ENERGY AND ENVIRONMENTAL PERFORMANCE BASED DECISION SUPPORT PROCESS FOR EARLY DESIGN STAGE OF RESIDENTIAL BUILDINGS

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Architecture

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July 2016
İZMİR

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ACKNOWLEDGEMENTS

I would first like to thank my thesis advisor Dr. Zeynep Durmuş Arsan, since she allowed this study to be my own work, but steered me in the right the direction whenever she thought I needed it.

I would also like to thank the expert who was involved in the usability survey for this research project: Serdar Bolposta from SRD Architecture and Project Management Office. Without his passionate participation and input, the survey could not have been successfully conducted.

I am equally grateful to Assoc. Prof. Dr. Christian Struck and Assoc. Prof. Dr. Liam O'Brien for their contributions with their important reviews, informative comments and guidance about energy simulation and analyses stages of this thesis.

Most importantly, I must express my very profound gratitude to my parents Kemal, Kalbiye, and my brother Hüseyin Gerçek for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. None of this would have been possible without the love and patience of my family. You have been a constant source of love, concern, support and strength all these years, thank you for letting me be myself.

Last but not the least, I am very thankful to "Tüm" for making me feel his existence around me all the time with an endless patience and encouragement in spite of my unbearable grumpiness. Thank you for your endless support in my academic and personal life. My thesis would not have been completed without your efforts and accompaniment.

ABSTRACT

ENERGY AND ENVIRONMENTAL PERFORMANCE BASED DECISION SUPPORT PROCESS FOR EARLY DESIGN STAGE OF RESIDENTIAL BUILDINGS

Deficiencies in systematic approaches for design decision support to increase energy and environmental performance of buildings in Turkey are projected as the major problem of this study. Rare usage of computational methods for evaluating and improving building performance, need for informational assistance in design, as well as lack of interaction between systematic knowledge and building practice are the secondary problems.

This thesis mainly aims to test usability of the decision support process assisting architects in early design stages of residential buildings. Assessing the uncertainties in building performance caused by design parameters and climate change, in terms of determining the most significant parameters on annual energy consumption for heating, cooling and operational CO_2 emissions in hot humid climatic region of Turkey is the significant objective of the study.

The relation between input parameters and building performance indicators is examined by the uncertainty and global sensitivity analyses for a residential building in İzmir, Turkey. The process is supported by usability testing held with the architect in practice.

The results indicate that, the sensitivity between input and output parameters changes according to the projected weather conditions and different floors of the building. The SHGC of windows on south-west, north-east facades, and window U values are the most effective parameters on energy and environmental performance. The proposed decision support process is approved to be applicable for early design stages of the selected building, and helps creating consciousness about the importance of systematic design decision approach for the building professional.

ÖZET

KONUT YAPILARININ ERKEN TASARIM AŞAMASI İÇİN ENERJİ VE ÇEVRESEL PERFORMANSA DAYALI KARAR DESTEK SÜRECİ

Türkiye'deki binaların enerji ve çevresel performansını arttırmak için kullanılan tasarım karar desteğindeki sistematik yaklaşım eksiklikleri, bu çalışmanın ana konusu olarak ele alınmıştır. Bina performansının değerlendirilmesinde ve geliştirilmesinde sayısal yöntemlerin nadiren kullanımı, tasarımda bilgilendirme desteğine duyulan ihtiyaç ve sistematik bilgi birikimi ile yapı uygulamaları arasındaki bağlantının kurulamaması, ikincil sorunlar olarak görülmüştür.

Bu tez esas olarak, erken tasarım aşamasındaki konut yapılarında mimarlara yardımcı olan karar destek sürecinin kullanılabilirliğini test etmeyi amaçlamaktadır. Türkiye'nin sıcak ve nemli iklim bölgesinde bulunan, erken tasarım aşamasındaki konut yapılarının yıllık ısıtma, soğutma tüketimi için harcanan enerji ve kullanıma ait karbondioksit salınımındaki en etkili parametrelerin belirlenmesi açısından tasarım parametreleri ve iklim değişikliğinin bina performansı üzerinde yol açtığı belirsizliklerin hesaplanması bu çalışmanın önemli bir hedefidir.

Tezde, girdi değişkenleri ve bina performans göstergeleri arasındaki ilişki, İzmir, Türkiye'de bulunan bir konut yapısı için belirsizlik ve kapsamlı hassasiyet analizleri kullanılarak incelenmiştir. Bu süreç, piyasadaki bir mimar ile yapılan kullanılabilirlik testiyle de desteklenmiştir.

