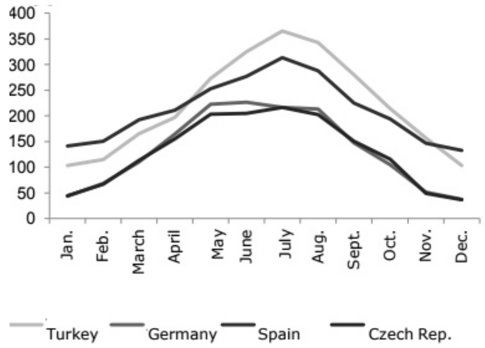
Figure 1.2 Categorical classification of residential sector energy use in the United States (Efficiency, 2009)

According to the EU Commission Yearbook “Statistical yearbook on candidate countries” in 2003, among the European Union (EU) nominee countries, the second largest energy consumer country has been indicated as Turkey. Especially, the residential buildings category is the essential cause of the increasing energy demand in Turkey where CO_2 emissions have been soaring like energy consumption. Among twenty European countries, Turkey ranks seventh for total CO_2 emission from the residential building annually. As declared by the overview arranged by EURIMA (European Insulation Manufacturers Association), total CO_2 emissions of residential buildings per year is 25.948 million tons in Turkey (Manufacturers), 2004).

Opportunities for renewable sources, such as solar, wind, hydropower, biomass, geothermal, are abundant in Turkey. According to the General Directorate of Renewable Energy, the average annual radiation in Turkey is 2,640 hours annually. In addition, the average solar radiation is 1,311 kWh/m² per annum. Figure 1.3 shows the average sunshine duration (hour/year) and total average solar radiance (kW/m²) in the seven main regions of Turkey (Turkey, November 2013) (Turkey, November 2013).



Region	Average sunshine duration (hour/year)	Total average solar radiance (kWh/m²)
SE Anatolia	2,993	1,460
Mediterranean	2,956	1,390
E Anatolia	2,664	1,365
C Anatolia	2,628	1,314
Aegean	2,738	1,304
Marmara	2,409	1,168
Black Sea	1,971	1,120



Source: YEGM, National Oceanic and Atmospheric Administration

Figure 1.3 Average Solar Radiance and Average Sunshine Duration in Turkey (Turkey, November 2013) (YEGM, National Oceanic, and Atmospheric Administration)

Despite the various energy sources, the awareness is not enough to implement the use of natural sources in daily life. According to the Economist Intelligence Unit (EIU), energy demand in Turkey increased at an annual ratio of 4.5% until 2015 in alignment with the growth expected of the Gross Domestic Product (GDP). Studies stress on primary energy consumption demand which will go up by 1.6% per annum from 2011 to 2030 for Turkey. In addition, it causes to rise by 36% to global consumption by 2030. Other studies show that energy demand of Turkey in 2023 is expected to account for nearly USD 110 billion. Thus, it is more than double the overall amount spent during the following ten years ("Energy and Renewables "). International Energy Agency mentioned in 2016 that The Turkish energy sector and energy regulations are required to be in accordance with the necessities for cities and industries of Turkey. These necessities should be fulfilled in order to meet the rise in energy demand and the maintenance of sustainable economic development (IEA, 2016).

1.2. PROBLEM STATEMENT

In the current time, awareness of the environmental impacts of the building is being heightened, while energy modeling and control strategies are developing so as to reduce a building’s energy consumption and maximize natural sources usage (Harish & Kumar, 2016). Thus, one of the basic energy saving impacts of the environment is using natural daylight that provides both using natural sources and reducing energy demands intensely in residential buildings. To use natural daylight effectively, well design building envelopes are essential for the whole building. The building envelope divides the building into the indoor and outdoor environment. In terms of architectural aspect, several kinds of openings can be defined as windows, façade, yards, skylights and so on so forth in the building envelope. Hence, they are highly affected by the outdoor climate. Because of being the weakest part of the building envelope, the openings must be located in the correct direction and place towards the sun. For instance, in this field, heat transmission from windows constitutes an important percentage of total energy usage in the building. In addition, using too much artificial lighting instead of profiting from natural daylight through windows is the other significant proportion of energy usage too. These design strategies and technologies optimize the big amount of heat losses from glazed surfaces due to the high thermal conductivity in winter and cooling problems related to the extreme solar gains in summer.

Furthermore, energy and daylight are properly are acquired thanks to the well-designed building envelope strategies integrated with advanced fenestrations, optimal building insulation, and proper glazing types considering with climate (Agency, 2013). Briefly, this is a complex system involving multiple requirements in terms of the architectural and engineering aspects. Also, these requirements contain multi-objectives conflicting with each other in most of the cases. Moreover, these objectives are intensely affecting how to adjust the last form of architectural design solutions. Beside their complexity, the last inventions in technology have offered a wide range of window fenestration designs.

In conclusion, to sustain a performed-based design considering with energy and daylight, the fenestration strategies are supposed to be carefully planned due to several reasons:

- The fenestration strategies provide good daylight quality. By presenting daylight into buildings, residents are satisfied with the point of orientation, weather, time, and the outdoor environment. Moreover, the natural daylight occurs favorable impacts on health, productivity and biological clock of human (Li & Tsang, 2008).
- Windows and glazing can be changeable with respect to weather conditions and building requirements. Therefore, a well-designed fenestration reduces by more than 10% of the building's total energy consumption with considerable influence (DOE, 2014).
- It plays a significant role in the building's character that enhances the aesthetic appearance of the building as well as transparency, visual connection between indoor and outdoor(Chatzikonstantinou, Ekici, Sarıyıldız, & Koyunbaba, 2015a).

Therefore, these statements clearly show that glazed windows present many benefits to the occupants and the designers. Although current buildings are designed to meet the occupant's demands, the designs lack awareness of both the local climatic condition and natural sources utilization. Also, they do not consider energy conservation decisions. In order to benefit from the performance of the building fenestration design, the strategies need to be described and very carefully planned considering both daylight performance and energy saving in the early stage of the design process (J. Kim, 2012). Due to creating the form and evaluating the results properly, the designers take advantages of the opportunities by computer simulation tools at the early design phase. At this point, the role of the architect is not only facing with design concerns but also presenting a well-performed solution at the final process (Azhar, Brown, & Farooqui, 2009).

1.3. AIM AND OBJECTIVES

To tackle the issues, the current study aims to investigate the impact of optimum fenestration strategies on building performance in the context of residential buildings in Turkey. In this context, the main aim is to reach near optimum fenestration results which maximize daylight and minimize energy demand of the hypothetical test box model in each climate zone of Turkey. The second aim is, then, to validate the optimization results by implementing them in real residential cases.

After observing alternatives found as a result of this study, energy and daylight efficient design’s significance for residential buildings has been highlighted regarding the building energy regulations and standards, TS825, in the context of 4 zones of Turkey by taking into consideration of climatic condition. Because the building designs have become much more complex, detailed analysis of various alternatives of fenestration design should be run. Hence, the influence of these design strategies on building energy load has been assessed in this manuscript. In this manuscript, the optimization objectives are Useful Daylight Illuminance (UDI) (Nabil & Mardaljevic, 2005) and Energy Use Intensity (EUI) are selected for daylight and energy performance, to form multi-objective optimization problem. The research has studied the impact of wall window ratio at each orientation on energy demand and daylight.

1.4. SIGNIFICANCE AND CONTRIBUTION

A lot of research depends on different variables of building such as orientation, climate, number of residences, floor height, heating-cooling systems, structure, insulation, etc. as well as simulating various computational tools regarding climatic conditions. Some of them have a limitation as some parameters or design constants.

However, almost none of them study real case buildings, variables, and the other objectives considering the local climatic condition as well as international and regional regulations or standard. This research is convenient to those who design residential buildings as well as architects and engineers. The study is important to the designer also owner who will want to observe the better utilization of the natural sources in their design considering with both climatic conditions and regional standards.

1.5. METHODOLOGY

The method used in this manuscript is quantitative that based on objective measurements and numerical analysis of whole data. The decision variables; wall window ratio, and window orientation are used for finding a set of fenestration design alternatives to reach near-optimal daylight and energy efficient solutions.

The study is designed as a quasi-experimental research (Peterson, 2010). Subjects are measured before on the test box model. Then experimental data results to change between behavior and performance before and after are compared. Data are collected and tested using computational techniques. Calculations and analysis are based on DIVA, Ladybug and Honeybee simulation software, that are plug-in of Grasshopper 3D (GH) (Roudsari, Pak, & Smith, 2013). To provide the connection and automation between the parametric model and simulation tools, Radiance, Daysim (Jakubiec & Reinhart, 2011), Octopus (Vierlinger & Zimmel, 2015) are used. The final calculations and analysis, which are collected from the test box model, are validated in the context of 4 different Turkish climate zones on the real case buildings. The structure of the current study is explained clearly in order to be repeated and be used in different researches.

1.6. SCOPE AND LIMITATIONS

This manuscript aims to achieve using optimum daylight at low energy consumption on the proper building envelope alternatives for residential buildings. This is further underlined regarding the building energy regulations and standards, TS825, in the context of 4 zones of Turkey by taking into consideration of climatic condition. Even though a lot of researches have noticed about energy efficiency in fenestration designs, a significant research analyzing simultaneously the mutual impact of; wall window ratio at each elevation on the energy demand, is missing. Furthermore, two constraints exist related to illuminance levels and climatic zone differences.

As a result, in this manuscript, different fenestration alternatives are analyzed and discussed for finding near-optimal design solutions for each 4 zones in the context of Turkey according to the TS825. This observation emphasizes better utilization of the natural sources in the design in order to use the performance of energy efficiency measures for buildings.

1.7. OUTLINE

The remainder of this manuscript is structured as follows: In section 2, literature is critically reviewed and interpreted. In section 3, methodology and explanation of case study including a brief regional climatic condition, properties of loads, description of research objectives, decision variables are presented. The problem definition with the details of the explanation case building model and formulation of the objective functions and constraints are also introduced. Section 4 shows the parametric model developed into GH proposed for the design of the residential case building. The results of the analysis thoroughly explained in Section 3 are interpreted and discussed. Finally, Section 5 concludes the study.

CHAPTER TWO
BACKGROUND & LITERATURE REVIEW

Chapter two deals with the critical review of the literature, which forms a foundation for problem statement (1.2) and methodology of the research (1.5). In the first section of the literature review, a general approach to parametric design was outlined. Within the content, origins and definitions of parametric design along with its application to performance-based design was critically reviewed and reported.

The second section, on the other hand, focused primarily on the literature, which studied the problem at hand: energy efficiency and daylight optimization by means of fenestration strategies. In the literature, several literature articles have been reviewed about energy consumption related to daylight performance. When researches carried out regarding improving energy performances of residential buildings are reviewed and analyzed, they can be categorized into three different approaches; energy efficiency with using several daylight performance strategies in a residential building, evaluating several methodology and simulation strategies, analyzing energy and daylight performance in Turkey.

The last part of the chapter presents a summary of the literature review and discusses the current state of computational design integrated to the energy and daylight.

2.1. ON PARAMETRIC DESIGN

Parametric design requires multiple solutions for architectural design problems by using parametric models. The term parametric is originally a mathematical term and its use in describing three-dimensional models dates to the first half of the 19th century. The parametric design relates the general action of the design to the adoption of “parameter” (Dictionary, 2002). The term of ‘parameter’ in relation to mathematical meaning is a constant quantity in the case. However, it varies and diversifies in different cases. In this manuscript, the term ‘parameter’ is defined as any measurable factor that identifies a structure or specifies its boundaries.

The parametric design is a process emerged from the problem description by applying variables. By altering the variables, each value changes for each parameter. Then the model reoccurs so as to display the new form and various design solutions are generated. Finally, depending on some principles an optimum solution is chosen (Alvarado & Munoz, 2012).

Almost a hundred years later in the 1940s, before the development of computers, the first use of the term 'parametric architecture' in architecture discipline emerged in the writings of Luigi Moretti (Davis, 2013). Moretti described parametric architecture as the study which explains the links between the architectural systems and the various parameters (Davis, 2013; Tedeschi & Andreani, 2014). Moretti collaborated with the mathematician Bruno De Finetti made use of computers in his research (Tedeschi & Andreani, 2014).

However, according to (Prousalidou, 2006), 'Philips Pavilion' is the first building which is constructed by adopting parametric systems without computational methods. Le Corbusier and Iannis Xenakis created this building for the Brussels World´s Fair in 1958. According to (Shelden, 2002), the Barcelona Fish is designed by Frank Gehry also according to (Szalapaj, 2013) and (Gane, 2004), Extension of Waterloo Station by Nicholas Grimshaw are the early works of parametric design. Those buildings were designed by using a three-dimensional digital model. In addition, Antoni Gaudi and Frei Otto are other pre-digital pioneers of parametric design approach in architecture (Burry, 2016).

A few years later, Ivan Sutherland (1963) developed the first interactive Computer-aided Design (CAD) program, called as 'Sketchpad'. It was fundamentally a parametric system. The invention based on an advanced associative logic and parametric change. This system uses parameters in order to employ numeric data which is adjustable and controllable. After that, it results in the related parts automatically (Davis, 2013; Gun & Woodbury, 2010; Tedeschi & Andreani, 2014).

Despite striving greatly in parametric approaches, which have utilized computers since 1960, the first commercial CAD programs did not employ parametric features. Rather, they attempted to aid technical drawings and representation. The first version of parametric modeling software, Pro/ENGINEER, was released from Parametric Technology Corporation (PTC) in 1988. The aim of the software was to enable engineers to consider easily a variety of design alternatives. The parametric modeling role of the software was achieved by recording the operator's command steps. It was called as “history tree”. With the use of the recorded history tree, in case of any change of parameters, the software would automatically regenerate the model. When working on large models, this feature of the program was a time-saver (Weisberg, 2008).

In the field of architecture, the influence of parametric modeling started only about the year 2000 (Gun & Woodbury, 2010). Today, various software platforms for architects, engineers and researchers provide to work with parametric models. That software varies from history-based modelers such as Catia, Solidworks, Pro/ENGINEER, to visual scripting platforms such as Generative Components, ParaCloud Modeler, Grasshopper, Dynamo and textual programming environments, which are included with most CAD programs (Davis, 2013).

Parametric design is a CAD approach. It makes use of parametric modeling and scripting techniques to deal with the geometric properties of any design. In this technique, geometric properties of a design are considered as variables. The designers construct a network, which allows continuous design adjustments along with generating options and variations, this is called a ‘parametric design model’. At any time, the parametric model outputs a determinate instance of the design depending on the set of currently chosen values. However, the essential characteristic of the parametric design resides in the way in which constituent parts of the model are interrelated and arranged. It is the relationships and dependencies that is designed, not a single determinate instance (Schumacher, 2015).

Parametric design is a process which allows parameters and rules to control design variants. These parameters and rules describe the logic and the intent of a parametric and associative geometry. The superiority of this method lies in its ability to adapt to changes. It is possible to change the associative model by changing a few parameters (Jabi, 2013). Dino (2012) stated that parametric design is a sub-category of algorithmic design (Dino, 2012). There is a strong relationship between parameters and algorithms. While algorithms operate on parameters, on the other hand, a parametric system graph is an algorithm itself. The essential difference of a parametric system is its emphasis on the clear and direct use of the parameters to alter the design geometry (Dino, 2012).

A parametric description of the form provides to be changed easily according to the proper situation to represent complex surfaces. Burry used parametric techniques on the analysis of the ruled surfaces designed by Antonio Gaudi. In addition to his advanced work, he utilized parametric design software in order to remodel and determine the surfaces of Sagrada Familia with the aim of a measurable clarification (Burry, 2016). The models were used to find geometric alternatives by modifying parameters to find configurations.

Designers can generate an infinite number of design objects by transferring specific values to the parameters in the algorithmic schemata, which they created previously (Kolarevic, 2003). Thus, a parametric model signifies many possible designs. Different specific designs can be produced by changing the inputs. Hudson (2010) made a categorization for the parametric design tasks; creation of a parametric model process and use of this model to explore better alternatives in the design space. Establishing the model, which is a repetitive process, needs to develop the problem definition. While considering the interactions and methods, a parametric model is being set up and examined. Looking for the problem space needs to specify values for parameters and produce solutions that are evaluated. After that, the designers either turn back to the original problem determination by altering according to their findings or they purify selected variables and generate the following alternative. Woodbury et al. (2006) put forward that exploring the design space of parametric models is one of the main challenges for future parametric modeling researchers. Choosing the best alternative gains importance after generating the logic that produces multiple outcomes. However, searching for better design alternatives, parametrically in a wide design space requires more than manually changing values in the design parameters and monitoring the associative values of performance indicators.

Computer power comes into place again for the repetitive task of searching for better design alternatives within the designer-defined boundaries. Buro Happold (BH) operated two engineering firms in the UK. They are called as Software Modelling Analysis and Research Technology (SMART) and the Generative Geometry Group. Both enable other project designers within the practice and architectural customers to have parametric and proliferous geometry support (Hudson, 2010). They originate a software as plug-ins to Rhinoceros (McNeel, 2015).

To sum up, the term of ‘design’ explains how to describe a definition of a problem in this manuscript. After the description, creating and seeking amongst alternatives are applied in order to encounter the problem. “Parameter” is a measurable factor that states a system or defines its boundaries. “Parametric design” is a process where a description of a problem is generated by using variables. While altering these variables, a range of alternative solutions is produced. Final solution selection depends on various principles that are related to performance, aesthetics of the building, facilitation of construction process, financial limits, user requirements so on so forth.

2.2. BUILDING ENVELOPE DESIGN STRATEGIES IN BUILDING PERFORMANCE: A CRITICAL OVERVIEW

The previous works aim at determining several design strategies. To achieve analyzed and developed for reducing a building’s energy consumption while maximizing daylight. According to (Cheong, Kim, & Leigh, 2014), one of the basic energy saving impacts of the environment is using natural daylight. It provides both using natural sources also decreasing energy demands considerably in residential buildings. To using natural daylight effectively, well design building envelopes are one of the most significant components of the whole building. In the literature, various types of design strategies such as windows, façade, courts, skylights and so on so forth in the building envelope are defined.

Particularly, there are several works about designing different fenestration strategies to minimize energy consumption related to optimizing daylight performance regarding different parameters such as wall window ratio, window position (high–middle-low), glazing properties and window orientation (north-east-south-west).

