Optimization Method for Building Envelope in Terms of Thermal and Visual Comfort

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ABSTRACT

Recently, by enhancing the knowledge of the effect of indoor air quality, thermal and visual conditions on works' productivity, health and comfort, concerns over indoor environment have increased. Although the construction industry shows a lot of progresses in field of sustainability, well integration of comfort conditions is still a big case of argument. In this case, today's computer-based analysis capabilities have reached a point at which daylight availability, occupants' visual and thermal comfort conditions, user behavior, total energy consumption and cost can be combined and presented in a comprehensive performance dashboard.

This digital progress helped researchers to estimate and calculate the effect of every element of buildings. However, here the problem is that it is difficult to define the design parameters about building performance. There are too many variables and as architects, we have to know our minimum requirements for thermal comfort, visual comfort and energy performance, before making decision. In this case, the aim is to establish and develop a model for architects, in order to find an optimum solution for buildings' envelop design, in different design stages (pre-design, design and existing building), according to thermal and visual comfort. This model has the ability to be adapted with all the three stages with some considerations. However, based on the research limitations, it is uniquely tailored for Famagusta's buildings design stage as an example to test the methodology authenticity. The research outcomes have gone on to inform the Cyprus building code and can be the first step to create a reference building in Cyprus. Meanwhile, it leads to propose a standard method, which can be applied on buildings with various functions, locating in different climates in order to assess the optimum amount of energy efficiency, visual and thermal comfort simultaneously.

Keywords: Optimization Method, Energy Efficiency, Thermal Comfort, Visual Comfort.

ÖZ

Günümüzde iç mekan hava kalitesi, termal ve görsel koşulların çalışma mekanlarının ve çalışanın üretkenliği, sağlığı ve konforu üzerindeki etkileri hakkındaki bilgilerin artması, konu hakkındaki araştırmaları yoğunlaştırmıştır. İnşaat endüstrisi sürdürülebilirlik alanında çok ilerleme kaydetmesine rağmen, iç mekan konfor koşullarının etkin olarak sağlanması konusunda hala büyük sorunlar yaşamaktadır. Günümüzün bilgisayar tabanlı analiz sistemleri, gün ışığının kullanımı, kullanıcıların görsel ve ısıl konfor koşulları, toplam enerji tüketimi ve maliyetinin birleştirilebilmesine ve kapsamlı bir performans değerlendirmesinin yapılabilmesine olanak sağlamaktadır. Bu teknolojik ilerlemeler, araştırmacıların bina performansı ile ilgili birçok unsuru tahmin etmelerine ve hesaplamalarına yardımcı olmaktadır. Ancak burada sorun bina performansı ile ilgili tasarım parametrelerinin belirlenmesinde yaşanmaktadır. Mimar veya tasarımcı, tasarım kararları verebilmesi için öncelikle ısıl konfor, görsel konfor ve enerji performansı minimum gereksinimleri bilmelidir.

Bu çalışmada amaçlanan, mimarların bina kabuğu tasarımında ısıl, görsel konfor ve enerji ekonomisi açısından optimum tasarımların yapılmasını sağlayacak bir model geliştirilmesidir. Model tasarım öncesi, tasarım aşaması ve mevcut binaların tasarımında kullanılabilecek aşamaları içermektedir.

Geliştirilen model, Mağusa ölçeğinde seçilmiş örneklem çalışma ile test edilmiştir. Bu çalışmanın sonuçları, Kuzey Kıbrıs'ta bu alanda oluşturulması gereken standartlara veri sağlayacak bir ön çalışma niteliğini de taşımaktadır. Ancak, önerilen model

kullanılarak, farklı iklim koşulları ve tasarım aşmalarına sahip herhangi bir örnek için kullanılabilecek şekilde tasarlanmıştır.

Anahtar Kelimeler: Optimizasyon Yöntemi; Enerji Verimliliği; Termal Konfor; Görsel Konfor.

DEDICATION

I dedicate this thesis to

my beloved family

for their constant support and unconditional love.

I love you dearly.

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Undertaking this academic level has been a truly indescribable and life-changing experience for me and it would not have been possible to do without the support and guidance that I received from many beloved people.

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LIST OF ABBREVIATIONS

AL	Artificial Lighting
AMV	Actual Mean Votes
ANN	Artificial Neural Networks
aNSGA-II	NSGA-II with active archive
aPMV	Adaptive Predicted Mean Vote
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BBO	Biogeography-Based Optimization
BESTs	Building Energy Simulation Tools
BIM	Building Information Modeling
BOPs	Building Optimization Problems
BPS	Building Performance Simulation
CAD	Computer Aided Design
CBDM	Climate Based Daylight Modelling
CFD	Computational Fluid Dynamics
CMA-ES/HDE	Covariance Matrix Adaptation Evolution Strategy with the Hybrid Differential Evolution
CMA-ES/SA	Covariance Matrix Adaptation Evolution Strategy with Sequential Assessment
DA	Daylight Autonomy
DAcon	Continuous Daylight Autonomy
DFs	Daylight Factors
DGI	Daylight Glare Index

DGP	Daylight Glare Probability
DOE	Department of Energy
DT	Target Daylight Factor
DTM	Minimum Target Daylight Factor
EA	Evolutionary Algorithm
EIA	Energy Information Administration
EPBD	Energy Performance of Buildings Directive
GA	Genetic Algorithm
GHG	Greenhouse Gases
HJ	Hooke–Jeeves
HP	Heat Pipe
HVAC	Heating, Ventilating, and Air-Conditioning
IBC	International Building Code
IEQ	Indoor Environment Quality
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
MIHEA	Mutual Information Hybrid Evolutionary Algorithm
MM	Mixed-Mode
MOO	Multi-Objective Optimization
MOPSO	Multi-Objective Particle Swarm Optimization
NSGA-II	Non-dominated Sorting GA
NV	Natural ventilated
pNSGA-II	NSGA-II with a passive archive
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied

PSO	Particle Swarm Optimization
PSOIW	PSO with Inertial Weight
RB	Reference Building
RBF	Radial Basis Function
SA	Sensitivity Analysis
SQP	Sequential Quadratic Programming
SIEC	Semi-Indirect Evaporative Cooler
SMOT	Standard Method of the Test
SVR	Support Vector Regression
TMY2	Typical Meteorological Year 2
UDI	Useful Daylight Illuminance/ Index
UGR	Unified Glare Ratio
VP	Visual Programming
VPL	Visual Programming Languages
WSM	Weighted Sum Method
WFR	Window to Floor Ratio
WWR	Window to Wall Ratio

Chapter 1

INTRODUCTION

1.1 Preface

Today, energy is playing an unignorable role in countries' socio-economic developments. Considering fossil fuels as one of the world's greatest energy resources, shows the importance of decreasing this amount of consumption or discovering alternative renewable energy sources. Construction industry is one of the biggest energy consumers and responsible for a large part of the worldwide greenhouse gas (GHG) emissions. It is claimed that almost 40% of the world's energy usage is from building sectors (IEA, 2008) (Saelens, Parys, & Baetens, 2011). In this respect, energy saving in this sector leads to not only reducing financial statements, but also increasing environmental positive effects and decrease CO_2 emission.

Subsequently, in order to increase building energy efficiency, different techniques of environmental design have been popularly used and developed. One of these strategies, which can be applied in hot climates is preventing from extra solar radiations, to decrease the thermal heat gain and as a result reduce building total cooling loads through decreasing the opening sizes, installing shading devices, tinting glasses and so on. Nowadays, as people spend a great amount of their time indoors, there is magnificent concern about IEQ issues, which will enhance health effects and develop work productivity simultaneously.

Natural window views with daylight can be considered as one of the most critical issues of indoor environmental quality increment. Recently, these environmental tendencies have led scientists to analyze the beneficial aspects of interior spaces, which is the combination of daylight and window views to achieve visual comfort. In this respect, the importance of a view from the window, for creating positive physiological effects on residents has been discussed. Visual comfort can be reached by making balance among various parameters such as; illuminance, luminance distribution, illuminance uniformity, color rendering, glare factor index, amount of daylight and so on.

By enhancing the knowledge of the effect of thermal and visual conditions and indoor air quality on works' productivity, comfort and health, concerns over indoor environment have increased. Researches illustrate that performance of the space occupants has a close relation to the IEQ. This term can include lighting, indoor air quality, thermal environment, acoustic and so on.

Furthermore, among all different energy efficiency measures, building envelope's components have an unignorable effect on building energy usage reduction, especially in hot summers of Northern Cyprus. Therefore, this research will carry out developing a model to simulate the effect of elevation properties on total building energy performance and indoor air quality. In this case, building will be considered in the condition that with little fluctuations, indicates an acceptable comfort level, both thermally and visually by consuming the optimum amount of energy.

1.2 Problem Statement

Generally, constructions are built to make convenient environments. Therefore, in many edifices, such as offices, where discomfort conditions may lead to losing productivity, abstention and cost in terms of working hours, the inhabitants' wellbeing might be considered as a serious issue in comparison with the energy consumption. Because of this issue, managers are, more inclined to invest in air conditioning systems and spend more energy to ensure comfortable interior conditions. Thus, the air conditioning system usage has increased rapidly. The increasing demand for building services and human comfort levels has spurred energy consumption worldwide. Therefore, the way of reducing air conditioning/ HVAC systems energy consumption is the key factor to be addressed in building industry.

In other words, buildings are designed for long term occupancy and it is the duty of architects, engineers and contractors to design for the entire life-cycle of the buildings. While greater levels of uncertainty will inevitably be noticed in any analysis, planning for the future is a valuable practice in helping to notice what the reflection of today's design decisions will be in future. However, as these buildings will be used for upcoming years, architects must evaluate the effects of their today's decisions on the future. In this regard, designers' decisions in all buildings' stages as pre-design, design and even for existing buildings have significant effects on the world's sustainable development.

Consequently, the new design approaches are not only based on reducing the energy consumption, but also are mainly concentrating on the issue of energy efficiency. This energy performance optimization may guarantee the desired indoor comfort conditions simultaneously. Benefiting such approaches at a design process commencement is very crucial to achieve a sustainable output. In this respect, building envelope can be considered as a critical element in order to control the building energy performance and also the amount of daylighting.

Although lots of researches have been established every day, the lighting quality and visual comfort concept is still abstract and is not defined clearly. This maybe because of the reason that the energy reduction ratio of daylighting can be neglected in comparison with heating and cooling parts. In this case, researchers normally focused on a single criterion such as illuminance distribution, uniformity, luminance ratio and so on. Such studies contribute significant findings regarding the perspective of individual evaluation on a lighted environment. However, they are unable to review the interrelationships between different indicators of daylight performance.

Daylight may have lots of positive effects on creating human comfort conditions. Also, by benefiting it as a source of renewable energy, it will reduce electricity usage for heating and lighting demands. Nonetheless, uncontrolled daylight may have negative effects on the space comfort conditions. For example; intense daylight may create glare problems or daylight with extreme solar gains leading to cooling energy loads increasement.

Therefore, in offices, based on the extreme contrast between the zone, close to the fenestration and the opposite end of the space, daylight might be a potential source of problem. Furthermore, uncontrolled solar radiation penetration may increase the thermal loads and consequently raise up the un-satisfaction thermal comfort conditions or the air conditioning systems loads, especially in summers. This problem can be solved by adjusting the proper glazing/shading systems and transparency ratio in order to balance overall energy performance and enhancing sufficient lighting levels with visually comfortable uniformity. The main reason for the unwillingness toward this issue is the lack of data on its potential to save energy and daylighting suitability.

Unfortunately, these types of considerations are not common in today's building designs. In other words, the potential contributions of material properties such as color and texture, and also benefiting shading devices and adjusting opening sizes are not consciously done in building designs for increasing the effectiveness of daylighting, visual and thermal comfort. Qualitative aspects such as human visual comfort are worked out in empirical ways or no other. Another reason for this is the lack of information about daylighting diffusion control systems and devices that use high solar radiation during the year in climate issues. And in this way, the choices of the designers, who usually use highly reflective glazing systems or shading devices, but depend almost exclusively on electrical lighting for visual tasks, are restricted.

In previous literatures the impact of single environmental conditions on occupants' indoor comfort were mainly considered and emphasized. For instance; several literatures investigated the conditions leading to satisfaction with the visual environment. Some others concentrated on prioritization of factors influencing indoor environmental conditions. These types of studies again considered satisfaction with a single environmental condition, such as thermal or visual environment. Consequently, almost no comprehensive review or research has been carried out summarizing the possible impact of various factors on entire indoor environmental quality, being an interaction of visual and thermal conditions as well as energy efficiency is evaluated.

In this case, as a consequence of the growing interest in energy saving and environmental sustainability in buildings, in recent years many studies have been carried out about the potential of window sizes to reduce the energy consumption. However, the problem is that there is not enough knowledge about the effect of these proportions on visual comfort, thermal comfort and consequently energy efficiency at the same time. In other words, the lack of optimization method to design the building envelop according to thermal and visual comfort is significant. Therefore, this research attempts to suggest the model to fill this gap in architectural regulations.

1.3 Research Aim and Objective

These days, there are not too many researches showing the effects of saving energy on residents' comfort and life quality, although this can be considered as a meaningful issue in regions suffering strict climate situation. In a research context, evaluating human subjects has a superior contribution to knowledge and a longer-lasting value for the research community than simulated evaluations resulting from a comfort model. Throughout this research, physiological tests and subjective evaluations were carried out on human subjects with the goal of exploring the impact of energy saving on human comfort and shed light on people's thermal comfort requirements.

In today's regulations, in contrast with vernacular architecture principals, small size windows are more preferable in the case of protecting from extra heat gain and heat loss. Nevertheless, according to the advantages of daylighting, attaining more heating loads in cool seasons and the value of view and connectivity to the outdoor, large windows are also preferred. They may provide several psychological and physiological profits for occupants. For instance; improving productivity or maintaining occupants' positive mood. In this case, the challenge in hot-humid climates like Cyprus is not about daylight quantity, but to control the quality. So, building users might require to be protected from direct exposure of the sky component and solar radiations by controlling transparency ratio and applying shading systems.

However, inappropriate shading device usage or transparency ration may sacrifice daylighting or making discomfort glare. Several occupants close windows entirely with blinds in case of avoiding discomfort glare. Consequently, the abundance of daylight in such mentioned climates are still needed to be utilized. Thus, making a balance between controlling the amount of discomfort glare, heat gains prevention and harvesting proper daylight is important for improving energy efficient, visual and thermal comfortable design.

In this case, in order to maximize building users' comfort, a new multi-objective method, which can be adapted in different design stages by examination of optimizing window to wall ratio (WWR) and building's insulation thickness has been proposed in this research. The proposed optimization method may not only protect users from glare, but also optimize daylight entering the space according to the building users' preferences. Furthermore, the Cypriot vernacular architecture and climatic design principles, such as site planning (vegetation, orientation, and so on), design of the building (form, plan, material, system, height and etc.) and other elements (shading elements, openings and etc.) are some of the key features, which are considered and adjusted during the evaluation stage of the research.

To sum up, this study falls into the vast categories of engineering and architecture. Nowadays, most of the knowledge in the field of IEQ has its origin in engineering, which is more concentrating on minimizing or eliminating health hazards and discomfort constraints, and also improving energy efficiency and buildings' productivity. Therefore, this research tries to develop an architectural approach, concerning to reach visual and thermal comfort in case of optimum energy usage that are more sympathetic to climatic contexts and natural environment, based on the different design stages.

It aims to address the basic problem of how to characterize the inhabitant's adaptive thermal comfort, as well as the implementation of the principle of thermal adaptation concept in design, evaluation and control of built environments to minimize energy consumption. In this case, the aim is to establish and develop a model for architects, in order to find an optimum solution for buildings' envelop design according to thermal and visual comfort, which is uniquely tailored for Famagusta buildings sector as an example. The research outcomes can be benefited to prepare the Cyprus building code and can be the first step to create a reference building in Cyprus.

In other words, this work has shown that today's computer-based evaluation techniques have achieved a level, where daylight availability, occupants' visual and thermal comfort, building user activity and overall energy usage can be integrated and displayed in a robust power dashboard. Therefore, the main concern of the study is to expand a multi-objective method to define a building envelope elements property for a building conceived for Famagusta climate as an example, under a compromise between daylight levels on work plan, thermal comfort and energy efficiency.

1.4 The Research Design & Method of Section

1.4.1 Research Methodology

Generally, this dissertation is based on a theoretical approach, which is mainly supported by the results of case study analysis and a literature survey. On the other hand, as a combination of two main phases, qualitative and quantitative methods of data collection, it involves fieldwork and more especially literature review. Therefore, in order to be more accurate; the methodology used in the present study can be divided into five stages: acquisition a theoretical background, available standards and reference measurement, virtual model generation (specification of different characteristics), running simulation and eventually statistical analysis of the results.

The dynamic interaction between building systems and outdoor climate is acutely a complex process, which includes a large number of difficulties to predict variables. To analyze the effect of different climate and climate change on the built environment, benefiting building simulation methods with the aid of forecast weather data are often required. In other words, the first step in assessing energy efficiency presented by achieving minimum acceptable amount of visual performance and daylight needs by accurate evaluation of the daylight amount entering the sample testing room and then adjusting it with thermal comfort minimum acceptable requirements and optimize it according to the selected design scenario.

On the other hand, energy simulation software can be utilized to analyze cost-effective energy conservation measures before constructing a building. In this regard, a detailed computerized energy calculation by applying hour-by-hour energy simulation method has been selected. Such simulation programs are utilized to evaluate hourly energy usage of the space and its sub-systems of an average weather year. Programs can offer detailed analysis of the energy use of a building, accounting for various factors, such as the occupancy of the building as well as the building mass. It is also possible to provide life cycle cost analysis with various output options based on the particular purpose of the system or the study. Such systems consist of a set of clearly defined test case-building plans and specifications for mechanical equipment. In accordance with diagnostic reasoning, the performance values for the instances are evaluated and used to evaluate the causes of predictive discrepancies. Finally, it should be mentioned that based on this method, for data evaluation, some software such as 'EnergyPlus', 'Ladybug', 'Honeybee', 'Radiance', 'OpenStudio' and so on are used in 'Grasshopper' interface.

The main concern of this study is to propose a multi-criteria method to define and optimize building elevation components like opening place and ratio or even building height, under a compromise between daylight levels on work plan, thermal comfort and energy efficiency. In this case, the energy costs, GHG emissions and other environmental impacts can be decreased by implementing the following structures and processes required to enhance energy production, including energy quality, usage, consumption and intensity. Therefore, the following method helps architects to pursue a systematic approach to continual improvement of energy efficiency and emission control in all design phases. It is also benefited to show architects and designers commitment to energy efficiency and environmental management systems and achieving thermal and visual comfort levels simultaneously. This improvements in energy performance provides rapid benefits for the construction industry by decreasing both energy consumptions and costs.

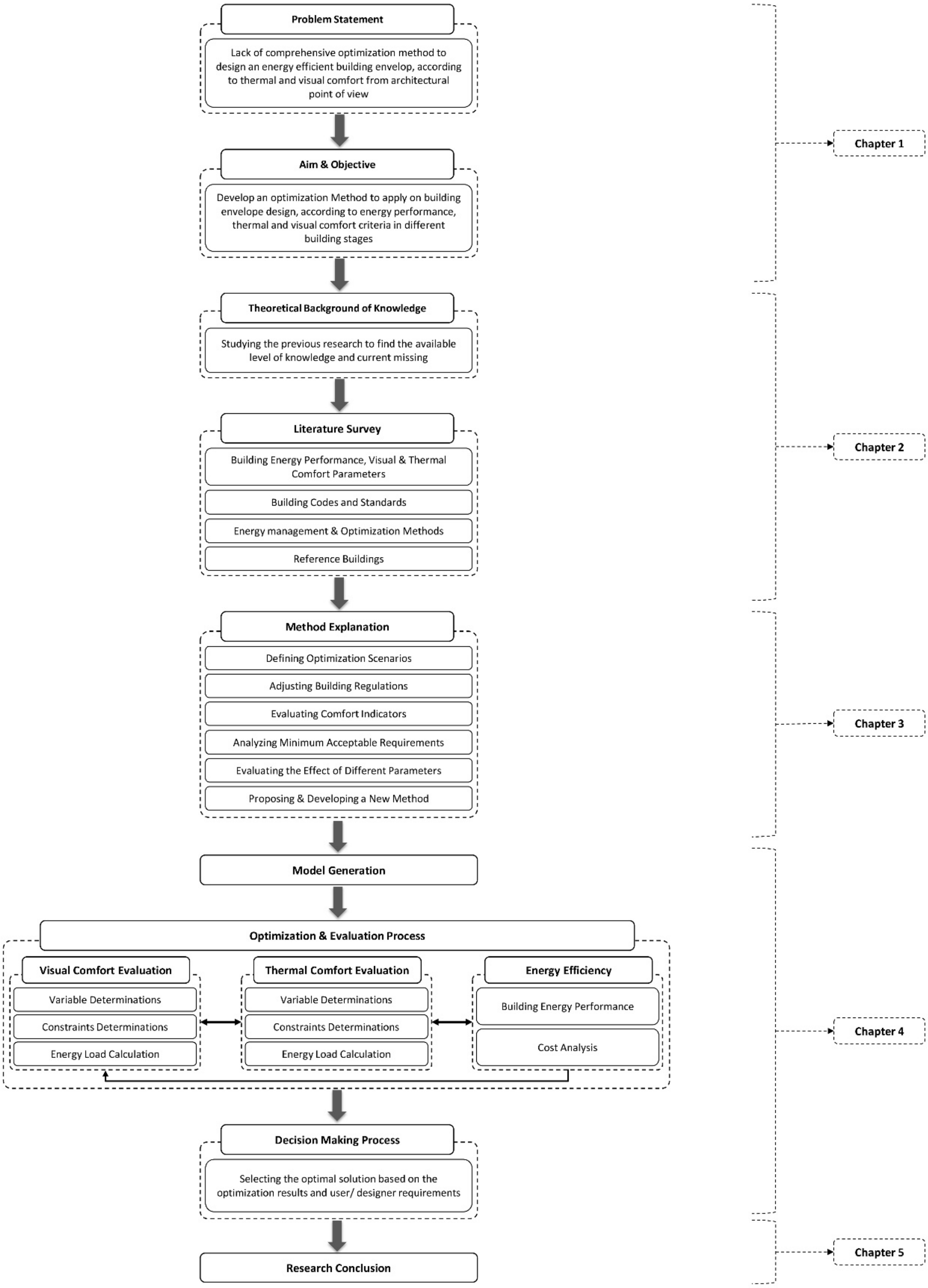


Figure 1: Research General Structural Approach

In this regard, an alternative way of achieving the above-mentioned pop-ups and designing a system for recommending the optimal transparency ratio in terms of achieving both thermal and visual comfort is to take advantage of the parametric architecture analysis process, suggested through consideration of the shortcomings of current approaches and missed points. The main objective of the proposal is to link theory and experience by placing current methods in the design process skeleton and by developing a structured way of thinking and planning for computation and construction, which can be applicable for both future designs and existing buildings.

In general, this model formed from three main evaluation steps, can be named as project modeling according to the selected scenario, comfort analysis and evaluation, optimization process and decision-making process based on the project limitations and considerations. Based on the building designers' considerations, this method is able to evaluate all the mentioned criteria at the same time or separately. It is also possible to eliminate some factors or add some, like shading systems. Or it can be programmed according to building certificate systems such as LEED and so on.

1.4.2 Scope and Limitations

Recently, there has been a growing trend in promoting the reduction of energy in buildings. Three types of approaches should be seen in order to accomplish the sustainable design as the study goal. The first one is planned for first investment costs, depending on electricity, facilities, and so on, and has effective first investment costs with low environmental effect and can be included in pre-design and construction phases. The second is design for efficient operations costs, providing efficiency by the application of design with minimum environmental impacts and mainly applicable in the design level. Eventually, the last issue is concentrating on end cost and end use, which implies energy and material efficiency over the building's whole life cycle and then recycle them with low environmental impacts, which is observed in existing building stage.

The main focus of this dissertation is to propose an adaptable method to achieve energy efficiency and reduce the costs by improving all three mentioned strategies and decreasing the entire life cycle costs of buildings. This method has an ability to adapt with all mentioned construction stages as; pre-design stage, design stage and existing building. However, based on the time limitation of the study and also in order to make the process much clearer and more understandable, the proposed methodology has been tested only in design stage. However, the applicability of the method and the process on the other stages has been briefly explained at the end of chapter four.

Any type of function can be adjusted and evaluated in this method. However, in this research, a typical office building is examined. This selection has been done because of two main reason; the first reason, which is more important is that as one of the aims of this study is to evaluate visual comfort by highlighting the effect of daylighting, office buildings, actives during daytime periods can be most fitted for the evaluation process. Also, the second reason is the size of office buildings in comparison to the other functions are more controllable and easier to explain the process.

A few assumptions were made, when modeling the workplace. Several previous works have shown that the design variations of modelling with and without furniture range between 0-30% (Lim, Kandar, Ahmad, Ossen, & Abdullah, 2012). This amount is varied by different types of furniture arrangement, window distance, sun angle, and etc. Therefore, different furniture arrangements will result in specific illuminance distribution. It seems that it is not really practical to generalize the furniture arrangement in daylighting research. Therefore, in this study, in case of simplification, office furniture was ignored.

In order to maximize sense of comfort; thermal and visual comfort issues will be analyzed in parallel manner. In enclosures the criteria, influencing thermal comfort can be divided into two major categories, personal and environmental. Personal parameters include activity level and clothing. In this case, the space occupants' behavior is a complex process, which has newly been emphasized and concentrates on heating and cooling energy demand, natural ventilation (window opening behavior), and scarcely on blind adjustments and natural light.

Environmental parameters can be classified as relative humidity, air temperature, mean radiant temperature and air velocity. As the effect of each parameter on human comfort is different, body reaction changes to these parameters. Thus, as the effect of these parameters are different to each building's occupant, based on standards and regulations, some of these effects are considered as a constant amount for occupants and thermally and visually a comfortable zone is defined accordingly.

In case of visual comfort; benefiting daylighting and avoiding discomfort glare are the main concerning issues. It is a difficult process to assess the accurate effect of controlling daylight on lighting and total energy savings according to the complex interactions between solar heat gain through openings, natural and artificial lighting, and also human factors. Field measurements and simulation analysis have reported that by controlling the amount of daylight, up to around 60% of lighting energy can be saved (Ihm, Nemri, & Krarti, 2009). However, based on recent low emissive lighting products, the total energy usage in this section even in 24hours artificial lighting scenario can be neglectable. So, a considerable number of owners, engineers, and designers are not encouraged to adopt daylighting control systems in their projects, because these findings do not provide enough incentives. Therefore, a major limitation of this method is that the comfort ranges provided by the technical standards do not account for the entered solar radiation hitting the person, which is actually relevant, when analyzing transparent components.

However, modeling the building occupants' behavior with openings and shading elements is considered as one of the most challenging parts of every study. In this respect, several literatures claimed that occupants do not usually redeploy drapes or blinds, even after disappearing high glare conditions for benefitting from daylights. Therefore, based on the archetypical behavior pattern of active users a light-switch model can be proposed. These active users assumed to close the blinds; once direct sunlight become more than a certain density (typically 50 W/m2) or when DGP >40%. This ability is considered in the proposed model, but in order to more clarify and simplify the method, in case study evaluation, it is tried to reach optimum transparency ratio by avoiding glare. In this case, the impact of active user encounters with blinds and windows is limited to minimum.

On the other hand, models such as Light-switch, introduced for office buildings, are difficult to implement in actual circumstances, where the occupants' duties and positions are always uncertain, and the furniture may be organized in different ways. These widely used models are focused on the implementation of regulations and standards, but the limitation is the use of sedentary or nearly sedentary physical activity rates in normal office work as they were primarily evaluated (adaptive model) and established (heat control model) against field measurements taken from office environments.

It should be also mentioned that in order to analyze the building energy consumption, the first step might be defining the climate of the study area. In this method all different climates data, site locations and contexts can be considered as input and adapted accordingly. However, here, based on the time limitation, Famagusta, Northern Cyprus, is set as an evaluation context for testing the applicability of the methodology.

1.5 The Study Significance

Unfortunately, nowadays, climate is changing. It is most likely due to human behavior, which poses critical threats to a wide variety of human and natural systems and resources. Adding every ton of greenhouse gas results in further changes and increasing risks. In this regard, buildings consume a huge amount of energy, which comes from fossil fuels combustion, producing CO_2 in the process, and it is also calculated that buildings are responsible for approximately 45% of overall energy consumption and just a little less than 50% of all CO_2 emissions (Cao, Dai, & Liu, 2016).

On the other hand, people spend more time indoors after industrialization than ever before. In this case, building interior spaces, such as work environments and offices, must be analyzed according to their design, configuration and characteristics. These issues may have a considerable effect on human health, well-being and productivity. Offices can be unpleasant at different levels and have serious effects on the occupants' absenteeism from work, which may lead to considerable costs for the employer. Nowadays, statistics display the increasing concern of new building construction to the issue of decreasing the use of non-renewable energy sources. This is due to the fact that almost 50% of the mentioned consumed energy in buildings refers to cooling and heating the spaces to make sense of thermal comfort in buildings.

Therefore, design principles and sustainability go hand-in-hand. Principles like optimization of buildings' envelope elements such as considering the optimum size of openings, gives architects a great foundation on which to establish a much sustainable architecture. However, although designers and architects can shape new types of architectural designs by adopting a few basic design rules, this research aims to address one of the most challenging and controversial problems facing mankind over the next century, provides the need to build buildings that are in line with human needs and are more energy efficient. It deals with human thermal and visual comfort, energy conservation and economy. On the other hand, one of the main motivations of designers and building contractors to build green is reducing the building initial costs. By doing life-cycle cost (LCC) analysis, it is possible to get a clear overview of the total cost.

Since long time ago, daylighting was used as a source of architecture expression. Moreover, these days, additional benefits of daylighting such as improving occupants' health, well-being and reducing energy usage are concerned. It is proven that occupants' health is partly influenced by their working environment. For instance; inappropriate lighting may cause illnesses like headaches, eye fatigue, visual stress and so on. Nevertheless, just providing daylight in a building will not always lead to gaining positive results. Daylighting has beneficial and positive impacts, if adequately implemented. It is important to ensure that adequate and proper illumination is available and shadows, reflections and glare are avoided, therefore, careful design is required. Unfortunately, creating a successfully daylight building is often a challenge.