Sonuçlar, girdi ve çıktı parametreleri arasındaki hassasiyetin, öngörülen iklim koşulları ve binadaki farklı kat seviyelerine göre değiştiğini göstermektedir. Güney-batı, kuzey-doğu cephelerindeki pencerelerin güneş ısısı kazanım katsayısı ve pencerelerin U değerlerinin, enerji ve çevresel performans üzerindeki en etkili parametreler olduğu ortaya çıkmıştır. Önerilen karar destek sürecinin, seçilen yapının erken tasarım aşamalarında uygulanabilir olduğu onaylanmış ve sistematik karar destek yaklaşımının önemi konusunda yapı uzmanı üzerinde bir farkındalık yaratmaya yardımcı olduğu gözlenmiştir.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AC	: Air Conditioner
AAC	: Autoclaved Aerated Concrete Block
BEP-TR	: Regulation of Energy Performance of Buildings (Bina Enerji Performansı Hesaplama Yöntemi)
CO_2e	: Carbondioxide equivalent
DSM	: Dynamic Simulation Modelling
EPBD	: Energy Performance of Buildings Directive
EPC	: Energy Performance Certificate
EU	: European Union
FAST	: Fourier Amplitude Sensitivity Testing
GHG	: Greenhouse Gas Emissions
HVAC	: Heating, Ventilating and Air Conditioning
IDF	: Input Data File
IPCC	: The Intergovernmental Panel for Climate Change
LHS	: Latin Hypercube Sampling
OAT	: One Parameter at a Time
PHIUS	: Passive House Institute US
SI	: Sensitivity Index
SHGC	: Solar Heat Gain Coefficient
SPEA	: Spearman Coefficient
SRC	: Standardized Regression Coefficient
SRES	: Special Report on Emission Scenarios
SRRC	: Standardized Rank Regression Coefficient
TRNSYS	: Transient System Simulation Program
U value	: Heat transfer coefficient

CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Increasing energy demand together with environmental problems resulted from global warming and climate change have accelerated the global attraction about energy and environmental issues. The most effective solutions of these problems are mainly provided by decreasing energy consumption and greenhouse gas (GHG) emissions.

Most of the total energy consumption is originated from buildings. For instance, it is indicated in the report published in 2013, by The Turkish Ministry of Energy and Natural Resources (MENR, 2013) that, residential buildings are account for 35.11% of energy consumption in Turkey (Figure 1.1.). Moreover, total CO_2 equivalent GHG emissions increased 125% from 1990 to 2014, while energy consumption covers 67.8% of total releases according to 2014 statistics (Figure 1.2.). Therefore, particular importance is given to building sector because of its potential to diminish the global problems. In fact, building design decisions affect energy consumption features of the building throughout its entire lifespan. They may be involved with different stages of design from initial steps to retrofitting of existing buildings. At that point, it is stated that, decisions in earlier stages of design are even more significant to reach projected performance goals (US Energy Information Administration, 2011).

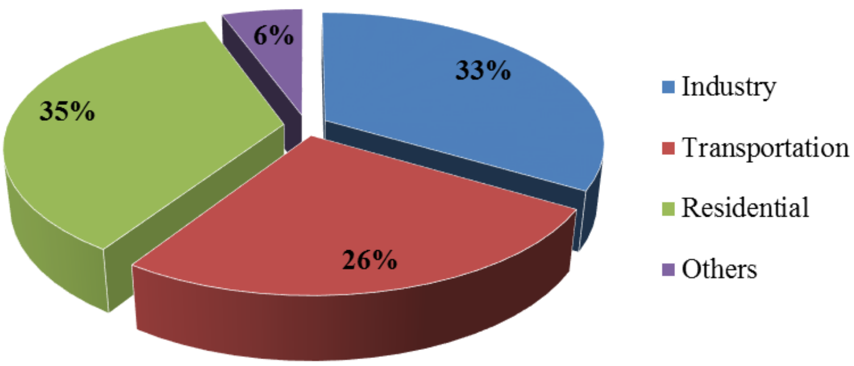

Figure 1.1. Turkey's total energy consumption by sectors
(Source: MENR, 2014)