In early studies, the impact of wall window ratio and glazing properties are considered concurrently (Stegou-Sagia, Antonopoulos, Angelopoulou, & Kotsiovelos, 2007). Authors study on window design problem, with the aim of daylight and energy. The consideration is the maximizing natural daylight while minimizing energy consumption as a multi-objective problem. Another work by (S. Kim, Zadeh, Staub-French, Froese, & Cavka, 2016), is investigated for several window design options changing window position, wall window ratio, glazing properties, window orientation. Their findings suggest that hypothesized variables have an important influence on the total energy requirement of the structure. The analysis was based on building information models (BIM), change in 65 scenarios with using case building. The single-family case building locates in Vancouver, Canada. The simulation process occurs into two phases. The first stage is modeled by 29 scenarios and shows how the wall window ratio and window position affect the total energy of the building. In the next phase, the effect of the position and orientation of windows are evaluated through 36 different scenarios. To conclude this multi-objective optimization, authors chose one of the near-optimal solutions and calculated regarding energy efficiency as analyzed by Autodesk Green Building Studio. As a result, they declared the optimum position for efficiency for the building while the window orients in the east and locates at the middle height.

In other studies (Husin & Harith, 2012), it is focused on only the wall window ratio and the position of the windows. The study consists of three building in Malaysia. Several scenarios are evaluated in order to maximize daylighting and reduce the consumption of artificial lighting simultaneously. Three different types of windows are presented. They are casement with an obscure glass window (CWOGW), fixed louver with a clear glass window (FLWCGW) and adjusted louver with a tinted glass window (ALWTGW). In conclusion, the results show and suggest that the optimum daylight quantity entered the living area especially in the residential buildings.

Based on several works, façade design has a significant effect on not only daylight distribution of the building interior, but also effect on structural performance (Chatzikonstantinou et al., 2015a; Perera & Sirimanna, 2014). In the literature (Chatzikonstantinou et al., 2015a), authors are attempted to identify opening forms configurations on the façade, including elements of the glass panel frames and construction materials, which maximize daylight performance of the building. Several scenarios are formulated regarding the multi-objective problem. In (Wright & Mourshed, 2009), the optimization objective is minimizing energy regarding several fenestration strategies that are geometry, number, and position of windows. The case building, locates in Chicago, USA, tests by using EnergyPlus simulation tool. Buornas et al. (Bournas & Haav, 2016), investigates the fenestration design strategies for multi-story buildings considering heating, daylight autonomy. The optimum window size, position, and shape were assessed as a function of achieved optimum daylight and energy required. Different fenestration strategies under the proper input data are generated and analyzed for each zone of two different real case buildings.

In (Koohsari, Fayaz, & Kari, 2015), authors are attempted to determine optimum window size and its position on building's façade that would provide to minimize energy performance. The author studies in one location that is typical, traditional living room in Giulan province, Iran. 450 different fenestration scenarios are applied in the building. As a conclusion, they emerge different window width and elevation of the façade through affecting the total energy consumption, respectively. They claim that window height should be designed concern with energy in the early design stage. Also, visual comfort and climate should be considered and analyzed.

Another study (Ferdyn-Grygierek & Grygierek, 2017) reveals that early design decisions are influenced on the energy performance of the building significantly. In this multi-variable optimization problem in the single-family case, the house is considered with its loads and its temperate climate condition. The optimum range of the design solutions is conducted by using the EnergyPlus simulation program. Different types of glazing, window area, and frame surface, building orientation, insulation of construction materials were chosen as decision variables. Depending on 7 different analyzed cases, because of the optimization, energy percentage decreases from %7 to %34.

(Azari, Garshasbi, Amini, Rashed-Ali, & Mohammadi, 2016) study the multi-objective optimization problem. The study aims to investigate the impact of optimum building envelope designs on building performance in the context of a low-rise office building in Seattle. Design variables are insulation materials, window material, window type and wall window ratio with regarding energy and life cycle role to the effects on the environment. The results show that the optimum design parameters and impact on the early envelope design significance.

The extensive amount of the total heat loss of buildings happens within the building envelope. Although windows cause unwanted results in terms of energy conversion, a small number of researches are related to the fenestration strategies and alternatives in buildings. In short, building envelope strategies and parameters are received more attention in the literature. The literature review shows that especially fenestration parameters (window size, position, glazing properties, etc.) are variables to generate different design solutions.

2.3. METHODOLOGICAL APPROACHES IN ENERGY AND DAYLIGHT MODELLING

By looking at the side of formulating strategies as optimization problems, in the literature, there are several works for integrated daylight and energy simulations. The advanced building simulation tools ease the process of analysis and help designers effectively. This type of analysis facilitates to observe of design parameters impacts on building in the early design stage. Several approaches and programs have been developed for the buildings and presented in the literature.

(Hviid, Nielsen, & Svendsen, 2008), present a simple building simulation tool that is called Window Information System (WIS) program. It evaluates several glazing types and shading alternatives to the aim of optimizing thermal performance by considering the aesthetic approach. The daylight and thermal simulations and calculations are analyzed in order to find out shading alternatives regarding the indoor environment and the sun position. The simulation tool, Radiance, is chosen for validation of the daylight calculation with reference single office room model. Three variables; a clear glazing, external blinds adjusted to cut-off angle and an external screen, are implemented.

(Li, Wong, Tsang, & Cheung, 2006), evaluate daylighting performance in residential buildings. Five parameters; building area, wall window ratio, glazing type, building orientation, shading and external obstruction, are simulated in order to evaluate the interior daylight illuminance via computer simulation techniques. Computer-based building energy simulation tool, Energy Plus, is utilized to analyze the daylighting performance of the building. In another attempt, (Al-Saadi & Budaiwi, 2007) aims to analyze thermal characteristics of the building envelope that provides both improve indoor thermal conditions and reduce energy consumption in residential buildings in Riyadh and Dhahran. The study identifies envelope thermal design parameters (i.e. various windows to wall ratio (WWR), orientation, and glazing types). More, the work evaluates the impact on a thermal performance by using energy simulation program, Visual DOE 4, considering with climate condition. After defining the proper building envelope design parameters, the most effective strategies are selected and simulated to identify energy consumption for the eight envelope designs considering with regional standards and regulations. The selected alternatives regulate to thermal design principles for residential buildings envelopes in hot climates.

(J. Kim, 2012) studies the optimization daylight performance via a computational process to generate alternatives opening patterns on the building envelope. The alternatives are tested for finding optimum design in terms of daylight performance. In these studies, energy efficiency strategies are adopted to minimize notably the energy demand. (Erlendsson, 2014) analyzes daylight in the buildings, and he compares several daylight simulation tools in detail. Five simulation tools; Rhinoceros, Grasshopper, Honeybee, Daysim, and Radiance assess the daylight distribution in the room. Similarly, (Bournas & Haav, 2016), 5 different simulation program are combined under the same platform. For achieving optimum daylight, and energy strategies in each zone, simulations are run on the software program. Further, the parametric analysis is performed to select the optimum measurements for the daylight distribution and energy efficiency.

In the works of Jaber and Ajib (Jaber & Ajib, 2011a, 2011b), Gasparella et al. (Gasparella, Pernigotto, Cappelletti, Romagnoni, & Baggio, 2011), Cheung et al. (Cheung, Fuller, & Luther, 2005), Ruiz and Romero (Ruiz & Romero, 2011), Chastas et al. (Chastas, Theodosiou, Kontoleon, & Bikas, 2017) and Yu el al. (Yu, Yang, & Tian, 2008), several glazing types, orientation and size of window energy demand on each season are studied in residential buildings. The variables are considered in line with energy, cost, and environmental aspects. The studies are performed using TRNSYS, EnergyPlus, and DOE-2 simulation program for different climate conditions. Besides, Rodrigues and Freire (Rodrigues & Freire, 2014, 2017a, 2017b) studied a thermal characteristic of a single-family residential building and an apartment. The thermal simulations are evaluated design alternatives by using EnergyPlus program.

In many studies, optimization algorithms are used to solve the multi-objective optimization problems in the building. The genetic algorithm (GA) is employed to optimize the energy performance of the building by controlling the heating, and cooling parameters. (Abido, 2002; Wright, Loosemore, & Farmani, 2002). In a study (Ferdyn-Grygierek & Grygierek, 2017), the mutual effect of; window types, wall window ratio, building orientation, insulation of construction materials are noticed about energy efficiency in the building design. Multi-objective optimizations and the building performance simulation program are worked together by using GAs in order to minimize the energy demand and life-cycle costs of the residential building in Poland. The optimization process performs with Energy Plus simulation tool. In addition, Tuhus-Dubrow and Krarti (Tuhus-Dubrow & Krarti, 2010), Znouda et al. (Znouda, Ghrab-Morcos, & Hadj-Alouane, 2007), Han et al. (Han, Srebric, & Enache-Pommer, 2014), Hasan et al. (Hasan, Vuolle, & Sirén, 2008) are studied optimization of several envelope alternatives in order to minimize energy consumption. GA is used to select optimal values of parameters related to building envelope design alternatives for building orientation, structural component insulation, wall window ratio, glazing type, and thermal mass, so on so forth.

2.4. THE CONTEXT OF TURKEY: STANDARDS AND REGULATIONS

Based on literature scan results, the little consideration in the field of the building envelope optimization for both energy and daylight objectives according to local climate condition as well as national standards of the region and their connection to international ones.

In the study (Stegou-Sagia et al., 2007), the calculation and simulations on the two real case buildings are located in Greece. The authors consider applying international standards, ASHRAE, for research analysis and simulations. The buildings are simulated using the computer tool, and they have been used as an input data for the study. In conclusion, the authors underline the importance of the glazing choice for energy efficient solutions while considering with local climate conditions. Another study (Schütz, Schiffer, Harb, Fuchs, & Müller, 2017), in exact optimization models, concurrently relates energy systems to building envelopes. It is highlighted regarding the building of German energy regulations and standards, ISO 13790 and ASHRAE 140. However, the local climate conditions of the building are not considered. The researchers in (Jaber & Ajib, 2011b) point out that, the effects of window orientation, windows size, U-value, glazing types are studied considering both energy and investment costs annually. The problem is analyzed and discussed to find near-optimal design solutions for three climate zones; Amman, Aqaba, and Berlin. In conclusion, optimum design alternatives are selected in order to optimize energy saving fenestration solutions for each climate conditions. In (Ruiz & Romero, 2011), the authors present several passive strategies in order to reach optimum energy and environmental improvements. The relevant Spanish regulations for residential buildings are taken into consideration in the early design phase of this analysis. In addition, the simulations are conducted by Energy Plus simulation program.

As a result, the geometry and strategies of fenestration are complex tasks. Therefore, more detailed researches should be carried out in order to find optimum fenestration parameters regarding compatible climatic condition in Turkey. At this point, the current study observes that most of the previous works aim to increase thermal comfort while reducing energy demand for different climate regions in Turkey regarding relevant regulations and standards (i.e. (Mangan & Oral, 2014), (Özkan E., 1997)). Especially two main regulations as Energy Performance Regulation in Buildings and TS 825 Thermal Insulation Requirements in Buildings in Turkey are determined and discussed. The research (Özkan E., 1997) by TUBITAK(The Scientific and Technical Research Council of Turkey) studies in developing applicable economic and energy efficient building envelope design alternatives for the existing residential buildings in Istanbul. Various decision variables such as insulation materials' thickness, orientation, glazing types are presented related to energy consumption. Briefly, this study shows that using single glazing has the highest value during the life-cycle of the building. This thesis can also determine diverse cities and building systems as decision variables and make a comparison between them regarding their deficiency and efficiency. In the study (Esiyok, 2006), the regulations, related to energy performance in the residential buildings in Turkey, are discussed. However, the research mentions that these Turkish regulations on energy conservation and saving are not enough and elaborative. In addition, they are not intensely provable and approvable. In (Mangan & Oral, 2014), retrofit energy performance strategies for different climate conditions in Turkey are reviewed. The optimal retrofit scenarios (i.e. insulation on the external wall components, glazing systems, PV system, solar control device) base on relevant laws and regulations. After defining reference residential building and retrofit solutions, combinations for 4 different climate regions of Turkey are evaluated. In conclusion, energy efficient solutions are suggested based on the cost analysis results.

Prior to this study, a significant number of comparative researches and reviews are investigated. Based on these studies, like the main approach of low energy design, many strategies have been developed to improve the energy performance of residential buildings and the impact of these strategies has been assessed. Nevertheless, these strategies aiming to assess the performance of residential buildings in terms of economy, energy, and environment are expected to alter according to weather conditions, users' requirements, building properties, and related standards. Therefore, applying current strategies, used before or improved appropriate approaches ought to be used as an essence of the researches regarding both current and new residential buildings' performance development in the local climatic conditions.

2.5. SUMMARY

One of the advances in the contemporary design field was the introduction of the parametric design approach. In the first section of the literature review, a general approach to parametric design was outlined. Parametric design approach aims for thinking about alternatives and variation itself. Furthermore, as Davis (2013) also noticed that, finding better solutions, with using parametric design, is a challenge that is brought out by this multiplicity of alternative solutions (Hudson, 2010; Woodbury et al., 2006). This approach leads to new research questions about how to explore and select from the set of design alternatives that the parametric model generates.

In this section, the literature review reveals that the design problem is created and understood clearly using parametric design. Seeking for an answer to the problem of how to evaluate design alternatives and environmental concerns gave rise to performance-based design, which is an approach driven by information. Parametric models coupled with simulation engines allowed for predicting the performance of any design instance. The parametric model is to provide alteration of the design process. Therefore, the designers are informed about how possible design solutions perform; thus, make better decisions (Oxman, 2008; Shea et al., 2005; Turrin et al., 2013). Integration of performance criteria made the endless variations generated by parametric models more meaningful.

In this thesis, the 'parametric design' term is defined as the values of parameters adjusted by a computer simulation tool automatically during the early design phase.

Within the content, origins and definitions of parametric design along with its application to performance-based design was critically reviewed and reported. To find out the optimum solution, parametric design strategy is a suitable technique. The significance of exploring concepts by combining a parametric design with a façade system has been proposed.

The second section, on the other hand, focused primarily on the literature, which studied the problem at hand; energy efficiency and daylight optimization by means of fenestration strategies. In the literature, several literature articles have been reviewed about energy consumption related to daylight performance. When the review of the literature carried out regarding improve of residential buildings' energy performances are analyzed. It can be categorized into three approaches; energy efficiency with using several daylight performance strategies in a residential building, methodological approaches in energy and daylight modeling, analyzing energy and daylight performance strategies in Turkey relevant standards and regulations.

In the literature, to use natural daylight effectively, well design building envelopes are one of the most significant components of the whole building. A few works tackled daylight and energy performance by taking them as a multi-objective optimization problem. When various types of design strategies were defined in the literature about building envelope system, especially windows, façade, roof openings, courtyards, skylights, are analyzed. Particularly, there are several works about designing different fenestration strategies to minimize energy consumption related to optimizing daylight performance.

The review of the literature revealed that different parameters of fenestration strategies such as wall window ratio, window position (high–middle-low), glazing types and window orientation (north-east-south-west) under the proper input data have an influence on the building daylight and energy performance significantly. The optimum parameters were assessed as a function of achieved optimum daylight and energy required.

In the literature, the authors attempted to identify optimum parameters to aim maximizing daylight and minimizing energy consumption. However, none of the studies in the literature handled the design problem from a wall window ratio, and window orientation considering the climatic conditions and regional standards. Whereas, when the early design stage, fenestration is designed to attempt optimum wall window ratio with suitable orientation in the façade regarding proper glazing type. These parameters must be considered together.

On the other hand, by looking at the side of formulating these strategies as optimization problems, in the literature, there are several works for integrated daylight and energy simulations. Today’s new technology via computer science enables designers, engineers, and researchers to reach enhanced analysis by building simulation tools. This type of analysis helps to estimate the design variables’ impacts on energy demand of the building. Several approaches and programs have been developed and presented. The literature helps in this regard by providing access to evaluated programs and helped to select criteria to do own assessments.

This manuscript aims to analyze the performance of daylight and energy to reach an optimum solution for residential buildings considering parametric design. Therefore, this multi-objective optimization problem is evaluated by several fenestration strategies while using a parametric model in order to advance the human comfort.

On the other hand, according to the recent studies, there is a little awareness of both energy and daylight objectives in the field of the building envelope optimization in strictly the local climate condition as well as international and national standards of the region.

In addition, the previous literature review reveals that Turkey has a significant amount of natural energy sources. Strategies to analyze the performance of residential buildings in terms of energy, daylighting, economy and environment are contextual. Values and properties of design variables depend on climate, users’ needs, building properties, and related standards. Therefore, applying current approaches, used before or improved appropriate approaches ought to be used as an essence of the researches regarding both current and new residential buildings’ performance development in the local climatic conditions.

The reviewed studies helped situate this manuscript focus within the broader academic field of fenestration optimization. In conclusion, this paper addresses this gap by analyzing the performance of energy and daylight in the residential building in the context of Turkish 4 climate zone considering with regulation and standards, at the same time vernacular requirements. The interdependence between optimization objectives was shown to vary based on wall window ratio, and window orientation.

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CHAPTER THREE
METHODOLOGY

3.1. INTRODUCTION

The present study investigates different fenestration strategies concerning minimizing energy consumption and using optimal daylight. Subjects are measured before on the test box model that is created regarding relevant properties based on standards and regulations. The decision variables; wall window ratio and window orientation, are used for finding a set of fenestration design alternatives to reach near-optimal daylight and energy efficient solutions. The final calculations and analysis, which are defined by test box model, validation real case buildings are established in the context of 4 different Turkish climate zones. For calculations and analysis are based on DIVA, ladybug and Honeybee simulation software, that is a plug-in of Grasshopper 3D (GH). The simulated energy consumptions and quantitative calculations of the models are compared with the actual yearly energy consumption for each climate zone. In short, to solve the problem dividing into phases:

- Defining a reference test box model as parameters
- Filtering regulations their performance in terms of energy and daylight and generating a form of fenestration strategies regarding relevant standards,
- Validating and making optimization the alternatives to identify fenestration configurations suitable for 4 climate regions in Turkey for each real case building.

The flow of processes in this quantitative design outlines in Figure 3.1.