In brief, there are three tenets that encourage the author to undertake this study. First of all, sustainability at the most fundamental level, which is a strategy that aims to obtain a sort of protection that can maintain sustained access to natural resources for the next generations. Secondly, architects are believed to be able to make a significant impact and can contribute to achieve a sustainable future. Lastly, it is clear that sustainability and energy efficiency attempts can only be achieved, by taking human comfort into consideration.

Chapter 2

LITERATURE REVIEW

2.1 Background Knowledge of the Study

In order to analyze building energy performance parameters and decrease GHG emission, very vast amount of researches focus on evaluating and developing existing buildings' performance through energy retrofits. Since previous decades it was believed that developed countries residents spent most of their time (approximately 90%) indoors (Hoppe & Martinac, 1998). This displays the importance of even thermal or visual comfort conditions, air conditioning and indoor air quality. Meanwhile, air conditioning systems are widely used everywhere for heating, cooling and ventilation in HVAC systems. The aim of these extensive uses is to provide the inhabitants thermal comfort and an acceptable indoor air quality. However, still several field studies have recorded a considerable rate of dissatisfaction with indoor environment and thermal comfort (Fanger, 2001) (Kaynakli & Kilic, 2005) (Putra, 2017) (Piasecki, Fedorczak-Cisak, Furtak, & Biskupski, 2019).

2.1.1 Thermal Comfort

In case that deeper analysis is required, thermal comfort evaluation parameters might be considered in building energy performance analysis. Furthermore, some researchers have focused on applying adaptation possibilities for reducing building energy needs (Nicol & Humphreys, 2002) (Ferrari & Zanotto, 2012). For instance; the European Technical Standard (CEN/ EN15251, 2007) proposes this method for buildings without mechanical heating and cooling systems. Other studies; developed different scenarios for achieving thermal comfort approach by comparing Predicted Mean Vote (PMV) and adaptive models (Fanger, 1970). The comfort ranges, which are mentioned by adaptive and non-adaptive models, have been evaluated and compared by Van Hoof and Hensen (Hoof & Hensen, 2007).

Several methods and techniques have been tested to achieve a comfortable indoor environment. One of the most acceptable ones is founded by Ole Fanger, a Danish scientist doctoral thesis in the 1960s (Fanger, 1970). Based on the laboratory steady-state experiment, he concluded that parameters such as air temperature, mean radiant temperature, air velocity, water vapor pressure, combined with thermal resistance of inhabitants' clothing and their activity levels are the main affecting factors, which can make around 90% of the occupants' sense of comfort (Fanger, 2001). He should have considered the fact that each person differently feels indoor environment. However, since his experiment relied on the steady-state condition, the minority encountered less than comfortable conditions (Bell & Green, 1982) (Fanger, 1970) (Fransson, Vastfjall, & Skoog, 2007).

After Fanger's theory, estimation of indoor thermal comfort is primarily based on his procedure, by calculating Predicted Mean Vote (PMV) and, as a result, Predicted Percentage of Dissatisfied (PPD) indices. Extensive numbers of construction codes and regulations, such as ISO 7730 and ASHRAE 55, also accept and support this approach (ISO 7739, 1984) (Andreasi, Lamberts, & Candido, 2010) (ANSI/ASHRAE Standard 55, 2004) (Al-ajmi, 2010) (EN 15251, 2007). In this case, the thermal acceptability zone will be achieved when PMV is in the range of -0.5 to +0.5 and PPD less than 10%. However, comfort condition in various regulations, are classified in different groups like A, B and C in European regulations ((E) ISO/FDIS 7730, 2005). (Andreasi, Lamberts, & Candido, 2010).

Therefore, based on the standards; the amount of thermal comfort satisfaction is indirectly inferred from PMV values, which are ranging from negative (cool) to neutral and to positive (warm) ((E) prEN 15251, 2005). ‘A’ class values of PMV-PPD are the most thermally comfortable situation offered by European standards (Arens, Humphreys, de Dear, & Zhang, 2008). However, on the other hand, this class is unsustainable in case of control projects from the energy cost and maintenance view point. In this regard, ASHRAE 55 recommends a graphical approach for standard indoor environments with a variety of operating temperatures resulting in 80% approval, based on the 10% dissatisfaction criterion for the thermal protection of the entire body based on the PMV-PPD indices (Andreasi, Lamberts, & Candido, 2010).

However, as spaces are dynamic in reality and they are unstable from physical and metabolic rate values perspective, some researchers argued that it is not acceptable to use Fanger’s method to predict thermal comfort (Chun, Kwok, & Tamura, 2004) (Cheng, Niu, & Gao, 2012). Vast number of field data illustrate the insufficiency of static methods, such as PMV-PPD in order to describe sense of thermal comfort satisfaction in free-running spaces (Busch, 1992) (Nicol & Humphreys, 2002) (de Dear & Brager, 2002) (Nicol & Humphreys, 2010) (Lotfabadi & Hançer, 2019). An adaptive comfort standard in the 2004 edition of ASHRAE’s 55 was introduced as an alternative to the PMV based method for Naturally ventilated (NV) buildings. After publishing this edition of ASHRAE, a European counterpart has also replicated an experiment through European countries. In this study, 26 offices were surveyed for almost a year. This experiment develops a European adaptive comfort algorithm and for instance has been applied in the European EN15251 standard (CEN/ EN15251, 2007) (Deuble & de Dear, 2012).

In other words, to define acceptable thermal conditions in natural ventilated building (NVB), the US standard presented an optional method based on graph and indoor comfort temperatures; thermal acceptability limits of 80% and 90% are possible. For spaces equipped with operable windows, with or without mechanical ventilation systems, this can be applied and the occupants can adapt their clothing level freely. The proposed operative temperature is limited to monthly mean outdoor temperatures lower than 10ºC or higher than 33.5ºC. To define thermal acceptability for NVB, prEN 15 251:2005(E) advised the same graphic method (ANSI/ASHRAE Standard 55, 2004) ((E) prEN 15251, 2005) (Andreasi, Lamberts, & Candido, 2010).

Based on the relationship between thermal sensation and thermal comfort, thermal sensation indices such as PMV, ET, SET and so on are widely used to determine thermally uniform and steady conditions. Likewise, in a non-uniform or dynamic environment, few researchers focus on the relationship between the overall thermal sensation and thermal comfort (Hunter & Schmidt, 1990) (Nicol & McCartney, 2001) (Wong , et al., 2002) (Feriadi & Wong, 2004) (Hussein & Rahman, 2009) (Lotfabadi & Hançer, 2019). For instance; Zhang explored an overall thermal comfort method for dynamic environments according to the human reaction to the local thermal comfort environments. The model is based on the overall thermal sensation and local thermal sensation (Zhang, Wang, Chen, Zhang, & Meng, 2010). It should be mentioned that this model is a rule-based one consisting of two rules for different situations and no consistent mode is obtained for all conditions. In addition, under uniform and non-uniform conditions Andamon evaluated the relationship of overall thermal sensation, comfort and acceptability. He reported that thermal dynamic sensation strongly influenced thermal comfort in non-uniform conditions, but in dynamic conditions no results were obtained (Andamon, 2005) (Nguyen, Singh, & Reiter, 2012).

In addition, extensive amount of field studies have illustrated the failure of Fanger steady-state thermal comfort theory for free running buildings, not only in hot climates, but also in temperate climates. This is because of the fact that human behavior changes and people can slowly adjust their preferences and expectations with surrounding environment, which were not considered in this model (Nguyen, Singh, & Reiter, 2012).

In 1972, the steady-state theory was first criticized by Nicol and Humphreys. They discussed this theory limitations and proposed the concept of occupants' adaptation. Later, this adaptive model was applied to several regulations and standards such as ASHRAE 55; 2004 and EN15251; 2007 (CEN Standard EN15251, 2007). Furthermore, some other detailed researches have displayed that use of adaptive comfort theory in actual circumstances offers an unavoidable potential in saving energy (McCartney & Nicol, 2002) (Abdullah & Alibaba, 2018). In comparison with a fixed temperature set point that is indicated by conventional comfort theory, around 30% of the cooling load can be saved (Nguyen, Singh, & Reiter, 2012) (Nicol & Humphreys, 2002). In another case, Nicol did a survey by analyzing 25 cases in hot and humid climate and discussed that adaptive comfort temperature in hot and humid climate has meaningfully varied in comparison to temperate and hot dry climate (Nicol J. F., 2004) (Nguyen, Singh, & Reiter, 2012).

It is proved that indoor thermal environment directly affects building energy usage, even more, several researches concentrated on the relation of human thermal comfort and building use of energy (Tham & Ullah, 1993) (Yang & Su, 1997) (Karyono, 2000) (Corgnati, Fabrizio, & Filippi, 2008) (Martin, Martinez, & Gomez, 2008). As an example; Holz et al. analyzed a building's energy efficiency by using DOE-2 modeling software to take into account three energy saving measures and human comfort (Holz, Hourigan, Sloop, Monkman, & Krarti, 1997). Sensitivity analysis of the six different comfort factors displayed that mean radiant temperature, air temperature, the occupants' clothing level and the level of activity; all have meaningful impacts on human sense of thermal comfort (Wan, Yang, Zhang, & Zhang, 2009).

Mean radiant temperature depends on surfaces heat transfer by radiation. In this regard, materials heat absorbance or emissivity quality might be considered (Luma Sense Technologies, 2016) (Kalwry & Alibaba, 2018). In buildings thermal comfort analysis, both air temperature and surface temperature of the space should be evaluated. However, maintaining all surfaces temperatures in the building is definitely time-consuming, and computation of the corresponding angle factors is even a more time-consuming process. Thus, in most cases; the 'Operative Temperature' or 'Equivalent Temperature' has been used in calculations. However, finding a balance between mean radiant temperature and operative temperature will create a pleasant living environment. It can be accomplished by appropriate design criteria, such as the use of low temperature radiant for heating, high temperature radiant for cooling and even types of glazing (Mclntyre & Griffiths, 1972).

Martin et al. has studied on the relationship between building energy consumption and human thermal comfort. He researched a heat pipe (HP) device as a Semi-Indirect

Evaporative Cooler (SIEC) to reduce energy consumption (Martin, Martinez, & Gomez, 2008). Tsutsumi et al. experimentally investigated the impacts of low humidity on sense of comfort after a step change from warm and humid to thermally neutral condition at constant effective temperature. They found that the effects of humidity on thermal comfort can be measured by taking into account the effective temperature (Tsutsumi, Tanabe, Harigaya, Iguchi, & Nakamura, 2007).

Another research has experimentally tested the impact of extremely hot and arid environments on human thermal perception and overall comfort by applying the energy balance model of Fanger (Becker, Potchter, & Yaakov, 2003). During certain activities the energy balance model was used to evaluate the average thermal perception under the conditions of a set of indoor parameters. This study shows that the measured and experienced heat stress under extremely hot and arid conditions would differ significantly (Wan, Yang, Zhang, & Zhang, 2009).

In a variety of applications such as designing mechanical heating and cooling systems for buildings, modeling the human body’s thermal response under various environmental and personal conditions is important. Thus, since 1970, many models of human thermal reaction have been developed for the human body based on the equations of the energy balance. Generally, the PMV-PPD model from Fanger and the transient two-node model from Gagge are two primary models used to calculate thermal sensation (Gagge, Stolwijk, & Nishi, 1971).

The first multi-segmented human body model has been developed by Stolwijk in 1971 (Stolwijk, 1971). Afterward, multi-segmented models have been more improved and developed. These include the Yigit study (Yigit, 1999), Berkeley comfort model

(Huizenga, Hui, & Arens, 2001) Fiala et al. (Fiala, Lomas, & Stohrer, 2001), the models discussed by Tanabe et al. (Tababe, Kobayashi, Nakano, Ozeki, & Konishi, 2002), Yi et al. (Yi, Fengzhi, Yingxi, & Zhongxuan, 2004), Fengzhi and Yi (Fengzhi & Yi, 2005), and Kaynakli et al. (Kaynakli & Kilic, 2005) AUB model (Salloum, Ghaddar, & Ghali, 2007) (Wang, Zhang, Arens, & Huizenga, 2007) (Al-Othmani, Ghaddar, & Ghali, 2008) (Zhang, et al., 2010).

2.1.1.1 Thermal Comfort Models

The existing thermal comfort models, which tackle asymmetry environments need to be further improved and developed. For example; the Fiala model appears to specifically address transient conditions and the thermal comfort model of the UC Berkeley focuses on the cooling effects of warm environment. In addition, it is predicted that practical realistic estimation of heat flow between the human body and the environment can be achieved over the long term by means of CFD[1] techniques, which can be fed directly back to the model of human body thermal control, so that the thermal sensation and comfort of various body segments can be measured more accurately. This coupling needs to be maintained (Zhang, Wang, Chen, Zhang, & Meng, 2010).

In order to be able to overcome the above discrepancies, a combination of adaptive model and heat balance by addressing both issues of thermal and non-thermal effects of occupant reaction in buildings, seems to be the most acceptable option. Based on the "Black Box" theory, a theoretical adaptive model of thermal comfort has been established to propose a model, which combines the two described approaches. This model takes into account several parameters like temperature, physical, economic,

[1]**Computational Fluid Dynamics** (**CFD**) is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyze problems that involve fluid flows.

psychological and behavioral adaptations, which have a significant impact on the senses to detect thermal comfort. This method is named as the Adaptive Predicted Mean Vote (aPMV) model (Yao, Li, & Liu, 2009). In many experimental researches, the use of this approach has been checked and proved (Conceição, Gomes, Antão, & Lúcio, 2012).

This correction was due to the fact that the results of extensive thermal comfort field study surveys led researchers to doubt the accuracy of the PMV model, which does not consider adaptations of the human body, which plays an essential role in determining subjective thermal sensation and perception (Bouden & Ghrab, 2005) (Becker & Paciuk, 2009). These experimental studies have established a difference between PMV and Actual Mean Votes (AMV) values, given by the thermal sensation votes recorded on the seven-point ASHRAE scale during comfort survey (Yao, Li, & Liu, 2009). A correction element, defined as the adaptive coefficient, is mathematically developed to fit the values of AMV and PMV in this way. This correction factor was applied to the value of the PMV and was calculated and estimated for increasing air temperature of the outdoor. The adaptive PMV index (aPMV) is proposed as a correction mechanism to the Fanger PMV-PPD model on the basis of the above study (Conceição, Gomes, Antão, & Lúcio, 2012).

Moreover, in case of naturally ventilated buildings, several field experiments concluded that the PMV model predicts warmer thermal sensations rather than the ones that the inhabitants really experience in the space (Brager & de Dear, 1998). Throughout certain cases, it overestimates the residence responses at high temperatures and underestimates them at low temperatures, leading to more energy usage of the air conditioning system than required. Furthermore, adaptive models also indicate that the thermal comfort temperature is a function of outdoor temperature (Conceição, Gomes, Antão, & Lúcio, 2012).

From the aforementioned topic, it can be concluded that while there are several researches on the relationship of indoor thermal comfort and energy consumption, few studies have focused on the relation of energy consumption, indoor human thermal comfort and indoor design parameters such as relative humidity and temperature. Therefore, it does not appear to be a science-based framework available for determining energy efficiency, indoor design parameters with consideration of human thermal comfort. Here, Table 1 presents a brief overview on the mentioned previous researches about thermal comfort.

Table 1: Thermal Comfort Available Researches Summary

Category	Year	Research Subject	Comments
Adaptation Possibilities	1970	Comparing adaptive and Predicted Mean Vote (PMV) models	Developed a new scenario for achieving thermal comfort
	1972	First criticism of steady-state theory	Explanation about limitations of steady-state theory and proposing the concept of occupants' adaptation
	2007	Analysing buildings without mechanical systems	---
	2007	Comparing adaptive and non-adaptive models	---
	2002-2012	Effect of adaptive comfort theory on saving energy	Use of adaptive comfort theory in real circumstances offers an unavoidable potential in saving energy
	2004-2012	Difference of adaptive comfort temperature in hot-humid climate & temperate/	---
Energy Performance	1997	Building energy usage of three energy conservation measures & human comfort is analyzed	Using DOE-2 simulation software
	1993-1997-2000-2008	Relation of human thermal comfort and building energy usage	---
	2008	Experimental study to find the relationship of building energy consumption & human thermal comfort	SIEC system is applied to decrease energy consumption
Defining Acceptable Thermal conditions	2002-2010	Inadequacy of 'static' models, such as PMV-PPD in order to describe the amount of thermal comfort satisfaction	Especially in free-running buildings
	2004	Adaptive comfort standard is introduced as an alternative to the PMV based method	Used for Natural ventilated (NV) buildings
	2005-2010	Based on graph and indoor comfort temperatures, optional method is presented	Can be applied for spaces that are equipped with operable windows, both with & without mechanical systems
	2007	Effects of low humidity on human comfort	Effects of humidity on thermal comfort can be estimated by using effective temperature
	2009	Effective factors on human thermal comfort	Six comfort factors have been evaluated
	2003-2009	Effect of extremely hot and arid conditions on human thermal perception	Heat stress can vary significantly under extremely hot and arid conditions
	2010	An overall thermal comfort model for dynamic conditions	It is based on the local thermal sensation and overall thermal sensation
	2005-2012	Relation of overall thermal sensation, comfort and acceptability	Dynamic thermal sensation affected thermal comfort strongly in non-uniform conditions
	2007-2012	Developing adaptive comfort algorithm	Used for Natural ventilated (NV) buildings
	2016	Effective factors on human thermal comfort	Mean radiant temperature has been evaluated
	2005-2019	Relation of the overall (whole body) thermal sensation and overall thermal comfort	Studied under non-uniform or dynamic environment

2.1.2 Visual Comfort

Since the last decade of 20th century, acceptable lighting quality was determined as a balance of different parameters such as; architectural design, humans' needs, economic and environmental issues. Appropriate lighting system might be provided to reach required visual performance level, but it also specifies spatial appearance. It must consider safety issues in one hand, and contributing to health and wellbeing on the other hand (Rea, 2000). Since the early debates on studying the impact of light on human well-being, the idea of lighting efficiency has got more complicated, and the way of thought has undeniably changed (Veitch, 2006). Recently, studies have more concentrated on finding a correlation between human health/ performance and lighting, with positive results. In this regard, it is recognized that standard human rhythms can be disturbed by insufficient or inappropriate light exposure, which itself has severe negative consequences on health, safety and performance. (Burgess, Sharkey, & Eastman, 2002) (Bellia, Bisegna, & Spada, 2011).

The subject of daylighting, which is often accessible and can be addressed in the workplace during working hours, is typically considered separately. It is also measured by daylight factors (DFs), in most cases. This method has already been in use up to now and different variables and criteria have been proposed and added, such as Useful Daylight Illuminances (UDI) (Nabil & Mardaljevic, 2006). Another possible issue is that the daylight glare level is not well known, the Daylight Glare Index (DGI) was not accurately reported, although other glare indices were proposed in the scientific studies (Kim & Koga, 2005) (Wienold & Christoffersen, 2006). More recent studies are concentrating on daylight and its potential to save energy. It is further highlighted by the European Code 'Energy performance in buildings-energy lighting requirements', which demonstrates the calculation techniques to be utilized for calculating the amount of lighting energy consumption (EN 15193, 2007). Nevertheless, there are almost no regulations entirely relating to circumstances under which current daylighting and electric lighting are presented. Recently, this topic is discussed in EN 17037 (EN 17037, 2018).

In the past decade, by proving the effect of natural lighting on environmentally benign and increasing sense of psychological satisfaction form living and working environment (Leslie, 2003) (Du & Sharples, 2011), lots of studies have been focusing on the impact of building openings on the overall interior daylighting (Baker &

Steemers, 2002)(Bougdah & Sharples, 2009) (Lartigue, Lasternas, & Loftness, 2014). The primary research approaches are focused on a numerical analysis of the distribution of daylight in rooms under different ambient conditions (Ünver, Öztürk, Adıgüzel, & Çelik, 2003)(Ghisi & Tinker, 2005) (Husin & Harith, 2012). Many noteworthy outcomes have been obtained. For instance; Markus has stated that about twice as much area as three vertical windows would be illuminated by a long horizontal window in a room (Markus, 1967).

Boubekri presented the contours of daylight penetration with side windows of different widths that clearly demonstrate how the width of the window influences the depth and position of the daylight space in an unfurnished space (Boubekri, 2008). Su and Zhang measured lighting energy consumption of various windows' styles by focusing on window to wall ratio (WWR) (Su & Zhang, 2010). These days, testing methodologies have evolved from conventional on-site observations, static calculations in scaled or actual test rooms (Ruck, et al., 2000) to computer-aided dynamic simulations that utilize climate data (Reinhart & Wienold, 2011).

Furthermore, Eero et al. research results reveal that window area is the most important parameter in daylight calculation (Eero, Kimmo, & Peter, 2000). Bodart and Herde and Krarti et al., found that rising the WWR, specifically impacts the amount of indoor daylight (Bodart & de Herde, 2002) (Krarti, Erickson, & Hillman, 2005). Perez and Capeluto modeled an educational space in a hot-wet climate. They found that the WWR area should not be over 10% in the east-west direction and 12% for the north-south direction (Perez & Capeluto, 2009). Another study evaluated gymnasium daylighting in a severe cold region, and determined the linear effect of illumination and illumination uniformity with WWR (Jing & Gui wen, 2010). In this regard, Wang et al. have observed that the rise in WWR will raise the bright-field region's daylight factor, but the dark-field region's growth is limited (Gang, Wei, Xiao yun, & Xiaopeng, 2008).

Accordingly, the physical properties and size of openings not only affect building energy performance and visual comfort, but also the occupants' sense of thermal comfort (Oral G. K., 2000). It is induced especially by the absorption of solar radiation and the specific internal surface temperature and the consequent modification of the mean radiant temperature. When contemplating to get comfort with transparent surface interactions, it is necessary not to ignore the direct contribution of transmitted solar radiation with the occupants in order to find any numerical comfort methods.

Recently, several researchers analyzed the effect of solar radiations on occupants' sense of thermal comfort (Lotfabadi, 2015). In these studies, physical parameters evaluation and physiological responses to solar radiations are adopted as the two main technics to investigate the solar radiation effects on thermo-regulation. In other words, due to computer-aided simulation techniques; researchers have also analyzed the relation between energy consumption (Zain-Ahmed, Sopian, Othman, Sayigh, & Surendran, 2002) (Li, Lam, & Wong, 2005) (Ravikumar & Prakash, 2011) and design factors like; window height, glass type, etc. In this regard, some basic experiential models were also developed to predict the energy usage quickly (Catalina, Virgone, & Blanco, 2008) (Jaffal, Inard, & Ghiaus, 2009) (Rijal, Tuohy, Humphreys, Nicol, & Samuel, 2011).

The effects of glazing form/ type on human thermal sensation are investigated in a small enclosure, which simulates a vehicle (Trombe & Michel, 1972). Thermal comfort studies illustrated that one unit increment of PMV is the effect of increasing around 200 W/m² direct radiations. Glazing as a visual comfort parameter, has a meaningful effect on thermal comfort (Tereci, Elias Ozkan, & Eicker, 2013). For instance; some researchers assessed 15 different types of glazing systems (Hodder & Parsons, 2007). They consider the PPD and PMV as indexes with the correction for the solar radiation as well (Alibaba, 2016). However, the main problem is the lack of long-term implementation.

On the other hand, recently, there has been lots of literatures, which are involving daylight glare. Most researches are using simulation programs to deal with this issue. In this regard, normally 'radiance' program has been selected to simulate the visual field. By a simplified version of computational analysis on DGP's (Kleindienst & Andersen, 2009) with discussion on contrast base glare and vertical illuminance, it was shown that the term contrast especially under low illuminance conditions, needs more detailed analysis. In this case, in order to find the relations between useful daylight illuminance as a daylight metric and DGP, an initial research was conducted by Mardaljevic et al. (Nabil & Mardaljevic, 2006) (Mardaljevic, Andersen, Roy, & Christoffersen, 2012).

Araji and Boubekri tried to link vertical illuminance and glare to window size (Araji & Boubekri, 2011). However, there are fewer studies, which are actually involved experimental glare measurements, investigating the impact of large area sources (Rodriguez & Pattini, 2014), non-uniform luminance distributions (Kim & Kim, 2011), luminance variation (Kim & Kim, 2012), performing case studies using translucent facades (Matusiak, 2013), identifying modifications in existing glare indices (Fisekis, Davies, Kolokotroni, & Langford, 2003) (Nazzal, 2005), anidolic daylighting systems with electric lighting operation (Borisuit, Scartezzini, & Thanachareonkit, 2010) or photovoltaic windows (Piccolo & Simone, 2009) (Cannavale, Fiorito, Resta, & Gigli, 2013) (Konstantzos, Tzempelikos, & Chan, 2015). Meanwhile, Jakubiec and Reinhart working on the concept of adaptive glare zones, laying the foundation for investigating the positional dependence of glare (Jakubiec & Reinhart, 2011) (Jakubiec & Reinhart, 2013). However, still more studies are needed, as evaluating glare in complex scenes may require fundamental changes to the form of glare models (Clear, 2013).

The potential effect of specific window views on the subjective evaluation of the discomfort glare might be considered as an important issue (Tuaycharoen & Tregenza, 2007) (Aries, Veitch, & Newsham, 2010) (Yun, Shin, & Kim, 2011) (Shin, Yun, & Kim, 2012). In two separate experiments, Suk and Schiler (Suk & Schiler, 2012) and Suk et al. (Suk, Schiler, & Kensek, 2013) used DGP tests to verify the 'radiance' simulation system and to present their methodology to the creation of a relative and absolute glare index. Post-occupancy experiments of measurements and assessments under various sky conditions and façade settings highlight the difficulty of glare calculation with occupant preferences (Konis K. , 2013).

Surveys and detailed glare measurements were conducted by Hirning et al. (Hirning, Isoardi, & Cowling, 2014), to evaluate how different glare indices perform in open plan offices, and by Van den Wymelenberg et al. (Wymelenberg, Inanici, & Johnson, 2010) to study the effects of luminance ratios and distribution patterns. Large number of the above studies benefit from a camera-based glare evaluation method, with useful details provided by Reinhart et al. (Reinhart, Doyle, Jakubiec, & Mogri, 2020), and also employ extensive HDR imaging research related to luminance measurement techniques (Inanici, 2006) (Cai, 2013).

2.1.2.1 Visual Comfort Models

Daylight is studied in several researches published through the years; a conspicuous number of them have tried to change and replace the daylight factor (DF) by defining a new method to quantify the amount of available daylight in interior spaces (Cantin & Dubois, 2011). Some others have discussed the problems of simulating daylight, and have provided the variation that needs to be taken into account, and have proposed different solutions. That is the case, as few researchers discussed non-visual consequences of daylight and included them in the quality analysis of the daytime (Simpson, 2003)(Hua, Oswald, & Yang, 2011) (Bellia, Pedace, & Barbato, 2014).

The DF method generally considers the worst probable daylight condition, and consequently the diversity of daylight will be improved under other sky types. In this respect, it may be a valuable daylight criterion, which is often provided by different design manuals for design and evaluation. However, this method is not flexible enough to predict the dynamic variations in daylight illumination that occur as a result of changes in the position of the sun and when the weather state reaches non-overcast sky conditions (Littlefair, 1989) (Li, Cheung, Cheung, & Lam, 2010). In other words, DF shortcomings involve the fact that it is independent of the venue, the hour or day of the year and the space orientation too. however, as it is based on a single sky state, it has restricted capacity to report and monitor yearly availability of daylight (Reinhart, 2001) (Berardi & Wang, 2014).

In this regard, according to climate data and by considering the dynamic metrics a new perspective in lighting studies have been developed. This is done mainly by taking into consideration the amount of daily and seasonal variations of daylight from the weather data. This methodology has been applied as an alternative to replace old daylight metrics like DF, which was not able to investigate on dynamic aspects of light, such as; sky variations, the latitude, building orientation, the different seasons and times of the day and etc. (Reinhart, Mardaljevic, & Rogers, 2006) (Moreno & Labarca, 2015).

Therefore, according to the time variables, new metrics have been evaluated. In this case, Daylight Autonomy (DA) can be stated as a suitable index for determining daylight quantity. This dynamic index, defined as the percentage of the hours occupied in the year, in which a minimum threshold of illuminance is reached by daylight alone. Compared with DF, considers only overcast sky, the daylight autonomy considers all types of sky conditions throughout the year according to the weather data (Reinhart, 2005). Then, by developing DA index, Continuous Daylight Autonomy (DAcon) has been defined. This measure includes illuminance level, which is less than minimum illuminance value. Through this way, it creates a transition between compliance and non-compliance, recognizing a partial daylight contribution to the space (Heschong, et al., 2012).

Another important index can be the Useful Daylight Index (UDI). This reflects the percentage of time that daylight level is useful for the inhabitants (Nabil & Mardeljevic, 2005) (Nabil & Mardaljevic, 2006). This index is usually divided into three intervals: values more than 2000lux, from 100 and 2000lux, and finally less than 100lux, in the occupied period. It should be noted that the time between sunrise and sunset is represented in the occupied time. Values below the minimum lux are called ‘too little’, while values above the maximum (2000lux) are referred to as ‘too much’. This threshold is one of the indicators, which detects periods in which visual discomfort may occur. Useful daylight is considered, when luminance level is in the range of 100 to 2000lux. UDI enables analyzing whether an area is under-lit or over-lit, and the overall distribution of well day-lit area (Berardi & Wang, 2014).

Another metric called Daylight Glare Probability (DGP) is considered as one of the most common indices used to test daylight glare (Wienold & Christoffersen, 2006). Experimental evidence in private office spaces is derived from this index, containing human test subjects. This is a metric, predicts the presence of discomfort glare in daylight spaces. In other words, DGP may be known as one of the key climate-based daylight indicators for evaluating daylight quality (Cantin & Dubois, 2011) and establishing adaptive zones (Jakubiec & Reinhart, 2012).

Table 2: Visual Comfort Available Researches Summary

Category	Year	Research Subject	Comments
Lighting Quality	2006	The role of light on human health	---
	2002-2011	Correlation between environmental lighting and human health & performance	positive results
	2003-2011	environmentally benign & psychologically satisfying effects of daylighting	--
	2002-05-12	Numerical analysis of daylight distribution in rooms in different ambient conditions	--
Energy Performance	2007	Daylight potential to save energy	highlighted by the European Code
	2010	Lighting energy consumption of different window types by considering WWR	---
	2002-05-11	The relationship between window size, glass material & energy consumption	WWR can limit the growth of dark-field region
	2008-09-11	The effect of solar radiations on occupants' thermal comfort	Simple experiential model evaluation
	2007-2016	Assessing 15 different types of glazing systems	Glazing as a visual comfort parameter, has a significant effect on thermal comfort
Effect of Windows on Lighting Quality	1967	Evaluating a window form	A long horizontal window can illuminate almost twice as much area in a room as three vertical windows
	2000	Evaluating the effect of window area on daylighting	Window area was the most important factor for
	2002-2005	Effect of WWR on the amount of interior space daylighting	Interior daylighting effect will be maximized
	2008	WWR can increase the daylight factor of bright-field region	WWR can limit the growth of dark-field region
	2008	Contours of daylight penetration with side windows of different widths	The effect of window width on the depth & position of the daylight area
	2002-09-14	Effect of windows on the overall interior daylighting	--
	2009	Simulated an education building in a hot-wet area	Concluded that the WWR should not exceed
	2010	Examined gymnasium daylighting in a severe cold region	Illumination and illumination uniformity showed
Daylight Glare	2009	A computational analysis of DGP	More detailed analysis is needed
	2011	Linked window size with vertical illuminance and glare	---
	2006-2012	Study to relate DGP with a daylight metric such as UDI	Showing the initial potential
	2011-2012	Effect of window views on the subjective assessment of discomfort glare	Creating the foundation for investigating the positional dependence of glare
	2012-2013	Concept of adaptive glare zones	Creating the foundation for investigating the positional dependence of glare
	2013	Using DGP measurements in two different studies to validate Radiance simulations	Developing a relative and absolute glare index
	2013	Concentrating on the complexity of assessing glare	Including occupant preferences
	2014	Investigating the impact of large area sources on creating glare	---
	2014	Evaluating glare indices differences, perform in open plan offices	Detailed glare measurements is conducted
	2010-2015	Evaluating anidolic daylighting systems with electric lighting operation	Showing the effectiveness
	2015	Experimenting glare measurements by performing case studies with translucent facades	Identifying modifications in existing glare indices

2.2 Building Energy Performance, Thermal and Visual Comfort Parameters

2.2.1 Thermal Comfort Parameters

Thermal comfort is a condition, in which the thermal environment is subjectively felt satisfied by a person. By this concept, it can be recognized that the terms satisfaction and mind (feeling subjectively) are unpredictable variables. However, at the same time, it also accentuates that assessing sense of thermal comfort is a cognitive process containing different parameters, which is influenced by psychological, physiological, physical and other processes as well (ASHRAE, 2009) (Lotfabadi, 2014). In general, the most significant parameters, influencing the sense of thermal comfort, can be categorized into two groups, as follows (Auliciems & Szokolay, 2007) (ASHRAE, 2009);

- **Primary Parameters:** Clothing insulation, metabolism, air temperature, air flow, humidity and mean radiant temperature are parameters that have a direct effect on sense of thermal comfort. These factors are known as primary parameters affecting thermal comfort;
    - Occupants perceptions and feelings of thermal comfort in a space is affected by both air temperature and surfaces' temperature of the space. The mean radiant temperature is presented as this surface temperature and is controlled by enclosure performances. Defining an equilibrium between the operational temperature and mean radiant temperature may lead to generating a more comfortable zone (Mclntyre & Griffiths, 1972). This can happen through effective building design, interior design, and using low-temperature radiant heating and high-temperature radiant cooling (ANSI/ASHRAE Standard 55, 2004).
- **Secondary Parameters:** In some references, this item is considered as a subtitle of personal parameters, due to the fact that it mainly considers the psychological and physical fitness of the human body. Or sometimes this item is known as a contributing parameter (Auliciems & Szokolay, 2007). Since these types of parameters cannot be considered as permanent ones, it is difficult to propound a specific numerical optimum degree of thermal comfort accordingly.

2.2.2 Visual Comfort Parameters

Unfortunately, it is so hard to clarify a strait forward path to follow in making visually comfortable environment in building section. However, there are several parameters, which are related to lighting issue that may prevent visual discomfort in buildings (Boyce, Human Factors in Lighting, 2003). The main point of concentration in the current standards and regulations is mainly based on the elimination of visual discomfort (ZUMTOBEL, 2013).

Generally, the issue of visual comfort is related to light distribution, quality and quantity. It can be achieved, whenever the objects are seen sharply, clearly in a pleasant colored atmosphere without any tiredness. A comfortable visual environment leads to create healthier environment and increase occupants' productivity. Insufficient visual comfort can lead to tiredness and/or other similar eye problems, accompanied with sense of discomfort and diminishing visual performance.

Parameters, which are playing a predominant role in defining visual comfort can be categorized according to the physical parameters, such as glare index, brightness and luminance, illumination and luminous spectrum. The observed objects' size and also the observation duration should not be neglected. The last but not the least is the effect of psychological and physiological parameters on obtaining visual comfort, which are coming back to individual personality such as age, gender, his/her visual acuity and so on. Therefore, if we want to group them, they can be set as the following order;

- **Physical Parameters:** In order to develop visual comfort, there are so many various types of predictive models and parameters. The group, which has the most importance for architects and designers, is measurable physical parameters. In different sources and regulations, different category types can be found (Araji, 2008). There are four key visual function parameters, which affect the aspect of visual comfort as follows: illuminance, glare index and light direction, light distribution, daylight factor and luminance. However, still there are several other factors affecting visual comfort like: uniformity of lighting, veiling reflections, shadows, flicker, object size, observation time and duration, etc.

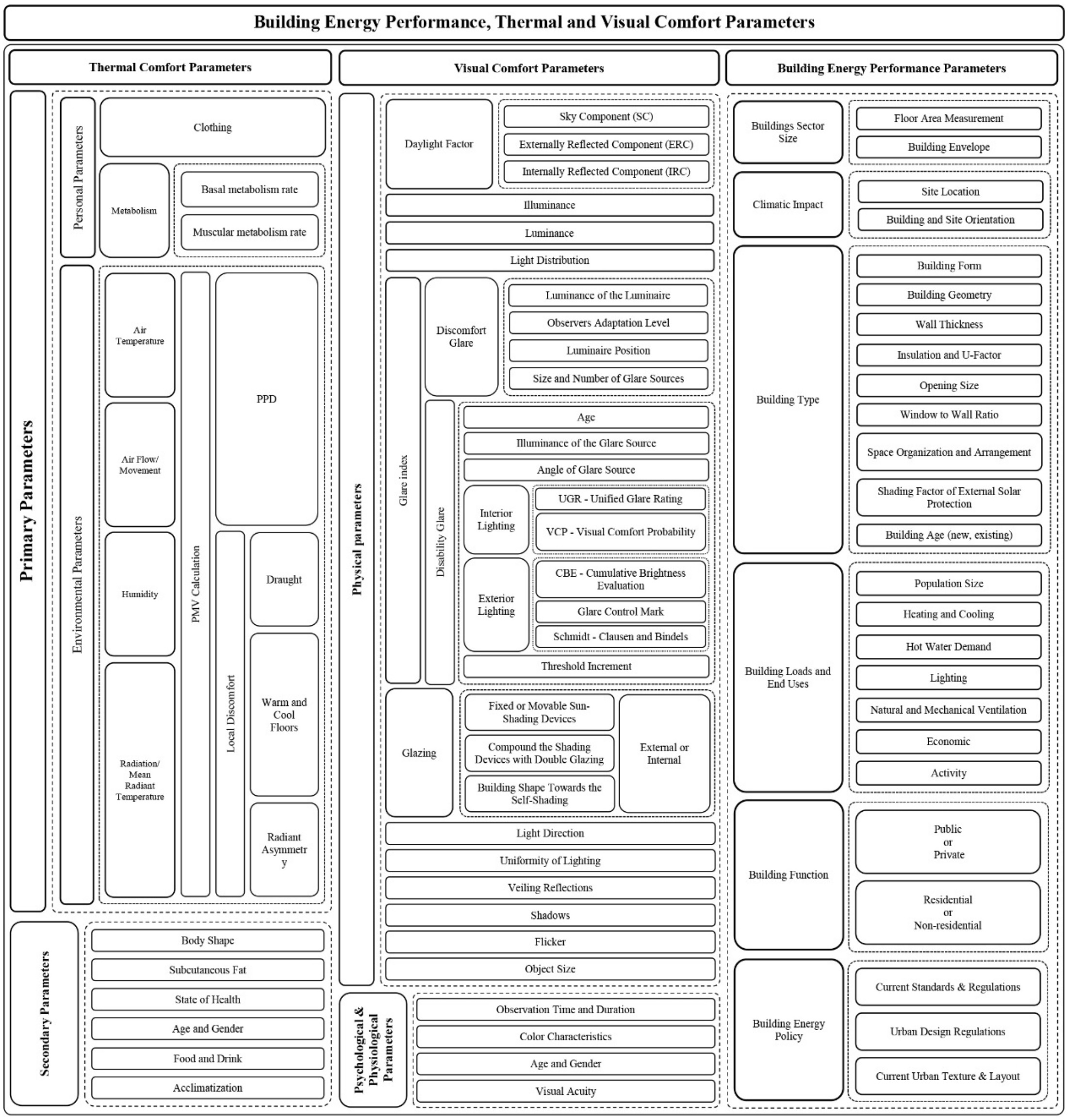
- **Psychological and physiological parameters:** At the same environment and identical conditions, the level of visual comfort can be different for each occupant. In other words, not all the occupants have the same attitude and sensation, when they are exposed to the same lighting conditions (Sun & Lian, 2016). Thus, the subjective evaluations can be used as a method in order to measure some parameters, affecting the level of visual comfort. Some of these parameters can be considered as; color characteristics, age and gender, visual acuity and etc. (Boyce, Human Factors in Lighting, 2003).

2.2.3 Building Energy Performance Parameters

Analyzing building energy performance is a way to evaluate and measure building energy efficiency (Leipziger, 2013). Designing more efficient buildings leads to reducing energy consumption, decrease detrimental impacts and hazards to the natural environment and finally increase financial returns (IMT, 2012). Thus, assessing building energy performance makes a baseline from which efficiency development can be created.

There are several various methods to evaluate energy performance of buildings and applying them largely depends on local policies. There are only a few energy performance parameters or rating system methods, which is accepted and applied in multiple countries. Therefore, here, it is attempted to mention and categorize the most common and effective building energy performance parameters. Finally, in order to make more understandable categorization, the author summarized all the above information in one table, which is presented afterward;

Table 3: Building Thermal Comfort, Visual Comfort and Energy Performance Parameters



2.3 Building Codes and Standards

2.3.1 Thermal Comfort Codes and Standards

Building codes are a set of regulations provided by construction professionals and policy makers, created to manage the design, construction, repair or alteration, and general maintenance of buildings. Codes can be delivered locally or internationally. In general, it is the responsibility of municipalities to adopt the overarching building codes set out in the International Building Code (IBC). This may not only prevent them from having to "reinvent the wheel" but also provides a solid foundation as a guideline. Such rules or regulations remain under continuous development and evaluation to be prepared to adapt to the progress, technical changes, innovations and real-life circumstances of the buildings sector, under which devastation may have been avoided with a change in rules and codes. However, as there is not a proper building code in Northern Cyprus, this research tries to be based on the other building codes and regulations and by comparing their minimum requirements, tries to suggest the optimum amount for this country.

Table 4: Thermal Comfort Analyzed Codes and Standards

Standards	Country	Type	Analysis Method	Minimum Requirements	
ASHRAE Handbook Fundamentals: 2017 (American Society of Heating, Refrigerating and Air Conditioning Engineers)	USA	guidance on building envelope, indoor environmental quality, load calculations, duct and piping system design, refrigerants, energy resources, sustainability, and more.	Based on heat balance models, also referred to as static or constancy models, which formed the basis of the early pioneering work in climate chambers by Gagge and Fanger Steady-State Energy Balance PMV-PPD Model: PMV; PPD Two-Node Model: Skin Compartment; Core Compartment Multisegment Thermal Physiology and Comfort Models Adaptive Models	The operative temperature ranges based on a 10% dissatisfaction criterion are roughly 20-23.5°C in winter and 23-26°C in summer.	Floor temperatures need to be within the 18-29°C range. Radiant temperature asymmetries are specified for two cases. Vertical asymmetries shall be less than 5K, while in the horizontal direction they shall be less than 10K.
ANSI/ASHRAE Standard 55: 2010 (American Society of Heating, Refrigerating and Air Conditioning Engineers)	USA	The North-American standard in thermal comfort evaluation criteria	Based on expressing zones of thermal comfort in terms of operative temperature	The operative temperature ranges based on a 10% dissatisfaction criterion are roughly 20-23.5°C in winter and 23-26°C in summer.	Floor temperatures need to be within the 18-29°C range. Radiant temperature asymmetries are specified for two cases. Vertical asymmetries shall be less than 5K, while in the horizontal direction they shall be less than 10K.
ISO 7730: 2005 (International Standard Organization)	Europe	Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria	General or whole-body thermal comfort is evaluated with the PMV-model by Fanger Method A: Calculate the number or percentage of hours during the hours the building is occupied, the PMV or the operative temperature is outside a specified range. Method B: The time during which the actual operative temperature exceeds the specified range during the occupied hours is weighted with a factor which is a function of how many degrees the range has been exceeded. Method C: The time during which the actual PMV exceeds the comfort boundaries is weighted with a factor which is a function of the PPD. Starting from a PMV distribution on a yearly basis and the relation between PMV and PPD Method D: The average PPD over time during the occupied hours is calculated. Method E: The PPD over time during the occupied hours is summed.	PMV lies between –0.5 and +0.5. With the PMV, a parameter called Predicted Percentage of Dissatisfied (PPD) can be calculated.	In winter, floor temperatures need to be within the 19-26°C range. Radiant temperature asymmetries need to be smaller than 10K, relative to a small vertical surface which is positioned 0.6m above floor level.
EN ISO 13790: 2006	Europe	Energy performance of buildings–Calculation of energy use for space heating and cooling	Method A: A fully prescribed monthly quasi-steady state calculation method (plus as a special option: a seasonal method) Method B: A fully prescribed simple hourly dynamic calculation method Method C: Calculation procedures for detailed (e.g. hourly) dynamic simulation methods	See minimum requirements below	
CEN/TC 156 - prEN 15251: 2006	Europe	Indoor environmental input parameters for design and assessment of energy performance of buildings-addressing indoor air quality, thermal environment, lighting and acoustics	Design indicators Calculated indicators of indoor environment: Simple indicator; Hourly criteria; Degree hours criteria; Overall thermal comfort criteria (weighted PMV criteria) Measured indicators Subjective evaluations	See minimum requirements below	
CEN/TC 156 - prEN 15251: 2006	Europe	Indoor environmental input parameters for design and assessment of energy performance of buildings-addressing indoor air quality, thermal environment, lighting and acoustics		See minimum requirements below	

Minimum Requirements – EN ISO 13790: 2006

Building Function	Heat production appliances during operation time Φi,APP / Afl (W/m2)	Fraction of time present ƒapp	Average heat flow rate from appliances
Office	15	0.20	3
Education	5	0.15	1
Accommodation	4	0.50	2

Minimum Requirements – CEN/TC 156 - prEN 15251: 2006 (first entry)

Category		PPD (%)	PMV	Operative Temperature Range (˚C): Residential buildings: living spaces (bed rooms,	Residential buildings: other spaces: storages,	Single office (cellular office)	Landscaped office (open plan office)	Classroom
I	Winter	<6	0.2<PMV<+0.2	21	18	21	21	21
	Summer			25.5		25.5	25.5	25
II	Winter	<10	-0.5<PMV<+0.5	20	16	20	20	20
	Summer			26		26	26	26
III	Winter	<15	-0.7<PMV<+0.7	18	14	18	18	19
	Summer			27		27	27	27
IV		>15	PMV<-0.7 or PMV>+0.7					

Minimum Requirements – CEN/TC 156 - prEN 15251: 2006 (second entry)

Category	PPD (%)	PMV	Operative Temperature Range (˚C): Winter (1clo & 1.2met)	Summer (0.5clo & 1.2met)
A	<6	-0.2<PMV<+0.2	21-23	23.5-25.5
B	<10	-0.5<PMV<+0.5	14-20	23-26
C	<15	-0.7<PMV<+0.7	19-25	22-27

2.3.2 Visual Comfort Codes and Standards

‘Daylighting’ is used as the term, given to the controlled use of natural light in and around buildings. It is the deliberate positioning of glazed elements such as windows, skylights and roof glazing, in the building design in order to increase daylight quality and quantity. Daylighting is an un-ignorable issue in architecture design. It has a direct effect on visual comfort and energy performance of buildings (Ozturk, 2008) (Ihm, Nemri, & Krarti, 2009). Daylight amount, which is gained through a space mostly forms building openings. These openings may create more pleasing and attractive interior atmosphere and also increase visual access to the outside views (Muneer, Abodahab, & Kubie, 2000). As a key step in daylighting design, daylight illuminance prediction for a given location in a building can be mentioned.

There are lots of building regulations, codes and standards, concentrating on the lighting and daylighting design requirements. In this regard, a recent European standard for daylighting aims to change the focus of designers and also the role of glazing in designing buildings, in order to enhance inhabitants sense of comfort and building total energy efficiency (EN 17037, 2018). It indicates that these days, it is much more important than ever to construct buildings that have healthy, safe, convenient living and working spaces.

Table 5: Some of the Most Acceptable Worldwide Visual Comfort Codes and Standards

Standard	Country	Type	Minimum Requirements									
				View out		Sunlight	Glare	Daylight provision				
			Recommended Level	Hz Sight Angle	Outside Distance of the View	Sunlight Exposure	$DGP_e < 5\%$		Method 1	Daylight Factors (DT)	Method 2	Illuminance Levels: Target Illuminance	Illuminance Levels: Min Target Illuminance
EN 17037: 2018	Europe	CEN European Daylight Standard	Minimum	≥ 14˚	≥ 6 m	1.5 h	0.45	a target daylight factor (DT) across a fraction of the relevant floor area 50% & the minimum target daylight factor (DTM) should be achieved across 95% of the area.		DF< 2		300 lx	100 lx
			Medium	≥ 28˚	≥ 20 m	3 h	0.40			2< DF< 5		500 lx	300 lx
			High	≥ 54˚	≥ 50 m	4 h	0.35			DF> 5		750 lx	500 lx

Standard	Country	Type	Space Function		URG	Ra	$\bar{E}_m$	Remarks	Surface Reflectance: Ceiling	Walls	Working Planes	Floor
CEN/TC 156 - prEN 15251: 2006	Europe	Indoor environmental input parameters for design and assessment of energy performance of buildings-addressing indoor air quality, thermal environment, lighting and acoustics	Office Buildings	Single Offices	< 19	80	500 lx	at 0.8m				
				Open Plan Offices								
				Conference Rooms								
			Circulation Areas	Till Area	< 19	80	500 lx	at 0.8m				
				Corridor	< 28	40	100 lx	at 0.1m				
				Stairs	< 25		150 lx					
EN 12464-1: 2002	Europe	Light and lighting - Lighting of work places - Part 1: Indoor work places	Office Buildings	Filing, copying, etc.	< 19	80	300 lx		0.6 - 0.9	0.3 - 0.8	0.2 - 0.6	0.1 - 0.5
				Writing, typing, reading, data processing			500 lx	DSE-work: see 4.11				
				Technical drawing	< 16		750 lx					
				CAD work stations	< 19		500 lx					
				Conference & Meeting Rooms			500 lx	Lighting should be controllable				
				Reception Desk	< 22		300 lx					
				Archives	< 25		200 lx					
ISO 8995 CIE S 008/E: 2005	Europe	Lighting of Indoor Work Places	Office Buildings	Filing, copying, etc.	< 19	80	300 lx		0.6 - 0.9	0.3 - 0.8	0.2 - 0.6	0.1 - 0.5
				Writing, typing, reading, data processing			500 lx					
				Technical drawing	< 16		750 lx					
				CAD work stations	< 19		500 lx					
				Conference & Meeting Rooms			500 lx	Lighting should be controllable				
				Reception Desk	< 22		300 lx					
				Archives	< 25		200 lx					
ANSI/IESNA RP-1-04	USA	American National Standard Practice for Office Lighting	Office Buildings		< 19Direct glare must be reduced to	100, 300, 500 & 1000 lx (depending on contrasts & task size)	Hz: 1000 lx Vert: 500 lx	Min illuminance (hz) computer: 300lx	> 0.8	0.5 – 0.7		0.2 – 0.4

Table 6: Some of the Most Acceptable Regional Visual Comfort Codes and Standards

Standard	Country	Type	Space Function		Minimum Requirements: URG	Ra	$\bar{E}_m$	Remarks	Surface Reflectance: Ceiling	Walls	Working Planes	Floor
DIN EN 12464-1	Germany	Lighting of work places – Part 1: Indoor work places	Office Buildings	Single Offices		80	500 lx	Surrounding area: Em =	0.7 - 0.9	0.5 - 0.8	500 lx	0.2 - 0.4
				Open Plan Offices								
				Conference Rooms								
				Technical Drawing	< 19							
			Circulation Areas	Corridor	< 28	40	100-200lx	Uniformity is 0.40	0.7 - 0.9	0.5 - 0.8		0.2 - 0.4
				Stairs	< 25		100-150lx					

Standard	Country	Type	Space Function	Minimum Requirements: URG	$\bar{E}_m$	Min illuminance for drawing	Remarks	Surface Reflectance: Ceiling	Walls	Working Planes	Floor
ISO 8995 CIE S 008/E	Australia	Interior lighting - Safe movement	Office Buildings	< 19	320 lx	600 lx	Min illuminance (hz) computer: 320lx Illuminance (vert) on screens (simple): 240lx Illuminance (vert) on screens (detail): 320lx Illuminance (vert) on screens (fine detail): 600lx	> 0.8	0.3 – 0.7	0.2 – 0.5	< 0.4
AS 1680.1-2006		Interior and workplace lighting - General principles & recommendations									
AS 1680.2.0-1990		Interior lighting: Part 2.0 - Recommendations for specific tasks and interiors									
AS 1680.2.1-1993		Interior lighting: Part 2.1- Circulation spaces and other general areas									
AS 1680.2.2-1994		Interior lighting - Office and screen-based tasks									
AS 1680.2.3-1994		Interior lighting: Part 2.1- Educational and training facilities									
JIES-008: 1999	Japan	Indoor Lighting Standard	Office Buildings	Range of quality class of discomfort	500 lx	750 lx	hz: 1000lx vert: 500lx	> 0.6	0.3 – 0.7	0.3 – 0.5	0.1 – 0.3
GB 50034-2004	China	Standard for lighting design of buildings	Office Buildings	< 19	Level1: 500lx			0.6 – 0.9	0.3 – 0.8	0.2 – 0.6	0.1 – 0.5
SNiP 23-05-95	Russia	Daylight & Artificial Lighting: Construction Standards & Rules of Russian Federation	Office Buildings	< 15	300 lx	500 lx	hz: 400lx vert: 200lx	0.7 – 0.8	0.4 – 0.5	0.25 – 0.4	0.25 – 0.4
CIE 29.2-1986	Brazil	Guide on Interior Lighting	Office Buildings	< 15	500 lx	750 lx	hz: 750 lx	> 0.7	0.3 – 0.8	0.2 – 0.4	0.25 – 0.5

2.4 Energy Management and Optimization

There is the necessity of a systematic process to assess the optimum system and/or mode of operation. This procedure is typically known as optimization. In other words, it is a process of finding the conditions, such as; the values of variables, giving the maximum (or minimum) acceptable of the objective function. In the literatures on energy efficiency, this term is often used in place of the proper word; improvement. These two words do not have the exact same meaning and sufficient care might be considered in the place of their usage. The decision whether which criterion should be optimized is of crucial importance and the particular application provides the answer.

In this regard, optimization methods were considered to be the following two groups; some of them were direct search methods that only require a subroutine to calculate function values, such as DSC, a method developed by Davies, Swann and Campey (Swann, 1964), Fletcher discussed this method (Fletcher & Powell, 1964) (Fletcher, 1965). Nelder and Mead (1965) developed the simplex method (Nelder & Mead, 1965) and Spendley, Hext and Himsworth (1962) worked on it as well (Spendley, Hext, & Himsworth, 1962). In this era, another approach used by Powell to reduce a general equation without measuring the derivatives (Powell, 1964). This was in case of gradient approaches allowing both the first function derivatives to be computed and the function itself. For instance: a process, defined by Fletcher and Reeves (Fletcher & Reeves, 1964), using conjugate direction properties. Or the method originally defined by Davidon (Davidon, 1959), and by Fletcher and Powell in simplified form (Fletcher & Powell, 1963).

On the other hand, only limited numbers of design features have been evaluated in the previous studies in the field of optimization analysis. Some of these studies mainly concentrate on optimizing the building shape (Yi & Malkawi, 2009) (Wang, Rivard, & Zmeureanu, 2006). Other works, studied on designing buildings' envelope construction style optimization and also selecting insulation level for walls, floors and roofs (Znouda, Ghrab-Morcos, & Hadj-Alouane, 2007) (Dikmen, Elias-Ozkan, & Haydaraslan, 2017) (Ume & Alibaba, 2019). In this respect, the most detailed optimization method was usually performed in designing low-energy buildings. For example; Wang et al. performed a multi-objective optimization by analyzing economic and environmental metrics to determine a rectangular building's orientation, design style, and size and type of window (Wanga, Zmeureanu, & Rivard, 2005). To build a thermal comfort zone with an emphasis on the mechanical system, Wright et al. also worked on a similar multi-objective optimization (Wright J. , 2002) (Tuhus-Dubrow & Krarti, 2010).

Another study has applied optimization of the office building's envelope features including walls and roof construction, WWR, and glazing solar heat gain coefficient (Ouarghi & Krarti, 2006). They applied genetic algorithms (GA) as optimization technique. In this case, their estimation and analysis focuses on both energy costs alone, and combination of energy and construction costs. Caldas and Norford explored a design tool to reduce annual energy usage, while exploring heating, cooling , and lighting trade-offs (Caldas & Norford, 2003) (Tuhus-Dubrow & Krarti, 2010). Also, Asadi examined GA and Artificial Neural Networks (ANN) for the optimization of the three objective functions: energy use, retrofit cost, and thermal discomfort hours, in a school building as a case study (Asadi, E., et al., 2014).

In order to distinguish the optimal design variables of solar energy usage in buildings, Peippo et al. tried the Hooke and Jeeves pattern search method (Peippo, Lund, & Vartiainen, 1999). Bouchlaghem benefited from the simplex method of Nelder and Mead and also the non-random complex method of optimization of building envelopes (Bouchlaghem, 2000). Michalek et al. tested GA, Simulated Annealing (SA) and Sequential Quadratic Programming (SQP) to find global solutions for building's design optimization (Michalek, Choudhary, & Papalambros, 2002).

Later, Ant colony optimization for discrete problems with the aid of Radiance simulation program have been used in case of finding a trade-off between cost and lighting performance of a media center in Paris (K. Shea & Antonuntto, 2006). Wang et al. repeated a simulation-based optimization by applying GA for designing a green building (Wang, Rivard, & Zmeureanu, 2005). Chantrelle et al. also investigated on a multi-criteria tool, by using GA to find the optimum amount of energy usage, thermal comfort, cost and life-cycle environmental effects (Chantrelle, F.P., et al., 2011) (Mangan & Oral, 2016).

Meanwhile, Fesanghary et al. developed a harmony search algorithm to minimize CO_2 emissions and life cycle cost (Fesanghary, Asadi, & Geem, 2012). A graphical optimization methodology has been used to find the trade-off between visual comfort and energy usage for glazing systems in an office building (Ochoa Morales, Aries, Loenen, & Hensen, 2012). Non-dominated sorting genetic algorithm has been employed to minimize energy usage for heating, cooling and lighting of an open space office with respect to building envelope configurations (Oral, Yener, & Bayazit, 2004) (Méndez Echenagucia, Capozzoli, Cascone, & Sassone, 2015). The weighted sum method (WSM) and the particle swarm optimization algorithm (PSO) have been used to optimize the annual cooling, heating, and lighting electricity usage (Delgarm N. , Sajadi, Kowsarya, & Delgarm, 2016). Lin et al. applied Tabu Search to optimize envelope configurations for an office building (Lin, Tsai, Lin, & Yang, 2016).

There are considerable numbers of comparative studies, concerning Building Performance Simulation (BPS). In this case, Ostergard et al. categorized these studies as solar energy design, SA methods, simulation tools and software, computational optimization methods and so on (Evins, 2013) (Ostergard, Jensen, & Maagaard, 2016). Whilst BPS is mainly valuable in the early design stages, its application is still reduced in the final design stages due to several challenges. These issues can be known as input uncertainties, time-consuming modeling, conflicting requirements, large design variability and several other factors (Touloupaki & Theodosiou, 2017).

Generally, most methods of optimization in early stages of design, emphasis on non-geometric variables. For instance: changing system requirements, U-values and scarcely put the analyses in context of project specific architectural solutions. Obviously, mandatory and ambitious usage of optimization methods will be an architectural issue in the early design stage (Touloupaki & Theodosiou, 2017). To assess the building maximal feasible heat transfer coefficient (U value), which minimizes energy conservation while ensuring thermal comfort, a method was investigated by Oral and Yilmaz (Oral & Yilmaz, 2002). The limit U-value depends on the shape of the building, represented as coefficient of shape, type of glazing, WWR and orientation of the wall. This technique was evaluated in three location; Ankara, Istanbul and Erzurum, representative area of temperate dry, temperate humid and cold zones Turkey. The result shows that this method can be used in temperate and cold areas with long and intensive heating periods (Zhang, Zhang, & Wang, 2016).

If independent variables, some or all of the pre-specified parameters are probabilistic (nondeterministic or stochastic), then the problem of optimization is a stochastic programming one. Otherwise, it is a problem of deterministic programming. According to the number of objective functions, optimizations are classified to single or multi-objective programming problems. In most problems there is no single point satisfying all the objectives, meanwhile, a subjective compromise is often needed.

Bouchlaghem and Letherman developed a numerical optimization method for thermal design of non-air-conditioned buildings as a combination of an optimization technique and a thermal analysis model in early 1990 (Bouchlanghem & Letherman, 1990). Early optimization studies desired to apply the generic optimization algorithm, but later, it is believed that multi-objective optimization (MOO) methods are more appropriate to solve the complex nature of the problems. This is in case that they may allow to assess multiple variables or conflicting objectives, and find sets of global Pareto optimal (non-dominated) solutions (Wanga, Zmeureanu, & Rivard, 2005). Marks believed that optimization criteria, decision variables and constraints, which are also called objective functions, are the basic notions in the formulation of a multi-criteria optimization problem (Marks, 1997). This gives the ability to select the preferred solution over various optimal Pareto ones, using an additional criterion such as personal aesthetics. In this case, one can seek to minimize greenhouse emissions, energy costs, building performance and other parameters (Touloupaki & Theodosiou, 2017).