3.2. CLIMATE ZONES IN TURKEY

While designing a building, the climate affects extremely on the energy demand and natural daylight usage of buildings. Climate characteristics of the surrounding environment shape building envelopes in the early design phase of the building.

Hence, when engineers and architects design the building, one of the basic design phases is climatic conditions' analysis. The solar heat gains that come from glazed areas directly affect the indoor thermal environment.

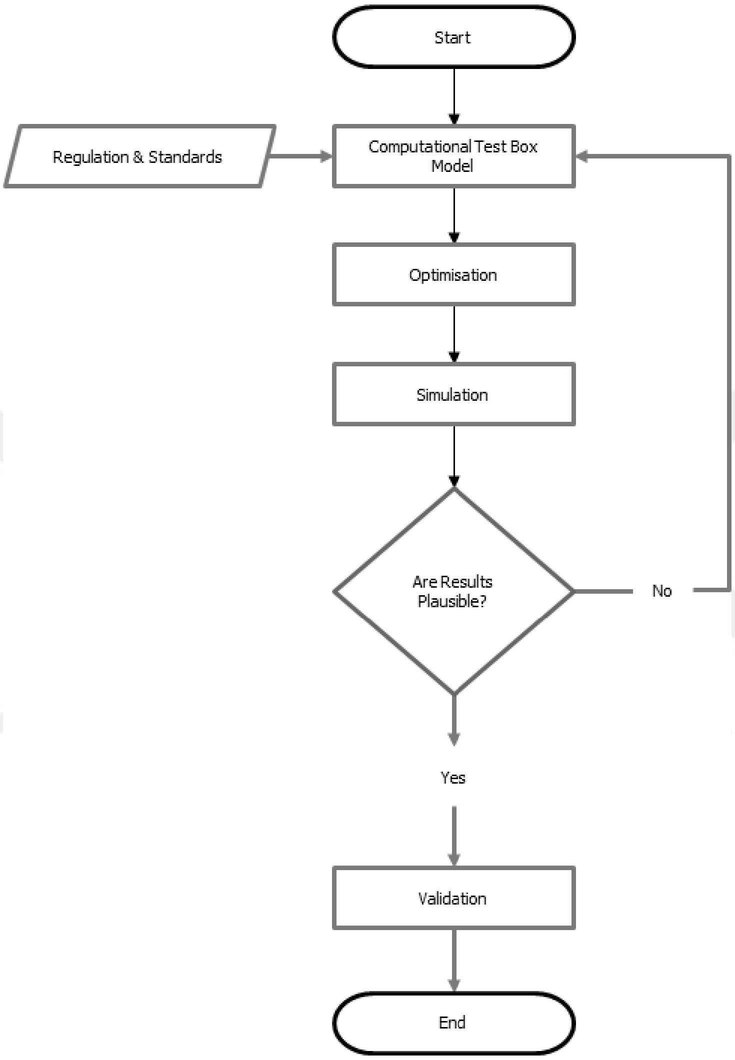

Figure 3.1 Flowchart of the general research process

Turkey is located at the Mediterranean. It is situated between 36° and 42° N latitudes in a large geographical location. It is in the Northern Hemisphere at the connection of Europe and Asia. Thrace is the European part and Anatolia is the Asian side of Turkey. The neighboring countries are Azerbaijan, Greece, Iran, Bulgaria, Georgia, Armenia, Iraq, and Syria. The total length of borders is 2753 km and the coastal length is 8333 km. The coastal zones are Black Sea, Marmara Sea, Aegean Sea, Mediterranean Sea and the passages of Bosporus and Dardanelles. In Turkey, large parts of 20.8 million hectares are planted forests. The geographical formation is very sloping and rough. The half of the land area in Turkey involves 26 basin areas and the 9 of them are river basins (Bektas Ekici, 2015).

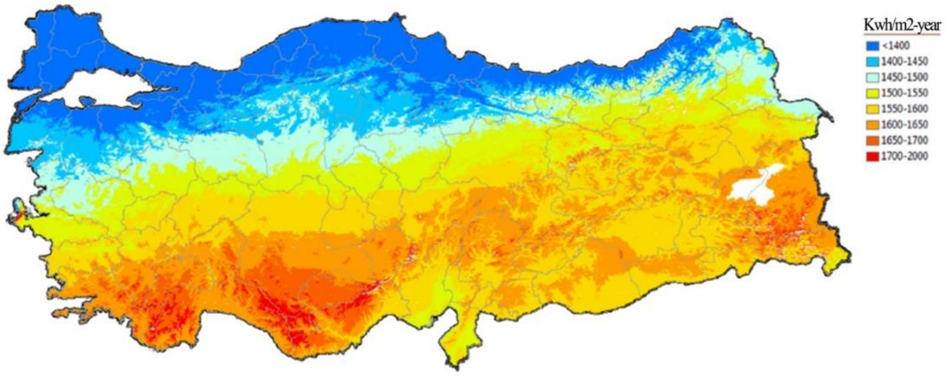

Figure 3.2. Average global solar radiation of Turkey (Recourses, 2015)

Due to its geographical situation, it has a significant potential for solar energy, that is calculated as 380 billion kWh/year. Also, turkey has an opportunity to benefit from this natural source in building design (EKİCİ, 2014). According to the Turkish Solar Energy Map (SEM), studied by the Renewable Energy General Directorate, the total insolation time is 2.737 hours (a total of 7.5 hours per day) annually and the total solar energy derived is 1.527 kWh/m² per year (total 4.2 kWh/m² per day) ("Turkey-Energy Efficiency in Buildings,"). The Southeast Anatolian region of Turkey has an average sun’s radiation of 14.37 MJ/m².day and sunshine duration of 8.2 h/day. The Black Sea region has an average sun’s radiation of 11.02 MJ/m².day and sunshine duration of 5.4 hours per day, respectively. In Turkey, the unrestricted potential of the sun in terms of technology, economy or environment is evaluated at 90 Mtoe per year ((MENR), 2016; IEA, 2016; Kaygusuz, 2011; Nalan, Murat, & Nuri, 2009). The average annual temperature is between 18ºC-20ºC south. Also, it changes between 14-16ºC along the coast of the west and alters between 4-18ºC at the center of the Turkey (Sözen, Arcaklioğlu, & Özalp, 2004). It shows that average Global Solar Radiation of Turkey. (Recourses, 2015). Figure 3.2 shows the average global solar radiation potential of Turkey.

In Turkey, TS825 is a mandatory national building energy regulation that emphases thermal insulation in Turkey. The rules for decreasing energy demand in buildings implemented on residential and commercial buildings that are new or renovated are regulated. TS825 was first issued in 1999 and The Ministry ensures that this standard is mandatory for all new buildings to be built after June 14th, 2000. It has been reviewed several times and the last publication was written in 2013. It sets minimum U-values for envelope components ("Turkey- Energy Efficiency in Buildings,"). Owing to the building design solutions and components selected properly, TS825 energy performance standard divided Turkey into 4 climatic zones based on average temperature and heating degree-days. The detailed classification of climate zones was shown in Figure 3.3 and Table 3.1, respectively. In addition, as mentioned this standard, total heat transmission coefficient (U) of 4 climate zones for the considered building elements are presented in the following Table 3.2.

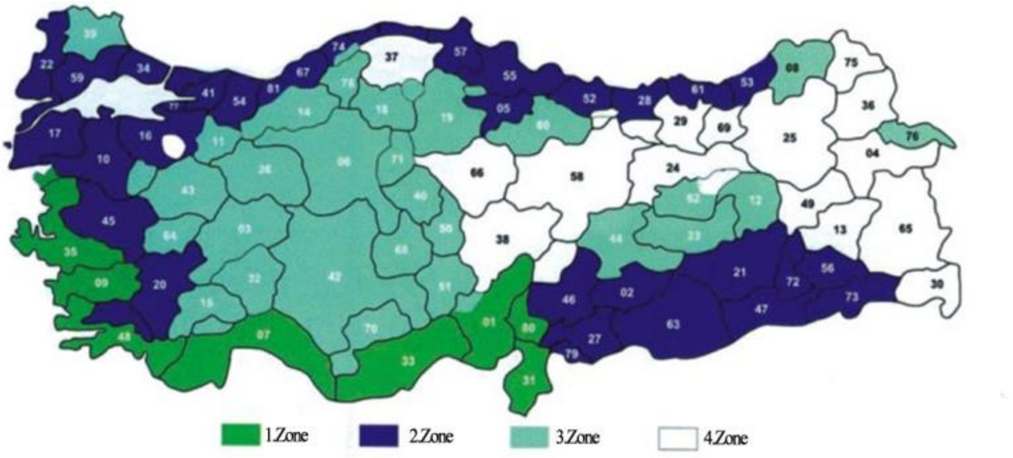

Figure 3.3 Climatic zones of Turkey according to TS 825

Table 3.1 Characteristics of climatic zones

Climate Region	Representative City	Latitude-Longitude	Heating Degree Days	Cooling Degree Days	Global Horizontal Radiation(kWh/m^2/y)
1	Izmir	38°24'45.83"N-27°8'18.17"E	1500	1061	1496
2	Istanbul	41°0'49.82"N-28°56'58.78"E	1667	676	1612
3	Ankara	39°55'11.53"N-32°51'15.37"E	2793	476	1473
4	Erzurum	39°54'31"N-41°16'36.98"E	4957	86	1393

Table 3.2 Maximum U-values of construction sets according to climatic zones in Turkey.

	U value (W/m^2.K)			
	I. Region	II. Region	III. Region	IV. Region
Wall	0,70	0,60	0,50	0,40
Slab	0,70	0,60	0,45	0,40
Ceiling/Roof	0,45	0,40	0,30	0,25
Window	2,4	2,4	2,4	2,4

3.3. TEST BOX DEFINITION

3.3.1. MODEL AND GEOMETRY

A test box model, demonstrated in Figure 3.4, is the beginning of all simulation process in this manuscript. Simulations are achieved as “Reference case” and “validation case” for two case stages. Firstly, the referenced test box model regarding several fenestration strategies is determined and simulations are carried out. After simulation-based optimization is performed, the well-performed solutions, which outperformed the remainder, are chosen to minimize energy consumption also maximizing daylight performance of the building

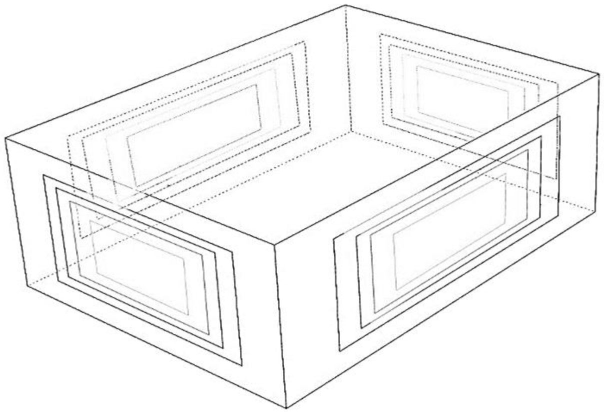

Figure 3.4 Test box model building and its WWR alteration

The dimensions of the model are referenced from ASHRAE 2003 standards the base case building. The tests describe in ANSI/ASHRAE Standard 140-2001, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs (ANSI/ASHRAE 2001) are performed. As mentioned in its Preface, Standard 140-

2001 is a standard method of test. It is applicable to describe and diagnose variables regarding energy simulation software of the building. (Henninger & Witte, 2003). For this reason, while generating a test box model, the ASHRAE standards measurements are considered.

The scenario focuses on the parametric design of one simple test box model 4 different climate zones in Turkey. The simple rectangular shaped building is specified as 8 m width, 6 m length, and 2.7 m height. It has 4 windows; each of them is located in each façade of the building. The window to wall ratio at each elevation, namely north, south, west, east, formed decision variables. To evaluate the wall window ratio (WWR) effect on building energy demand, the current work allows WWR to fluctuate between 10% and 90% by 5% intervals. Initial parameters of the test box model are provided in Table 3.3

The strategies and analysis are defined and evaluated from the test box model using computational simulations. Then the appropriate parameters are selected and validated in a real case. Parameters, such as glazing ratios, glazing types, and U-values of construction properties are set to expose the data collected from the regional standard, TS825. Because the model is formed via a computational simulation tool, these parameters could easily be changed for each real case building and every simulation. The next part defines the base test box model load properties.

Table 3.3 Parameter initiation of the test-box model

Parameters	Values
Location	Turkey
Building Function	Residential
Average Interior Temperature	19ºC

3.3.2. LOADS

Properties of materials, which are basic properties of test box model, come from TS825 regulation. The key purposes of the standard are a limitation of energy loads to maximize energy performance in Turkey while indicating and determining the calculation techniques and estimations ("Turkey- Energy Efficiency in Buildings,"). All values which formed the crucial inputs of the building performance simulations are given in Table 3.4

Table 3.4 Parameter initiation of the test box model

Parameters		Values
Internal Loads	Equipment Power Density	5 W/m^2
	Infiltration Rate	0.003 m^3/s -m^2
	Lighting Power Density	10 W/m^2
	Occupant Density	20 m^2/person
Design Temperatures	Set point Temperatures	20 ºC -25ºC
	Setback Temperatures	18 ºC-28 ºC
Ventilation and Outside Air	Outside Air Rate/Person	10 L/s person
HVAC Schedule	Operating Hours	6 am-10 pm

3.3.3. CONSTRUCTION SETS

Regarding TS825 standard, the building energy loads significantly based on the building envelope components, such as walls, slabs, windows, roofs, and so on so forth. Also, their materials and thickness are the main effective data of the energy efficiency analysis for TS825. As mentioned this standard, to reduce building components effects on energy consumption, using maximum and minimum thermal transmittance (U-value) values are significant for building envelopes by considering climate region. Therefore, through the simulation process, the heat transmission coefficient (U) of construction sets of the test box in four different climate zones of Turkey were referenced from TS825 standard. A visualization of these U-value requirements for the four considered building elements wall, ceiling/roof, floor, and windows was presented in Table 3.2.

3.4. VARIABLES & CONSTRAINTS

3.4.1. INDEPENDENT (DECISION) VARIABLES

A large amount of energy savings and increasing daylight performance can be achieved by applying numerous simulations to improve and reach building envelopes providing energy efficient strategies. In this manuscript, objectives are shown to vary based on wall window ratio at all elevations, namely south, north, west, east. These WWR values at each elevation are varied simultaneously. That is, different controllers are appointed. The parameters' effects on the energy consumption are argued to determine the plausible one and display the proper parameters to designers.

The aim is to provide an effective control and to minimize the energy consumption and maximize daylight of the buildings. Decision variables are given in Table 3.5.

Table 3.5 Decision variables used in the current work

Notation	Description
x_1	WWR Ratio in North Elevation
x_2	WWR Ratio in East Elevation
x_3	WWR Ratio in South Elevation
x_4	WWR Ratio in West Elevation

To design the building envelope, wall window ratio (WWR) corresponds to the window area. The ratio of whole window area to the total gross exterior wall area is defined as WWR.

According to ‘Investment support and promotion agency of Turkey’, among the different functions of windows, daylight admission is the most appreciated, especially in regions where the overcast sky is the dominant sky condition. ("Energy and Renewables ")

In this manuscript, the test box model glazed area is one of the design variables. The glazed area is represented as a ratio to the heated useful area, and it is discretized into levels: 5%, 10%, 15% .. 85%,90%, 95%. The ratio changes between %5 and %95 and the percentage value go five by five. In addition, it is designed and evaluated for 4 different orientations as south, north, east, west.

The different types of design parameters represent that high energy savings can be obtained through basic design strategies, involving WWR, and the orientation of windows regarding the performance of daylight and energy in the building. To do this, required notations are given in Table 3.5.

3.4.2. DEPENDENT VARIABLES

In this manuscript, the optimization objectives are Useful Daylight Illuminance (UDI) (Nabil & Mardaljevic, 2005) and Energy Use Intensity (EUI) are selected for daylight and energy performance, to form multi-objective optimization problem. The first objective is formulated to minimize energy in the building. The other objective is to formulate as to maximize UDI as follows:

$$min\left(EUI, \frac{1}{UDI}\right)$$

where UDI is the performance of daylight for each generated design alternative during the optimization process. Objectives and constraints are in relation to decision variables during the optimization process.

DAYLIGHT OBJECTIVE

UDI is a daylight performance metric offered by (Nabil & Mardaljevic, 2005). Contrary to the common daylight factor, a climate-based analysis uses realistic, time-varying sky and sun conditions and estimates hourly levels of total daylight illuminance. The term ‘UDI’ is defined as the percentage of hours through the year where illuminance ranges between 100-2000 Lux. The reason for selection in this range is that the values outside of this range are not suitable. Also, it is not enough for appropriate illumination, and it is related to too much horizontal illumination (Chatzikonstantinou, Ekici, Sarıyıldız, & Koyunbaba, 2015b). The UDI paradigm notifies about both the suitable levels of daylight illuminance and the propensity for excessive levels of daylight that are related with user’s discomfort and undesirable solar gain. UDI is calculated as follow:

$$UDI(P_{t_1}) = \frac{1}{n}\sum_{j=1}^{n} H(P_{t_1}, j) \times 100$$

The illuminance values, L, is attained via a ray tracing simulation. $L(a, b)$ indicates the result coming from the simulation for sampling point i and time (within a year) j. $H(x)$ is a function that, given an illuminance value, outputs one, if the input value changes between 100 and 2000, or it equals to zero. As the formulation given below:

$$H(x) = \begin{cases} 1, \text{if } 100 \leq \text{x} \leq 2000 \\ 0, \text{otherwise} \end{cases}$$

ENERGY OBJECTIVE

According to ASHRAE Standard 105-2007, Energy Use Intensity (EUI) is the main approach to benchmark the energy performance of the buildings. It is indicated as the energy demand for each unit of floor area (kWh/m^2) of a building over one year. Thus it eases to contrast between the other buildings, and it gives an idea of how the buildings are affected by energy. (Yang, Sun, di Stefano, Turrin, & Sariyildiz).

$$EUI = \frac{\text{Annual Building Energy Demand (kWh)}}{\text{Building Area(m2)}}$$

In addition to the formulation of the EUI, EUI is impacted by many factors, which are climate zone, building type, LEED certification, and HVAC system types, occupant schedules, maintenance, occupancy rates, plug loads and a host of others. The same building used differently or placed in a different climate can have drastically different EUIs regardless of the EUI formulation. EUI is substantially affected by climate owing to the differences in heating and cooling demands according to the regions (Peterson, 2010).