On the other hand, over the last decade, one of the main targets of the buildings' energy performance studies have been directed toward simulation-based optimization. These are done in order to estimate the most appropriate building parameters and architectural configurations to promote its energy efficiency (Delgarm N. , Sajadi, Kowsarya, & Delgarm, 2016). Integrated dynamic models combine design tools, building performance simulation tools and a visual programming language (VPL) (Negendahl, 2015). This VPL is used with BIM for energy modeling of entire buildings and for dynamic solar shading studies (Kensek, 2015).

In this regard, parametric research provided several instances of energy use and daylighting, benefiting from Diva/ Daysim to build operable blinds and electrical lighting schedules for thermal analysis, and utilizing genetic algorithms in optimizing multidisciplinary designs (Lotfabadi, 2016) (Konis, Gamas, & Kensek, 2016). In other words, parametric analysis is not a new concept, but software availability and automation has made the process much easier to pursue. The growth and advancement of integrated dynamic models, where a VPL would dynamically merge a design tool with one or more BPS tools made it possible for non-developers to introduce new measurement methods in the early design phases (Negendahl, 2015).

2.4.1 Optimization Methods

In the recent decades, several Building Energy Simulation Tools (BESTs) have been designed and developed to help architects and other professionals analyze buildings' energy consumption. 417 of these tools have been listed on the website of the U.S. Department of Energy (DOE, 2018). However, although a great number of researches prove the potential capability of BESTs to make correct design decisions, less than 30% of architects employ it in their designs (Weytjens & Verbeeck, 2010). On the other hand, while lots of studies have been concentrated on the Building Optimization Problems (BOPs), the selection of the right optimization algorithm remains an open question yet, as it is highly dependent on the specifics and details of the problem

(Wolpert & Macready, 1997). Much attention has been paid to the fact of performance evaluation of optimization algorithms in solving BOPs.

Architects may use numerous forms of techniques and methods to find an optimal solution, such as: multi-objective optimization, genetic algorithms, parametric analysis, and also passive optimization. Nevertheless, in the early design stage, none of the aforementioned current methods and models will completely meet the needs of architects. Therefore, it is a need to do further studies and developments.

The early design stage has more influence on building energy performance rather than the late design stages (Suh, Park, & Kim, 2011). In the early design stage, about 20% of design decisions were made. These decisions estimated to have 80% impact on the final building energy performance (Bogenstätter, 2000). However, most of the simulations conducted in late design phases in order to validate whether the design adjusts the energy standards and codes or not. Thereby, facilitating building energy simulation aided design in the early design stages is of great importance, particularly in the preliminary design (pre-design) level.

Passive optimization is known as a process that most designers believe to do it by generating and evaluating few alternatives or options, mentally evaluating them against previous experience and then intuitively distinguishing the best approach. Despite the experienced and professional architects in case of passive strategies, who might be able to do it properly, some might have inaccurate intuition, especially for climate zones, on which they might have no experience before. Thus, in general simulation is a safer method.

Axel Kilian defined parametric design as a method of choosing an appropriate collection of parameters with the most suitable correlation to answer the design question criteria (Kilian, 2006). The main privilege of using parametric design is to plan and synthesize total requirements and relationships of various design elements in one form. This process gives the designer the chance to quickly explore various probable solutions (Ercan & Elias-Ozkan, 2015). In this regard, parametric design can be described as: "a process that is based on algorithmic thinking enabling the expression of parameters and rules which, together clarify, end and define the relationship of design response and design intent" (Jabi, 2013). In other words, algorithmic or parametric design is an efficient way of flexibly creating or describing a geometry through scripting, a way in which decision parameters and variables are linked to geometry.

Janssen discussed four specific forms of parametric modeling techniques as follows: object modelling, data flow, associative and procedural, which differs primarily in the capacity of iteration support (Janssen & Stouffs, 2015) (Touloupaki & Theodosiou, 2017). In this period, VP systems were built to allow designers to build parametric models in writing scripts process. Myers described a VP system in the 1990s as "any system enabling the user to specify a program in a two or more, dimensional fashion" (Myers, 1990). Halbert introduced VP systems as a valuable tool to make fairly complex programs with little practice and training for non-programmers (Halbert, 1990). It is now clear that VP frameworks have evolved tremendously, making parametric modeling increasingly available through programs such as Grasshopper and its generative components for designers (Touloupaki & Theodosiou, 2017).

VPL is a well-known method, which is able to change design variables and cover optimization components by designers. Visual programming is a type of computer programming, that instead of typing lines of text code, users can graphically interact with program elements. For instance: Honeybee, Dynamo, Ladybug, and Grasshopper. Nodes are generated in a VP environment: numbers, sliders, functions and operators, graphic creators, scripts, notes, list manipulation tools, customizable nodes and even nodes from other developers (e.g. components for optimization). Later, they are virtually linked together. Grasshopper, which is used as a Rhino plug-in, is a widely used VPL within the construction industry. However, other VPLs such as Dynamo or Marionette are becoming more widespread in commercial industry. Grasshopper has the ability to interact with numerous tools and plug-ins for simulation-based environmental analysis, such as Honeybee, Ladybug, Archsim, Gerilla, and DIVA. Grasshopper also includes modules for single (Galapagos) and multi-objective evolutionary (Octopus) optimizations as well.

In order to relieve the computational burden, the usage of surrogate models or so-called Meta models are commonly spread out. It is a mathematical approximation of a system model, which is working by collecting data from experimental experiments or simulations for describing the original system behaviors. Several methods are using the system of surrogate model. For example: Support Vector Regression (SVR), Kriging, Radial Basis Function (RBF), Artificial Neural Networks (ANN) and so on (Kecman, 2001) (Haykin, 2009). This model can be benefited in different phases of building construction like estimating energy performance in design stage or operation phase (Neto & Fiorelli, 2008) (Buratti, Barbanera, & Palladino, 2014) (Khayatian, Sarto, & Dall’O’, 2016) (Ascione, Bianco, De Stasio, Mauro, & Vanoli, 2017).

However, the main challenge of constructing surrogate models is to achieve the highest prediction accuracy with the least computational cost.

According to several researches, ANN can be considered as one of the most used surrogate models in both building optimization and energy prediction (Magnier & Haghighat, 2010) (Gossard, Lartigue, & Thellier, 2013) (Asadi, E., et al., 2014) (Buratti, Barbanera, & Palladino, 2014) (Melo, Versage, Sawaya, & Lamberts, 2016) (Khayatian, Sarto, & Dall'O', 2016) (Naji, et al., 2016) (Ascione, Bianco, De Stasio, Mauro, & Vanoli, 2017). Hence, the surrogate method performance strongly depends on the number and quality of samples, used to create the model. Moreover, all BOPs studies used the random sampling method, which suffers from extra computational cost for labelling non-informative samples.

Generally, multi-objective optimizations are applying to analyze two variables such as energy consumption for lighting versus heating/ cooling loads for different window sizes. However, when talking about the cost of computing speed we can achieve an arbitrary number of objectives by applying this method. The Pareto ranking refers to a solution surface in a multidimensional solution space that is formed by multiple criteria that represent the objectives. The Pareto front usually uses to show the results of optimization. All feasible solutions for the given goals and constraints are connected by a curve. A visual solution space is provided that ideally spans from one extreme trade-off to another for multi-variable solutions.

The multi-criteria or multi-objective optimization is applicable, when there is more than one objective function of optimization. This is popular in building design problems and these functions are often contradictory. In general, in multi-objective optimizing two types of strategies have been used. One is weighted sum function, in which each objective is summed up and normalized with its associated weight factors in order to obtain only one cost function. Typical optimization algorithms may be used to overcome it. However, it is not possible to obtain the knowledge, informing us about how various sub-objectives interact with one another. Testing different weight factors results an increment in the numbers of the optimization problems, which in turn requires longer processing times.

As mentioned earlier, Pareto presents another common multi-objective optimization approach. In situations, where there is no other feasible alternative/ solution enhancing one objective without worsening at least another, Pareto non-dominated or optimal can be an alternative. These multi-objective algorithms lead to a set of non-dominated solutions, called Pareto frontier. The Pareto frontier may be presented as a curve in cases, where the problem consists of more than one target.

In other words, Vilfredo Pareto proposed one of the most practical methods of multi-objective optimization. Pareto/ non-dominated approach can be accepted as a solution, where there is no other feasible way to improve one objective without deteriorating another. In multi-objective optimizations, all points on the Pareto front can be considered as a potential of an optimum solution. Therefore, a decision-making mechanism is necessary in order to select the final optimum configuration from all feasible points. There are several methods for decision-making to solve the multi-objective optimization issues. These techniques are categorized into two general groups: a classical multi-objective optimization method, which deals with a single objective problem for each Pareto-optimum solution, while another one seeks for all non-dominated solutions at the same time.

In today's world, which is full of complexity, using a single objective technique may avoid reaching a comprehensive result. In other words, the final decision may deviate from considering cost factor by concentrating on other factors such as social, environmental, aesthetic or other relevant issues. However, multi-objective optimization method, attempts to consider two or more parameters/ objectives simultaneously. In this type, reaching optimum point may not satisfy each objective in isolation, but it corresponds to a compromise, often subjective, of the various objectives.

The weighted sum method (WSM) is considered as one of the most typical multi-criteria decision-making approaches. A multi-objective problem of minimizing a vector of criteria functions is turned into a scalar problem by summing up normalized objective functions multiplied by the WSM's weighting coefficients. Hence, the mentioned methods have both advantages and disadvantages simultaneously. It is pointed out that while algorithms that offer Pareto solutions concentrate on exploiting the vastness of solution, there is also proof of insufficient efficiency and effectiveness (Cao, Huang, Wang, & Lin, 2012). The WSM is more effective and simpler to apply, but needs advanced experience and does not include information on the compromise between the objectives.

Since the middle of 1980s, by introducing the multi-objective evolutionary algorithms, substantial literature has been improved and several types of evolutionary algorithms (EAs) such as; ant colony optimization, genetic algorithms, covariance matrix adaptation evolutionary strategy, evolutionary programming and genetic programming, harmony search, differential evolution, simulated annealing and particle swarm optimization have been identified (Touloupaki & Theodosiou, 2017). From all the mentioned types of EAs, Genetic Algorithms (GA) dominate in building design optimization from different aspects such as; form, envelope, HVAC, renewable energy systems and so on (Evins, 2013).

Tuhus-Dubrow and Karati's investigated the efficiency and accuracy of GA for 10 or more variables (Tuhus-Dubrow & Krarti, 2010). The GA is usually applied in simulation-based optimizations, this is because of some advantages of this method; the objective functions do not need to be continuous for GA; it is a global search technique and can escape from local optima more easily and it can also find multiple Pareto solution. In a GA, candidate solutions' population, which is also known as individuals, creatures, or phenotypes, is evolved toward better solutions. A set of properties like chromosomes or genotype exist in each candidate solution, that can be altered and mutated; traditionally, while other encodings are possible, solutions are represented in binary as strings of 0s and 1s.

Evolution, which is an iterative process, typically begins with a population of randomly generated individuals, in which the population is called a generation in each iteration, the fitness of each individual in the population is evaluated in each generation; in the optimization problem, fitness is usually the value of the objective function that is solved. The more fit individuals are randomly chosen from the current population, the more of each individual's genome is modified (recombined and possibly stochastically mutated) to form a new generation. So, new generation of candidate solutions is benefited in the next iteration of the algorithm. Generally, the algorithm stops, when either a maximum number of generations have been produced or a satisfactory fitness level has been achieved.

Furthermore, Hamdy et al. had compared the performances of seven multi-objective evolutionary algorithms due to different criteria (Hamdy, Nguyen, & Hensen, 2016). They concluded that two-phase optimization, using the genetic algorithm (PR-GA) might be the first option to solve multi-objective BOPs. In this case, Bucking et al. had compared Mutual Information Hybrid Evolutionary Algorithm (MIHEA) results and the modified EA, against the Particle Swarm Optimization with Inertial Weight (PSOIW) algorithm applied in Genetic Optimization (Bucking, Zmeureanu, & Athienitis, 2013). Results illustrated that MIHEA finds better solutions with less computational time.

Genetic algorithm-based optimization has been applied over the last decade in extreme numbers of engineering fields including design and operation of building energy systems. In fact, GA optimization has implemented in selecting buildings' shape (Wang, Rivard, & Zmeureanu, 2006) (Wright J. , 2002), or some other building envelope features (Znouda, Ghrab-Morcos, & Hadj-Alouane, 2007) (Wanga, Zmeureanu, & Rivard, 2005) (Wright J. , 2002) (Ouarghi & Krarti, 2006), as well as to design and control heating, cooling, ventilating, and air conditioning systems (Mossolly, Ghali, & Ghaddar, 2009) (Fong, Hanby, & Chowa, 2006). The verification analysis has demonstrated that in case of considering over 10 parameters in the optimization process, GA is considered to be more efficient, in comparison to sequential search and PSO approaches. Specifically, the findings reveal that the optimal solution can be located by GA approach within 0.5% accuracy needing less than 50% of the iterations required by PSO and sequential search methods (Tuhus-Dubrow & Krarti, 2010).

In addition, in order to reduce buildings energy consumption, Znouda et al. investigated an optimization program, combining GA with a simplified tool for building thermal evaluation (CHEOPS) (Znouda, Ghrab-Morcos, & Hadj-Alouane, 2007). In this respect, Wetter and Wright also compared the performance of the Hooke–Jeeves (HJ) algorithm and GA (Wetter & Wright, 2003). They claimed that in comparison to the HJ algorithm the GA has a better performance and the HJ algorithm may also more easily fall into a local optimum. According to the buildings' primary energy usage and the initial cost investment, Karmellos et al. proposed a methodology and a software tool for optimizing energy efficiency measures prioritization (Karmellos, Kiprakis, & Mavrotas, 2015). Furthermore, Yu et al. stated a novel multi-objective genetic algorithm model using non-dominated sorting genetic algorithm (NSGA-II) to optimize buildings' energy efficiency and thermal comfort (Yu, Li, Jia, Zhang, & Wang, 2015).

Magnier and Haghighat applied the artificial neural network, the TRNSYS simulations and multi-objective genetic algorithm to optimize building design (Magnier & Haghighat, 2010). In another study, Wright et al presented the implementation of a multi-objective genetic algorithm search tool in the identification of the optimal pay-off feature between the sensation of occupant thermal discomfort and energy expense of the building (Wright, Loosemore, & Farmani, 2002). Furthermore, Lu et al. compared a multi-objectives non-dominated sorting genetic algorithm (NSGA-II) with a single objective genetic algorithm, in case of optimizing buildings' renewable energy systems (Lu, Wang, Zhao, & Yan, 2015).

Zhou et al. compared the performance of Nelder Mead Simplex, SA, Quasi Newton and a hybrid algorithm including GA, Tabu search and Scatter search and developed an optimization module integrated with EnergyPlus. The results show that Nelder Mead Simplex is the best alternative for optimizing a three-floor office (Zhou, Ihm, Krarti, Liu, & Henze, 2003). Mahdavi and Mahattanatawe compared Hill climbing algorithm with different restart strategies with SA algorithm for maximization of visual and thermal (temperature) performance, and also maximization visual and energy preferences. They observed that Hill climbing algorithm performed better in the comparison (Mahdavi & Mahattanatawe, 2003).

In another research, Wetter and Wright compared nine different optimization algorithms, including Hybrid Particle Swarm Optimization/Hooke-Jeeves (PSO-HJ) algorithm, two versions of particle swarm optimization, direct search algorithms (Coordinate search algorithm, HJ algorithm and Simplex algorithm of Nelder-Mead), a gradient-based algorithm (Discrete Armijo gradient algorithm), genetic algorithm, in order to solve both simple and complex building models (Wetter & Wright, 2004). It was observed that among all mentioned tested algorithms, the PSO-HJ reduced the largest amount of energy usage. Results also presented that the GA is close to the optimal point with fewer simulations than PSO-HJ. However, Nelder and Mead and Discrete Armijo gradient algorithms failed to find high-quality solutions. Wright and Ajlami evaluated the robustness of the GA in control parameters' selection, in an unconstrained BOP (Wright & Alajmi, 2005). It was found that the GA was not sensitive to the choice of its control parameters.

In case of BOPs, Tuhus-Dubrow and Krarti compared PSO and GA, and concluded that with fewer building simulations; GA can obtain a close solution to PSO (Tuhus-Dubrow & Krarti, 2010). Another research evaluated PSO, GA and Sequential Search technique, and revealed that for the Sequential Search technique the computational attempts are higher than others (Bichiou & Krarti, 2011). Hamdy et al. compared the three different multi-objective optimization algorithms, Non-dominated Sorting Genetic Algorithm-II (NSGA-II), NSGA-II with a passive archive strategy (pNSGA-II) and NSGA-II with active archive (aNSGA-II) (Hamdy, Palonen, & Hasan, 2012). They stated that aNSGA-II is more consistent in case of finding optimized solutions with a lower number of function evaluations.

In case of finding the optimized size for the components of solar thermal system for a single-family house, a slightly better performance than GA was shown by PSO (Bornatico, Pfeiffer, Witzig, & Guzzella, 2012). Another study showed that a combination of GA with a modified simulated annealing algorithm might yield more accurate results than the GA alone (Junghans & Darde, 2015). Futrell et al. have recently evaluated four optimization algorithms for daylight efficiency in a building design (Futrell, Ozelkan, & Brentrup, 2015). They compared the Simplex Algorithms of HJ, PSO-HJ, NM, and PSOIW. They conclude that PSO-HJ found solutions that are very close to the best solutions in less time but PSOIW found the best overall solution.

Table 7: Optimization Techniques Available Researches Summary

Category	Year	Methods/ Algorithms	Recommended Method(s)	Comments
Building Thermal Performance	1990-2007	Single Objective GA, Multi-Objectives GA	Multi-Objectives GA	GA is insensitive to its parameters
	2013	GA, PSO, Evolutionary Programming & Genetic Programming, Covariance Matrix Adaptation Evolutionary Strategy, Differential Evolution, Harmony Search, Ant Colony Optimization & Simulated Annealing	GA	Building Design Optimization (Envelope, Form, HVAC & renewable energy systems)
	2015	GA, PA, MOO, NSGA-II	NSGA-II	Energy efficiency & thermal comfort
	2017	GA, MOO	MOO	The preferred solution over several Pareto optimal ones can be chosen by using an additional criterion
Visual Performance	2003	Hill Climbing with Different Restart Strategies & SA	Hill Climbing Algorithm	Evaluating visual performance, energy & temperature
	2015	NM, PSOIW, HJ & PSO-HJ	PSOIW	PSO-HJ competitive algorithm
	2016	Parametric analysis (PA), GA	PA	It is easy for non-developers to implement it
Energy Performance	1964-65	DSC, Powell Method, Simplex Method	Powell Method	For problems with up to twenty independent variables is preferred
	1997	GA & PSO	BBO	BBO shares some features with other evolutionary optimization methods
	2003	GA & HJ	GA	Comparable number of function evaluations
	2004	Discrete Armijo Gradient Algorithm , Coordinate Search Algorithm, HJ, Nelder-Mead (NM), GA, PSO, PSO-HJ	PSO-HJ	Fast convergence of GA, unrecommended algorithms: NM & discrete Armijo
	2005	GA with Different Parameter Sets	GA	GA is insensitive to its parameters
	2010	CMA-ES/HDE & PSO-HJ	CMA-ES/HDE	PSO-HJ performs better for more than 10 parameters
		GA, PSO & Sequential Search Methods	GA	GA is more efficient for more than 10 parameters
	2012	GA & PSO	PSO	PSO is slightly better
		Multi-Objective Problem, Pareto Solutions & WSM	WSM	The weighted sum methods are more efficient and easier to implement, but require prior knowledge and they don't provide information on the compromise between the objectives
	2014	GA & CMA-ES/SA	CMA-ES/SA	Less computational time of CMA-ES/SA
	2015	Integrated dynamic models combine a design tool, a VPL & a building performance simulation tool	VPL	The preferred solution over several Pareto optimal ones can be chosen by using an additional criterion
	2013-16	BPS, SA & Computational Optimization Methods	BPS	Its application is still reduced in the final design stages
	2019	SA, Simulation Analysis Method	SA	---
Electricity consumption & Costs	2003	Nelder Mead Simplex, Quasi Newton, Tabu search, Scatter search, SA & a hybrid algorithm including GA	Nelder Mead Simplex	Long computational cost of hybrid algorithm
		MIHEA, PSOIW & Modified EA	MIHEA	High convergence of both EA
Life Cycle Costs	2010	GA & PSO	PSO	GA found solutions close to PSO with fewer building simulations
	2011	GA, PSO, Sequential Search Methods	GA & PSO	Sequential Search consumes lots of computational time
	2012	aNSGA-II, NSGA-II & pNSGA-II	aNSGA-II	Better repeatability of aNSGA-II and it has high convergence
	2015	GA & hybrid GA with SA	GA-SA	GA-SA is more reliable
	2016	MOPSO, pNSGA-II & two-phase optimization using the GA (PR-GA)	PR-GA	It is easy for non-developers to implement it

2.5 Reference Buildings

There has always been an attempt to collect data on the existing national reference buildings (RB) or to develop national sets of RB. Hence, a significant methodology, which can support defining these reference buildings has not clearly been defined in Cyprus. Thus, it will be appropriate to identify a standard set of required criteria for characterizing RBs and to establish a basic guideline for the country's selection and compilation of RBs.

RBs might be considered as effective methods for assessing energy-saving of an entire building stock. RBs are models, which display nearly the same type of buildings under the same conditions of use and climatic category. They might be listed as a first measurement of the thermal and energy performance in buildings. Through times, several researches tried to develop RBs. They displayed a trend of increasing its application as a starting point. Therefore, the RBs have become an important research interest especially in case of analyzing buildings' thermal and energy performance (Benejam, Mata, Kalagasidis, & Johnsson, 2012) (Dascalaki, Kontoyiannidis, Balaras, & Droutsa, 2013) (Filogamo, Peri, Rizzo, & Giaccone, 2014) (Schaefer & Ghisi, 2016).

In the revision of EPBD (Energy Performance of Building Directive) (2010/31/EU 2010), RB represents a type of building, that is determined by its geographical location and functionality, which consists of indoor and outdoor climate conditions. The guidelines of the EPBD accompanying it considered that the main objective of a reference building represents the average and/or typical building stock in a certain region (Brandão de Vasconcelos, Pinheiro, Manso, & Cabaço, 2015).

US department of energy proposes a massive database on commercial reference models for buildings' energy and thermal performance, which is categorized by type, energy usage and climatic region (Schaefer & Ghisi, 2016). U.S. Department of Energy (DOE) has provided 16 RB models that cover more than 60% of U.S. commercial building stock. They concentrated on presenting building features and construction practices in a realistic way. Such projects contained a multi-family residential building as well as 15 commercial buildings. They were grouped in 3 different construction periods as; pre-1980, post-1980 and new buildings (DOE, 2020). The carried-out research aimed at developing energy codes and standards, optimizing designs, assessing new technologies, analyzing advanced controls, and conducting lighting, day lighting, indoor air quality and ventilation studies.

According to the DOE reference building models, Corgnati et al. investigated the data collected to propose that RBs may be gathered in four areas that represent a broader range of features as follows: form (building size, scale, geometry and type), envelope (design technique and collection of materials), system (heating , cooling and ventilation systems, and additional renewable sources) and finally operation (operational parameters affecting the building performance) (Corgnati, Fabrizio, Filippi, & Monetti, 2013).

Recent experiments have applied classification criteria in facing with building-stock energy performance. This categorization can be based on three aspects: the year of completion, climate zone and form and style of buildings. Other existing approaches aim to classify model building typologies that can be considered as representatives of large building stocks in terms of energy use and the energy needs of lighting and other equipment. Hence, these methods do not represent and support the typical and/or average building stock. They can represent the same class buildings energy behavior (Brandão de Vasconcelos, Pinheiro, Manso, & Cabaço, 2015).

The main intention of the RB is characterizing the typical buildings' energy performance with their internal loads, HVAC systems and typical construction and types. In order to analyze the buildings' performance, detailed energy model with several pieces of information is necessary. In this respect, Deru et al. grouped these data into form, fabric, program, and equipment (Deru, et al., 2011).

Torcellini et al. proposed to collect data based on different categories as follows; materials, construction systems, forms, operation and equipment. Data from each of the mentioned categories can be considered as a subset of the building features (Torcellini, Deru, Griffith, & Benne, 2008). The first category; building materials and systems, relates to the heat exchange with the external environment, and the building envelope's thermo-physical properties. The second category, form; describes typology of the building according to the design, geometry and function. Operation; accounts for how the building is operated by the user, through the operation of different systems, equipment, openings, spaces occupancy, and so on. Finally, equipment; deals with the building energy performance and existing systems, such as lighting equipment, heating, cooling and air conditioning, and etc.

The data collection can be completed from both literatures and sources of field study and categorized as proposed by Torcellini, who analyzed them in order to obtain the most representative features in each case. Three methods are proposed on the EPBD recast guidelines for determining models from the data collected as follows: theoretical reference building, example reference building, real reference building (Brandão de Vasconcelos, Pinheiro, Manso, & Cabaço, 2015).

From all the above information, it can be understood that this chapter documents a set of in-depth analysis in current literatures in case of building energy performance, thermal and visual comfort parameters and tried to categorize them in tangible groups and tables. Also, it tried to do a survey on available thermal comfort, visual comfort and optimization techniques and models, in order to validate the current situation and find the missing points, which its results are presented in the separate tables. These data, which illustrate the lack of optimization method to design the building envelop according to thermal and visual comfort is significant. Therefore, this research attempts to suggest a model to fill this gap in architectural regulations.

Chapter 3

RESEARCH METHODOLOGY

3.1 Method Explanation

In general, this work is based on a theoretical approach supported mainly by the outcomes of a literature review and analysis of case study. On the other hand, it involves simulation analysis and, more specifically, a literature survey as a combination of two main phases, namely, the qualitative and quantitative methods of data collection. The dynamic relationship between outdoor climate and building systems is a complicated mechanism, which includes a wide range of difficult to predict variables.

In other words, the main concern of this research is to propose a multi-criteria method to define and optimize building façade components like opening place and ratio or even façade materials, under a compromise between daylight levels, thermal comfort and energy efficiency. In this case, based on the previous researches, a step by step algorithmic model has been developed to integrate comfort conditions from different aspects.

This method is displayed as an algorithmic model, which can be applied in design process manually or can be modeled and/or installed as a plug-in in simulation software such as grasshopper. Therefore, the results can be saved and presented as different alternatives by numerical charts in countries' regulations or can be evaluated for each project with its own limitations and considerations separately. This energy performance optimization may guarantee the desired indoor comfort conditions simultaneously. In other words, in addition to developing energy simulation tools, this study covers emerging modular type tools and commonly applies creative low-energy design concepts. Activities will include the development of analytical, empirical and comparative methods of previous models for assessing, diagnosing and correcting errors.

Likewise, building constructors may decrease electricity cost, GHG emissions and other environmental impacts by implementing the following systems and processes, required to increase energy performance, including energy efficiency, use and intensity. Therefore, the following strategy helps architects to take a structured approach to continually enhance energy efficiency and emission control. It also demonstrates designer’s commitment to effective management of energy and environmental issues and maintaining thermal and visual comfort, simultaneously. Improved energy performance provides the construction industry rapid benefits by cutting both energy costs and consumption.

In general, this method is designed in six steps. However, based on the user requirements some steps can be eliminated or more deeply analyzed. Based on the aim of the study, optimization technic can also be adjusted case by case. The next graph displays the initial schematic steps, to reach the target of the study in different design scenarios.

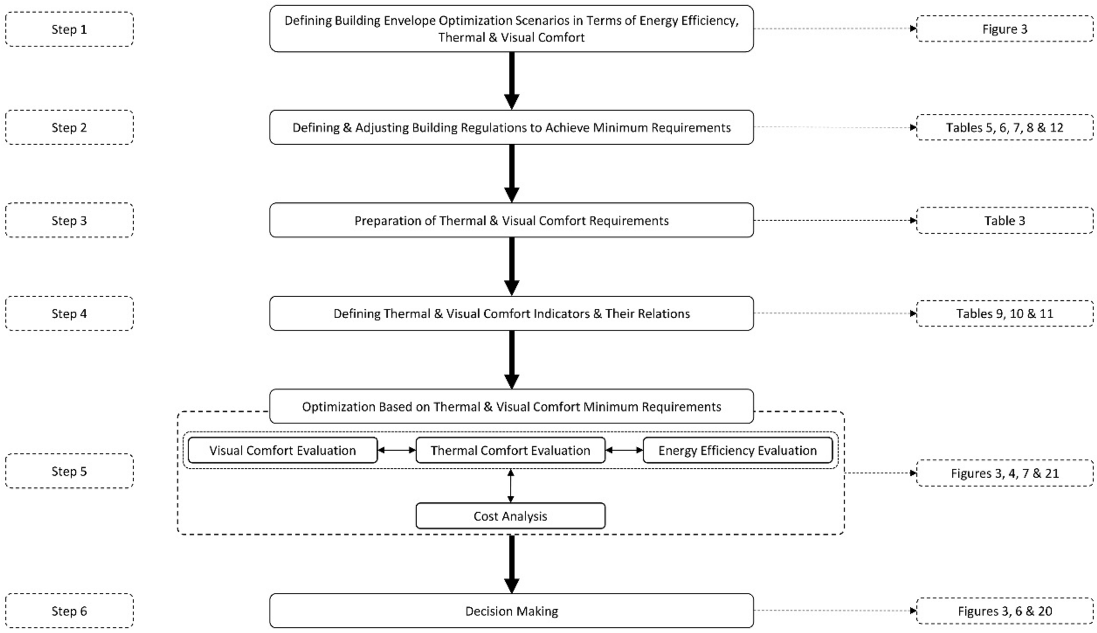


Figure 2: Schematic Steps of the Methodology

3.1.1 Step 1: Defining Building Envelope Optimization Scenarios in Terms of Energy Efficiency, Thermal and Visual Comfort

In comfort evaluations, the main problem is that the effect of each factor varies in different building levels. Even some of them cannot be applicable in some levels. Therefore, buildings are categorized into three groups from constructional process levels. In other words, they are defined as the following scenarios: Pre-design Stage, Design Stage, Existing Building. Then, effective building parameters are re-categorized in different groups, based on their types and effects on the construction levels. Later, the applicability of each parameter on the mentioned design stage has been analyzed (figure 3). It should be mentioned that according to research limitation, this part mainly concentrates on design stage.

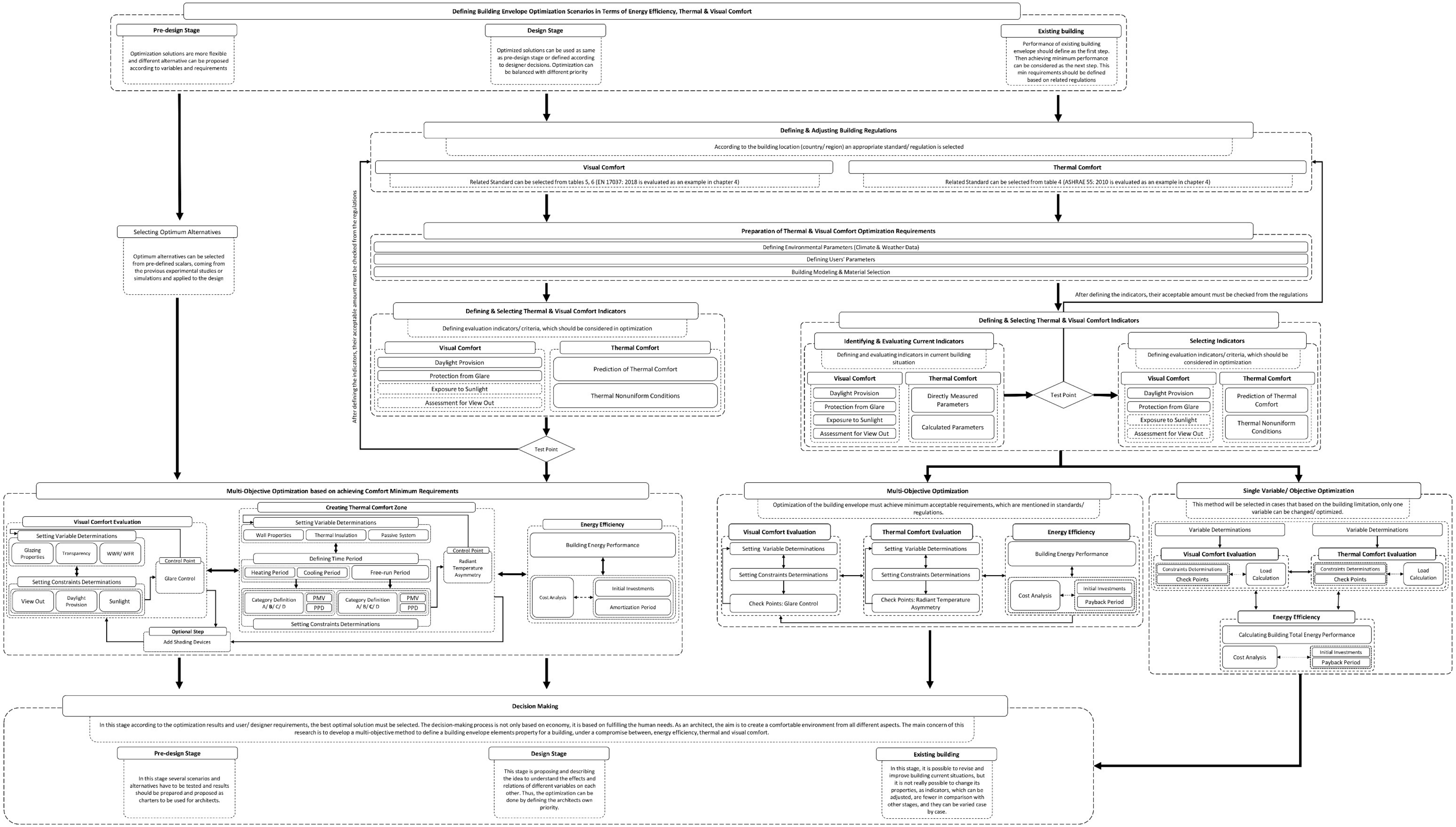


Figure 3: Building Construction Stage Scenarios and Effective (Evaluation) Parameters

3.1.2 Step 2: Defining and Adjusting Building Regulations to Achieve Minimum Requirements

Just afterwards, as a guideline to evaluate minimum requirements, a standard or building regulation should be considered. Building codes and standards can be categorized for visual and thermal comfort separately (tables 4-6). Here, the list of some of the most applicable regulations in the world, analyzed in this research has been presented (table 8). Here, based on the literature, EN 17037: 2018 and ASHRAE 55: 2010 are advised to used. This is in case of their updated way of evaluating comfort parameters, which can be adapted in the research proposed method.

Table 8: Regulations to Select Minimum Acceptable Requirements

Studied Regulations to Select Minimum Acceptable Requirements	
Visual Comfort	**Thermal Comfort**
EN 17037: 2018	ASHRAE Handbook Fundamentals: 2017
CEN/TC 156 - prEN 15251: 2006	ANSI/ASHRAE Standard 55: 2010
EN 12464-1	ISO 7730
ISO 8995 CIE S 008/E	EN ISO 13790
ANSI/IESNA RP-1-04	CEN/TC 156 - prEN 15251
DIN EN 12464-1	CEN Report 1752

3.1.3 Step 3: Preparation of Thermal and Visual Comfort Requirements

At the next step as a type of prerequisite step, initial building settings must be applied. After selecting site location, climatic issues should be considered. To analyze the effect of different climate and climate change on the built environment, benefiting building simulation methods with the aid of forecast weather data are often required. As most of simulation software - for analyzing thermal comfort and energy evaluation - need hourly meteorological input data, the provision of appropriate weather data is essential as well.

In this respect, all references to time in this study apply to local standard time and conclude that: hour 1 is equivalent to the time between midnight to 1a.m. Holidays are not considered in schedules so as to simplify it. The weather details provided in TMY2 format are in hourly bins and correspond to the standard local time. These weather data files in TMY2 format are with modifications and the initial fundamental sequence of mechanical equipment tests can be managed quite tightly. The TMY format data are three-month data files, which are implemented in the original field trials of the test procedure; the TMY2 format data are year-long data files that could be more user friendly. The TMY and TMY2 data sets are equivalent for HVAC BESTEST, using a near-adiabatic building envelope. It should be mentioned that in case of low internal gains, there are minor variations in solar radiation, wind speed and so on, resulting in a sensible loads difference of 0.2% -0.3%.

Another effective parameter to evaluate comfort is building size, considered as building footprint and massing in the method (form factor). In this study for assessing the effect of size, dimensions are analyzed as proportions. This is because of this fact that proportions have the capacity to be applied to a larger group of samples more easily. Therefore, in order to prevent using random sizes, space dimensions are computed as a function of the Room Index (K). This K factor is normally benefited to define the number of artificial lighting elements in space; however, it is adapted in this method for defining the space size.

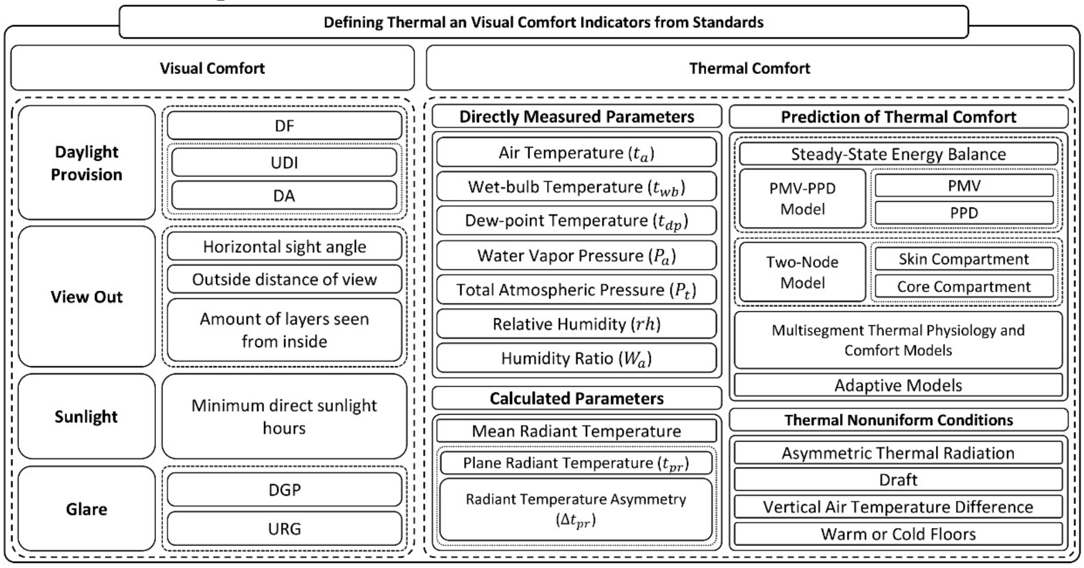
$$\mathrm{K} = \frac{WD}{(W+D)h} \text{ (CIBSE, 1999)} \qquad \text{(Eq. 1)}$$

Where K is the room index (non-dimensional), D is the overall space depth (m), W is the overall space width (m) and h is the mounting height between the working surface and the ceiling (m). In other words, such an index can be used to represent the relationship between area, perimeter and height. Generally, room indices vary from 0.60 for small rooms to 5 for large spaces (Ghisi & Tinker, 2005).

3.1.4 Step 4: Defining and Selecting Thermal and Visual Comfort Indicators and Their Relations

After selecting regulations and modeling, it is time to identify variables, which are affecting sense of comfort for space operators. Meanwhile, in order to be able to evaluate these variables, comfort indicators and their relations to these variables should be analyzed. In this case, table 9 displays visual and thermal indictors, affecting creating comfort zone based on EN 17037: 2018 and ASHRAE 55: 2010.

Table 9: Defining Thermal and Visual Comfort Indicators



In this research different scenarios have been introduced. In this regard, in the next phase it is tried to identify and categorize different affecting indicators on each scenario. These categories can be seen in the next table.

Table 10: Defining and Categorizing Thermal and Visual Comfort Indicators for Different Scenarios

Defining Thermal & Visual Comfort Indicators for different Scenarios

Scenarios	Pre-design Stage	Design Stage	Existing Building
Define Needs			
Building Programming	✓	✓	✓
Building Form	✓	✓	✗
Selecting Site Location	✓	✗	✗
Building Geometry	✓	✓	✗
Building Function	✓	✓	✓
Space Configuration	✓	✓	✓
Reduce Loads			
Façade Properties	✓	✓	✓
Wall Thickness	✓	✓	✗
Thermal Insulation	✓	✓	!
Using Thermal Mass	✓	✓	!
Glazing Size & Location	✓	✓	!
Window to Wall Ratio	✓	✓	!
Shading Options	✓	✓	✓
Building Orientation	✓	✓	✗
Passive Heating/ Cooling	✓	✓	✓
Daylighting Strategies	✓	✓	✓

Scenarios	Pre-design Stage	Design Stage	Existing Building
System Design			
Reduce Installed Lighting	✗	✓	✓
Reduce Equipment Power	✗	✓	✓
Use Appropriate & Efficient Equipment	✗	✓	✓
Optimizing Operation			
Lighting Controls	✗	✓	✓
HVAC Controls	✗	✓	✓
Thermal Storage	✓	✓	✓
Future Impact of Plug-in Vehicles	✗	✓	✓
Ventilation System	✓	✓	✓
Increasing Synergy			
Reuse Waste Streams	✓	✓	✓
Heat Recovery	✗	✓	✓
Hot Water Demand	✗	✓	✓
Explore Alternative Power			
Renewable Energy	✓	✓	✓

Legend ✓ It has a direct effect ✗ It doesn't have a direct effect ! It may not have a direct effect

As it was mentioned in the research limitations, this study concentrates on the design stage phase. Therefore, in the next level, it is tried to evaluate the effect of the most important indicators of different scenarios, especially design stage, on creating sense of visual comfort, thermal comfort and the amount of energy efficiency (table 11). For instance; adding or improving thermal insulation of the façade doesn't have any significant effect on sense of visual comfort. However, it can improve the level of thermal comfort, which leads to more saving in energy consumption. Or increasing the window to wall ratio, may improve visual comfort, but after some percentages it has negative effect by creating glare. Generally, by increasing heat transfer, it reduces thermal comfort and as a result increasing energy usage.

Table 11: Effect of Different Indicators on Energy Efficiency, Thermal and Visual Comfort

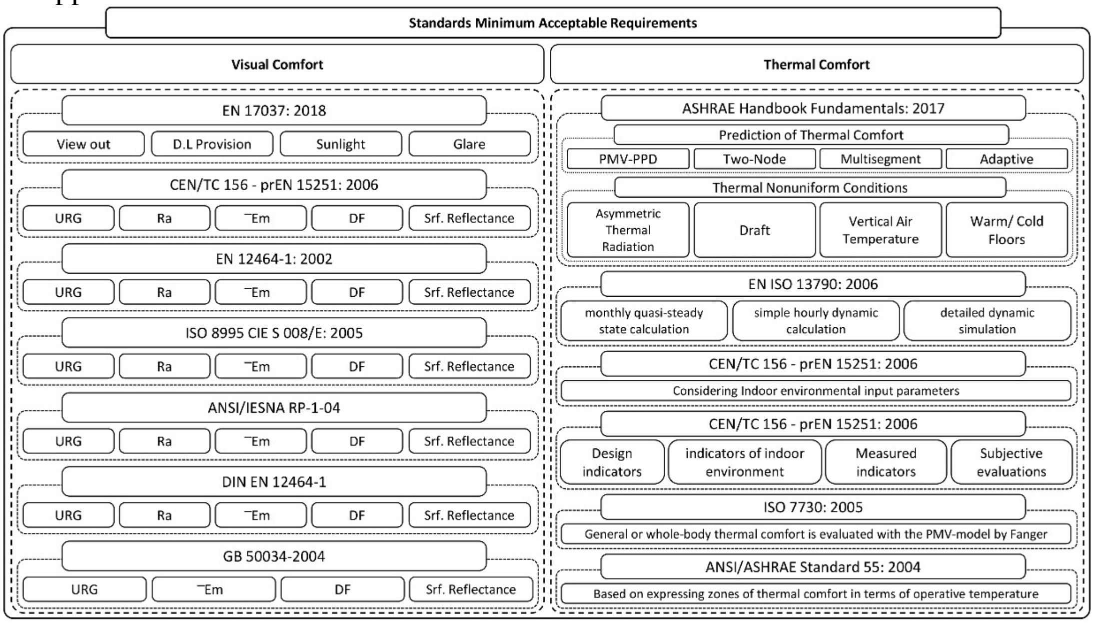
Evaluating Thermal & Visual Comfort Indicators for different Scenarios

Indicators	Visual Comfort	Thermal Comfort	Energy Efficiency
General Properties			
Building Programming	It has positive effect	It has positive effect	It has positive effect
Building Form & Geometry	It has positive effect	It has positive effect	It has positive effect
Building & Site Orientation	It has positive effect	It has positive effect	It has positive effect
Space Configuration	It has no effect	It has no effect	It has no effect
Building Physical Properties			
Wall Properties/ Materials	It has no effect	It has positive effect	It has positive effect
Wall Thickness	It has no effect	It has positive effect	It has positive effect
Thermal Insulation	It has no effect	It has positive effect	It has positive effect
Passive Heating/ Cooling	It may have indirect effects	It has positive effect	It has positive effect
Using Thermal Mass	It has no effect	It has positive effect	It has positive effect
Shading Devices	Till a certain range it has positive effect and then vice versa	Till a certain range it has positive effect and then vice versa	Till a certain range it has positive effect and then vice versa
Window to Wall Ratio	Till a certain range it has positive effect and then vice versa	It has negative effect	It has negative effect
Opening Shape	Till a certain range it has positive effect and then vice versa	Till a certain range it has positive effect and then vice versa	Till a certain range it has positive effect and then vice versa
Opening Location & Orientation	It has positive effect	It has positive effect	It has positive effect
Glazing Transparency	It has positive effect	Till a certain range it has positive effect and then vice versa	Till a certain range it has positive effect and then vice versa
Glazing Properties	It may have indirect effects	It has positive effect	It has positive effect
Explore Alternative Power			
Renewable Energy	It has no effect	It has no effect	It has positive effect
Buildings Size			
Building Height	It has positive effect	It has negative effect	It has negative effect
Building Depth	Till a certain range it has positive effect and then vice versa	It has negative effect	It has negative effect
Facade Dimensions	It has positive effect	It has negative effect	It has negative effect
System Design			
Reduce Installed Lighting	It has negative effect	It has no effect	It has positive effect
Reduce Equipment Power	It has no effect	It has negative effect	It has positive effect
Use Efficient Equipment	It has no effect	It has no effect	It has positive effect
Optimizing Operation			
Lighting Controls	It has positive effect	It has no effect	It has positive effect
HVAC Controls	It has no effect	It has positive effect	It has positive effect
Thermal Properties	It has no effect	It has positive effect	It has positive effect
Impact of Plug-in Vehicles	It has no effect	It may have indirect effects	It may have indirect effects
Mechanical Ventilation	It has no effect	It has positive effect	It has negative effect
Natural Ventilation	It has no effect	Till a certain range it has positive effect and then vice versa	Till a certain range it has positive effect and then vice versa
Increasing Synergy			
Reuse Waste Streams	It has no effect	It has no effect	It has positive effect
Heat Recovery	It has no effect	It has no effect	It has positive effect
Hot Water Demand	It has no effect	It has no effect	It has positive effect

Legend: It has no effect; It may have indirect effects; It has positive effect; It has negative effect; Till a certain range it has positive effect and then vice versa

It should be mentioned that the previous table data are tested in different researches. Here, based on the limitations, the author only presented the effect of different indicators in a graphical way. The information is later benefited in final proposed method as advised testing indicators. Furthermore, after defining indicators, standards/ regulations should be re-checked and adjust again accordingly (table 12). In this case, any missing dada will be considered and solved based on the requirements.

Table 12: Regulations to Select Minimum Acceptable Requirements and Their Method of Application



3.1.5 Step 5: Optimization Based on Thermal and Visual Comfort Minimum Requirements

Normally, optimization techniques are focusing on reducing total building energy performance, which has the direct effect on building expenses as well. However, this issue may lead to neglecting some qualitative factors in buildings. For instance; in construction sector, by developing low energy consumption lighting elements such as LED or SMD lamps, the importance of daylighting may be eliminated. This is only because of the fact that artificial lightings are consuming really low energy in comparison with mechanical systems. Therefore, building optimizers were preferred to reduce the size of openings in case of saving more energy.

However, this method in buildings helps change the role of glazing and the focus of building design to improve occupant comfort and overall energy efficiency. The need to well distributed daylight and providing proper openings to interior spaces, while considering the balance between solar gain and heat loss must reduce artificial lighting use.

So, the initial intention of this study is to develop a methodology for daylight provision in buildings, which could consider variations related to geographical and climatic differences in Cyprus. At the first phase, this method recommends the minimum acceptable parameters in order to achieve the adequate amount of visual comfort based on the selected standard/ regulation and then test other parameters to achieve thermal comfort and optimize energy consumption as well. In other words, first minimum acceptable level of visual satisfaction must be achieved, and later energy optimization will be evaluated mainly based on adjusting building thermal properties.

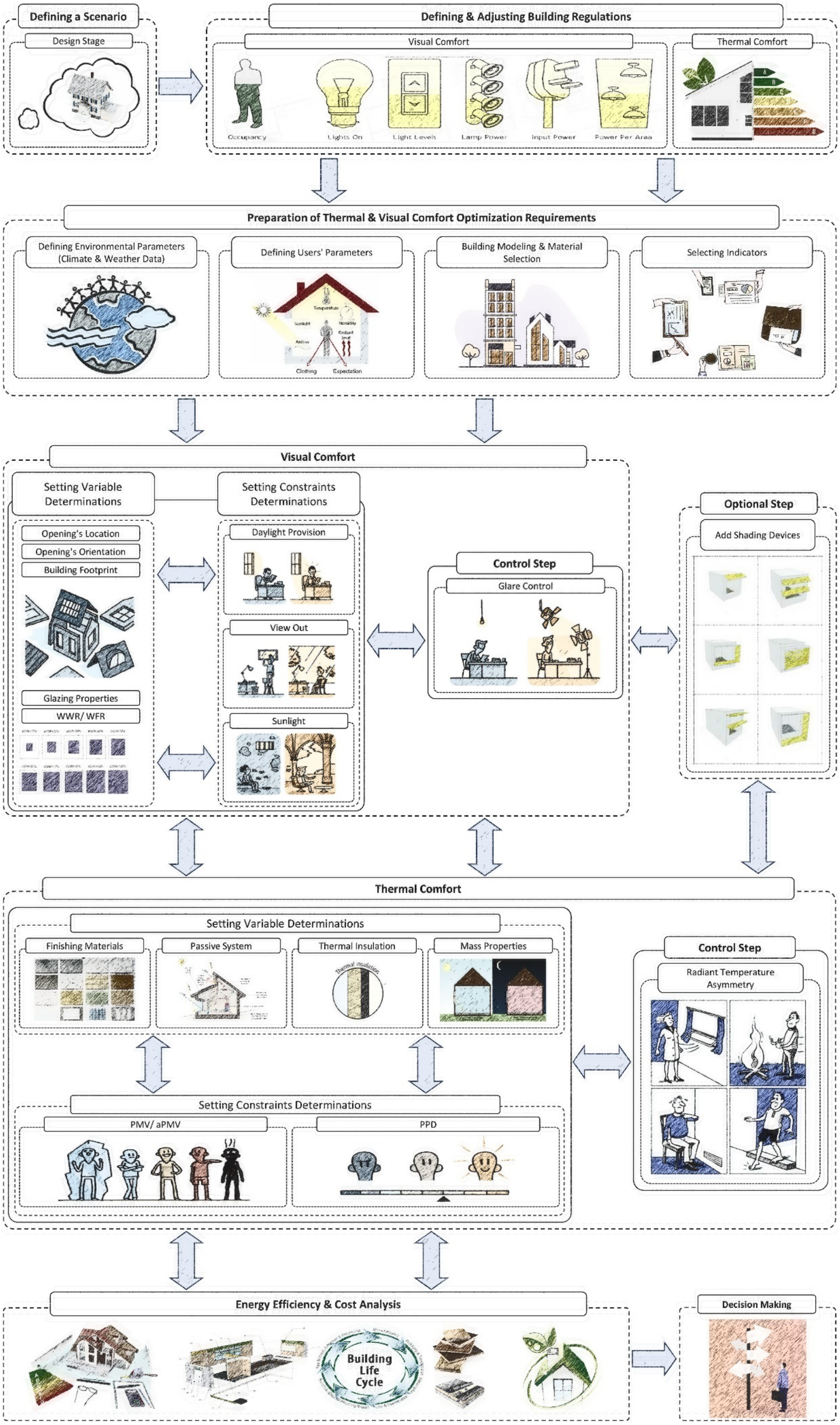


Figure 4: Graphical Model of Evaluation in the Design Stage

3.1.5.1 Visual Comfort Evaluation

In each case, there are two types of settings. The first one is ‘Variable Determinations’; which are some physical parameters, which can be adjusted in a building to make the next factors acceptable. The second one is ‘Constraints Determinations’; which are some test factors. These factors must be at least at the minimum acceptable range, which is defined in regulations. In order to set these factors in standard range, the mentioned variables can be changed.

In this case, in order to achieve an adequate subjective impression of lightness indoors, view out and a method to limit glare, EN 17037: 2018 has some recommendation. The lighting needs of any type of building can significantly be provided by daylight. In other words, openings, attracting daylight should have appropriate areas to provide adequate daylight throughout the year. In this regard, day light provision is one of the evaluated indicators. For openings in the façade, daylight design should achieve a target daylight factor (DT) across a fraction of the relevant floor area (50% vertical) and across 95% of the area the minimum target daylight factor (DTM) should be achieved (EN 17037, 2018). For evaluating daylight provision; Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) are calculated.

Furthermore, as Daylight Factor (DF) is considered as one of the oldest methods of daylight evaluation, this parameter is also considered as an initial step of this stage. If any of the mentioned parameters dose not fulfill the minimum requirements, the process might go back to the previous step. And variables must determinate again. For instance; WWR might change or etc. Then the process can be continued.

Next, for ensuring an adequate view out, the following criteria should be considered: view opening(s) as seen from the reference point of view should have a total horizontal sight angle higher than a minimum value, in the utilized area. if horizontal sight angle is more than 14˚, the process will be continued. Then the distance to the outside view should be larger than a minimum value. This level is to ensure that minimum distance to external obstacles is maintained. This distance can be considered minimum 6m from the external obstacle. Another evaluation parameter is the number of layers that can be seen from at least 75% of inside utilized area. At least a minimum number of layers might be seen, in the utilized area. These layers are ground, landscape and sky (EN 17037, 2018). However, the last to parameters are mainly depending on urban policies and regulations and the sample test has not been evaluated and only horizontal sight angle has been considered.

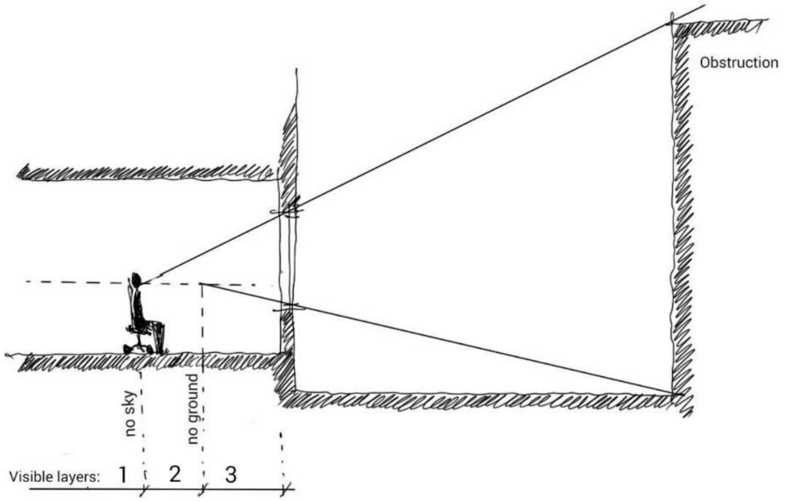


Figure 5: Number of Layers Seen from Inside (EN 17037, 2018)

It is recommended that for a given reference day, a space should receive sunlight for at least a predefined number of hours. This factor can also be controlled by adjusting the variables in step three. After finishing this stage, glare protection is added as a control level for achieving visual comfort.

High luminance differences between dark and bright areas or direct sunlight can increase the glare risk. Daylight Glare Probability (DGP) is a metric, benefited in order to predict discomfort glare appearance in a daylit space. A certain fraction of the reference usage time should not be exceeded by this threshold values. In this study, based on the selected standard DGP should be less than 0.40. In other words, glare may be perceived in space, but mostly not disturbing the occupants.

However, in order to evaluate the effect of artificial lighting another metric should be tested. Unified Glare Ratio (UGR) deals with glare from luminaires, bright light sources and light through windows. In case of controlling this factor, designing lighting elements for its occupied environment might be in an appropriate way in case of position, number and so on. For these luminaires, UGR must be less than 19.

Applying shading devices in spaces with natural light is recommended. This helps to decrease glare risk and protects occupants from direct view to the sun or its reflection. However, this step is not considered mandatory in the proposed method. This is due to the fact that adding shading devises affects both thermal and visual sense of comfort simultaneously and make the evaluation more complicated. However, based on the requirements and limitations, if applying shading elements are necessary, it is predicted in the model. In general, after adding shading elements again the whole mentioned process must be double checked.

3.1.5.2 Thermal Comfort Evaluation

In order to evaluate thermal comfort, again we will face two types of variables and constraints determinations. The first part mainly concentrates on building physical properties. In this phase it is tried to evaluate some parameters such as wall properties, which does not have a direct effect on visual comfort. Adjusting these parameters leads to setting next part constraints in a comfort range.

Before starting thermal comfort evaluation, the indoor thermal regime must be defined. These regimes can be defined as free-run air ventilation, 24hours air-conditioned, daytime ventilated and night time ventilated. Each of mentioned regimes can be subcategorized in heating, cooling and free-run periods. While the vernacular architecture of countries was mainly focused on the concept of free-run period, with the people lifestyles development, it seems almost impossible to attain thermal comfort without mechanical systems today. Therefore, a mixed-use mode is proposed for this model.

Mixed-mode (MM) or so-called hybrid ventilation is the core principle of ensuring adequate and satisfactory indoor conditions by mixing and integrating both natural and mechanical systems. A choice for free-running or a naturally ventilated mode provides ideal air quality and thermal efficiency, while reducing the carbon footprint and keeping down costs. Meanwhile, these spaces will revert to mechanical systems for heating, cooling, ventilation and air conditioning (HVAC), whenever external conditions make the natural ventilation option untenable for occupants (Brager, 2006) (Lotfabadi & Hançer, 2019).

The results of previous researches demonstrate the disparities in air conditioned and naturally ventilated buildings or steady state and adaptive comfort models (Humphreys & Nicol, 1998). Regulations recognize PMV-PPD in different ranges, according to their specific categories (table 4). This acceptable range will vary depending on the application of the mechanical ventilation system. In this case, ASHRAE Standard 55:

2010 classifies mixed-mode buildings as air-conditioned buildings and, as such, increases the operating limits of these buildings to the more acceptable range of indoor thermal conditions PMV–PPD (ANSI/ASHRAE Standard 55, 2010).

In other words, categories A or B are usually specified for completely mechanical ventilated buildings, however, due to ASHRAE 55:2010; where the PMV ranged from -1 to +1, the free-run cycle can be accepted as the thermal comfort period. Therefore, mechanical ventilation can be eliminated in these time periods. It should be mentioned that the evaluation system formed on the hourly based results. Total percentages of acceptable hours that are in the PMV range for each day is determined from these hourly results.

In order to check PMV, first of all, the mechanical system set point temperature must be set. This temperature might be set to maximum proposed temperature of regulations in heating period and minimum in cooling period. Afterwards, PMV will be checked, if it won’t be in range, set point temperature will be changed. It will be reduced in case of heating period and increased in cooling period. When PMV gets to the acceptable range, PPD will be checked. If it contains less than an acceptable percentage, the process will be continued, otherwise, it comes back to the setpoint temperature and previous process will be repeated again till it gets to the acceptable percentage range.