Simply calculating the energy consumption amount for each process is not taking into account the size of the building, the structure form or building type of use. The Energy Use Intensity (EUI) indicator uses the means to equalize the method that energy consumption is compared to different building types and assess total energy saving alternatives.

3.4.3. CONSTRAINTS

To realize this complex study, different fenestration strategies solutions provide optimum performance of the buildings in the sense of daylight and energy based on different climate regions considering applicable standards and regulations. Moreover, while abiding by the regional building regulations and standards also examine the deficiency and mistake concerned about energy and daylight use at the same time and making suggestions for these deficiencies.

In this manuscript, objectives and constraints are in relation to decision variables during the optimization process. In addition, two constraints are defined in order to discover fenestration alternatives in acceptable margins. The first constraint function is mentioned above in ‘3.1.1.1. Daylight objectives’. In accordance with equation (3), the illuminance value of each generated solution during the optimization process is kept within safety margins as the first constraint of the study.

Illuminance Level is the quantity of light evaluated on a surface. In other words, it is the overall luminous flux event on an illuminated surface per unit space. The most significant works in the room or space are assumed as a work plane. Illuminance is calculated in foot candles ($ftcd, fc, fcd$) or it is commonly used a Lux. Lux is a metric SI unit (Nabil & Mardaljevic, 2006).

Generally, the illuminance impacts the lighting quality, amount of flicker, light, glare, contrast, and shadows. Each parameter should be set separately to optimize illumination in an emergency, safety, and operations conditions. In addition, in diverse locations with diverse targets most of the concerns about 'Lighting Standards'; design, placement, installation, and low energy needs and efficient illuminance distribution perform, besides the productivity, strength, cost, and sustainability.

According to the City of Los Angeles, Department of Public Works, Bureau of Street Lighting's 'design standards and guidelines' (City of Los Angeles, 2007), is a guide for the recommended light level in residential houses in 150 Lux (Table 3.6)

Table 3.6 Common light levels outdoor during the day (City of Los Angeles, 2007)

Condition	Illumination(Lux)
Sunlight	107.527
Full Daylight	10.752
Overcast Day	1.075
Very Dark Day	107
Twilight	10.8
Deep Twilight	1.08
Full Moon	.108
Quarter Moon	.0108
Starlight	.0011

3.5. METHOD OF ANALYSIS

Numerous daylight and energy simulation programs are available to researchers and designers. However, few of them are implemented in the pre-design phase. Computational simulation strategies are performed for optimizing researches. Each of these tools is mainly served for different task through the overall design process. In this research, due to the complexity of the parameters under study, several simulation engines are combined. A single simulation run provides to result in data regarding multiple objectives, including daylight and energy. Important questions concerning the design of fenestration strategies of the residential building are responded through parametric studies using GH, which is a visual programming language integrated into the Rhino3D modeler (McNeel, 2015) and simulations with Honeybee, Ladybug, and DIVA for GH (Roudsari et al., 2013). For performing daylight analysis in detail, thermal simulation tools Radiance / DAYSIM with EnergyPlus and DIVA are used. These computational programs serve parametric modeling, numeric simulation and mathematical optimization automatically. The GH plug-ins are Honeybee (HB), Ladybug (LB), Daysim, and EnergyPlus (EP) link and modify between them.

In this manuscript, using a computational simulation of case geometries, the placement of correct openings in the correct locations with proper fenestration alternatives are analyzed regarding total annual energy requirements. These building envelope alternative' effects on energy and daylight performance are analyzed. Finally, the entire simulations are compared with their primary plan for each building and reveal the impacts of fenestration strategies regarding optimum daylight and low energy usage principles. Using the Rhino and GH tools, a building parametric model is created by subtracting and clarifying the basic design perception. Depend on the parametric model, the design variables are denoted by four notations which are revealed in Table 3.5.

Rhinoceros generates of three dimensional complicated NURBS models (Reinhart & Wienold, 2011). NURBS geometry represents as a mathematical description of all line, form or surface (Tedeschi, 2011). Rhino software has two plug-ins;

- Grasshopper plug-in for geometric design (GH)
- DIVA plug-in for analyzing of daylight

One of the advances of latest years within the context of algorithmic modeling is the release of GH. Using productive algorithms and associative modeling methods, GH has been improved to create a shape (Lagios, Niemasz, & Reinhart, 2010; Tedeschi, 2011). It is a node-based editor operates on Rhinoceros. David Rutten at Robert McNeel & Associates generates the Rhinoceros program. The plug-in is a suitable environment to create three-dimensional models in a flexible way. In addition, it helps to control the design process (Tedeschi, 2011). One of the main benefits of this platform that it is possible to develop and add new plug-ins to GH. These plug-ins extend the capacity of the program. It is possible to make environmental, structural or physics simulations by means of these plug-ins. These capabilities of GH make it be suitable for form-making as well as form-finding (Tedeschi, 2014). The use of GH provides a new perspective on the computer-aided analysis.

In this manuscript, the virtual test box and a parametric model of a fenestration system are developed by using Rhino/GH algorithmic modeling platform. Using parametric modeling tools help to control and to explore different alternatives of the fenestration systems. In the next step, the parametric model is coupled with environmental simulation engines for exploration of the performances.

On the other hand, DIVA analyzes the daylight performance on the design space. The Radiance and Daysim programs are appropriate for daylight, the lighting analysis and visualization in the building design (Jakubiec & Reinhart, 2011). Daysim measures illuminance, visual quality, the space appearance and new knowledge about lighting and daylighting (Reinhart & Wienold, 2011).

In this manuscript, for calculation of UDI (Nabil & Mardaljevic, 2005) is calculated using illuminance and luminance values in non-empty spaces obtained through the Radiance simulation software. It creates use of ray-tracing, a technique originally developed for realistic display of geometric models on a computer screen, for calculating the lighting levels at a point. Radiance is a free daylight simulation tool that is validated and accurate (Ward & Mardaljevic, 1998). In this manuscript, Gensky, that is Radiance’s sky generator program, is used. It creates sky models based on CIE (International Commission on Illuminance) standards, which are clear or intermediate skies. It provides different types of sky conditions based on the input parameters.

For the energy approach of the case buildings, the total volume is measured to assess the energy performance. Depend on the knowledge, the building should be more compact the volume to maximize energy performance. An EP computer program (Energy, 2016) enables integrated measurements to transfer of mass and energy in the building. In addition, this integrated simulation program calculates thermal load demands of a building model. Depend on an occupant selection of the building's features, it solves building, system and plant parts of the model simultaneously, to obtain physically realistic simulations. These features are a climatic condition, construction material properties, building size, structural information, and so on so forth. By using EP, it is possible to study the thermal performance of a building, calculate energy loads such as heating, cooling, electric, water, and lighting, etc., in question for a given location. Also, the EP makes it possible to achieve simulations parallel with each other. Thus, the optimization process is sped up.

Additionally, by using ‘Ladybug and Honeybee’, to link and to automate between the parametric model and simulation tools, such as Radiance and Daysim, are generated. These plug-ins also carry out as additional points for numerous simulation settings, such as the structural materials selection, lighting, and air conditioning system settings, etc.

Ladybug (LB) and Honeybee (HB) are two plug-ins of GH and Rhinoceros 3D program. They assess the environmental performance of the buildings. LB imports EP weather files (.EPW) into GH and provides a variety of 3D interactive graphics to support the decision-making process in the early design phase. In this manuscript, different climatic zones and weathers were analyzed with a plug-in. LB is only used complementary to HB. It is required to import .epw weather files and to read EP surface results. HB associates the visual programming environment of GH to EP, Radiance, and Daysim. It evaluates energy consumption, thermal comfort, and daylighting of the buildings (Roudsari et al., 2013). The plug-in helps the designers to form geometry and produce Radiance-materials and skies. Since HB employs both Radiance and Daysim, simulations can be served for one sky condition at a time using Radiance. Otherwise, alternatively, annual illuminance profiles are measured considering weather and geographic locations with Daysim (Roudsari et al., 2013).

3.6. OPTIMIZATION

In the literature, various types of research have been published with respect to the multi-objective optimization problems (MOP)s. Evolutionary Algorithms (EAs) are one of the most common optimization algorithms. In this context, consideration of EAs to MOPs are called to as Multi-Objective Evolutionary Algorithms (MOEAs). Moreover, MOEAs are currently in the agenda of architecture to cope with complex design problems, namely multi-objective architectural problems (MOAPs) (Aydin, Dursun, Chatzikonstantinou, & Ekici, 2015; Ugurlu, Chatzikonstantinou, Sariyildiz, & Tasgetiren, 2015)

MOPs result in a set of points that are grouped together as a stochastic-curve or a shaped base on the objectives. This is called the Pareto-optimal set. Its genetic algorithms are called to as ‘Pareto-front’(Fonseca & Fleming, 1993). The Pareto-front domain is a proper set to use when analyzing the superiority of several performances. The fact that the Genetic algorithm (GA), is not governed by any laws, the fitness function may evaluate any performance criteria desired (Turrin, 2011) for optimization purposes. GA greatly reduces the time to finalize the optimization process and reaching optimum solutions.

Bader and Zitzler originated the Hypervolume Estimation Multi-Objective algorithm (HypE). It belongs to the type of indicator-based MOEAs portion (Bader & Zitzler, 2011). HypE for multi-objective optimization, by which the accuracy of the estimates and the available computing resources can be traded off. Thus, MOPs become possible with HypE, and also the runtime can be inconstantly adjusted. The experimental results specify that HypE is greatly effective for MOPs in the contrast of existing multi-objective evolutionary algorithms. To calculate the HV, 100 non-dominated solutions are employed considering the maximum value for each objective as a reference point. At the end of the process, we extracted 100th generation from each of the 49 optimization processes in total, for further operations. During the optimization process, Pareto-front has not performed any change after 29th generations. Therefore, 30 generation is sufficient when implementing this manuscript.

3.7. VALIDATION

Arguably, one of the most significant parts is the design of validation and the control of these strategies for building energy simulation and optimization. Having case models in good precise of the building energy systems to design and adjust the parameters and to simulate their performance is critical. In line with that, the current work employed real buildings’ layouts.

After analyzing and evaluating the several fenestration strategies on the test box model, selected fenestration strategies are used to observe building energy and daylight performance. Having the results of the simulation, alternatives are implemented to validation case buildings that are selected from four different cities according to TS825 ‘Thermal Insulation Requirements in Buildings’ are selected.

TS825 energy performance standard divided to Turkey into 4 climatic zones based on average temperature, heating, and cooling degree-days (recall Table 3.1 and Figure 3.3). The selected cities from these climate zones are Izmir (1.zone), Istanbul (2.zone), Ankara (3. zone) and Erzurum (4. zone) in respect to TS825.

The four case buildings are selected real layouts for each zone. To designate the diversity between energy and daylighting performance of buildings in each region, different fenestration strategies are compared regarding wall window ratio and window façade. In each case study, the window of each facing side is concentrated. The results which reach optimum energy efficiency and daylight in the validation case building, alternatives are applied to that climatic region’s building types.

3.7.1. VALIDATION IN CLIMATE ZONE I: CASE OF IZMIR

The first scenario located in the 1st regional zone of Turkey, having 38°24'45.83"N latitude, 27°8'18.17"E longitude, and 15m. altitude. Case building location is Izmir that is in the west part of Turkey. The coastal city has a hot-summer Mediterranean climate according to the ‘Köppen Climate Classification’ (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). Izmir average annual sunshine duration is 2986 h. (). The temperature averages 16.7°C. In this respect, Izmir is approximately whole days of year sunny, so it can be an advantage for architects to improve daylight performance of a building in Izmir.

Regarding the focused building, it has 4 multi-story residential building that each story is a 2.70 cm floor high as shown in Figure 3.5. Each story has one apartment per 240 m², totally 4 apartments. Each apartment has 9 different zones. 4 each facade of the building has a fenestration that is located 2 windows located on the north, 3 are on the south façade, also 4 are west and 2 windows located on the east façade. The windows glazing types of the building which made up a layer of glazing double low-e according to TS825 regional standard. Energy saving is gained greatly by using many simulations and improve the energy efficiency of the building envelopes. Building floor plan was presented in Figure 3.6.

Figure 3.5 Perspective view of the validation case 1

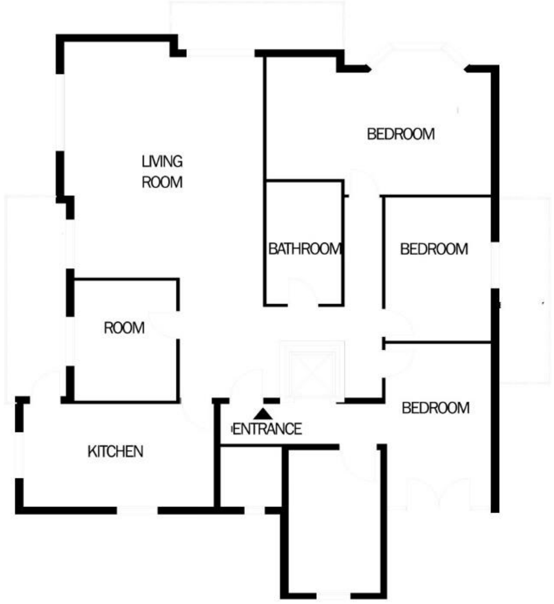

Figure 3.6 Layout plan of the validation case 1

3.7.2. VALIDATION IN CLIMATE ZONE II: CASE OF ISTANBUL

The second scenario located in the 2nd regional zone of Turkey that is Istanbul, having 41°0'49.82"N latitude, 28°56'58.78"E longitude and 40 m. altitude. Istanbul is located in the northwest part of Turkey. Its average annual sunshine duration is 2446 hours. It has a Mediterranean climate according to the 'Köppen Climate Classification' (Kottek et al., 2006). During the year, the average temperatures vary by 17.5 °C.

This validation scenario building has 5 multi-story residential building that each story is a 2.70 cm floor high. Each story has 2 apartments per 109 m², totally 10 apartments. Each apartment has 12 different zones. 3 each facade of the building has a fenestration, that is located 4 windows located on the north, 4 are on the south façade, 4 windows located on the east façade too. The windows glazing types of the building, which made up a layer of glazing double low-e according to TS825 regional standard. Energy saving is gained greatly by using many simulations and improve the energy efficiency of the building envelopes. A building model is available in Figure 3.7 and building floor plan is showed in Figure 3.8

Figure 3.7 Perspective view of the validation case II

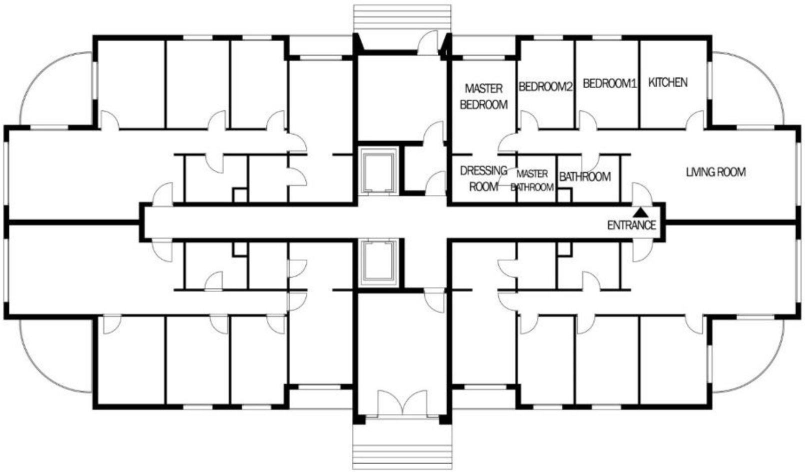

Figure 3.8 Layout plan of the validation case II

3.7.3. VALIDATION IN CLIMATE ZONE III: CASE OF ANKARA

The third scenario located in the 3rd regional zone of Turkey that is Ankara is located 39°55'11.53"N, 32°51'15.37"E longitude, 800-850 meters altitude (Cicek & Turkoglu, 2005). It has a hot humid continental climate in accordance with the ‘Köppen Climate Classification’ (Kottek et al., 2006). The average temperature is more than 20ºC in the summer season. It is between 10 and 20 °C in four months that are April, May, September, and October. Also, in November, December, January, February, and March, it is less than 10ºC. (ÇİÇEK, 2017).

This validation scenario building has 3 multi-story residential building that each story is a 2.70 cm floor high. Each story has 4 apartments per 58 m², totally 12 apartments. Each apartment has 12 different zones. 4 each facade of the building has a fenestration, that is located 6 windows located on the south, also 6 are north façade and 2 windows located both on the east and west façade. The windows glazing types of the building, which made up a layer of glazing double low-e according to TS825 regional standard. Energy saving is gained greatly by using many simulations and improve the energy efficiency of the building envelopes. Building perspective and floor plan were given in Figure 3.9 and Figure 3.10.

Figure 3.9 Perspective view of the validation case III

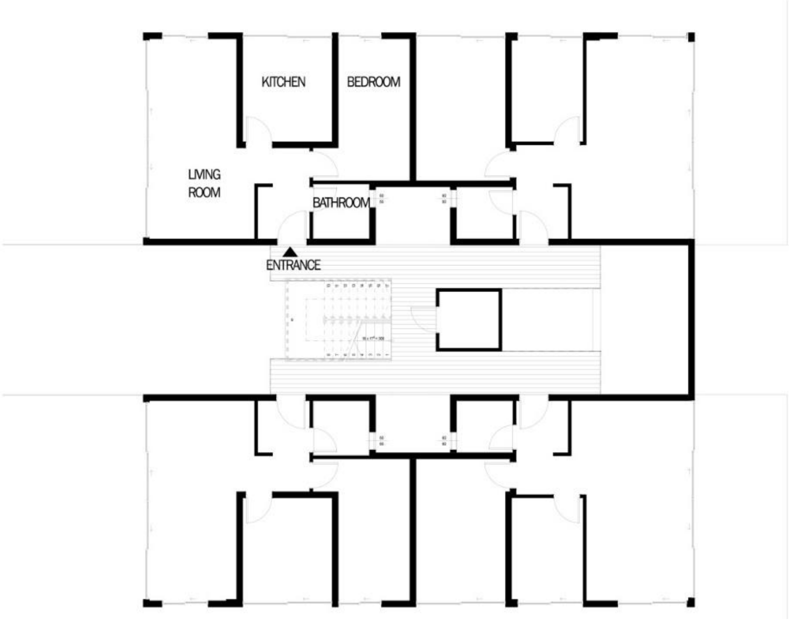

Figure 3.10 Layout plan of the validation case III

3.7.4. VALIDATION IN CLIMATE ZONE IV: CASE OF ERZURUM

The fourth scenario located in the 4th regional zone of Turkey, having 39°54'31"N, 41°16'36.98"E longitude in the east part of Turkey. It is located 1757 meters' altitude. In this region, the climate has big seasonal temperature alterations with hot summers and cold winters. While the heating degree days are in high level, the cooling degree days are almost in a low level. It has a warm humid continental climate in accordance with the 'Köppen Climate Classification' (Kottek et al., 2006). It is one of the coldest cities in Turkey. It is very cold and snowy in winter with an average minimum during January of around -16°C (Dursun & Yavas, 2016).