If all the proposed temperatures by regulations have been tested and PMV and/or PPD cannot fulfill comfort satisfaction requirements, or by any other reason or consideration the set point temperature will be fixed, then in order to continue, the process should be stepped back to change the setting of variable determinations. After changing one or some variables, the process continues the same as the mentioned explanations till all thermal comfort parameters rest in the range.

3.1.5.3 Cost Analysis

Furthermore, apart from energy efficiency, thermal and visual comfort, cost efficiency is another criterion expected to be considered in designing a building. In cost analysis, several parameters such as initial investments, life-cycle cost (LCC) and so on should be evaluated. LCC is the ratio of the initial cost to the life span that is expected to be. Therefore, if a space is able to save more energy, the payback period will be less and vice versa. This period is called amortization period/ time, which is one of the key indicators in case of cost analysis. In order to optimize amortization calculations, it is advised to use common materials and construction techniques, which are easily constructed.

Meanwhile, the main factors of cost analysis evaluation are: Initial investment, total annual energy cost, inflation, rate of interest and the maintenance cost, which are all influencing the amortization period. Based on the stated factors and their relationships, for optimizing an energy efficient building, an equation was developed to calculate amortization period for cost efficiency as follow (Boostani & Hancer, 2018):

$$y = \frac{\log\left[1 - F\left(\frac{i-f}{1+f+r}\right)\right]}{log\left(\frac{1+f}{1+i}\right)} \qquad \text{(Eq. 2)}$$

In this formula; (y) is amortization time period, (F) is the value coefficient, (r) is the maintenance cost, (i) is yearly interest rate and (f) is inflation rate. It should be mention that in hot and humid climates, in which buildings' lifespans are shorter, according to a simplified method; the amortization time period can be considered less than 10 years.

3.1.6 Decision Making

In this stage according to the optimization results and user/ designer requirements, the best optimal solution must be selected. The decision-making process is not only based on economy, it is based on fulfilling the human needs. As architects, the aim is to create a comfortable environment from all different aspects. The main concern of this research is to develop a multi-objective method to define a building envelope elements property for a building, under a compromise between, energy efficiency, thermal and visual comfort.

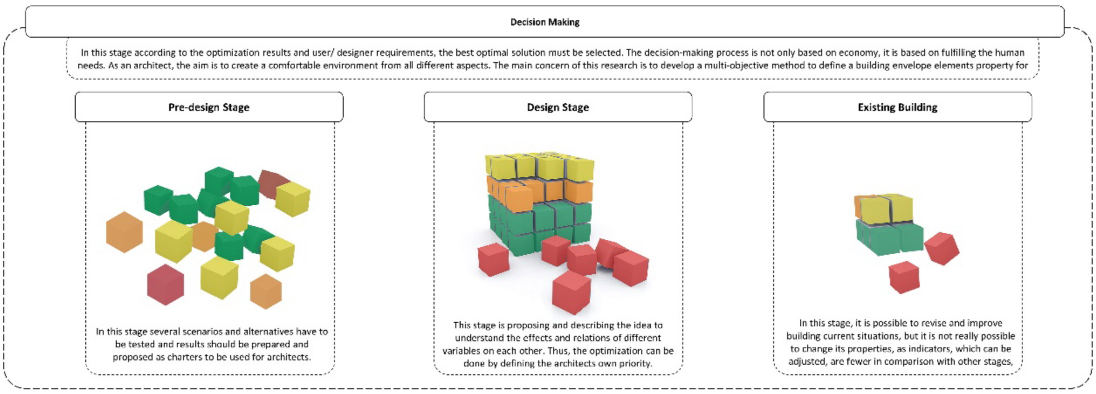


Figure 6: Sketch from Decision-Making Process

Here, the decision-making process has been modeled schematically by using colors. As it was shown in figure 6, architects have more possibility for doing optimization in design stage. It is in case that in this level there are lots of affecting variables that can be adjusted for optimization. The process can be generally considered as same as design stage in existing building level. However, the main difference is that as the building is existing, there might be less variables that can be manipulated for optimization. Finally, several scenarios and alternatives have to be tested and results should be prepared and proposed as charters to be used for architects in pre-design stage. In this construction level optimized results can be used as pre-set variables.

3.2 Model Proposal

All building models are simplified reality. Here the philosophy is to produce a number of outcomes from many programs results that are widely recognized as reflecting the state of the art of simulation programs. Here, the propounded model tries to undertake pre-normative research to develop a comprehensive and integrated suite of building energy analysis tool tests involving empirical, comparative, and analytical methods. This aim is pursued by accomplishing the following objectives:

- Create a widely available comprehensive and integrated suite of IEA Building Energy Simulation Test (BESTEST) cases for diagnosing, evaluating, and correcting building energy simulation. Tests will address modeling of the building thermal fabric and building mechanical equipment systems in the context of innovative low energy buildings.
- Make widely available high-quality empirical validation data sets, including unambiguous and detailed documentation of the input data required for a selected number of representative design conditions.
- Expand and maintain analytical solutions for building energy analysis evaluation.

Generally, it is difficult to create worthwhile test cases that can be analytically or quasi-analytically solved. However, these types of solutions are extremely useful when possible. Analytical or quasi-analytical solutions present a ‘mathematical truth standard’, providing the underlying physical assumptions in the case definitions, there is a mathematically correct solution for each case. In this regard, the underlying physical assumptions regarding the mechanical equipment as described in the optimization part are representatives of standard manufacturer data typically benefited in design practitioners in construction. To produce these results, simulationists were asked to apply the most detailed modeling methods that their software allows, along with consistent modeling methods.

In other words, simulations are performed to obtain the annual levels of indoor daylight and energy demands. Based on the previous methods, here, it is tried to propose a standard method, which can be applied on buildings with various functions, locating in different climates and contexts in order to assess the optimum amount of energy efficiency, visual and thermal comfort simultaneously (figure 3). In addition, Moreover, in order to get simulation results, along with benefiting from consistent methods of modeling, simulationists are mainly required to use the most detailed modeling approaches their program allows. The outcomes of the example simulation are the product of multiple iterations to add clarifications to the creation of simulation software, corrections of the input deck and test specification.

In general, the incorporation of Building Information Modeling (BIM) with other methods has considerable potential for building sustainability evaluation and is a subject discussed by various scholars. Nonetheless, there are many obstacles to this convergence, such as the lack of interoperability between various methods and the requirement for a specific data format. Thus, it is possible to use several distinctive energy simulation applications, each utilizing a particular degree of modeling sophistication and complexity. Unfortunately, not all of the experiments match these energy simulation programs. Therefore, the Standard Method of the Test (SMOT), recommended by the ASHRAE, is used here to distinguish and verify predictive differences of the simulation program. Most simulations were probably caused algorithmic variations and discrepancies, coding mistakes or errors, certain computational limits and also input discrepancies.

A method testing the evaluation calibration methods (SMOT) was applied to adjust building energy models along with measured energy consumption data. This process also uses calibration methods by applying computer software, predicting the energy performance of buildings. This makes it possible for the users to construct their own test models and specifications. The test model can be useful in several ways, such as: 1) it tests a single calibration method to find out how well it works under different test conditions; 2) it tests several calibration methods to see when each one gives the best result under different conditions; 3) it investigates the type and quantity of information content needed in the synthetic data in order to achieve better calibrations using different calibration methods (for example: monthly vs daily vs hourly data, and availability of disaggregated data or different types of sub-metered data); 4) it tests different kinds and amounts of noise in the synthetic data; and 5) diagnostic testing.

The main objective of the proposed method is to find a logical relation between different parts of system and create systematic way of thinking and designing for computation and construction, which can be applicable for both existing buildings and future designs as well. Based on the building designers' considerations, this method is able to evaluate all the mentioned criteria at the same time by applying multi-objective optimization or separately; with parametric analysis. It is also possible to eliminate some factors or add some. Or it can be programmed according to the LEED certificate and/or other applicable standards and certificates.

This method is displayed as an algorithmic model, which can be applied in design process manually or can be installed as a plug-in in simulation software such as grasshopper. Therefore, the results can be saved and presented as different alternatives by numerical charts in countries' regulations or can be evaluated for each project with its own limitations and considerations separately. This energy performance optimization may guarantee the desired indoor comfort conditions simultaneously. In other words, the model results' audience may be regulations, standard organizations and developers of energy simulation tools, who need methods for certifying software. However, the ultimate beneficiaries of the research are also tool users, such as architects, project managers, engineers, energy consultants and building owners.

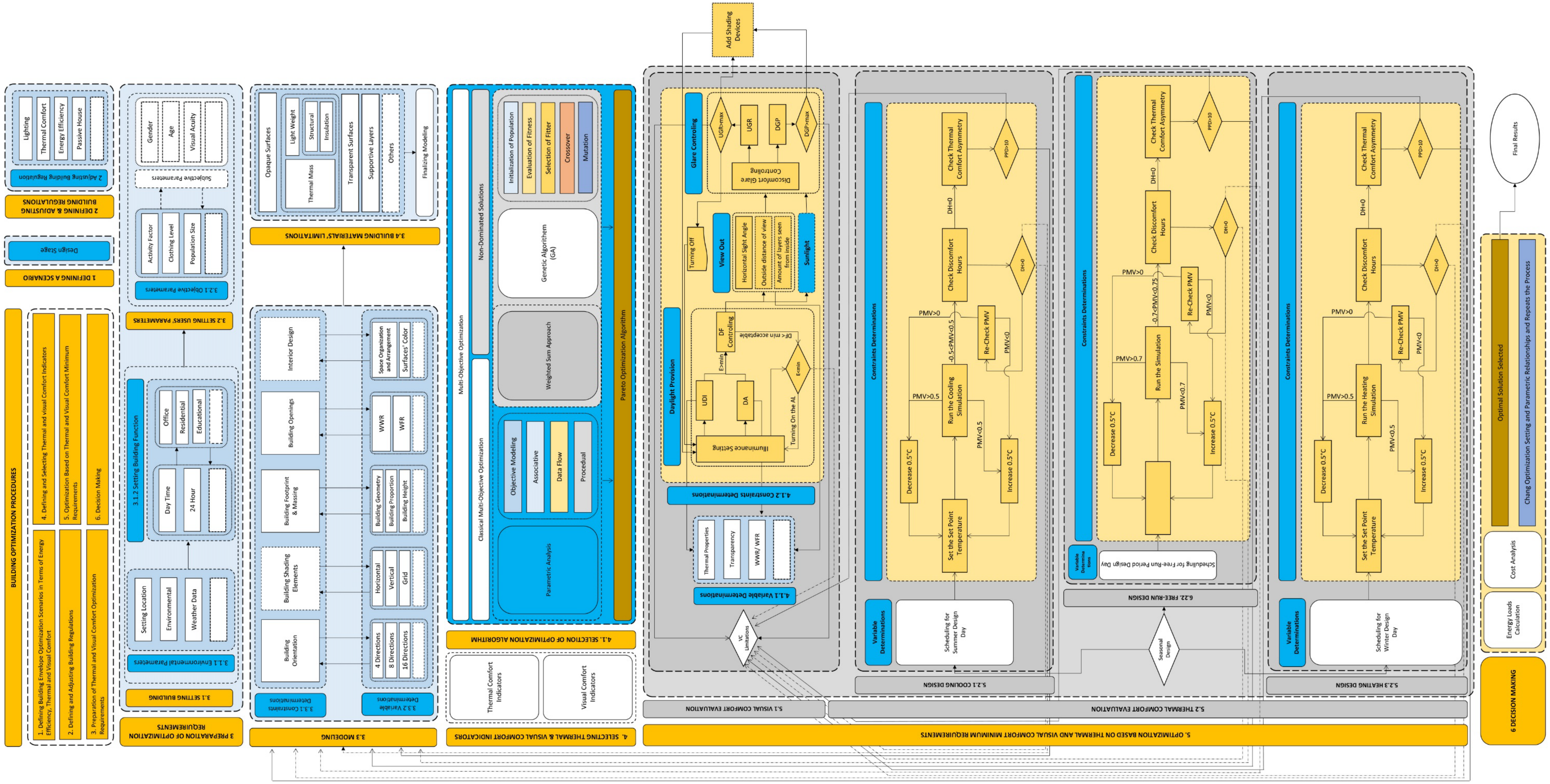


Figure 7: Detailed Research Methodology for Design Stage

It should also be mentioned that for raising the method usability, it is tried to use the same color for each group of related factors. For instance; when the user wants to evaluate the fitness in MOO, all the relevant parameters (fitness) are colored in light orange. Another consideration is that in this method all the process has been designed in algorithmic way and all the parameters and factors are subtitles of the more general one. Therefore, as a result, all the process can be summarized in 6 steps, which is illustrated in the beginning of the method as a guideline.

Chapter 4

TESTING THE METHODOLOGY

4.1 Applied Programs Chain Explanations and Verifications

This chapter tries to evaluate the applicability of the proposed methodology in the previous chapter. Therefore, in this section, it is tried to present the way, in which the mentioned methodology works by simply testing some parts of it. In other words, the aim is to optimize buildings' elements performance according to energy efficiency, thermal and visual comfort criteria. Therefore, it is tried to investigate the optimization method possibility by detailed modeling in a simulation software, which is known as grasshopper and different plug-ins.

Grasshopper creates a platform, benefitting from a range of free plug-ins and applications for environmental design assistance. It is one of the most extensive and comprehensive available programs for environment design, linking three-dimensional computer-aided design (CAD) interfaces to a number of validated simulation engines. The program runs with parametric visual scripting interfaces, allowing the automation of tasks and the exploration of design spaces. This platform is composed of modular components, making it capable to answer various questions and is flexible across different design stages.

Grasshopper is developed, based on a range of validated simulation engines, such as: EnergyPlus, Radiance, OpenStudio, Therm, etc. There are various approaches to analyze the validity of the simulation software, such as small-scale experimental research, full-scale experimental analysis, numerical approaches, etc. However, this methodology examination has been replicated with the same criteria as in DesignBuilder 3.1.0.080 Beta, which is a validated simulation program, to be able to produce more reasonable and reliable performance. Comparing the simulated results with physical on-site measurements, which have been done by author in the previous researches and experiences, shows a difference of approximately 3.7%, which is acceptable for the simulation program.

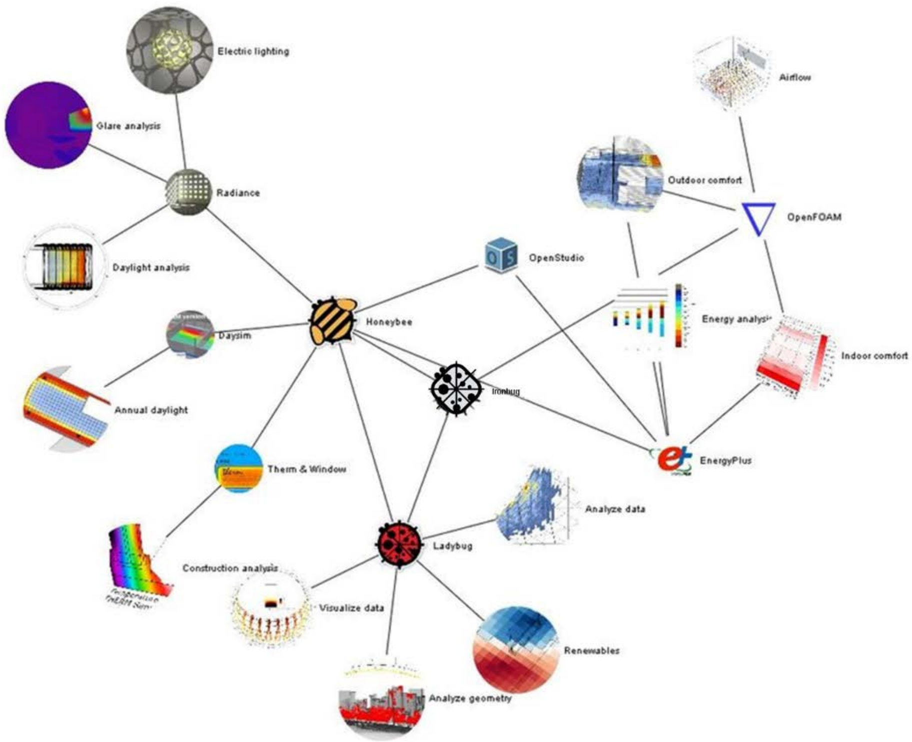


Figure 8: Programs Chain, Working in Grasshopper

Here, it should be mentioned that most of the simulation and optimization programs are using a statistical Monte Carlo approach. This method may lead to not getting exactly the same results by repeating a calculation with exactly the same model and options. However, the effect of this probable difference may be reduced by using higher detail settings, but still it is impossible to completely eliminate this effect.

4.2 Model Workout in Famagusta Case

In this section of the study, it is tried to test the proposed methodology. The software tests procedure over a broad range of parametric interactions and for a number of various output types, minimizes the concealment of algorithmic differences by compensating errors. The test is a subset of all possible tests that might be carried out. Significant attempt has been made to develop a sequence of tests that analyze the models of visual and thermal comfort applicable to simulate a building's energy efficiency and how it can be optimized. But, as simulation programs for building energy efficiency, operate in an immense parameter space, testing every combination of parameters over every possible function range is not logical and practical.

A series of mechanical equipment specifications and carefully described models are included in these tests. The output values for the cases are compared and used in conjunction with the diagnostic logic to determine the sources of predictive differences. The basic cases for the building thermal envelope test the programs' ability to model such combined effects as direct solar gain, window-shading devices, setback thermostat control, heat generated internally, infiltration, thermal mass and sunspaces. The in-depth case diagnosis is enabled by facilitating the excitation of different pathways for heat transfer. The ability of programs is tested by the cases of HVAC equipment to model the performance of unitary space-cooling equipment using the data presented as empirically derived performance maps of the manufacturer design.

4.2.1 Step 1: Defining Building Envelope Optimization Scenarios in Terms of Energy Efficiency, Thermal and Visual Comfort

As it was discussed in the previous chapter, the first stage defines a scenario. Buildings are categorized into three groups from constructional process levels as the following three scenarios: Pre-design Stage, Design Stage, Existing Building. Meanwhile, according to research limitation, this part mainly examines and concentrates on the design stage.

As architects have more freedom in design stage and can adjust and vary different parameters in this stage in order to analyze their effect on the building performance, the design stage, considered as the main concern and point of interest of architects, has been tested and explained here. However, the proposed model applicability in other stages has been briefly explained at the end of this chapter to show the similarity and differences of each stage.

4.2.2 Step 2: Defining and Adjusting Building Regulations to Achieve Minimum Requirements

In the next step, a standard or a building regulation should be considered as a guideline to evaluate minimum requirements. Building codes and standards can be categorized for visual and thermal comfort separately (tables 4-6). Here, based on the literature, EN 17037: 2018 and ASHRAE 55: 2010 have been selected for testing process. However, as these standards/ regulations are much closer to the author's points of view, have been selected and explained in this chapter. But, in other cases, in different contexts, the local standard/ regulation might be considered and replaced.

This step has been done in order to have a reference to check the minimum acceptable values for defined indicators later. In this case, as it was mentioned in order to be able to reach visual comfort zone, the indicators' values have been compared with the mentioned acceptable ones in EN 17037: 2018. The main affecting parameters, variables and the acceptable ranges/ values are presented in the next figure.

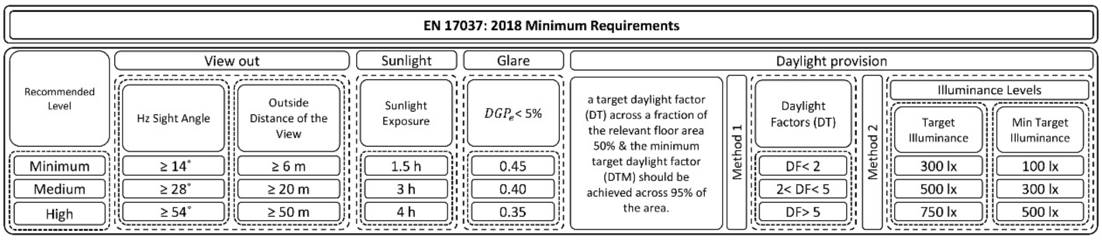


Figure 9: Visual Comfort Minimum Requirements based on the Selected Standard

The process is exactly the same for evaluating thermal comfort zone. In this stage the variables and indicators should be compared with proposed acceptable ranges in ASHRAE 55: 2010. It should also be mentioned that in some cases for defining some issues and make the process clearer, ASHRAE Fundamental: 2017 has been selected, these data have been illustrated in the next figure.

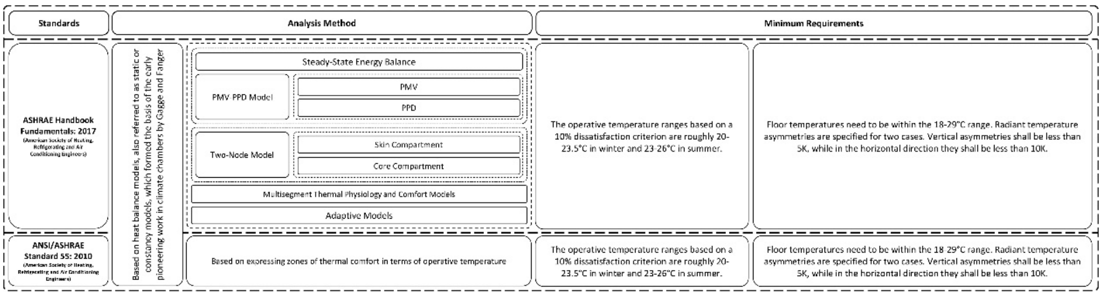


Figure 10: Thermal Comfort Minimum Requirements based on the Selected Standards/ Regulations

4.2.3 Step 3: Preparation of Thermal and Visual Comfort Requirements

4.2.3.1 Environmental Parameters Setting

In order to analyze the building energy consumption, the next step might be defining the climate of the study area. It is difficult to classify Cyprus as a definite climatic zone. However, in most researches, it is considered as hot and humid climate zone. In this categorization, Famagusta can be considered hot and humid as well (Kosonen & Tan, 2005).

Famagusta is located at 35°7'N and 33°55'E, 25m above sea level. It has a pleasant Mediterranean/ dry-summer subtropical climate, which is mild with moderate seasonality, according to Köppen-Geiger climate classification. In other words, it is hot and dry in summer due to subtropical high-pressure systems and has a moderate and rainy season, based on the polar front. In addition, in hot seasons, the average maximum temperature in the city is about 33°C. Meanwhile, for cold seasons, the average minimum temperature is about 17°C (Lotfabadi & Hançer, 2019)(Lotfabadi, 2020).

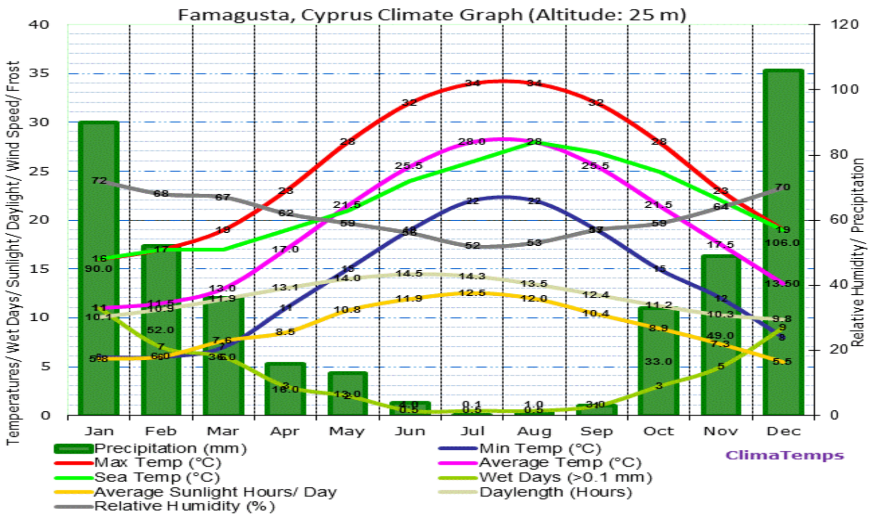


Figure 11: Famagusta Climate Graph (Famagusta Climate & Temperature, 2019)

Furthermore, the level of relative humidity is very high during the nights and early in the morning. It has rainy winters, almost without snow. As a result, the main features of this climate zone are abundant rainfall, high humidity and uniform temperature throughout the year (Kosonen & Tan, 2005). However, the TMY2 weather file of

Famagusta can be easily downloaded and applied to the program to be considered as climate information.

4.2.3.2 Defining the Building Function

According to the U.S. Energy Information Administration (EIA), offices by approximately 17% of energy usage, consume more energy in comparison with other commercial buildings (Abdullah & Alibaba, 2017). It should be remarked that this approach was distinguished by the aim of creating a display image for the office room layout without furniture. A visual performance that shows the workplace at a certain time of day can be considered and helpful as an aesthetic design aid, but does not include quantitative and practical feedback on room design, and is of no help in planning for energy efficiency. In the case of a daylighted office, the amount of electrical lighting energy use could be considered as zero. Nevertheless, the delighted office might be over heated by excessive solar radiation gain and energy may have to be expended on HVAC systems in order to control the thermal comfort. Thus, the entire energy consumption might be minimized by optimization of openings and shading systems size, position and so on.

4.2.3.3 Defining Users Parameters

Then it is time to adjust building's users' settings (personal parameters). Two adult office personals (a man and a woman) are considered to be in the space. Their activity level in seating position is 1.00. Furthermore, their clothing levels changes between 0.5 to 1.00clo according to different seasons. However, in this research based on the limitations, the effect of subjective parameters has been eliminated.

Table 13: Users and Thermal Comfort Parameters Settings

Activity Factor	1.00
Winter Clothing	1.00 clo
Summer Clothing	0.50 clo
Heating Set-point Temperature	20-23ºC
Cooling Set-point Temperature	23-26ºC
Heating Comfort PMV Set-point	-0.50
Cooling Comfort PMV Set-point	0.50
RH Humidification Set-point	10.00 %
RH Dehumidification Set-point	90.00%
Minimum Fresh Air	2.50 l/s-person
CO_2 Set-point	900 ppm
Minimum CO_2 Concentration	600 ppm
Target Illuminance	500 lux

4.2.3.4 Adjusting Building Form

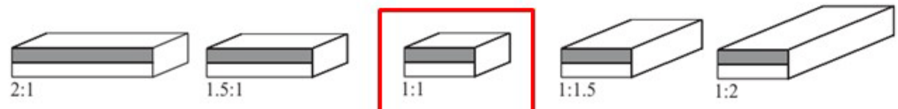
The next step is modeling the case study. An effective parameter in this level is building size, which is considered as building footprint and massing in the method. In this study for assessing the effect of size, dimensions are analyzed as proportions. This is because of this fact that proportions have the capacity to be applied to a larger group of samples more easily. Therefore, in order to prevent using random sizes, space dimensions are computed as a function of the Room Index (K).

This index presents the relationship between perimeter, area and mounting height between the working surface and the ceiling. In general, applicable room indices can be varied in range of 0.60 (small spaces) to 5.00 (large spaces). The next equation displays a room index calculation formula (CIBSE, 1999).

$$K = \frac{WD}{(W+D)h} \qquad \text{(Eq.1)}$$

In this formula, K can be considered as the room index (non-dimensional), D is the total room depth (m), W is the overall room width (m), and h is the mounting height between the working surface and the ceiling (m).

Table 14: Defining Building Dimensions by Applying K Factor



Space Size (m)		W:D 2:1 W=(3/2)2.2K		W:D 1.5:1 W=(2.5/1.5)2.2K		W:D 1:1 W=2×2.2K		W:D 1:2 D=(3/2)2.2K		W:D 1:1.5 D=(2.5/1.5)2.2K	
		W	D	W	D	W	D	W	D	W	D
K	0.7	4.62	2.31	3.85	2.57	3.08	3.08	2.31	4.62	2.57	3.85
	0.8	5.28	2.64	4.40	2.93	3.52	3.52	2.64	5.28	2.93	4.40
	1	6.60	3.30	5.50	3.67	4.40	4.40	3.30	6.60	3.67	5.50
	1.25	8.25	4.13	6.88	4.58	5.50	5.50	4.13	8.25	4.58	6.88
	1.5	9.90	4.95	8.25	5.50	6.60	6.60	4.95	9.90	5.50	8.25
	2	13.20	6.60	11.00	7.33	8.80	8.80	6.60	13.20	7.33	11.00
	2.5	16.50	8.25	13.75	9.17	11.00	11.00	8.25	16.50	9.17	13.75
	3	19.80	9.90	16.50	11.00	13.20	13.20	9.90	19.80	11.00	16.50

Meanwhile, another consideration is selecting the proportion itself. Lots of different proportions can be defined for designing an office. However, 1:1 proportion has been selected in this study. By selecting this proportion, in which the length is equal to the width of the space, the author wants to reduce the effect of changing the space proportion on other variables and reduce the effect of depth on natural lighting. Furthermore, among all possible alternative sizes, the smallest one has been selected to more execrate a little bit the effect of daylighting on the space and more clarify the methodology as well.

In this regard, the case study is a medium-prototype 3.08m by 3.08m rectangular single enclosed perimeter office (9.5m²). However, this size can easily change by adjusting the dimension sliders. Its orientation is according to south-north axes. The opening is located on the south façade without any shading devices and exterior obstructions. The building floor to ceiling height is 3m. Finally, it should be mentioned that here the method is evaluated during the daytime and this was the main reason of selecting an office building, which is working only during daytime.

4.2.3.5 Defining Building Thermal and Visual Properties

In order to evaluate the lighting requirements during given times, the office activity types, levels and a desired light level, might be considered as a constant amount. Then, based on the EN 17037: 2018 standard, an 85cm imaginary horizontal reference surface height, which is offset 50cm from the vertical surrounded surfaces can be considered as ‘work-plane’ or ‘reference plane’ to be benefited in simulation process. It should be mentioned that based on the applied standard this working plane height might be different. For instance; American standards normally considered this height as 75cm.

In this test, EN 17037 standard (European standard of daylighting) has been selected as a guideline. It covers four areas of daylighting: daylight provision, the prevention of glare, access to sunlight and assessment of the view out through windows. Although this standard is written for new buildings, its provisions may also apply to existing buildings. The provision of daylight can improve health issues and increase sense of comfort in buildings. However, offering occupants improved comfort through the benefits of daylight, and a connection to outside, requires a dedicated code of practice.

Based on the previous researches on typical office plans, it was presented that the entire perimeter cannot be daylighted. Therefore, when the daylight illuminance becomes lower than 500lux, the software automatically turns the artificial lighting system on, to reach the illuminance target. This method is also the same for thermal comfort conditions as well. In other words, in winter design days (Nov – Apr), when the temperature is out of 23-26ºC range and in summer design days (May – Oct), when the temperature is forth of 20-23ºC range, the air conditioning system will be automatically turned on to reach the mentioned temperatures (figure 10).

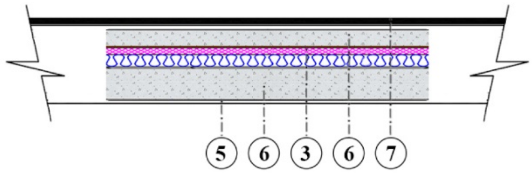
The construction materials, which are used in this model, are selected from the most common ones in North Cyprus. In this level user can easily define the construction materials. In this regards, two types of materials should be selected. The first is transparency percentage (WWR) and glazing and frame materials, which are selected for window/s. WWR can be set for each surface separately between the range of 0 to 100%. In this study, it is considered as an optimization variable in south surface. The window is adjusted as a clear double glazing with an Aluminum frame.

In the second part, the opaque surfaces' materials can be selected. It is possible to design different materials, construction technique and level of insulation, for each of the building's surfaces separately. However, insulation thickness is considered as another optimization variable. It should be remarked that as it was mentioned different materials can be selected and tested in this method, but here in order to make the research more practical, the materials have been selected from the most popular materials to use and presented in the next table. Also based on the previous researches of the author, the insulation material has been placed on the outer layer of walls and ceiling.

Table 15: Wall's Materials Properties and System Details

1.5cm Gypsum Plastering 17.5cm Brickwork, Outer Leaf Metal Framing, R-13 Insulation, Expanded Polystyrene, Molded Beads (Effective Insulation/ Framing Layers Added Above-Grade Mass Walls & Below-Grade Walls) Framing & Cavity Insulation Rigid Foam Insulation Wood Structural Sheathing Water Resistant Barrier 1cm Plaster (Dense)	

Table 16: Ceiling's Materials Properties and System Details

1.5cm Plaster (Lightweight) 10cm Concrete Metal Framing, R-13 Insulation, Expanded Polystyrene, Molded Beads 5cm Concrete 3.5cm Asphalt	

4.2.4 Step 4: Defining Thermal and Visual Comfort Indicators and Their Relations

Then, before starting the optimization process, effective variables on the building performance and occupants' sense of comfort must be defined. Meanwhile, in order to be able to evaluate these variables, comfort indicators and their relations to these variables should be analyzed. In this case, tables 10-11 illustrated visual and thermal indictors, which are affecting creating comfort zone based on EN 17037: 2018 and ASHRAE 55: 2010. Later, the applicability of each parameter on the design stage has been analyzed. In the next level, it is tried to evaluate some of these indicators' effects on creating sense of visual comfort, thermal comfort and the amount of energy efficiency in design stage.

4.2.5 Step 5: Optimization Based on Thermal and Visual Comfort Minimum Requirements

Before starting this stage, which can be considered as the core of the model. It should be mentioned that the optimization process in different levels such as energy performance, thermal and visual comfort evaluations should be run and evaluated together and at the same time. This is in case that different indicators and parameters may have different effects on creating sense of visual or thermal comfort. Although this process has been considered and done in simulation simultaneously, here, in order to make the explanations understandable and clear, they are described separately.

4.2.5.1 Visual Comfort Evaluation

Therefore, in the next phase, as a type of visual comfort assessment, daylighting is evaluated in the double glazing, clear glass window. When a minimum illuminance standard is reached over a fraction of the reference plane inside a room for at least half of the daylight hours, a space is considered to have adequate daylight. Therefore, when the average lighting illuminance becomes less than 500lux, the software tries to reach this amount by artificial lighting sources and this electricity usage has been stablished as lighting energy loads.

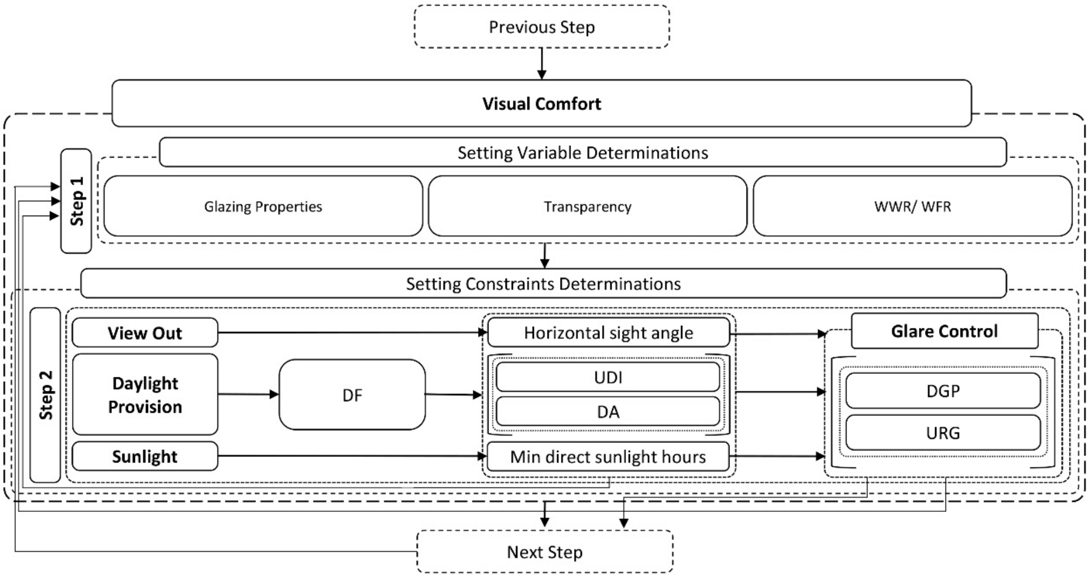


Figure 12: Visual Comfort Evaluation Process

It should be mentioned that the next step is evaluating daylight factor (DF), based on the selected standard (EN 17037: 2018) and function, it should be in the range of 2 to 5 and then discomfort glare index, which should be less than 19%. Therefore, one necessary thing is to asses and quantify the obtained daylight provision on the work-plane of the tested office, which has different dimensions and different fenestration areas.

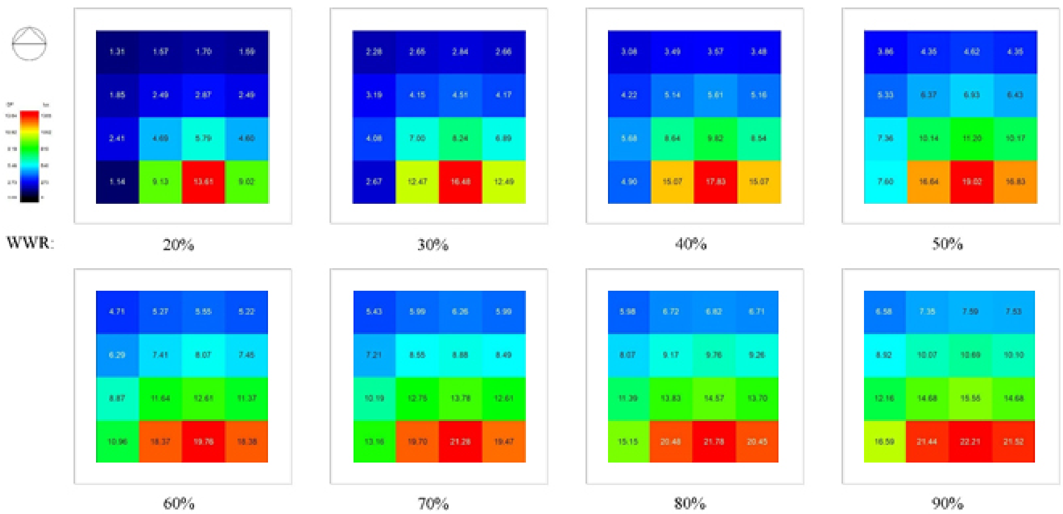


Figure 13: Calculation Method Using Daylight Factors on the Reference Plane

The issue of shortage of daylight supply on the rear side of spaces is quantified by an experiment, conducted by estimating the DFs in the office and also by evaluating the volume of glare index, to prevent discomfort glare beside windows. In an office environment. UGR must be less than 19 at desk level for the luminaire to be marked as low glare. Anything above this may cause discomfort. This process is repeated till the acceptable range of opening is obtained. Then, the process can be applied and tested for other probable scenarios such as different window shapes, orientation, office height and so on. This process will be repeated to estimate the daylight supply and energy savings on lighting likely to be obtained when the ideal WWR is applied.

In detailed simulation tools, DF is calculated only for a limited number of representative solar positions and days of a year for overcast and clear sky conditions. In new versions of EnergyPlus and Grasshopper, two additional types of clear turbid and intermediate sky conditions have been considered as well. These pre-calculated daylight factors are considered for hourly indoor computations of illuminance. However, in this method, the stored DFs are interpolated and superimposed to perform hourly calculations, based on solar times and sky conditions, which are read from the weather file. This is in case that in order to model dynamic daylighting controls, several studies have replaced daylight factors with daylight coefficients by reflecting the sky as numerous patches. Hence, in this work a more accurate and executable method of measuring daylight illuminances is introduced, which is advised by the daylight coefficient concept, taking into account the changes in the luminance of the sky components.

In this regard, for openings in the façade, daylight design should achieve a target daylight factor (D_T) across a fraction of the relevant floor area (50% vertical) and the minimum target daylight factor (D_{TM}) should be achieved across 95% of the area (EN 17037, 2018). Therefore, as it is illustrated in the next table, in order to achieve acceptable amount of DF, WWR must be more than 30% in this specific case. It should be also mentioned that for WWR≥50% the risk of glare has been increased. Thus, in these cases, special considerations, such as shading devices should be considered.

Table 17: Daylight Factor Calculation

W	D	WWR	Daylight Factor (DF)		
			DF< 2	2< DF< 5	DF> 5
		20%	37.5	37.5	25
		30%	0	62.5	37.5
		40%	0	56.25	43.75
3.08	3.08	50%	0	25	75
		60%	0	6.25	93.75
		70%	0	0	100
		80%	0	0	100
		90%	0	0	100

The metrics and methods incorporating climatic variables are analyzed to refine the needed climate data to apply dynamic methodologies. The different light changes in the lighting simulations are incorporated through Climate Based Daylight Modeling

(CBDM) in relation to the local climate, which produces a sequence of predictions for a specific moment, which are usually for any hour of a whole year; this is why it should be considered in the early stages of the study.

Based on the selected standard, the daylight autonomy threshold is assumed to be 500lux, which is also confirmed in recent literatures. Daylight Autonomy (DA) establishes an illuminance standard to guarantee autonomy to operate at daylight only. Nonetheless, an outstanding autonomy can still be achieved without guaranteeing visual comfort. Unless the upper illuminance level is not limited, there would be a risk of getting too much daylight at some periods of the year. In this case, Useful Daylighting Illuminance (UDI) provides an illuminance range that can be considered to constitute useful levels of illumination.

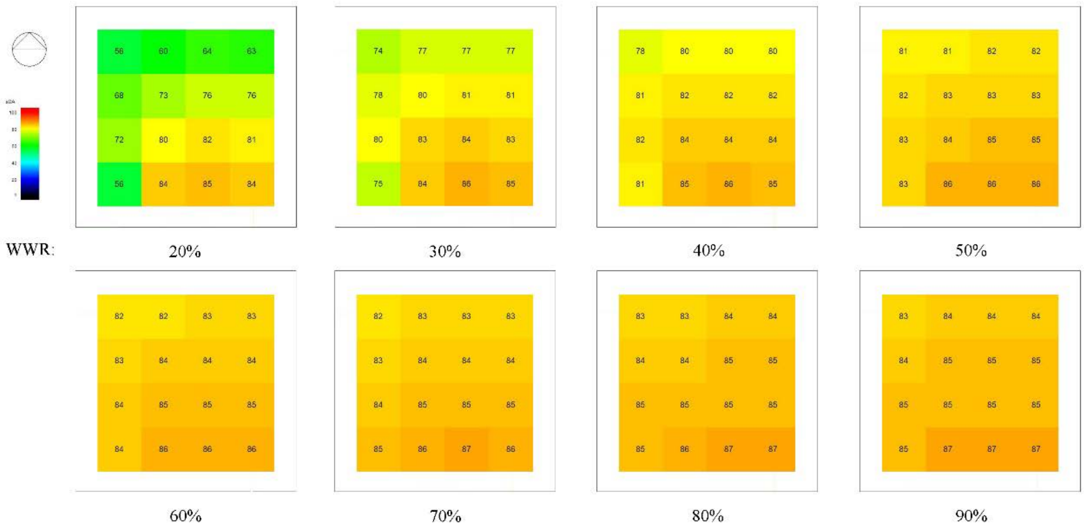


Figure 14: Calculation of Daylighting Autonomy (DA) on the Reference Plane

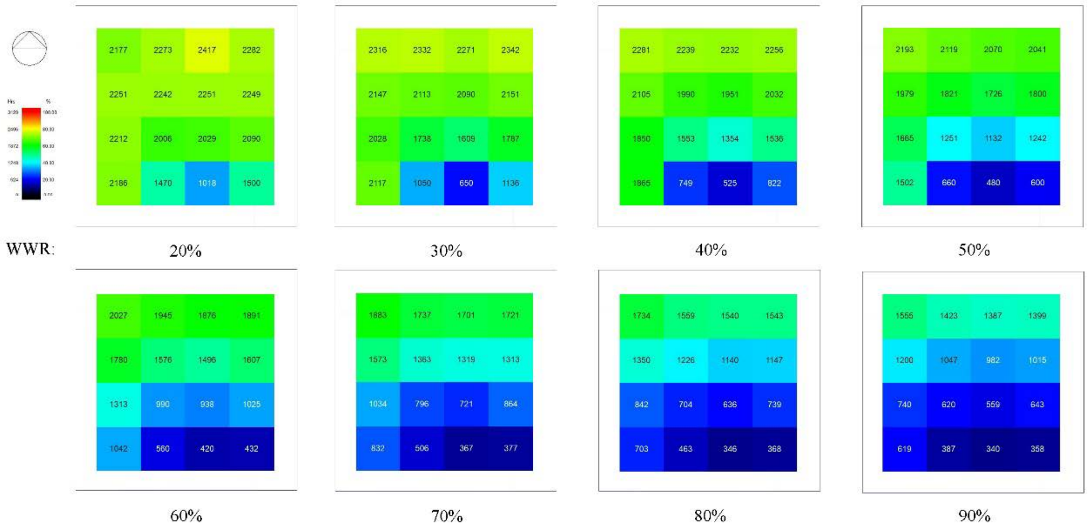


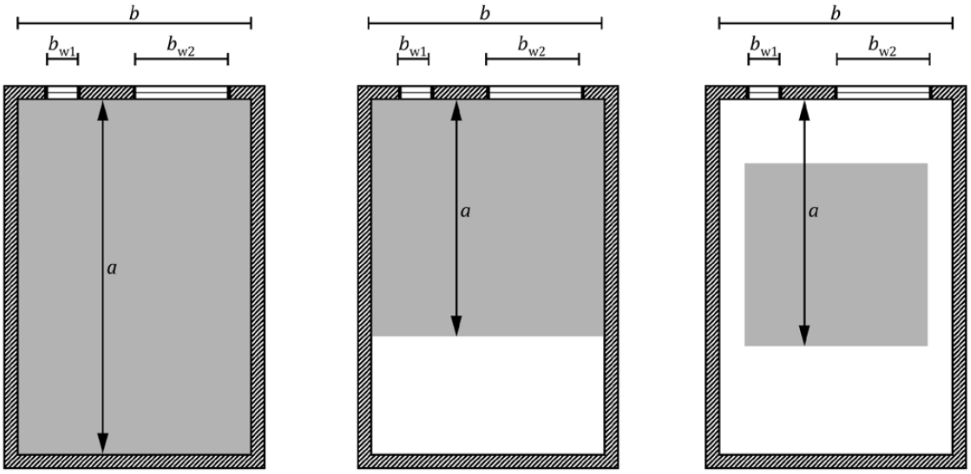
Figure 15: Calculation of Useful Daylighting Illuminance (UDI) on the Reference Plane

The room is assumed to have sufficient illumination, if for at least half of the daylight hours a minimum illuminance amount is met over a fraction of the reference plane within a space. Moreover, for spaces with vertical or inclined daylight openings, a minimum target illuminance level is also achieved across the reference plane. From the above photos, it can be concluded that in order to achieve minimum daylight provision, the range of 20 to 50% of WWR can be considered as acceptable. Although, DA is fulfilling the minimum requirements, analyzing UDI shows that after 50% of WWR, the acceptable area in space decreases to less than 50%, which shows the increment of glare effect probability.

Table 18: Calculation of DA and UDI for Different WWR

W	D	WWR	Window Height	Window Width	Window Sill	DA Area in Range (%)	UDI Area in Range (%)	DGP
3.08	3.08	20%	1.35	1.35	0.75	100	81.25	18.75
		30%	1.65	1.65	0.7	100	81.25	18.75
		40%	1.9	1.95	0.55	100	62.5	37.5
		50%	2.15	2.15	0.45	100	56.25	43.75
		60%	2.35	2.35	0.35	100	43.75	56.25
		70%	2.55	2.55	0.25	100	31.25	68.75
		80%	2.7	2.7	0.15	100	6.25	93.75
		90%	2.9	2.9	0.05	100	0	100

As it was mentioned in the previous chapter, in order to achieve the purpose of building view out, three parameters should be evaluated as follows: outside distance of view, number of layers seen from inside, and horizontal sight angle. The first two are related to the outside obstacles and come back to the urban regulations. However, the last factor should be considered in designing a building. In this case, it is recommended that width of window(s) horizontal sight angle should be less than 14˚. In other words, in the simplest way the minimum window width and height should not be less than 1 x 1.25m or $b_{w1} + b_{w2} \geq a/2$ (Eq. 3) (EN 17037, 2018). By considering the equation 3 formula, it can be claimed that as $a = (3.08 - 0.50)$, which is equal to2.58m, then $a/2 = 1.29$. Therefore, if the width of window is larger than 1.29m, then the horizontal sight angle can be considered as an acceptable range.



Key

a distance between the façade and the most remote part of the utilized area

b width of façade between interior walls

b_{w1} width view opening 1

b_{w2} width view opening 2

Figure 16: Horizontal Sight Angle Evaluation – Simplified Method (EN 17037, 2018)

Table 19: Calculation of Horizontal Sight Angle

W	D	WWR	Window			Horizontal Sight Angle
			Height	Width	Sill	
3.08	3.08	20%	1.35	1.35	0.75	≥1.29
		30%	1.65	1.65	0.7	≥1.29
		40%	1.9	1.95	0.55	≥1.29
		50%	2.15	2.15	0.45	≥1.29
		60%	2.35	2.35	0.35	≥1.29
		70%	2.55	2.55	0.25	≥1.29
		80%	2.7	2.7	0.15	≥1.29
		90%	2.9	2.9	0.05	≥1.29

The next evaluation factor benefits from minimum 1.5hour sun light. As the case study assumed to be in open spaces without any obstacles, and the window is located in south elevation, there would be no concern about this parameter. However, such a direct sunlight or high luminance variations within the field of view between bright and dark areas can increase the glare risk, which should be viewed as a control step in the optimization process.

In this case, current glare probability assessment metrics have been used, but their results have been inconsistent. In fact, glare probability often depended on the selected index. Furthermore, real perceptions and measurement were sometimes in conflict with simulation results. This clarifies the need to create rules for the glare probability to be adopted for the various current metrics. The DGP results the metric, which best fits the building's visual perception. Simulations were created to build the shadow elements and determine the windows' possible transmissibility, while the DGP profile estimates chances of glare.

Table 20: Calculation of Daylight Glare Probability (DGP)

W	D	WWR	DA Area in Range (%)	DGP
3.08	3.08	20%	100	18.75
		30%	100	18.75
		40%	100	37.5
		50%	100	43.75
		60%	100	56.25
		70%	100	68.75
		80%	100	93.75
		90%	100	100

DGP is a metric for predicting the existence of discomfort glare in daylight spaces. In this case study, which is not going to use shading devises, by only benefiting from venetian blinds DGP threshold values should not exceed 0.45 (45%) in more than 5% of the reference usage time (EN 17037, 2018). This means that here, by considering WWR≤60%, daylight glare probability can achieve an acceptable percentage.

Table 21: Summary of the Visual Comfort Affecting Parameters Calculation

W	D	WWR	Window Height	Window Width	Window Sill	Horizontal Sight Angle	DA Area in Range (%)	UDI Area in Range (%)	DF	DGP
3.08	3.08	20%	1.35	1.35	0.75	≥ 1.29	100	81.25	37.5	18.75
		30%	1.65	1.65	0.7	≥ 1.29	100	81.25	62.5	18.75
		40%	1.9	1.95	0.55	≥ 1.29	100	62.5	56.25	37.5
		50%	2.15	2.15	0.45	≥ 1.29	100	56.25	25	43.75
		60%	2.35	2.35	0.35	≥ 1.29	100	43.75	6.25	56.25
		70%	2.55	2.55	0.25	≥ 1.29	100	31.25	100	68.75
		80%	2.7	2.7	0.15	≥ 1.29	100	6.25	100	93.75
		90%	2.9	2.9	0.05	≥ 1.29	100	0	100	100

By comparing and summarizing the mentioned analysis in case of evaluating visual comfort, the minimum acceptable range of WWR, which was one of the optimization variables can be defined. Here, the aim was to define a range for variables, in which building occupants fill satisfaction by overcoming it. Therefore, by considering the above consideration, it can be concluded that in this specific case, the range between 30 to 50% of window to wall ratio is acceptable to fulfill the visual comfort requirement without any extra consideration such as shading devices. So, achieving visual comfort is considered as a compulsory parameter and creates some limitation for continuing optimization process.

4.2.5.2 Thermal Comfort Evaluation

Another variable, which is considered for optimization is the thickness of thermal insulation. Generally, the building insulation is made very thick to effectively thermally decouple the zone from ambient conditions. However, increasing the thickness doesn’t have linear direct effect on the improvement of thermal comfort sensation. Therefore, here it is tried to find optimum range of thermal insulation thickness. As this insulation doesn’t have any effect on visual comfort. After finding the acceptable range of WWR, different thicknesses have been tested in the mentioned range of WWR.

Thermal comfort evaluation is based on the ASHRAE 55:2010 and principals of the ASHRAE Fundamental 2017. Here, the main aim of this phase is to provide the minimum qualifications a building must gain to reach a certain level of human thermal comfort. In construction sector, it is almost infeasible to attain a 100% sense of thermal comfort satisfaction with natural ventilation. Neverthless, heating times of Northen Cyprus, have a potential to benefit from the free-run periods. Thus, here, according to the previous studies, the mixed-mode modle has been developed (Lotfabadi & Hançer, 2019). In other words, based on the time and energy usage purpose, three scenarios have been developed as heating period, cooling period and free-run period. In this regard, the periods, in which NV is capable of generating a comfort zone are considered as free-run periods without energy consumption and air-conditioned facilities create a thermal comfort zone for the rest of the year.

Generally, by adjusting heating-cooling schedule, the script works in such a way that in summer design day, when the temperature is forth of 20-23ºC range, and in winter design days, when the temperature is out of the 23-26ºC range, to reach the mentioned temperatures, the air conditioning system will be automatically turned on. Defining ventilation and air conditioning systems leads to achieving this target. The base-case building design is a quasi-adiabatic single-zone rectangle with only user-specified internal gains to drive heating and cooling load. A simple unitary vapor-compression heating-cooling system, or more specifically, a split-system is defined by a specification for mechanical equipment. Usually, the performance of this system is focused on ready-model HVAC equipment in program based on factory design data provided as empirically validated performance maps.

As it was mentioned, here insulation thickness is considered as a second variable of optimization. In this case, one of the affecting variables is the place of insulation. Based on the users’ requirements this parameter can be defined in the material section. Likewise, building façades considered with insulation in its exterior layer, which is most effective for this specific location, based on the author’s previous researches. And here, it is just considered as a fixed parameter for examination. The standard test walls thicknesses are 20cm without insulation. However, for doing evaluation the polystyrene insulation layer has been added from 1cm to the original wall thickness (20cm) and the results have been compared.

Table 22: Thermal Properties of Construction Materials

	Materials	Conductivity (W/m-K)	Specific Heat (J/kg-K)	Density (kg/m3)	Thermal Absorptance (emissivity)	Embodied Carbon (kgCO2/kg)	Thermal Diffusivity (m^2/s)
1	Gypsum Plastering	0.400	1000	1000	0.900	0.38	4×10^{-7}
2	Brick	0.840	800	1700	0.900	0.22	6.1×10^{-7}
3	Insulation	0.355	1470	10.00	0.900	----	2.4×10^{-7}
4	Plaster (Dense)	0.500	1000	1300	0.900	0.12	3.8×10^{-7}
5	Plaster (Lightweight)	0.160	1000	600	0.900	0.12	2.6×10^{-7}
6	Concretes	2.270	837.36	2321.40	0.900	----	1.2×10^{-7}
7	Asphalt	1.000	1000	2100	0.900	0.05	3.3×10^{-7}

Then, in the next phase, thermal comfort has been evaluated. In the proposed method, first of all PMV will be checked. If it becomes between -0.5 to 0.5, then discomfort hours will be checked automatically, which might be zero. Afterwards, thermal comfort asymmetry will be checked as a control point. In this case as a double check PPD should be less than 10%. If the simulation doesn’t meet any of the above criteria, it will repeat the process by new consideration, shown in figure 7. However, this phase is directly related to the previous one and any changes in each phase may change the results in the other one as well. This should be especially considered, when non-dominated solution algorithm is selected as the methodology. It should be also mentioned that for free-running periods a PMV is evaluated and the rest of process will be shaped accordingly. This process has been defined by adjusting thermal comfort indicators and calculations in the program.

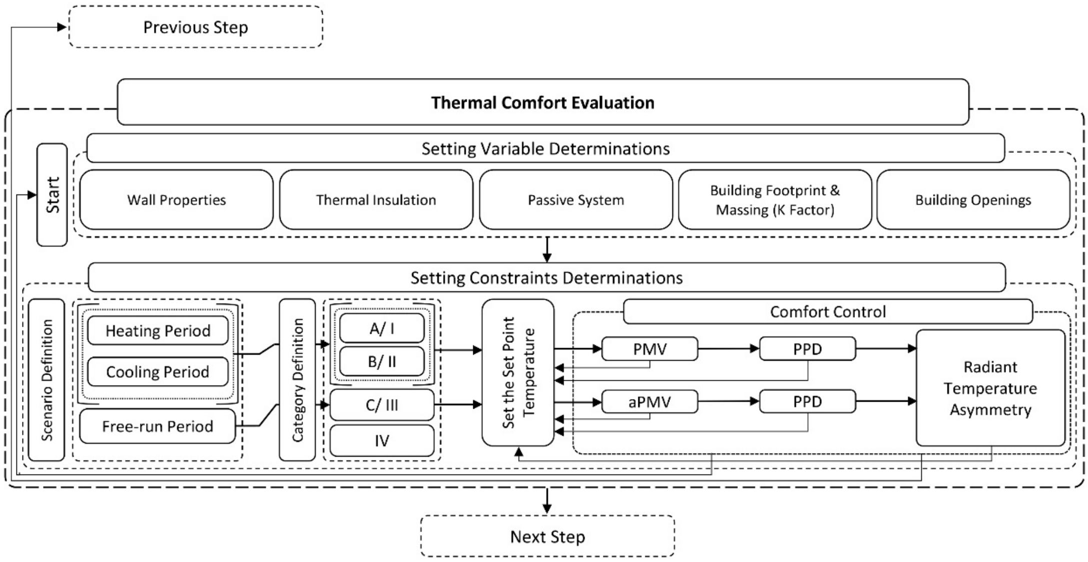


Figure 17: Thermal Comfort Evaluation Process

4.2.5.3 Energy Efficiency Evaluation

In this phase, it is turn to run the simulation. In this process, based on the requirements, simulation outputs and parameters will be defined. In this regard, analysis period is another considerable factor, defined as yearly (hourly-based) analysis. In other words, all results are collected from daily-hourly evaluations, Monday to Sunday, from 8:00am to 6:00pm of each month. As it was mentioned, in analysis period an entire week is considered without eliminating weekends, however, adjusting only weekdays is considered as an option in defining a time period for further cases. Then the average is calculated as monthly average energy consumption per day for evaluating the case study area in each month. In this case, all acceptable ranges of set temperature are evaluated. However, in order to find the minimum energy performance, it started form the highest acceptable set-point temperature in cooling period, and the lowest in heating period. In order to find and accept these temperatures, aPMV/PMV-PPD must be in its defined acceptable range. Then, as a control parameter radiant temperature asymmetry has been checked.

For the evaluation of radiant temperature asymmetry, the plane radiant temperature, which is the uniform temperature of an enclosure in which the radiant flux incident on one side of a small plane element is the same as in the actual environment, should be calculated. Typically, this plane is considered in the middle of the space to reflect the effect of all surrounding surfaces. However, as this study wants to evaluate the effects of building elevation elements, this virtual plan, considered 1m beside the south wall to emphasis this effect. This selection is based on the results of experimental studies, that this effect is maximized next to the surfaces, especially the ones, which have openings on them.

In order to calculate radiant temperature asymmetry, the plane radiant temperature, which is the uniform temperature of an enclosure in which, on one side of a small plane element, the incident radiant flux is the same as in the actual environment, should be evaluated. In this case another variable, which should be considered is angle factor between a person and selected surface. These data can be commutated from the next figures data (ASHRAE, 2017).

Figure 18: Analytical Formulas for Calculating Angle Factor for Small Plane Element (ASHRAE, 2017)

From the above information radiant temperature asymmetry can be estimated. In other words, radiant temperature asymmetry can be simply calculated by considering mean radiant temperature and angle factor. This process can be done manually by architects or it can be automatically calculated in the designed model in the simulation program. The results of these calculation are presented in the next table.