This validation scenario building has 5 multi-story residential building that each story is a 2.70 cm floor. Each story has 2 apartments per 150 m², totally 10 apartments. Each apartment has 10 different zones. 2 each facade of the building has a fenestration, that is located 5 windows located on the north, 5 are on the south façade too. The windows glazing types of the building, which made up a layer of glazing is double low-e according to TS825 regional standard. Energy saving is gained greatly by using many simulations and improve the energy efficiency of the building envelopes. Building perspective and the floor plan are showed in Figure 3.11 and Figure 3.12, respectively.

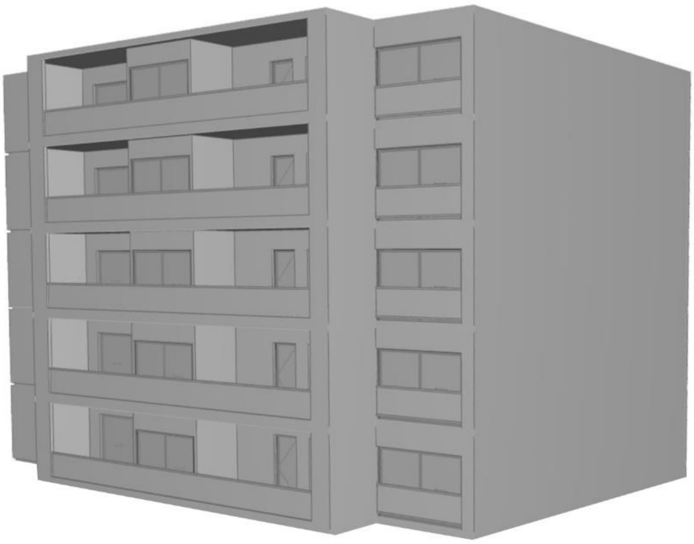

Figure 3.11 Perspective view of the validation case IV

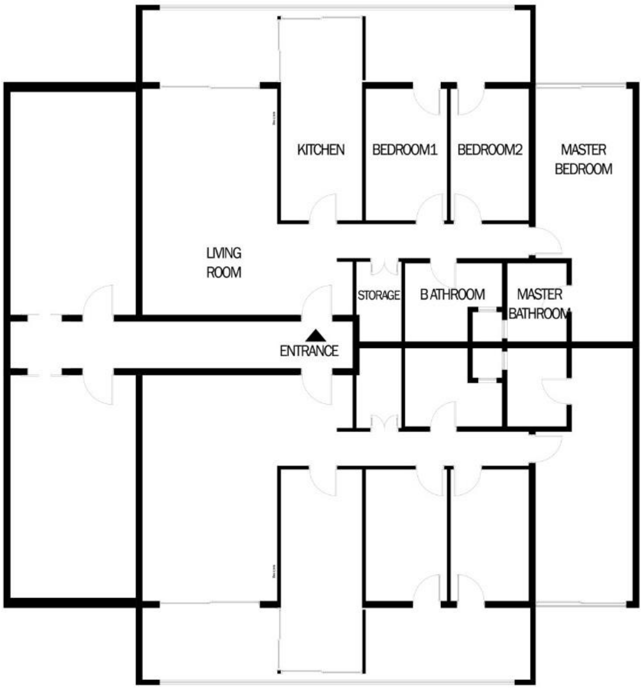

Figure 3.12 Layout plan of the validation case IV

CHAPTER FOUR

RESULTS & DISCUSSION

This chapter explains the selected optimum strategies of the analysis and interprets the fenestration design effects on daylight conditions and energy performance of the building. There are sections that comprise the test box model, which is carried out to analyze the design effects as built on the daylight and energy performance in the building. Before discussing the full solution on each case study defined by targets for daylighting and energy, the research investigated the effect of wall window ratio on space, and window orientation effects individually.

There are also sections, which interpret the results of each case study base on Turkish 4 climate zones. Eventually, the best performing cases are selected, and the validation process executed with a specified reference building.

4.1. TEST BOX MODEL RESULTS

This section presents the initial studies of the fenestration design of the test box model. As mentioned before, the impact of the parameters on the daylight conditions and energy performance is studied by simulating and comparing four different building climate conditions. The results of the different design conditions are compared and analyzed based on the daylight and energy conditions.

During the optimization process, the population size was taken as 100 and non-dominated solutions are employed considering the maximum value for each objective as a reference point. At the end of the process, we extracted 100th generation from each of the 49 optimization processes in total, for further operations. Through the optimization, Pareto-front has not altered after 29th generations. Therefore, 30 generations were sufficient when implementing this manuscript. The average computation time for each generation was 40 minutes. Thus for 100 population size and 29 generations as a termination criterion took 20 hours. In addition, when comparing 100 generations, most of them are at the same point in Pareto-chart for both UDI and EUI. Thus, the Pareto-front non-dominated solutions for each region show an alteration according to a number of solutions, which are detailed below.

Table 4.1, Table 4.2, Table 4.3, Table 4.4, present Pareto-front non-dominated solutions that are last optimum values at the 29th generation for each 4 climate zone separately. 100 non-dominated solutions are eliminated from the same results. After separation from equal values, final Pareto-front solutions are shown below. In addition, the following four figures for each 4 climate zones show Pareto-chart of HypE algorithms with the non-dominated solutions at the 29th generation. They present selected alternatives from MOEA. Three alternatives from each algorithm are chosen through visual inspection. Their visual diagram is illustrated in Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.4.

Table 4.1 Pareto front approximation for Izmir (climate zone I)

	WWR				UDI (%)	EUI (kWh/sqm)
	x_1	x_2	x_3	x_4	y_1	y_2
1*	0,20	0,10	0,10	0,10	32,75	138,46
2	0,35	0,10	0,10	0,10	35,00	143,17
3	0,30	0,10	0,10	0,10	34,50	141,61
4*	0,25	0,10	0,10	0,10	33,75	140,02
5*	0,15	0,10	0,10	0,10	32,25	136,83
6	0,35	0,10	0,20	0,10	36,25	148,94
7	0,35	0,10	0,20	0,10	36,75	151,88
8	0,10	0,10	0,10	0,10	31,50	135,21
9	0,35	0,10	0,10	0,10	35,50	146,05
10	0,25	0,15	0,20	0,10	33,00	139,63
11	0,30	0,10	0,20	0,10	35,75	147,44
Min.	0,10	0,10	0,10	0,10	31,50	135,21
Max.	0,35	0,15	0,20	0,10	36,75	151,88

**Selected solutions to be employed through validation*

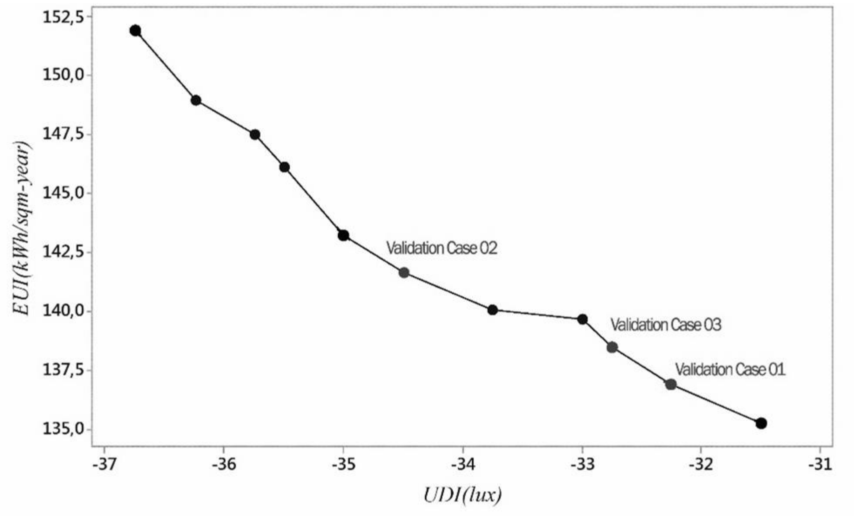

Figure 4.1 Pareto chart presenting solutions from the 29th generation for Izmir

Table 4.2 Pareto front approximation for Istanbul (climate zone II)

	WWR				UDI (%)	EUI (kWh/sqm)
	x_1	x_2	x_3	x_4	y_1	y_2
1*	0,15	0,10	0,10	0,10	32,00	192,93
2*	0,15	0,10	0,30	0,10	33,00	195,37
3*	0,30	0,10	0,15	0,10	33,50	198,39
4	0,10	0,10	0,20	0,10	32,50	194,27
5	0,10	0,10	0,10	0,10	31,50	191,95
6	0,25	0,10	0,15	0,10	33,25	197,46
Min.	0,10	0,10	0,10	0,10	31,50	191,95
Max.	0,30	0,10	0,30	0,10	33,50	198,39

**Selected solutions to be employed through validation*

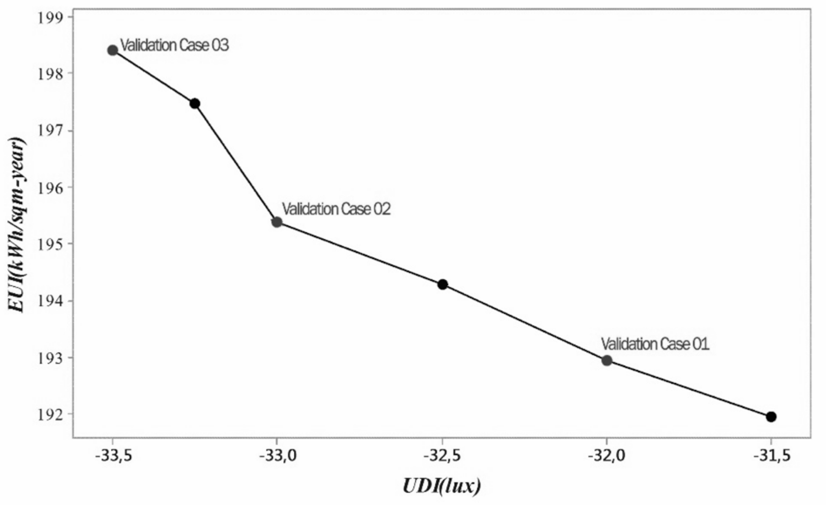

Figure 4.2 Pareto chart presenting solutions from the 29th generation for Istanbul

Table 4.3 Pareto front approximation for Ankara (Climate Zone III)

	WWR				UDI (%)	EUI (kWh/sqm)
	x_1	x_2	x_3	x_4	y_1	y_2
1*	0,10	0,10	0,15	0,15	31,00	212,00
2*	0,10	0,10	0,10	0,10	31,25	213,53
3	0,10	0,10	0,10	0,10	30,25	210,65
4*	0,30	0,10	0,10	0,10	31,75	216,26
5	0,25	0,10	0,10	0,10	31,50	214,98
Min.	0,10	0,10	0,10	0,10	30,25	210,65
Max.	0,30	0,10	0,15	0,15	31,75	216,26

**Selected solutions to be employed through validation*

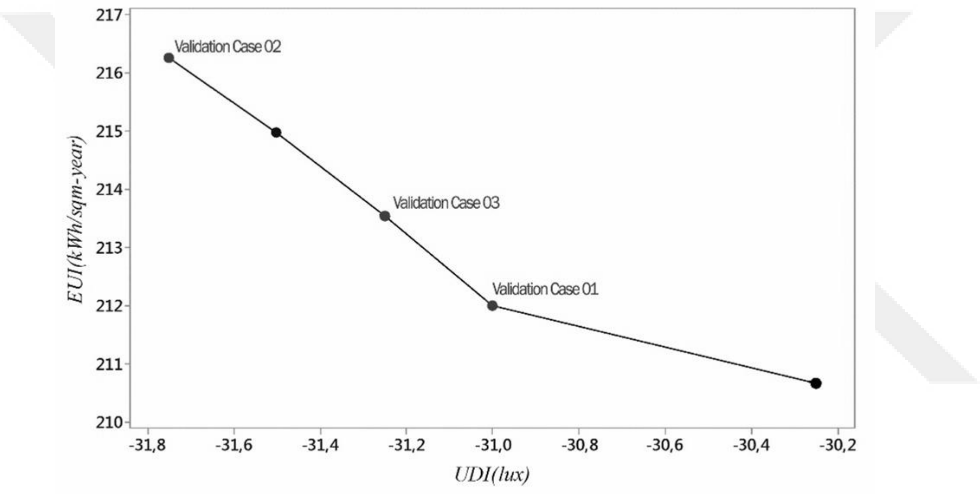

Figure 4.3 Pareto chart presenting solutions from the 29th generation for Ankara

Table 4.4 Pareto front approximation for Erzurum (Climate Zone IV)

	WWR				UDI (%)	EUI (kWh/sqm)
	x_1	x_2	x_3	x_4	y_1	y_2
1*	0,10	0,10	0,10	0,10	29,50	300,82
2*	0,15	0,10	0,10	0,10	30,00	302,75
3*	0,20	0,10	0,10	0,10	30,25	304,66
4	0,10	0,10	0,15	0,10	29,75	301,59
Min.	0,10	0,10	0,10	0,10	29,50	300,82
Max.	0,20	0,10	0,15	0,10	30,25	304,66

**Selected solutions to be employed through validation*

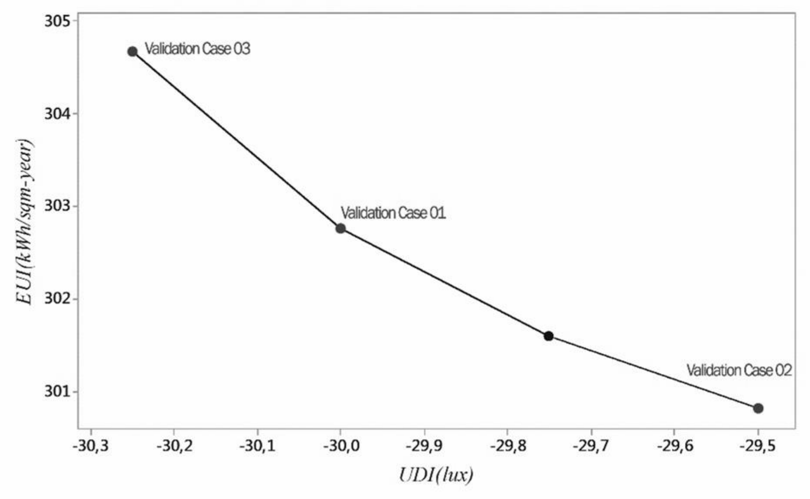

Figure 4.4 Pareto chart presenting solutions from the 29th generation for Erzurum

4.1.1. IMPACT OF WWR

Before discussing the combined effects of selected solutions, the impact of WWR and window orientation on space are interpreted simultaneously. The results are classified by window orientation, as Table 4.1, Table 4.2, Table 4.3, Table 4.4, for the test box model, a room with dimensions of 8 m width, 6 m length and 2.7 m height for each 4 climate zones. In the analysis, different designs of WWR for each window orientation are observed regarding daylight and energy performance of the building.

To evaluate the effect of WWR on building energy load, WWR is fluctuated between the range of 10% to 90% percentages by 5% percentage scale. Simulation of daylight and energy are run after each case study is modeled via computer and the results are collected. The parametric analyses and the charts demonstrating the optimum solutions indicate the alteration between various design and performance parameters base on daylight and energy performance of the building.

CLIMATE ZONE I

In the first climate zone Izmir, according to the Pareto-front solutions (see Table 4.1) the window on the north façade(x_1) values between the range of 0.10 to 0.35. The window on the east façade(x_2) values fluctuate between the range of 0.10 to 0.15 whereas the window on the south façade (x_3) values between the range of 0.10 to 0.20. The west façade(x_4) values are same all the time that is 0.10. Studies in Izmir reveal that the lowest load for EUI for residential buildings is 135.21 kWh/m^2/year and the highest load for EUI is 151.88 kWh/m^2/year. In addition, the minimum UDI percentage is 31.50, the maximum UDI percentage is 36.75.

In Table 4.1, the comparison between non-dominated solutions 2th and 5th, x_2 , x_3, x_4 are 0.10. The percentage of x_1 changes only effects of EUI and UDI. When x_1 percentage decreases, EUI falls 143.17 kWh/m^2/year to 136.83 kWh/m^2/year and UDI goes down simultaneously from the 35 to 32.25. When 2nd and 3rd Pareto-front solutions are compared, x_2, x_3 and x_4 are 0.10. Percentage of x_1 drops from 0.35 to 0.30. It leads to fluctuations, both in UDI and EUI. UDI goes down from 35 to 34.50 whereas EUI decreases 143.17 kWh/m^2/year to 141.61 kWh/m^2/year. Because of, the solutions are non-dominated, the fenestration design can be selected from aiming to energy or daylight. For instance, if the target is more daylight, the designer chooses 2nd solutions but it consumes more energy too. If any designer aims to use less energy, the building solar gains are less than the 2nd solution and the 3rd solution was selected. Another comparison is between 8th and 9th solutions; here it can be observed that, the increment of x_1 affects UDI and EUI values. Evidently, EUI and UDI change steadily thanks to the alteration in x_1. In short, these results present that the solution space for both daylight and energy conditions are satisfactory considerably depends on x_1.The proposal of this manuscript is achieved that both UDI and EUI rise or decrease, simultaneously.