Table 23: Radiant Temperature Asymmetry Evaluation Results

	0cm	1cm	2cm	3cm	4cm	5cm	6cm	7cm	8cm	9cm	10cm	11cm	12cm	13cm	14cm	15cm	16cm	17cm	18cm	19cm	20cm
50%	11.21	11.15	11.13	11.12	11.11	11.11	11.11	11.10	11.10	11.10	11.10	11.10	11.10	11.10	11.10	11.10	11.10	11.09	11.09	11.09	11.09
40%	10.52	10.46	10.44	10.43	10.42	10.41	10.41	10.40	10.40	10.40	10.40	10.39	10.39	10.39	10.39	10.39	10.39	10.39	10.39	10.39	10.39
30%	10.40	10.33	10.31	10.30	10.29	10.28	10.28	10.28	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.26	10.26	10.26	10.26	10.26	10.26

Then these amounts are compared with the acceptable values, which are proposed by ASHRAE standard for cool wall and warm wall separately based on doing evaluation on heating or cooling periods. However, as the effect of warm wall is not too much, to save time, it may be eliminated in calculations. Here, as the aim is to show the process, the effect of cool wall has been evaluated.

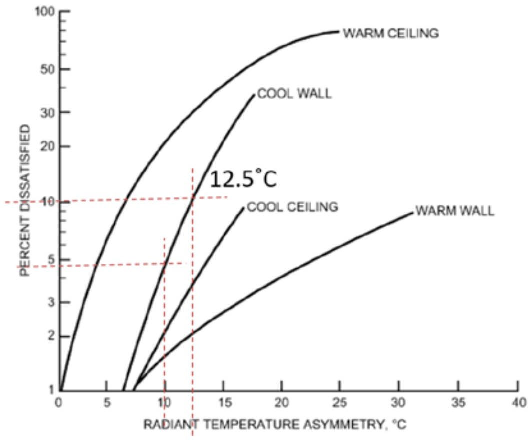


Figure 19: Evaluation of the Radiant Temperature Asymmetry from Warm Wall[2]

The previous figure, indicates that people are more sensitive to an overhead warm surface asymmetry rather than a vertical cold surface. The effect of an overhead cold surface or a warm surface located vertically is much less. These data might be especially meaningful, when using radiant panels in spaces with wide cold surfaces or cold windows to provide comfort. Therefore, as it was presented in the previous table, the results of temperature asymmetry calculation show that in this especial case, this parameter doesn’t have any negative effect on sense of comfort and all results are in acceptable range.

Therefore, the next step is to check energy performance. The results of energy consumption can be extracted from the running simulation part. However, in this study instead of presenting the results as energy consumption by Kw/h, they are presented as percentages. In other words, a case without insulation is considered as a base point with 100% of energy consumption, then the reduction effect of each centimeter increment in insulation thickness has been calculated by comparing with the base/ reference point. These results are presented in table 21.

[2] This graph is originally based on ASHRAE Handbook of Fundamentals: 2017

Table 24: The Effect of Increasing 1cm Insulation on South Elevation

	0cm	1cm	2cm	3cm	4cm	5cm	6cm	7cm	8cm	9cm	10cm	11cm	12cm	13cm	14cm	15cm	16cm	17cm	18cm	19cm	20cm
50%	100%	-3.5%	-4.9%	-5.6%	-5.6%	-6.2%	-6.2%	-6.2%	-6.2%	-6.2%	-6.9%	-6.9%	-6.9%	-6.9%	-6.9%	-6.9%	-6.9%	-6.9%	-6.9%	-6.9%	-6.9%
40%	100%	-5.0%	-6.6%	-7.4%	-8.3%	-8.3%	-9.1%	-9.1%	-9.1%	-9.1%	-9.1%	-9.9%	-9.9%	-9.9%	-9.9%	-9.9%	-9.9%	-9.9%	-9.9%	-9.9%	-9.9%
30%	100%	-7.1%	-9.2%	-10.2%	-11.2%	-12.2%	-12.2%	-13.3%	-13.3%	-13.3%	-13.3%	-13.3%	-13.3%	-13.3%	-14.3%	-14.3%	-14.3%	-14.3%	-14.3%	-14.3%	-14.3%

Although presenting the results as a percentage helps to understand them better, the effect of increasing insulation thickness is not clear yet. Therefore, it is tried to present the results as a comparison of increasing each 1cm thickness with the previous one. Thus, as an example; the next table shows that in case of 50% WWR, if the insulation thickness has been increased from 1cm to 2cm, 1.4% more energy saving will be occurred. And it also illustrates that after 5cm, it seems that increasing insulation thickness doesn’t have a significant effect of energy performance. Also, this table can prove the effect of adding insulation layer in building energy performance.

Table 25: The Effect of Increasing 1cm Insulation on South Elevation (Each cm Differences)

	0cm	1cm	2cm	3cm	4cm	5cm	6cm	7cm	8cm	9cm	10cm	11cm	12cm	13cm	14cm	15cm	16cm	17cm	18cm	19cm	20cm
50%	100%	-3.5%	-1.4%	-0.7%	0.0%	-0.7%	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40%	100%	-5.0%	-1.7%	-0.9%	-0.9%	0.0%	-0.9%	0.0%	0.0%	0.0%	0.0%	-0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
30%	100%	-7.1%	-2.2%	-1.1%	-1.1%	-1.1%	0.0%	-1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

This process has been repeated for evaluating the effect of decreasing WWR on building energy consumption as well. This time the biggest acceptable WWR (50%) has been considered as a base/ reference point and then its size decreasing effects have been evaluated as follows;

Table 26: The Effect of Decreasing 10% Window to Wall Ratio

	0cm	1cm	2cm	3cm	4cm	5cm	6cm	7cm	8cm	9cm	10cm	11cm	12cm	13cm	14cm	15cm	16cm	17cm	18cm	19cm	20cm
50%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
40%	-16.0%	-17.3%	-17.5%	-17.6%	-18.4%	-17.8%	-18.5%	-18.5%	-18.5%	-18.5%	-17.9%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%
30%	-31.9%	-34.5%	-35.0%	-35.3%	-36.0%	-36.3%	-36.3%	-37.0%	-37.0%	-37.0%	-36.6%	-36.6%	-36.6%	-36.6%	-37.3%	-37.3%	-37.3%	-37.3%	-37.3%	-37.3%	-37.3%

Table 27: The Effect of Decreasing 10% Window to Wall Ratio (Each 10% Differences)

	0cm	1cm	2cm	3cm	4cm	5cm	6cm	7cm	8cm	9cm	10cm	11cm	12cm	13cm	14cm	15cm	16cm	17cm	18cm	19cm	20cm
50%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
40%	-16.0%	-17.3%	-17.5%	-17.6%	-18.4%	-17.8%	-18.5%	-18.5%	-18.5%	-18.5%	-17.9%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%	-18.7%
30%	-19.0%	-20.9%	-21.2%	-21.4%	-21.6%	-22.5%	-21.8%	-22.7%	-22.7%	-22.7%	-22.7%	-22.0%	-22.0%	-22.0%	-22.9%	-22.9%	-22.9%	-22.9%	-22.9%	-22.9%	-22.9%

4.2.5.4 Cost Analysis

In the next phase cost analysis can be applied on the process. In this regard, at the first stage initial cost of constructing the model with the mentioned materials, different insulation thickness and window to wall ratios is calculated. In the next two tables, the increasing cost effect of adding each centimeter insulation layer is compared with the common construction style, without insulation building technique as a percentage. And the other scenario, which changes WWR is evaluated in comparison with the smallest ratio as well.

Table 28: Initial Investment Increment by Adding Each cm Insulation

	0cm	1cm	2cm	3cm	4cm	5cm	6cm	7cm	8cm	9cm	10cm	11cm	12cm	13cm	14cm	15cm	16cm	17cm	18cm	19cm	20cm
50%	100%	26%	51%	77%	102%	128%	154%	179%	205%	230%	256%	282%	307%	333%	358%	384%	384%	435%	461%	486%	512%
40%	100%	28%	55%	83%	111%	139%	166%	194%	222%	249%	277%	305%	333%	360%	388%	416%	416%	471%	499%	527%	554%
30%	100%	30%	60%	90%	120%	151%	181%	211%	241%	271%	301%	331%	361%	391%	422%	452%	452%	512%	542%	572%	602%

Table 29: Initial Investment Increment by Adding Each 10% Window to Wall Ratio

	0cm	1cm	2cm	3cm	4cm	5cm	6cm	7cm	8cm	9cm	10cm	11cm	12cm	13cm	14cm	15cm	16cm	17cm	18cm	19cm	20cm
30%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
40%	6%	4%	3%	2%	2%	1%	1%	0%	0%	0%	0%	0%	0%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%
50%	12%	8%	6%	4%	3%	2%	1%	1%	0%	0%	0%	-1%	-1%	-1%	-1%	-1%	-1%	-2%	-2%	-2%	-2%

These percentages directly show the amount of increase or decrease. For instance; if 2cm insulation is added to the building with 50% WWR, the initial cost will increase 51%. This increase is too much after 5 or 6cm. So, it seems that adding this much of insulation is not economical at the beginning of the process. However, here, it is continued to show the evaluation parameters for decision making process. Another considerable issue is that it seems that changing the insulation thickness can be more effective in initial cost rather than window to wall ratio.

As in the previous section, it is also mentioned here that based on simplified evaluation technique the amortization period in this type of climate can be estimated up to 10 years. These results are also displayed as percentages. It should be mentioned that in this part different factors such as yearly inflation rate has been considered in the estimation. Then, the next step is evaluating the amount of money, which can be saved by adjusting building insulation and WWR in 10 years. However, in order to make the decision much easier, next table shows the payback time for each scenario. It should be also mentioned that in this table, only results with maximum 10 years payback period are presented.

Table 30: Calculating Payback Period

WWR Increment	Insulation Thickness 0cm	1cm	2cm	3cm	4cm
50%	0	3.5	6.5	10.0	11.2
	0	4.0	7.0	9.5	11.5
30%	0	4.5	7.8	10.2	12.5

min Payback Period max

According to the financial results, it can be claimed that considering the case study with max 3cm insulation in all the mentioned WWRs seems economical.

4.2.6 Step 6: Decision Making

Finally, the decision-making process is not only based on economy, it is based on fulfilling the human needs. As an architect, the aim is to create a comfortable environment from all different aspects. In other words, the main concern of this research is to develop a multi-objective method to define a building envelope elements property for a building conceived for Famagusta climate as an example, under a compromise between, energy efficiency, thermal and visual comfort. Therefore, one of the core values of this project is to bring incredible sustainable architecture to people all around the word.

Here, based on the mentioned data and analysis the range of optimum window to wall ratio and accordingly insulation thickness in an office case in Famagusta can be presented as follows. It should be also explained that the logic of this figure is exactly like the previous ones, which is a kind of weighted sum method. In this regard, each evaluation criteria, is analyzed and presented separately. However, in each level, the effect of the previous level, is also illustrated. In other words, if some options cannot reach the minimum requirements according to the previous criteria, they are presented by faded colors in the next level. Therefore, in order to make this comparison much easier, colors have been added to it as a kind of visual reading technique for architects. Eventually, For the convenience of users, who wish to plot or tabulate their results along with the example results, an electronic version of the model will be included as a softcopy later.

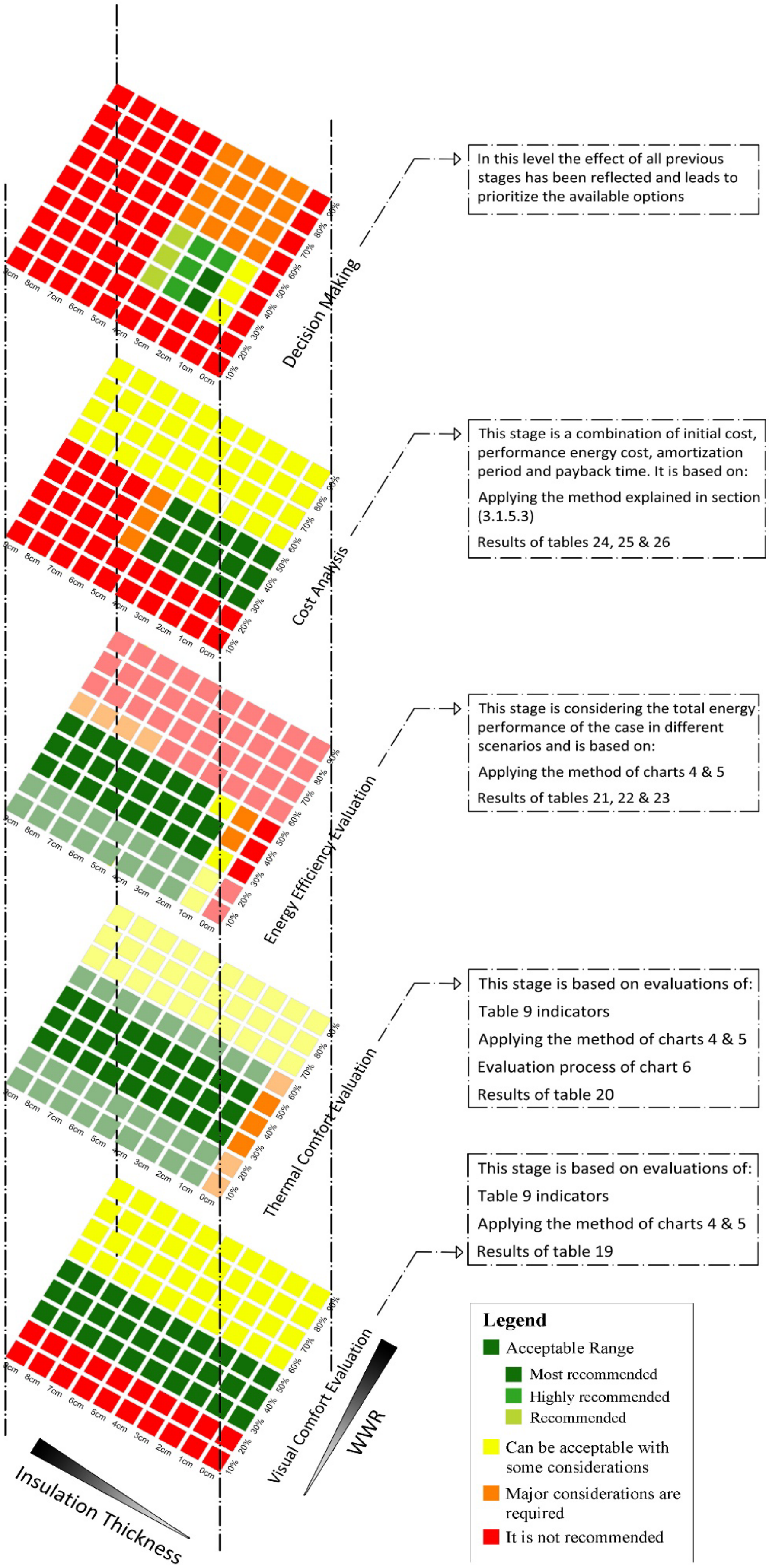


Figure 20: Decision Making Process

4.3 Other Scenarios

As it was discussed, this study attempted to suggest a systemic strategy for evaluating and maximizing comfort levels by considering the energy efficiency and has the ability to be applicable in different construction stages, which can be called as pre-design, design stage and existing buildings level. With some adjustments, the proposed method/ model has the potential to adapt in all three phases. However, according to the research limitations only design stage has partially been examined to clarify the application of the methodology.

As it was presented in figure 3, in case of existing building, the evaluation process in the first three steps are exactly the same as the design stage. In other words, after selecting this scenario, in order to find the minimum required acceptable values, the appropriate standard/ regulation must be selected. Then thermal and visual comfort requirements, such as weather data, user parameters, building form and so on, will be modeled. Afterwards, in the fourth step after defining and evaluating affecting indicators and their relations, the simulation must be run to evaluate the current performance of the building, which can be found as a test point in figure 3.

These results must be compared with minimum acceptable levels in the standards/ regulations, which were selected in step 2. This has been done to evaluate the existing building weaknesses points. Then, the process will be continued till step 4 again, in this stage, indicators will be defined one more time, accordingly. The last two steps can be considered almost the same. However, as there may be less possibility to change and optimize some parts of the building and there may be less flexibility with building parameters, the optimization process might be considered as single variable one or multi-objective process, like design stage. Therefore, these less amount of possible alternative of optimization, may lead to having much simple decision-making process. Therefore, in existing building level, it is possible to revise and improve building current situations, but it is not really possible to change its properties, as indicators, which can be adjusted, are fewer in comparison with other stages, and they can be varied case by case.

In comparison with design stage and existing building level, in pre-design stage, several scenarios and alternatives have to be tested and results should be prepared and proposed as charters to be used for architects. In other words, optimum alternatives can be selected from pre-defined scalars, coming from the previous experimental studies or simulations. These results can be considered as pre-sets in this stage.

However, after selecting these pre-sets data in this level, the effect of different selected parameters on each other must be evaluated by running multi-objective simulation. It should be mentioned that doing optimization in pre-design stage leads architects and building makers to consider different aspect of the project more widely. However, this is not enough and might not necessarily lead to obtaining a better building performance. Therefore, in order to achieve the purpose, optimization process should be continued in design stage as well. Furthermore, as it was mentioned; in this stage several scenarios and alternatives have to be tested and results should be prepared and proposed as charters to be used for architects in order to do the decision-making process.

Chapter 5

CONCLUSIONS

As it was presented in previous literature (chapter 2), there are lots of studies concentrating on thermal and visual comfort. Some of them also did their researches based on the energy consumption and efficiency. However, the main problem is that there are almost no researches concentrating on all these variables simultaneously. Or even if there are, they are not comprehensive multi-objective optimizations and only consider few parameters separately.

Another motivation of the author to do this research, is that as architects, we access to several standards and regulations. However, when and how to benefit from these data is a big question mark. In other words, there is no clear guideline for architects to apply thermal and visual comfort principals in different design stages. The instructions of current standards and regulations are somehow too complicated and time consuming. Likewise, these data are not available neither as building code/ regulation nor as ready charters for Northern Cyprus.

These days, simulation programs are developing day by day. This digital progress helped researchers to estimate and calculate the effect of every element of buildings. However, here the problem is that it is difficult to define the limits. There are too many variables and as architects, we have to know our minimum requirements for thermal comfort, visual comfort and energy performance, before making decision and designing. This study tries to establish a method, which at the first stage is based on the developments of missing parts of the previous methodologies, to fulfill this gap and define these minimum variables and indicators. Then, it proposes the model to optimize these mentioned parameters, by adapting and adjusting all of them simultaneously in the model as a systematic strategy.

Although there are lots of elements affecting building performance, based on the limitations, this study, mainly concentrates on building envelope. This is also because that these elements have the most effects on building performance on one hand, and formally playing an unignorable role for architects on the other hand. Therefore, this study proposes a methodology especially for architects to follow in order to find an optimum solution for their building envelope design according to energy performance, thermal and visual comfort criteria.

As it was mentioned in chapter one, this study tried to propose a systematic strategy to evaluate and optimize level of comforts by considering energy performance, which might be applicable in different design/ construction stages. These can be named as pre-design stage, design stage and existing building level. The proposed method/ model has the ability to adapt with all three stages with some considerations. However, based on the research limitations only design level has partially been examined to show the application of the methodology. This proposal can be summarized in the next figure.

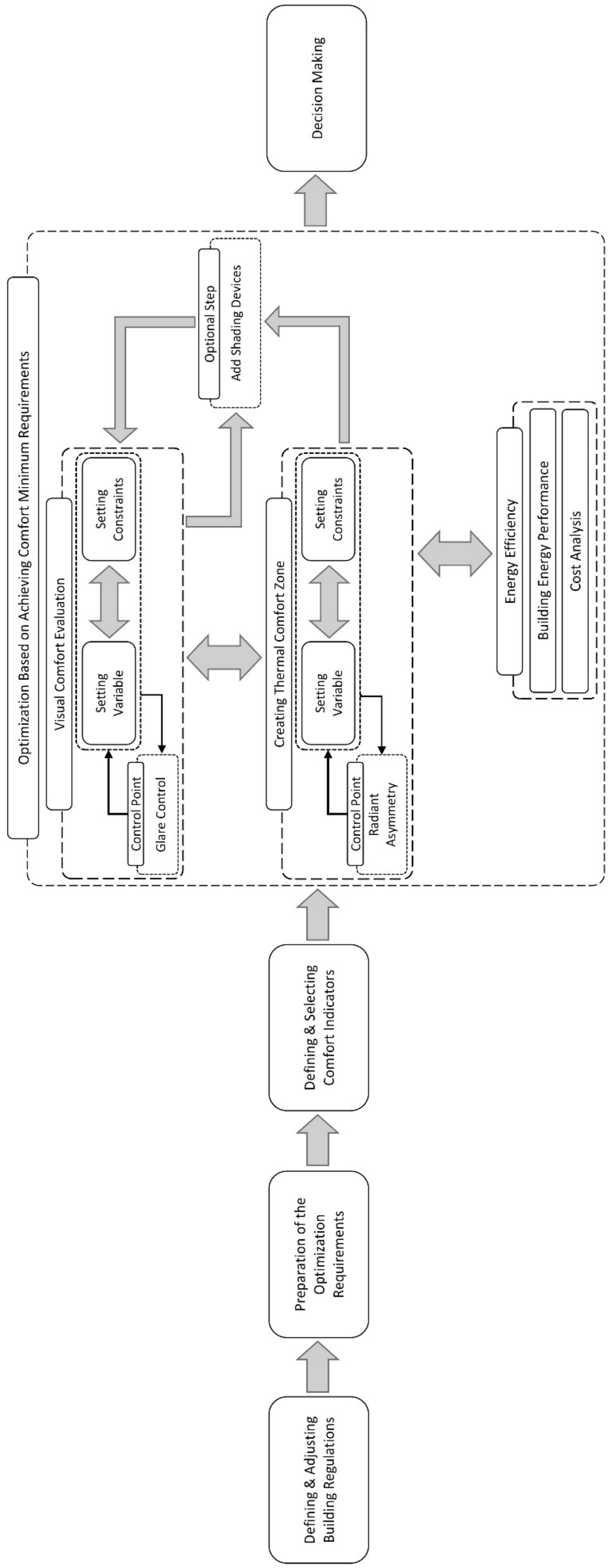


Figure 21: Proposed Model for Design Stage in Brief

Buildings are supposed to keep indoor environments permanently comfortable and healthy, with regard to various outdoor climate conditions. This issue requires heating and cooling energy demands in addition to high energetic performance of buildings' envelopes. Therefore, buildings cannot be considered as a single box with mechanical air conditioning systems. However, they should be able to spontaneously adapt themselves to a variable outdoor climate. In other words, a building context must be considered in design process.

This is due to the fact that buildings are dependent on various outdoor conditions like; solar irradiation, atmospheric pressure, air temperature and humidity, amount of precipitations, wind velocity and directions, and so on. In other words, in design stage, the initial decisions have been made based on the conceptional idea and some other limitations. In this stage; there are some possibilities to change building form, geometry, layout and so on. Therefore, through minimum range of changes in architectural ideas we can consider environmental issues in this level easily.

However, in pre-design stage, several scenarios and alternatives have to be tested and results should be prepared and proposed as charters to be used for architects. This issue is not mainly considered in this dissertation, because of the time limitation on one hand and this fact that the author as an architect does not want to block designers' creativity by dictating them fixed results, on the other hand. Also, it should be considered that applying the optimization model in pre-design stage does not eliminate the necessity of repeating it in design stage. It is recommended to iterate the process in design stage in order to be able to consider the probable effect of different parameters on each other in this level.

Therefore, in this study, it is tried to more concentrate on design stage, by proposing and describing the idea to understand the effects and relations of different variables on each other. Thus, they can do the optimization by defining their own priority. The author believes that this is a more tangible and applicable way for architects to consider comfort criteria by optimizing energy usage simultaneously. In other words, applying this methodology in design stage shows more respect to designer's ideas and technical comfort requirements at the same time.

In an existing building, it is possible to revise and improve building current situations, but it is not really possible to change its properties. This stage is really important because in construction sector, most buildings already exist, and normally are only renovated. Thus, they are playing the main role in building industry and energy performance. As indicators, which can be adjusted, are fewer in comparison with other stages, and they can be varied case by case. This scenario is not concentrated on, in this dissertation as well and can be done as further studies.

Furthermore, it should be noted that digital platforms provide new ways to lead architects build high-energy-performance projects, utilizing smart and efficient guided design exploration methods. Optimization algorithms are a common approach, primarily because they have the requisite capabilities to generate or discover successful solutions; nevertheless, such approaches typically require for a limited amount of user engagement through actual optimization or decision-making. Normally, optimization algorithms generate solutions according to performance criteria and do not focused on any understanding of design. As it is extremely doubtful that a designer would actually approve a design created by an optimization algorithm, an alternate solution would be a more dynamic search process, which would accept input from a designer and grant the designer a larger degree of control.

In this respect, an alternate method of achieving the above-mentioned popups and designing a system for recommending the optimum degree of comfort; as a case of optimum ratio of transparency and insulation level in terms of achieving both thermal and visual comfort gains from the parametric design thinking framework, suggested by considering the missed points and shortcomings of current approaches. The key purpose of the proposal is to connect philosophy and reality by taking existing tools and methods into the design procedure framework and developing a formal way of thought and planning for computational and parametric architecture, which would be relevant to contemporary architectural design.

In this case, beside the others, this methodology tries to develop previous ones by combining all various parameters from three different aspects, as thermal comfort, visual comfort and energy efficiency at the same time. As a final result, two different alternative optimization technics have been proposed. The first one is a figure (figure 3), displaying the whole process and can be used as a guideline to be considered by architects in different design stages. And also figures 4 and 7, which show the process with more details. This one can be a base to be considered in design process. Or it can be used as a check point to evaluate the various affecting parameters and indicators.

The second one, is in digital format. In this one, it is tried to present the proposed methodology in grasshopper as a kind of digital model, which can be applied in different cases. This model gives the users the opportunity to set different variables based on the regional regulations' recommendations. In this case, it can be tested for a certain case study or as a general study to compare different alternatives or adjusting and editing new standards. However, working with it needs initial computer knowledge. In other words, simulations are performed to obtain indoor comfort and building energy demands. Finally, the mentioned methods (both presented techniques), lead the researcher to propose a standard method, which can be applied on buildings with various functions, locating in different climates in order to assess the optimum amount of the energy performance, visual and thermal comfort simultaneously.

This method examined the general approach, which might be considered to optimize building energy efficiency by considering thermal and visual comfort criteria. Therefore, it can be used as a guideline or pathway for optimization, but details, such as effective indicators can be changed case by case and based on the regional requirements. It is also possible to adapt different steps details, such as cost analysis by common usable techniques for each region.

Meanwhile, this methodology is examined and tested in chapter four. Observing results display some differences in case of relation of thermal and visual comforts, which are more highlighted in visual parameters, which have been recommended to be considered in upcoming standards and regulations. It should be mentioned that, in general, this method tries to show the neglected role and importance of daylighting in buildings' design. In this case, it proposes that at the first stage, minimum level of visual comfort from natural sources must be reached. Then, thermal comfort affecting factors have been optimized according to more updated methods. In each level, some test points are considered to be compared with customary used methods. Later, cost analysis applied to complete the optimization process by selecting the best possible solution.

Likewise, building makers may decrease energy costs, GHG emissions and other environmental impacts by developing the following systems and processes required to increase energy performance including energy usage, efficiency and intensity. Thus, the suggested method encourages architects to take a comprehensive approach to continually increase energy efficiency and emission control, demonstrating their commitment to energy and environmental management systems, and simultaneously attaining thermal and visual comfort. Improved energy performance provides rapid benefits for the building industry by decreasing both energy consumption and costs.

Furthermore, at the first step, this study documents a set of in-depth analysis in current literatures in case of building energy performance, thermal and visual comfort parameters and tried to categorize them in tangible groups in a single table. Also, it tried to do a survey on available thermal comfort, visual comfort and optimization techniques and models, in order to validate the current situation and find the missing points, which its results are presented in the separate tables. This information can create a database for continuing and starting new researches in this field.

Meanwhile, this study starts with the aim of optimizing building envelope performance according to energy efficiency, thermal and visual comfort. In this regard, it tried to develop a new model to be a pioneer in creating a reference building envelope for architects by proposing a step by step, systematic evaluation method. In order to clarify and also evaluate a methodology, it is applied to the case in Famagusta, Northern Cyprus. However, based on the research limitations only some features of the method have been examined here. Therefore, the whole proses can be examined in later researches, whether for the same location or other parts of the word.

In other words, it can be claimed that this study tried to develop a method, which can be considered as a tool or a pathway for improving energy performance, while thermal and visual comfort circumstances have been obtained as well. In this regard, there are lots of variables and parameters in building envelope, such as materials' thermal heat gain that can be highlighted separately in the evaluation method. However, based on the research limitation and in order to make the process more understandable, they are not illustrated in the methodology. But these parameters have been automatically considered in simulation parts and entered as an input. It should be remarked in order to make the proposed model more flexible; some empty boxes have been considered in the methodology, create the ability for adding optional parameters based on the evaluation requirements and can be evolved and improved in further studies.

These results can be benefited to create a guideline for architects to design buildings' envelope. They can be proposed as separate charts, displaying building envelope elements performance separately or as a comparison of multi-variables. These graphs/ charts/ tables can be prepared and proposed for defined proposals or ready scenarios in a certain location. Therefore, they can be prepared to be used as a charter in countries regulations. This idea can be applicable especially for pre-design stage. In this level of design, charters can be used as an initial guideline or basic set points for starting a design.

On the other hand, currently, a significant number of simulation programs have been developed to evaluate the building output via the technology advancement. In this case ‘grasshopper’ is selected as a multifunctional software, which is able to do multi-objective optimization. This method has been adapted and developed in the program and can be used for different scenarios and cases. In this regard, it can be used for specific cases, whether in design stage or for existing building, and it is able to analyze requested building elements performances. However, in order to be more user friendly, the method can be developed as a kind of plug-in for the program.

Another way of developing and benefiting from the method is checking the results and calculating them for each square meter. In this case, it is also possible to compare and adapt the building, based on the passive design standards or other regulations and certifications like LEED. But, in this research it was not the main concern of the study.

In other words, the audience of the results of this model can be standards and regulation organizations, and even building energy simulation tool developers, which both need methods to certify building performances. Nonetheless, the ultimate and final beneficiaries of the study are tool users such as architects, developers, energy suppliers and consultants, engineers, product manufacturers and building owners, who will be informed through targeted reports, charters and software plugin.

In this case, it will be much easier for further development to test; different scenarios such as 24hours ventilated buildings, defining yearly free-run period, mixed use mood and so on, for building with different functions in different locations and climates. Meanwhile, each scenario can be considered as a part of bigger data bank for creating national building energy regulations. Moreover, these data can be organized to develop new approaches to propose reference buildings, especially for countries such as Northern Cyprus, suffering from lack of such approaches.

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