In Table 4.1, the comparison between Pareto-front solutions 7th and 9th represents, x_1 , x_2, x_4 are all same as 0.35,0.10 and 0.10. x_3 percentage value changes slightly between 0.20 to 0.10. The UDI and EUI values are affected by the alteration, that falls from 36.75 to 35.50 and 151.88 kWh/m^2/year to 146.05 kWh/m^2/year. In addition, there is the other comparison between 3rd and 11th, here x_1 , x_2, x_4 are the same, that are 0.30, 0.10 and 0.10. x_3 percentages alter slightly from 0.10 to 0.20. The south façade of the building WWR percentage alteration affects both UDI and EUI at the same time. While x_3 rises, UDI goes up from 34.50 to 35.75. At the same time, EUI rises from 141.61 kWh/m^2/year to 147.44 kWh/m^2/year.

On studying the results, one can see that for the variables considered, the results show that the wall window ratio has a big impact only on x_1 and x_3. The minimum WWR, 0.10, is almost always sufficient for x_2 and x_4 . x_1 has the maximum alteration of the WWR percentage. The results show that the largest influence on increasing the glazing area size is evident in the north façade. In other words, WWR of x_1 is a major value from other façades when aiming to optimize energy and daylight. However, the important thing that considers the early design target. The selection of WWR from non-dominated solutions depends on aiming to minimize energy or maximizing daylight.

CLIMATE ZONE II

Table 4.2 presented 6 optimum values from last 29th generation that the analysis of Istanbul was made to evaluate the performance of daylight and energy through selected wall window ratio and each window façades. The results shown in Table 4.2 demonstrate, respectively, the WWR of north façade (x_1) and the south façade (x_3) between the range of 0.10 to 0.30. Both x_2 and x_4 are the same, as 0.10. In addition, Table 8 displays values for maximum and minimum UDI and EUI. Maximum UDI percentage is between the range from 31 to 33.50 and EUI is between the range from 191.95 kWh/m^2/year to 198.39 kWh/m^2/year.

To demonstrate the impact of the window each façade of the building for Istanbul, the optimum Pareto-front solutions were created as Table 4.2. These solutions lead to finding out how to affect the energy load and daylight conditions from the window. In the 1st and 5th Pareto-front solutions, the percentage of north facing window was altered from high to low, 0.15 to 0.10, while the other façades of the building, that are x_2 , x_3, x_4 , are in the same percentage. The percentage of UDI changes from 32 to 31.50 whereas EUI decreases from 192.93 kWh/m^2/year to 191.95 kWh/m^2/year. Another comparison between 3rd and 6th Pareto-front solutions, x_1 goes down from 0.30 to 0.25. The fluctuation affects the UDI falls from 33.50 to 33.25, while EUI decreases from 198.39 kWh/m^2/year to 197.46 kWh/m^2/year. It can be observed that a decline of the north façade WWR affects both UDI and EUI diminish. In sum, the comparison results reveal that the north façade WWR changing affects the both UDI and EUI apparently. The other observation, wall window ratio of north façade reaches the maximum value in the 3rd solution. This 0.30 percentage value of x_1 affects that UDI rises maximum value too. Thus, this solution demonstrates the impact of x_1 for the UDI and EUI alteration briefly.

One can see in Table 4.2 when is considered the effect of x_3, the 1st and 2nd Pareto-front solutions are tackled. The percentage of x_1 , x_2 , x_4 are the same, that are

0.15,0.10 and 0.10. The alteration of x_3, from the 0.10 to 0.30, affects to EUI and UDI. UDI goes up and EUI rises whereas the percentage of x_3 rises. In addition to this relationship between x_3, and objectives, 4th, and 5th Pareto-front solutions are as same fluctuation as the previous comparison.

For estimating the impact of x_2 and x_4 for Istanbul, the WWR is always same as 0.10. They have not affected both UDI and EUI clearly.

In sum, the Pareto-front solutions for Istanbul demonstrate that north and south façades are the more obvious effect on optimizing UDI and EUI than the others for the whole year. In general, x_1 and x_3 rise affects UDI and EUI.

CLIMATE ZONE III

In the third climate zone Ankara, according to the Pareto-front solutions (see Table 4.3) the window on the north façade(x_1) values between the range of 0.10 to 0.30. The window on the south façade(x_3) and the west façade(x_4) values between the range of 0.10 to 0.15. The east façade(x_2) values are same all the time that is 0.10. The lowest load for EUI for residential buildings is 210.65 kWh/m^2/year and the highest load for EUI is 216.26 kWh/ m^2 /year. In addition, the minimum UDI percentage is 30.25, the maximum UDI percentage is 31.75.

To analyze the effects of the window each façade of the building for Ankara, the optimum Pareto-front solutions are created as Table 4.3. These solutions led which window orientation has the biggest effect on the energy and daylight performance. In the 3rd and 4th Pareto-front solutions, the percentage of north facing window was transformed from low to high, 0.10 to 0.30, while the other façades of the building, that are x_2 , x_3, x_4 , remain in the same percentage. The percentage of UDI increases 30.25 to 31.75 while EUI goes up from 210.65 to 216.26. Another comparison between 4th and 5th solutions, the results shows that the dependence of UDI and EUI on the percentage of x_1. While decreasing of wall window ratio of north façade, UDI reaches from 31.75 to 31.50, EUI drops from 216.26kWh/ m^2 /year to 214.98 kWh/m^2/year. In addition, as it can be seen in the 2nd and 5th solutions, there is another proof of UDI and EUI ratio based on x_1. Thus, both EUI and UDI go up steadily with the increases in x_1. In short, they have an inverse proportion between each other. The result indicates that, x_1 increment causes a rise in UDI and emerging a rise EUI at the same time.

However, while analyzing whole results, some Pareto-front solutions have unexpected UDI and heating, cooling demand for the building. For example, observing 2nd and 3rd solutions, the percentage of x_1, x_2 , x_3, x_4 are the same, that is 0.10. The alteration of UDI affects EUI. The percentage of UDI changes from 31.25 to 30.25 whereas EUI drops from 213.53 kWh/m^2/year to 210.65 kWh/m^2/year. When accounting for this decline, EUI alteration depends on the heating and cooling energy demand of the building. When the optimization process, one constraint is UDI must be range from 100 to 2000 lux. For this reason, when the daylight or glare of the space increases, the heating, and cooling demand go up for reaching the optimum UDI. In this example, because of the UDI percentage rises from the outside to inside of the building, the summer and winter season impacts are different. While more daylight is good for the winter season, the summer season has a reverse situation. Then, the heating and cooling system is used for against to undesirable UDI values. Thus, EUI the value increases naturally.

In contrast, the north, west and south façades, x_2 increment or decline does not impact to both UDI and EUI. The fluctuation of WWR is almost always 0.10.

In conclusion, the results for Ankara show that north façade is the more obvious effect on maximizing UDI and minimizing EUI than the others for the whole year. Depend on the overall calculations, it is defined that WWR of x_1 is a big impact to the daylight and energy performance of the building. According to these non-dominated solutions, x_1 , x_3 and x_4 rise affects both UDI and EUI increases for Ankara. Thus, the selection of WWR from non-dominated solutions depends on aiming at to minimize energy or maximizing daylight.

CLIMATE ZONE IV

The results of the current research for 4th climate zone, Erzurum, illustrated in Table 4.4. The window on the north façade (x_1) values between the range of 0.10 to 0.20. The window on the east façade (x_2) and the west façade(x_4) values are same all the time that is 0.10. In addition, the south façade window (x_3) values are between the range of 0.10 to 0.15. Studies in Erzurum show that the lowest load for EUI for residential buildings is 300.82 kWh/m^2/year and the highest load for EUI is 304.66 kWh/m^2 /year. In addition, the minimum UDI percentage is 29.50, the maximum UDI percentage is 30.25.

When one considers the effect of x_1, the 2nd and 4th Pareto-front solutions are tackled. The percentage of x_2 , x_3 , x_4 are the same, that is 0.10. The alteration of x_1, from the 0.15 to 0.10, affects to EUI and UDI. UDI reduces from 30 to 29.75 whereas EUI drops down 302.75 kWh/m^2/year to 301.59 kWh/m^2/year. Another comparison between 1st and 3rd, the decline of x_1 impacts to both UDI falls from 30.25 to 29.50 and EUI drops from 304.66 kWh/m^2/year to 300.82 kWh/m^2/year. The alteration of the percentage of x_1 affects to UDI and EUI values concurrently. In sum, it can be obviously seen that the shift of x_1 has a relationship with UDI and EUI simultaneously. For this reason, x_1 has a big impact on maximizing daylight and minimizing energy according to the designer's WWR selection from these non-dominated solutions.

For estimating the impact of x_3 for Erzurum, 1st, and 4th Pareto-front solutions are compared. The WWR of south façade jumps from 0.10 to 0.15 whereas both UDI and EUI increase. After the fluctuation of the x_3, UDI goes up from the 29.50 to 29.75 also EUI increases 300.82 kWh/m^2/year to 301.59 kWh/m^2/year. The results show that the wall window ratio of the south façade fluctuation is not proper for keeping the illuminance levels in the range 100-2000 lux. Because of these undesirable solutions, heating and cooling demands rise and EUI goes up naturally for reaching optimum UDI percentage. The values outside of this range are considered not appropriate. For this reason, the parameters are between in this range. Thus, the optimization process comprises both useful daylight illuminance levels and as well as a propensity for extreme daylight levels that are related to user discomfort and undesirable solar gain.

The percentage of UDI and EUI fluctuations give some insight into, x_1 has the maximum effect of both variables in Erzurum. Because of climate differences from the other zones, heating and cooling energy demand are much more than the others. The sunny days are almost low. It is one of the coldest cities in Turkey and also snowing is the main climatic properties. Therefore, it can be easily observed that EUI values are between from 300 kWh/m^2/year and the wall window ratio is almost the least. In short, the result shows that the solutions regarding both energy and daylight performance are satisfactory depends on x_1 and x_3. However, the climatic conditions and undesirable solar gain and daylight levels, Erzurum has a higher EUI and heating, and cooling energy demand than the other climate zones.

4.1.2. COMBINED EFFECTS

The building energy demand can be decreased by selecting the envelope designs properly. Since the residential buildings are envelope-load dominated buildings, the envelope features; climate characteristics, wall window ratio, and window orientation, affect them considerably.

These alternatives are analyzed to reach both the optimum WWR combination regarding the minimum energy load and maximum daylight conditions and the optimum window orientation in the building façade. The Pareto-front solutions of several wall window ratio in each building façade affect the building energy and UDI differently. Where in general it can be observed that it is the most important thing, when choosing from non-dominated solutions, is any designer's and owner's aim. If they reach sufficient UDI, the maximum UDI values are more suitable for them. However, it causes to jump up energy demand noticeably.

It clearly appears that, x_1 has the maximum alteration of the WWR percentage to the value of both variables for the 4 climate conditions. It is located in the north façade. It has an upper value for the energy savings and the number of solar gains. Especially, x_1 reaches the highest value that is 0.35, in Izmir. Both UDI and EUI go up whereas x_1 rises for Izmir, Ankara, and Istanbul. Because of climate conditions that are interpreted below the WWR alteration occurs unexpected UDI and EUI values. In addition, validation results show that the WWR on the west facing affects slightly on energy consumption and daylight. x_4 is approximately 0.10 for 3 regions expect from Ankara. It reaches the highest value that is 0.15 in Izmir. x_2 rises cause to be both UDI and EUI rises. x_4 is an as same impact as x_2 for the impact of UDI. When considered the effect of x_2, it is constant as a 0.10 in Istanbul, Ankara, and Erzurum. Thus, x_2 the increment is not proper for objectives and aims of this manuscript. In the early design phase, the fenestration arrangement should be taken into consideration to avoid any opening in the east direction, unless there is a need for that. When was considered the effect of x_3, it is like a x_1. The increment of x_3 emerges both UDI and EUI increase simultaneously for all 4 regions. It reaches the highest value that is 0.30 in Istanbul.

The Pareto-front solutions show that the climatic condition of the building has a big impact on this alteration of energy and daylight significantly. Because of conditions, the lowest total energy load is average 135.21 kWh/m^2 /year in Izmir. The highest total energy load is 304.66 kWh/m^2/year in Erzurum. It can be analyzed clearly the climate conditions influence for the reason wider fluctuation between for 4 zones. In addition, the total energy load description, Ankara has average 213.53 kWh/m^2 /year and Istanbul has average 195.37 kWh/m^2 /year. When the comparison of the UDI is between 100-2000 lux, the highest percentage is %36.75 in Izmir. The lowest percentage is %29.50 in both Erzurum and Ankara. It can indicate that Izmir's average annual sunshine duration is higher than the other regions. In this respect, Izmir is approximately whole days of year sunny. The heating degree days is 1500 for Izmir whereas it is 4957 for Erzurum. In addition, it is the same differences between cooling degree days. The degree days that are mentioned in Table 3.1. Therefore, the sunshine duration for each region affects the UDI significantly. Thus, the sunshine duration for each region and UDI percentage largely impact the heating, cooling demand of the building naturally. Owing to the differences in heating and cooling demands between different regions, climate affect considerably to EUI. Thus, the buildings are placed in a different climate can have drastically different EUIs.

4.2. VALIDATION RESULTS

After analyzing and evaluating the several fenestration strategies on the test box model by evaluating genetic algorithms, selected design strategies are used to analyze daylight and energy performance of the buildings. For implementing the Pareto-front solutions to validation real case building, three solutions from Pareto-chart of HypE algorithms with the non-dominated solutions at the 29th generation for each region are selected. The most significant part is the design of validation and the control of these strategies for building energy simulation and optimization. These solutions are selected from minimum, average and maximum values of the whole Pareto-front solutions. These are chosen considering EUI values as a minimum, maximum and average. A comparison between simulation results helped with the finding of how the changes of WWR influence the daylighting appearance under different climate conditions, window orientation, time over a year.

Firstly, when analyzing the first climate zone Izmir, real buildings' defaults according to TS825 are simulated. The objectives of the default case are observed for each room and each floor of the building. The building has 9 zones in each 4 floors and it has 72 windows totally. The building model is revealed in Section 3.7.1. The UDI and the heating, cooling loads alter room to room. They can be influenced by default window orientation and wall window ratio naturally. In addition, the room area causes a big difference between each daylight and energy values. Thus, the results depend on a lot of variables and constraints. The average UDI percentage according to total 36 rooms and 72 windows is 29.17. In addition, EUI value is 50.62 kWh/m^2 /year, the total thermal load is 29,9678.93 kWh/year, the total cooling load is 89,779.91 kWh/year and the total heating load is 209,899.02 kWh/year.

After analyzing the default case for Izmir, minimum, average and maximum, three optimum solutions were tackled. When the WWR of validation case 01 was manipulated the case building, x_1 is 0.15, x_2, x_3 and x_4 are the same as 0.10. The results show that the applied WWR has not the big impact on the objectives, which are EUI and UDI. They are approximately the same as default case results, likewise, the total thermal load, the total cooling load, and the total heating load are similar to default. It can be observed like the previous one when the second validation case WWR is applied to the case building in Izmir. x_1 is 0.25, x_2, x_3 and x_4 are the same as 0.10. In addition, validation analysis has indicated that the WWR of the validation case 03 has a minor impact on UDI percentage It has also maximum value on EUI when x_1 is 0.20, x_2, x_3 and x_4 are the same as 0.10. It is like test box Pareto-front results that have maximum EUI.

While observing visualization from selected optimum three Pareto-front solutions for Izmir, the minor alterations are not significant effect visibly for real case building in Izmir.

According to the Pareto-front solutions that were selected from the test box Pareto-chart for 2nd climate zone, Istanbul, illustrated in Figure 4.2. The real case building has 12 rooms in each 5 floor and 65 windows entirely. It reveals in Section 3.7.2. The total default UDI percentage for Istanbul is 21.80 whereas EUI is 68.59 kWh/m^2/year, the total thermal load is 584,369.71 kWh/year, the total cooling load is 6,0843 kWh/year and the total heating load is 523,525.74 kWh/year.

When the validation cases are implemented the real case building both UDI and thermal loads are as same as the default case. Thus, the three optimum Pareto-front solutions are not proper for this real case building too. It is evidence that the differences in the room number, window counts for each façade and their locations, floor-to-floor area for each room has a big impact on the UDI and EUI directly. In addition to these differences from building to building, the façade square meter in each orientation and their wall window size are important too.

For estimating the impact of three optimum Pareto-front solutions to the real case building in Ankara, firstly the default real model was analyzed. The average UDI percentage is 26.10. In addition, EUI value is 40.74 kWh/m^2/year, the total thermal load is 329,169.97 kWh/year, the total cooling load is 42,943.37 kWh/year and the total heating load is 286,426.61 kWh/year. The building has 12 rooms in 3 floor and the building model shows in Section 3.7.3.

According to minimum, maximum and average selection from the Pareto-front solutions, the WWR selection was implemented and calculated for each façade of default real case model. The implemented results for UDI and EUI demonstrate that the optimum three solutions have a minor impact on them.

Validation case 01, the WWR of north and east façade is 0.10 and the south and west façades are 0.15. It can be observed that the UDI and energy results are as same as the default case. When comparing to the other two validation cases, 02 and 03, have not big differences from the default case. Thus, it is like a previous climate zones, Izmir and Istanbul, the Pareto-front optimum results are not appropriate for Istanbul too.

The final climate zone, Erzurum, the default case building was simulated. After analyzing the default parameters, the UDI percentage is 16.93, and EUI value is 99.12 kWh/m^2/year, the total thermal load is 100,5402.10 kWh/year, the total cooling load is 18,197.69 kWh/year and the total heating load is 987,204.41 kWh/year. The real case building has 5 floors and each floor has 10 rooms. The default results show when they have compared the other three regions, Erzurum has a lowest UDI percentage, and it has the highest energy consumption per square meter too. When the three validation cases were manipulated to the real case building, the results are similar too. They have not posed a significant difference from the default case's results. It has the same reason as previous regions, why the test box optimum results do not benefit the building.

In sum, various fenestration strategies are observed and analyzed regarding the thermal comfort and daylight performance of the building. On the one hand, the results show that the WWR and window orientation depend on climate characteristic exactly, on the other hand, selected optimum results from the test box model are not fit all real buildings properly. When the test box optimum solutions are manipulated to the real case building, they have many differences from each other. For example, the test box model has only one zone, but real case buildings are multiple zones. In addition, the test box model is 48 m², but the real case buildings are various. It causes unwanted mistakes when the test box Pareto-front solutions were implemented in the real building. In addition, multiple rooms real building's interior walls have some unexpected effects on the UDI and EUI values. Because of the interruption of interior walls in the daylight that comes from outside, the results can be led faulty. Additionally, the test box model has 4 windows in each façade. However, the real case buildings' window number and distribution to the façades and rooms are diverse. In addition to the façade differences, the façade area for each orientation is diverse too.

Each building has different climatic conditions, orientations, several façades designs also their interior space designs are various. Thus, every property impacts to the energy and daylight simulations differently when the building is simulated and optimized. The results and discussions to the analysis demonstrate that the test-box model is not suitable when specifying standard ratios and orientations. The same pattern is observed throughout the year for all cases and only minor changes are observed due to the improper WWR parameters.

The buildings must be observed individually with advances in computer simulation allow for the possibility of daylighting and energy analyses. To use natural daylight effectively, well design building envelopes considering with its properties and surrounding are one of the most significant components of the whole building. Because of being the weakest part of the building envelope, fenestration must be located correct direction and place towards the sun. The building envelope divides the indoor environment from the outdoor of the building. Hence, they are greatly influenced by the outside climatic conditions. A suitable alternative to windows orientation and wall window ratio can minimize the negative impact of solar radiation.

Therefore, these statements clearly show that the architects and designers have to consider the building unique. When they apply to same WWR, window orientation or the other variables without any local and building properties consideration, the unexpected results occur. It can be seen when the test box Pareto-front results are applied to the real case buildings.

In the early design stage, they have to analysis site in detail. The sun direction, floor numbers, window distributions for each façade, materials of the building, wall window ratio, and especially climate conditions change the structure to structure. Selecting the most optimal WWR and window orientations are crucial about energy efficient building design. The variations of the building envelopes have a huge effect regarding energy and daylight performance of the building. The optimum selections can be utilized to reduce not only the too much solar gain into the buildings but also heating, and cooling energy demand. Hence, to maximize daylighting performance, space should design with both proper WWR and the window orientation. So that, it helps to distribute total illuminance value uniformly to the entire of the interior space. However, the proper WWR and window orientation are designed as unique for the building. In addition, the weather and local conditions, the visual and occupant comfort levels, demands are important too.

If the designers benefit from the simulation and optimization programs, they can be designed easily several optimum alternatives for each building individually. The design parameters should be designated and simulated with daylight and energy considerations. The design parameters are window orientation, geometry/shape, WWR, interior spaces, and daylight. It is important to do that, design elements should be decided and performed properly in the design process. Moreover, the analyses are intensely affecting how to shape final solutions of architectural design. They present many benefits to the occupants and the designers when they take into consideration in the primary design stage.

Even though the strategies are taken into consideration to the user’s needs, the building designs are not based on both the local climatic condition also using natural sources and saving energy. As a result, to use the potential of the building performance, fenestration strategies should be very carefully planned for each building individually considering both daylight performance and energy saving with the realization of performance-based design in the early design stage.

CHAPTER FIVE

CONCLUSION

In this manuscript, the proposal is showing early design how to impact on energy and daylight performance of windows is presented. The problem entails the decisions considering daylight and energy objectives, which are conflicting. The development of energy saving strategies early in building planning and design provides to optimize overall structural performance. Objectives are related with real-parameters, which have an important role by means of fenestration form finding. Even though a lot of researches are performed in the literature about fenestration strategies based on energy efficient design, a substantial research is missing which analyzes simultaneously mutual impact of; window orientation, and WWR on the energy and daylight performance of the residential buildings. Additionally, it is regarded necessary to determine the window performance not only with considering to the window orientation, and the wall window ratio, but also about two constraints related to illuminance levels and climatic zone differences.

The daylight and energy performance of the typical residential buildings in different climate zones in Turkey is evaluated under various envelope designs. The impacts of the parameters are analyzed by simulating and comparing four climate conditions. Simulations are achieved as “Reference case” and “validation case” for two case stages. A test box model is identified as a starting point for overall simulations in the manuscript. The preliminary work has been done in each zone in the early design phase of the optimization process. In sum, by performing the parametric model, firstly decision variables, weather conditions, limitations, problem objectives are selected, then, simulation automation is completed. Finally, the simulations are carried out. During the optimization process, the population size is taken as 100. 100 non-dominated solutions are employed considering the maximum value for each objective as a reference point. At the end of the process, we extracted 100th generation from each of the 49 optimization processes in total, for further operations. During the optimization process, Pareto-front has not performed any change after

29th generations. Therefore, 30 generation is sufficient when implementing this manuscript. The average computation time for each generation was 40 minutes. Thus for 100 population size and 29 generations as a termination criterion took 20 hours. The relationships between different fenestration parameters and impacts on the energy, and daylighting are analyzed for various side-lit room geometries representing four validation case buildings in Turkey. After simulation-based optimization is performed, the well-performed solutions, which outperformed the remainder, are chosen to minimize energy consumption also maximizing daylight performance of the building. In addition, the heating and cooling energy demand for each scenario are compared. Parameters are designed with regional standard, TS825 is a mandatory national building energy regulation that emphases thermal insulation in Turkey. The Pareto-front solutions of the test box model show that the climatic condition of the building has a big impact on this alteration of energy and daylight significantly. Because of conditions, the lowest total energy load is average 136.83 kWh/m^2 /year in Izmir and the highest total energy load is 304.66 kWh/m^2 /year in Erzurum. When the comparison of the UDI between 100-2000 lux, the highest percentage is %36 in Izmir and the lowest percentage % 29.50 in both Erzurum and Ankara. It can be indicated that Izmir's average annual sunshine duration is higher than the other regions. In addition, it clearly appears that north façade windows have the maximum alteration of the WWR percentage to the value of both variables for the 4 climate conditions. Achieving the optimum daylight and energy performance, windows must be carefully designed and located properly.

After analyzing and evaluating the several fenestration strategies on test box model, optimum design strategies are observed to reach minimum energy and maximum daylight performance of the buildings. For implementing the Pareto-front solutions to validation real case building, three solutions from Pareto-chart of HypE algorithms with the non-dominated solutions at the 29th generation for each region were selected. These are chosen considering EUI values as a minimum, maximum and average.

Firstly, when analyzing each climate zone, real buildings' defaults according to TS825 are simulated. The objectives of the default case are observed for each room and each floor of the building. When the validation cases are implemented the real case building both UDI and thermal loads are as same as the default case. The reason for this similarity, each building has different climatic conditions, orientations, various façade designs also their interior space designs are diverse. Thus, every property affects to the energy and daylight simulations differently when the building is simulated and optimized. The analysis demonstrates that the test box model is not suitable when specifying standard ratios and orientations. Therefore, these statements clearly show that the architects and designers must consider the building unique. When they apply to same WWR, window orientation or the other variables without any local and building properties consideration, the unexpected results occur. It can be seen when the test box Pareto-front results are applied to the real case buildings.

In conclusion, this manuscript gives information about fenestration strategies and its importance for residential building's energy control. Simulation provides with different ways of the envelope in the real case residential building to analysis their thermal environment to provide the basis for existing residential buildings energy-saving. It shows that the WWR parameters and window orientation affect differently, climate to climate and building to building. It clearly reveals that the architects and designers have to consider to the building with its characteristics and environment. When they apply to same WWR, window orientation or the other variables without any local and building properties consideration, the unexpected results occur. It can be seen when the test box Pareto-front results are applied to the real case buildings.

Further researches need to improve the efficiency of energy use capability, in various areas including appropriate insulation materials, suitable glazing types, proper shading devices techniques, reduction of artificial lighting etc. depend on standards such as ASHRAE, TS825 so on and so forth. In addition, future work identified by this manuscript includes a more extensive examination of the energy efficiency of high-performance fenestration, moreover, examine whether declined operating costs based on daylighting, cooling and heating energy use by optimizing the thermal comfort of the building.

REFERENCES

.

(MENR), M. o. E. a. N. R. (2016). Energy Statistics in Turkey.

Abido, M. (2002). Optimal design of power-system stabilizers using particle swarm optimization. *IEEE transactions on energy conversion, 17*(3), 406-413.

Agency, I. E. (2013). Transition to Sustainable Buildings.

Al-Saadi, S., & Budaiwi, I. (2007). *Performance-based envelope design for residential buildings in hot climates.* Paper presented at the Proc. Building Simulation.

Alvarado, R. G., & Munoz, J. J. (2012). The control of shape: origins of parametric design in architecture in Xenakis, Gehry and Grimshaw. *METU JFA, 29*(1), 107-118.

Aydin, E., Dursun, O., Chatzikonstantinou, I., & Ekici, B. (2015). *Optimisation of energy consumption and daylighting using building performance surrogate model.* Paper presented at the 49th International Conference of the Architectural Science Association.

Azari, R., Garshasbi, S., Amini, P., Rashed-Ali, H., & Mohammadi, Y. (2016). Multi-objective optimization of building envelope design for life cycle environmental performance. *Energy and Buildings, 126*, 524-534.

Azhar, S., Brown, J., & Farooqui, R. (2009). *BIM-based sustainability analysis: An evaluation of building performance analysis software.* Paper presented at the Proceedings of the 45th ASC Annual Conference.

Bader, J., & Zitzler, E. (2011). HypE: An algorithm for fast hypervolume-based many-objective optimization. *Evolutionary computation, 19*(1), 45-76.

Bektas Ekici, B. (2015). Evaluation of TS 825 Thermal Insulation Requirements in Buildings in Turkey in Terms of Solar Radiation. *MEGARON, 10*(1), 14-24.

Bournas, I., & Haav, L. (2016). Multi-objective Optimization of Fenestration Design in Residential spaces. The Case of MKB Greenhouse, Malmö, Sweden.

Burry, M. (2016). Antoni Gaudí and Frei Otto: Essential Precursors to the Parametricism Manifesto. *Architectural Design, 86*(2), 30-35.

Chastas, P., Theodosiou, T., Kontoleon, K. J., & Bikas, D. (2017). The effect of embodied impact on the cost-optimal levels of Nearly Zero energy buildings: A case study of a residential building in Thessaloniki, Greece. *Energies, 10*(6), 740.

Chatzikonstantinou, I., Ekici, B., Sarıyıldız, İ. S., & Koyunbaba, B. K. (2015a). *Multi-objective diagrid façade optimization using differential evolution.* Paper presented at the 2015 IEEE Congress on Evolutionary Computation (CEC).

Chatzikonstantinou, I., Ekici, B., Sarıyıldız, İ. S., & Koyunbaba, B. K. (2015b). *Multi-objective diagrid façade optimization using differential evolution.* Paper presented at the Evolutionary Computation (CEC), 2015 IEEE Congress on.

Cheong, C. H., Kim, T., & Leigh, S.-B. (2014). Thermal and daylighting performance of energy-efficient windows in highly glazed residential buildings: Case study in Korea. *Sustainability, 6*(10), 7311-7333.

Cheung, C., Fuller, R., & Luther, M. (2005). Energy-efficient envelope design for high-rise apartments. *Energy and Buildings, 37*(1), 37-48.

Cicek, I., & Turkoglu, N. (2005). Urban effects on precipitation in Ankara.

Atmosfera, 18(3), 173-187.

City of Los Angeles, D. o. P. W., Bureau of Street Lighting’s (2007). Design Standards and Guidelines.

ÇİÇEK, İ. (2017). Türkiye'de Termik Dönemlerin Yayılışı ve Süreleri. *DTCF Dergisi, 40*(1-2).

Davis, D. (2013). Modelled on software engineering: Flexible parametric models in the practice of architecture.

Dictionary, O. E. (2002). Oxford english dictionary. *Simpson, JA & Weiner, ESC.*

Dino, I. (2012). Creative design exploration by parametric generative systems in architecture. *METU Journal of Faculty of Architecture, 29*(1), 207-224.

DOE, U. (2014). Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies.

Dursun, D., & Yavas, M. (2016). Urbanization and the Use of Climate Knowledge in Erzurum, Turkey. *Procedia Engineering, 169*, 324-331.

Efficiency, E. (2009). Buildings energy data book. *US Department of Energy. http://buildingsdatabook. eere. energy. gov/. John Dieckmann is a director and Alissa Cooperman is a technologist in the Mechanical Systems Group of TIAX, Cambridge, Mass. James Brodrick, Ph. D., is a project manager with the Building Technologies Program, US Department of Energy, Washington, DC.*

EKİCİ, B. B. (2014). Evaluation of TS 825 Thermal Insulation Requirements in Buildings in Turkey in Terms of Solar Radiation.

Energy and Renewables

Energy, U. S. D. o. (2016). EnergyPlus™; version 8.7; Documentation, Engineering Reference.

Erlendsson, Ö. (2014). Daylight Optimization-A Parametric Study of Atrium Design: Early Stage Design Guidelines of Atria for Optimization of Daylight Autonomy.

Esiyok, U. (2006). *Energy consumption and thermal performance of typical residential buildings in Turkey.* Dortmund, Techn. Univ., Diss., 2007.

Ferdyn-Grygierek, J., & Grygierek, K. (2017). Multi-variable optimization of building thermal design using genetic algorithms. *Energies, 10*(10), 1570.

Fonseca, C. M., & Fleming, P. J. (1993). *Genetic Algorithms for Multiobjective Optimization: FormulationDiscussion and Generalization.* Paper presented at the Icga.

Gane, V. (2004). *Parametric design: a paradigm shift?* , Massachusetts Institute of Technology.

Gasparella, A., Pernigotto, G., Cappelletti, F., Romagnoni, P., & Baggio, P. (2011). Analysis and modelling of window and glazing systems energy performance for a well insulated residential building. *Energy and Buildings, 43*(4), 1030-1037.

Gun, O., & Woodbury, R. (2010). Geometric gestures. *Elements of Parametric Design*, 171-183.

Han, G., Srebric, J., & Enache-Pommer, E. (2014). Variability of optimal solutions for building components based on comprehensive life cycle cost analysis. *Energy and Buildings, 79*, 223-231.

Harish, V., & Kumar, A. (2016). A review on modeling and simulation of building energy systems. *Renewable and Sustainable Energy Reviews, 56*, 1272-1292.

Hasan, A., Vuolle, M., & Sirén, K. (2008). Minimisation of life cycle cost of a detached house using combined simulation and optimisation. *Building and*

Environment, 43(12), 2022-2034.

Henninger, R., & Witte, M. (2003). EnergyPlus Testing with ANSI/ASHRAE Standard 140-2001 (BESTEST). EnergyPlus Version 1.1. 0.020. *Ernest Orlando Lawrence Berkeley National Laboratory Berkeley, California, for US Department of Energy, Washington, DC*.

Hudson, R. (2010). *Strategies for parametric design in architecture: an application of practice led research.* University of Bath.

Husin, S. N. F. S., & Harith, Z. Y. H. (2012). The performance of daylight through various type of fenestration in residential building. *Procedia-Social and Behavioral Sciences, 36*, 196-203.

Hviid, C. A., Nielsen, T. R., & Svendsen, S. (2008). Simple tool to evaluate the impact of daylight on building energy consumption. *Solar Energy, 82*(9), 787-798.

IEA, I. E. A. (2016). Energy Policies of IEA Countries: Turkey 2016 Review.

Jaber, S., & Ajib, S. (2011a). Optimum, technical and energy efficiency design of residential building in Mediterranean region. *Energy and Buildings, 43*(8), 1829-1834.

Jaber, S., & Ajib, S. (2011b). Thermal and economic windows design for different climate zones. *Energy and Buildings, 43*(11), 3208-3215.

Jakubiec, J. A., & Reinhart, C. F. (2011). *DIVA 2.0: Integrating daylight and thermal simulations using Rhinoceros 3D, Daysim and EnergyPlus.* Paper presented at the Proceedings of building simulation.

Kapsalaki, M., Leal, V., & Santamouris, M. (2012). A methodology for economic efficient design of Net Zero Energy Buildings. *Energy and Buildings, 55*, 765-778.

Kaygusuz, K. (2011). Prospect of concentrating solar power in Turkey: the sustainable future. *Renewable and Sustainable Energy Reviews, 15*(1), 808-814.

Kim, J. (2012). *A methodology for daylight optimisation of facades: An investigation of the opening design strategy with cellular automata for an office building.* Paper presented at the Emerging Technologies for a Smarter World (CEWIT), 2012 9th International Conference & Expo on.

Kim, S., Zadeh, P. A., Staub-French, S., Froese, T., & Cavka, B. T. (2016). Assessment of the impact of window size, position and orientation on building energy load using BIM. *Procedia Engineering, 145*, 1424-1431.

Koohsari, A. M., Fayaz, R., & Kari, B. M. (2015). The Influence of Window Dimensions and Location on Residential Building Energy Consumption by Integrating Thermal and Lighting Analysis in a Mild and Humid Climate. *BRIS Journal Of Advances in Science and Technology, 3*, 187-194.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift, 15*(3), 259-263.

Lagios, K., Niemasz, J., & Reinhart, C. F. (2010). Animated building performance simulation (ABPS)–linking Rhinoceros/Grasshopper with Radiance/Daysim. *Proceedings of SimBuild, 4*(1), 321-327.

Li, D. H., & Tsang, E. K. (2008). An analysis of daylighting performance for office buildings in Hong Kong. *Building and Environment, 43*(9), 1446-1458.

Li, D. H., Wong, S., Tsang, C., & Cheung, G. H. (2006). A study of the daylighting performance and energy use in heavily obstructed residential buildings via computer simulation techniques. *Energy and Buildings, 38*(11), 1343-1348.

Mangan, S. D., & Oral, G. K. (2014). A study on determining the optimal energy retrofit strategies for an existing residential building in Turkey.

Manufacturers), E. E. I. (2004). The Critical importance of Building Insulation for the Environment.

McNeel, R. (2015). Rhinoceros. *NURBS modleing for Windows: http://www. rhino3d. com/jewelry. htm*.

Nabil, A., & Mardaljevic, J. (2005). Useful daylight illuminance: a new paradigm for assessing daylight in buildings. *Lighting Research & Technology, 37*(1), 41-57.

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings, 38*(7), 905-913.

Nalan, Ç. B., Murat, Ö., & Nuri, Ö. (2009). Renewable energy market conditions and barriers in Turkey. *Renewable and Sustainable Energy Reviews, 13*(6), 1428-1436.

Özkan E., A. C., Ünlü T. A., Sahal N. (1997). Mevcut Konutlarin Rehabilitasyonunda Yapi Dis Kabugunun Enerji Etkin Yenilenerek Gelistirilmesi. *TUBITAK Project*.

Perera, A., & Sirimanna, M. (2014). *A novel simulation based evolutionary algorithm to optimize building envelope for energy efficient buildings.* Paper presented at the 7th International Conference on Information and Automation for Sustainability.

Peterson, K. (2010). High Performing Buildings.

Prousalidou, E. (2006). *A parametric system of representation based on ruled surfaces.* UCL (University College London).

Recourses, M. o. E. a. N. (2015). Renewable Energy Turkey.

Reinhart, C. F., & Wienold, J. (2011). The daylighting dashboard–A simulation-based design analysis for daylit spaces. *Building and Environment, 46*(2), 386-396.

Rodrigues, C., & Freire, F. (2014). Integrated life-cycle assessment and thermal dynamic simulation of alternative scenarios for the roof retrofit of a house. *Building and Environment, 81*, 204-215.

Rodrigues, C., & Freire, F. (2017a). Building retrofit addressing occupancy: An integrated cost and environmental life-cycle analysis. *Energy and Buildings, 140*, 388-398.

Rodrigues, C., & Freire, F. (2017b). Environmental impact trade-offs in building envelope retrofit strategies. *The International Journal of Life Cycle Assessment, 22*(4), 557-570.

Roudsari, M. S., Pak, M., & Smith, A. (2013). *Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design.* Paper presented at the Proceedings of the 13th international IBPSA conference held in Lyon, France Aug.

Ruiz, M., & Romero, E. (2011). Energy saving in the conventional design of a Spanish house using thermal simulation. *Energy and Buildings, 43*(11), 3226-3235.

Schumacher, P. (2015). Design Parameters to Parametric Design. *The Routledge Companion for Architecture Design and Practice: Established and Emerging Trends*, 3.

Schütz, T., Schiffer, L., Harb, H., Fuchs, M., & Müller, D. (2017). Optimal design of energy conversion units and envelopes for residential building retrofits using a comprehensive MILP model. *Applied Energy, 185*, 1-15.

Shelden, D. R. (2002). *Digital surface representation and the constructibility of Gehry's architecture.* Massachusetts Institute of Technology.

Sözen, A., Arcaklioğlu, E., & Özalp, M. (2004). Estimation of solar potential in Turkey by artificial neural networks using meteorological and geographical data. *Energy Conversion and Management, 45*(18), 3033-3052.

Stegou-Sagia, A., Antonopoulos, K., Angelopoulou, C., & Kotsiovelos, G. (2007). The impact of glazing on energy consumption and comfort. *Energy Conversion and Management, 48*(11), 2844-2852.

Szalapaj, P. (2013). *CAD principles for architectural design*: Routledge.

Tedeschi, A. (2011). *Parametric architecture with Grasshopper®: primer*: Le Penseur.

Tedeschi, A., & Andreani, S. (2014). *AAD, Algorithms-aided Design: Parametric Strategies Using Grasshopper*: Le penseur publisher.

Tuhus-Dubrow, D., & Krarti, M. (2010). Genetic-algorithm based approach to optimize building envelope design for residential buildings. *Building and Environment, 45*(7), 1574-1581.

Turkey- Energy Efficiency in Buildings.

Turkey, I. S. a. P. A. o. (November 2013). Renewable Energy & Environmental Technologies.

Ugurlu, C., Chatzikonstantinou, I., Sariyildiz, S., & Tasgetiren, M. F. (2015). *Evolutionary computation for architectural design of restaurant layouts.* Paper presented at the Evolutionary Computation (CEC), 2015 IEEE Congress on.

Vierlinger, R., & Zimmel, C. (2015). Octopus.

Ward, G., & Mardaljevic, J. (1998). Rendering with Radiance: A Practical Tool for Global Illumination. *ACM SIGGRAPH'98 Course, 33*.

Weisberg, D. E. (2008). The engineering design revolution: The people, companies and computer systems that changed forever the practice of engineering. *Cyon Research Corporation*, 1-26.

Wright, J. A., Loosemore, H. A., & Farmani, R. (2002). Optimization of building thermal design and control by multi-criterion genetic algorithm. *Energy and Buildings, 34*(9), 959-972.

Wright, J. A., & Mourshed, M. (2009). Geometric optimization of fenestration.

Yang, D., Sun, Y., di Stefano, D., Turrin, M., & Sariyildiz, S. Impacts of Problem Scale and Sampling Strategy on Surrogate Model Accuracy.

Yu, J., Yang, C., & Tian, L. (2008). Low-energy envelope design of residential building in hot summer and cold winter zone in China. *Energy and Buildings, 40*(8), 1536-1546.

Znouda, E., Ghrab-Morcos, N., & Hadj-Alouane, A. (2007). Optimization of Mediterranean building design using genetic algorithms. *Energy and Buildings, 39*(2), 148-153.

ASHRAE. (2009). *ASHRAE Handbook :Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.

Bader, J., Zitzler, E., Optimization, M., Bader, J., & Zitzler, E. (2008). HypE : An Algorithm for Fast Hypervolume-Based, *19*(1), 45–76.

Burry, M. (2016). Essential Precursors to the Parametricism Manifesto. *Architectural Design*, *Volume 86*(2), 30–35.

Chatzikonstantinou, I. (2016). A Computational Intelligence Decision-Support Environment for Architectural and Building Design: CIDEA. *IEEE Congress on Evolutionary Computation 2016*, 3887–3894. https://doi.org/10.1109/CEC.2016.7744282

Chatzikonstantinou, I., & Sariyildiz, S. (2016). Approximation of simulation derived visual comfort indicators in office spaces a comparative study in machine learning. *Architectural Science Review, 59*(4), 307–322. https://doi.org/10.1080/00038628.2015.1072705

Choudhary, R., & Michalek, J. (2005). Design Optimization in Computer-Aided Architectural Design. *10th International Conference on Computer Aided Architectural Design Research in Asia*, 149–159. Retrieved from http://cumincad.scix.net/data/works/att/caadria2005_b_4a_b.content.pdf

Datta, S., Hanafin, S., & Woodbury, R. F. (2014). Responsive envelope tessellation and stochastic rotation of 4-fold penttiles. *Frontiers of Architectural Research*, *3*(2), 192–198. https://doi.org/10.1016/j.foar.2014.03.002

Davis, D. (2013). Modelled on Software Engineering : Flexible Parametric Models in the Practice of Architecture, (February), 243. Retrieved from http://www.danieldavis.com/papers/danieldavis_thesis.pdf

Dino, I. G. (2012). Creative design exploration by parametric generative systems in architecture. *Metu Journal of the Faculty of Architecture*, *29*(1), 207–224. https://doi.org/10.4305/METU.JFA.2012.1.12

Du Montier, C., Potvin, A., & Demers, C. M. (2013). Energy and daylighting potential for Adaptive Façades: Evaluation of movable insulated panels, (October). https://doi.org/10.13140/2.1.4343.9680

El Sheikh, M., & Gerber, D. J. (2011). Building Skin Intelligence. *Proceedings of the Annual Conference of the Association of Computer Aided Design in Architecture ACADIA*, 170–177.

Energyplus. (2016). EnergyPlus^{TM} Version 8.6 Documentation.pdf, (c), 1996–2016.

Evins, R. (2013). A review of computational optimisation methods applied to sustainable building design. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2013.02.004

Farley, K. M. J., & Veitch, J. A. (2001). A Room With A View: A Review of the Effects of Windows on Work and Well-Being, (August), 33. https://doi.org/http://doi.org/10.4224/20378971

Fathy, H. (1986). *Natural Energy and Vernacular Architecture*. Chicago and London: The University of Chicago Press.

Fausett, L. V. (1994). *Fundamentals of Neural Netwotks: Architectures, Algorithms and Applications*. Prentice-Hall.

Fotiadou, A. (2007). *Analysis of Design Support for Kinetic Structures*. TU Vienna.

Frazer, J. (1995). *An Evolutionary Architecture*. London: Architectural Association.

Gagne, J. M. L. (2011). An Interactive Performance-Based Expert System for Daylighting in Architectural Design, (2003), 1–6. https://doi.org/http://hdl.handle.net/1721.1/63057

Glassman, E., & Reinhart, C. (2015). Facade optimization using parametric design and future climate scenarios. In *13th Conference of International Building Performance Simulation Association,*. Chambery.

Grobman, Y. J., Capeluto, I. G., & Austern, G. (2016). External shading in buildings: comparative analysis of daylighting performance in static and kinetic operation scenarios. *Architectural Science Review*, *0*(0), 1–11. https://doi.org/10.1080/00038628.2016.1266991

Hausladen, G., de Saldanha, M., & Liedl, P. (2008). *Climate Skin*. Basel: Birkhauser.

Haykin, S. (2009). *Neural Networks and Learning Machines*. *Prentice Hall*.

Hu, J., & Olbina, S. (2011). Illuminance-based slat angle selection model for automated control of split blinds. *Building and Environment*, *46*(3), 786–796. https://doi.org/10.1016/j.buildenv.2010.10.013

Hudson, R. (2010). Strategies for parametric design in architecture. *Civil Engineering*, 274.

IESNA. (2000). *The IESNA Lighting handbook*. https://doi.org/99-76610

Jabi, W. (2013). *Parametric Design for Architecture*. London: Laurence King Publishing.

Karanouh, A., & Kerber, E. (2015). Inovations in dynamic architecture : The Al-Bahr Towers design and delivery of complex façades. *Journal of Facade Design and Engineering*, *3*, 185–221.

Kazanasmaz, T., Günaydin, M., & Binol, S. (2009). Artificial neural networks to predict daylight illuminance in office buildings. *Building and Environment*, *44*(8), 1751–1757. https://doi.org/10.1016/j.buildenv.2008.11.012

Kensek, K., & Hansanuwat, R. (2011). Environment Control Systems for Sustainable Design: A Methodology for Testing, Simulating and Comparing Kinetic Facade Systems. *Journal of Creative Sustainable Architecture & Built Environment*, *1*(Nov.), 27–46.

Kolarevic, B. (2003). Digital Production. In B. Kolarevic (Ed.), *Architecture in the Digital Age*. New York and London: Spon Press.

Kroner, W. M. (1997). An intelligent and responsive architecture. *Automation in Construction*, *6*, 381–393.

Lechner, N. (2015). *Sustainable Design Methods for Architects*. New Jersey: wiley.

Lee, D. S., Koo, S. H., Seong, Y. B., & Jo, J. H. (2016). Evaluating thermal and lighting energy performance of shading devices on kinetic fa??ades. *Sustainability (Switzerland)*, *8*(9), 1–18. https://doi.org/10.3390/su8090883

Lee, E. S., DiBartolomeo, D. L., & Selkowitz, S. E. (1998). Thermal and daylighting performance of an automated venetian blind and lighting system in a full-scale private office. *Energy and Buildings*, *29*(1), 47–63. https://doi.org/10.1016/S0378-7788(98)00035-8

Littlefair, P. J. (1988). Measurements of the luminous efficacy of daylight. *Lighting Research and Technology*, *20*, 177–188.

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

Malkawi, A. M. (2004). Developments in environmental performance simulation. *Automation in Construction*, *13*(4), 437–445. https://doi.org/10.1016/j.autcon.2004.03.002

Mardaljevic, J. (1999). Daylight simulation: validation, sky models and daylight coefficients, 313.

Mardaljevic, J., Heschong, L., & Lee, E. (2009). Daylight metrics and energy savings. *Lighting Research and Technology*, *41*, 261–283.

Moloney, J. (2007). A Framework For the Design Of Kinetic Facades, 461–474.

Moloney, J. (2011). *Designing Kinetics for Architectural Facades : State Change*. London and Newyork: Routledge.

Nabil, A., & Mardaljevic, J. (2005). Useful daylight illuminance: a new paradigm for assessing daylight in buildings. *Lighting Research and Technology*, *37*(1), 41–

59. https://doi.org/10.1191/1365782805li128oa

Nagy, Z., Svetozarevic, B., Jayathissa, P., Begle, M., Hofer, J., Lydon, G., & Willmann, A. (2016). The Adaptive Solar Facade : From concept to prototypes. *Frontiers of Architectural Research*, *5*(2), 143–156. https://doi.org/10.1016/j.foar.2016.03.002

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

Nielsen, M. V., Svendsen, S., & Jensen, L. B. (2011). Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight. *Solar Energy*, *85*(5), 757–768. https://doi.org/10.1016/j.solener.2011.01.010

Olgyay, A., & Olgyay, V. (1977). *Solar Control and Shading Devices*. New Jersey.

Oxman, R. (2008). Performance-based Design : Current Practices and Research Issues. *International Journal of Architectural Computing*, *6*(1), 1–17. https://doi.org/10.1260/147807708784640090

Pesenti, M., Masera, G., & Fiorito, F. (2015). Shaping an origami shading device through visual and thermal simulations. *Energy Procedia*, *78*, 346–351. https://doi.org/10.1016/j.egypro.2015.11.663

Reinhart, F, C., Mardaljevic, J., & Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. *The Journal of the Illuminating Engineering Society of North America*, *3*(1), 7–31. https://doi.org/10.1582/LEUKOS.2006.03.01.001

Riedmiller, M., & Braun, H. (1993). A direct adaptive method for faster backpropagation learning: The RPROP algorithm. *IEEE International Conference on Neural Networks - Conference Proceedings*, *1993–Janua*, 586–591. https://doi.org/10.1109/ICNN.1993.298623

Rossi, D., Nagy, Z., & Schlueter, A. (2012). Robotics for Environmental Performance , Occupant Comfort and Performance , Occupant Comfort and. *International Journal of Architectural Computing*, *10*(3), 341–360.

Sadeghipour Roudsari, M., & Pak, M. (2013). Ladybug: a Parametric Environmental Plugin for Grasshopper To Help Designers Create an Environmentally-Conscious Design. *13th Conference of International Building Performance Simulation Association*, 3129–3135. Retrieved from http://www.ibpsa.org/proceedings/bs2013/p_2499.pdf

Schleicher, S., Lienhard, J., Poppinga, S., Speck, T., & Knippers, J. (2015). Computer-Aided Design A methodology for transferring principles of plant movements to elastic systems in architecture. *Computer-Aided Design*, *60*, 105–117. https://doi.org/10.1016/j.cad.2014.01.005

Schumacher, P. (2016). Design parameters to parametric design. In M. Kanaani & D. Kopec (Eds.), *The Routledge Companion for ARchitecture Design and Practice*. New York: Routledge.

Sharaidin, K., Burry, J., & Salim, F. (2012). Integration of Digital Simulation Tools With Parametric Designs to Evaluate Kinetic Façades for Daylight Performance. *Physical Digitality: Proceedings of the 30th eCAADe Conference, 2*, 701–709.

Shea, K., Aish, R., & Gourtovaia, M. (2005). Towards integrated performance-driven generative design tools, *14*, 253–264. https://doi.org/10.1016/j.autcon.2004.07.002

Skavara, M. E. (2009). *Adaptive cellular automata façade trained by artificial neural network*. Barlett School of Graduate Studies, University Collage of London.

Tedeschi, A. (2014). *AAD_Algorithms-Aided Design :Parametric Strategies using Grasshopper*. Brienza: Le Penseur Publisher.

Tsanas, A., & Xifara, A. (2012). Accurate quantitative estimation of energy performance of residential buildings using statistical machine learning tools. *Energy and Buildings*, *49*, 560–567. https://doi.org/10.1016/j.enbuild.2012.03.003

Turrin, M., Stouffs, R., & Sarıyıldız, S. (2013). Performance-based Parametrization Strategies. In R. Stouffs, P. Janssen, S. Roudavski, & B. Tunçer (Eds.), *Proceedings of the 18th International Conference on Computer-Aided Architectural Design Research in Asia* (pp. 519–528). Hong Kong.

Usman, H. (2007). The Architectural Relevance of Gordon Pask. *Architectural Design*, *77*(4), 54–61. https://doi.org/10.1002/ad.487

Wagdy, A., Fathy, F., & Altomonte, S. (2016). Evaluating the Daylighting Performance of Dynamic Façades by Using New Annual Climate- Based Metrics Evaluating the Daylighting Performance of Dynamic Façades by Using New Annual Climate - Based Metrics, (August).

Ward, G. J., & Rubinstein, F. M. (1988). A new technique for computer simulation of illuminated spaces. *Journal of the Illuminating Engineering Society*. https://doi.org/10.1080/00994480.1988.10748710

Weisberg, D. (2008). The engineering design revolution : The people, companies and computer Systems that changed forever the practice of engineering. Retrieved February 2, 2016, from http://www.cadhistory.net

Wigginton, M., & Harris, J. (2002). *Intelligent Skins*. Oxford: Elsevier.

Woodbury, R. (2010). *Elements of Parametric Design*. Oxon: Routledge.

Woodbury, R., Williamson, S., & Beesley, P. (2006). Parametric Modelling as a Design Representation in Architecture : A Process Account. *Proceedings of the 11th International Conference on Computer-Aided Architectural Design Research in Asia. CAADRIA*, 158–165.

Wortmann, T., Costa, A., Nannicini, G., & Schroepfer, T. (2015). Advantages of surrogate models for architectural design optimization. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, *29*(4), 471–481. https://doi.org/10.1017/S0890060415000451

Zawidzki, M. (2015). Dynamic shading of a building envelope based on rotating polarized film system controlled by one-dimensional cellular automata in regular tessellations (triangular, square and hexagonal). *Advanced Engineering Informatics*, *29*(1), 87–100. https://doi.org/10.1016/j.aei.2014.09.008

Zhang, G., Patuwo, B. E., & Hu, M. Y. (1998). Forecasting with artificial neural networks:: The state of the art. *International Journal of Forecasting*, *14*, 35–62. Retrieved from http://www.sciencedirect.com/science/article/pii/S0169207097000447