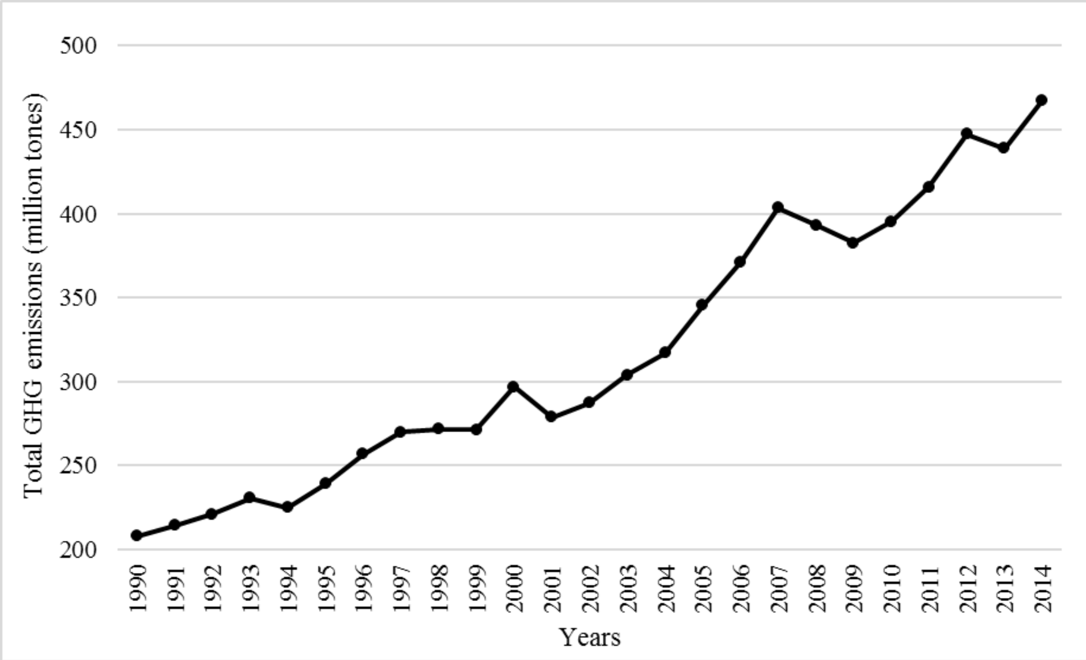

Figure 1.2. GHG emissions of Turkey between 1990 and 2014 (TUIK, 2014)

The concept of sustainable design has become a global medium, by which architects aim to meet human needs while preserving the environment. The architect has enormous task in the field of sustainability, since design involves systematic planning, dealing with creativity, functionality, aesthetic and economy. Sustainability in architecture is about minimizing the negative environmental impact of buildings by improving efficiency and moderation in the use of materials and energy, and space setup. Accordingly, many countries have already established laws and institutions subjected to climate change, energy savings and reduction of CO_2 emissions. Even though, there are few official attempts for increasing buildings' energy performance in Turkey, such as specifying minimal U values for different components of building envelope or initiating energy certification scheme, namely BEP-TR, to standardize energy consumption of new and existing buildings; they do not ensure designing energy efficient and environmentally friendly buildings solitarily. The architects should have certain knowledge and experiences; and consultancy may be required occasionally.

Architects in practice, however, may not have full of knowledge, or comprehend all parameters simultaneously, since design and construction is an imperfect process with a variety of inherent uncertainties, so that the importance of design decision support arises, as well. The connection between design decision assessment systems and architects in practice is poorly developed for design industry in Turkey. Especially, early stages of design are mostly proceeded with almost no consultancy for decision support about energy and environmental analyses. Instead, concerns of conceptual stage are mostly related with aesthetical issues.

The interaction of perspectives between academia and building professionals, i.e. architects in practice, may be increased by including academic experts into decision support procedure during early stages of sustainable building design, and by sharing overall information frequently via organizing meetings, interviews etc. Therefore, the necessity, or even lack, of knowledge of building professionals for sustainable building design may be covered. The possibilities of developing a sustainable project may increase the positive or negative feedbacks from decision support sessions. In addition, the more information is obtained, the more interference in design procedure is enabled by the project participants. The design quality may be increased by project assessment and comprehensive support of the institution providing consultancy.

Energy efficient and environmentally friendly design process requires more knowledge, multidisciplinary and collaborative environment when compared to conventional methods. Multiple design parameters should be handled simultaneously through an integrated design process, which requires an interdisciplinary teamwork including employer, architect, engineer, energy and environmental analyses experts, contractor etc. Design quality requires to be improved by different professions in order to reach to a certain energy and environmental performance level.

Building performance is not only affected by multiple design parameters, but the interaction among these variables are also involved with building operations. Consequently, it gets significant to examine the interaction among each input parameter, and relation between input and performance indicators, in order to obtain further knowledge about more significant parameters on building performance. Therefore, decisions for energy and environmental performance based design should have been made in terms of highlighting the most effective design parameters peculiar for each project.

The help of computational methods is essential for the quantification of design parameters' effect on building performance. They may improve the ability to predict consequences of changes in parameters, i.e. risks or potentials, that may result in. Yet, the complexity of relation between building performance indicators and design parameters could not be effectively examined throughout simplified calculation procedures. Recently, there is a demand for building performance simulation tools because of their ability of evaluating multiple parameters simultaneously, and providing opportunity to develop energy saving solutions.

Design decision process has impacts on overall performance of the building during its design, operation and maintenance phases. Since the lifespan of buildings are accepted as approximately 60 years; not only the recent behavior of buildings, but also energy and environmental performance in future is to be included in detailed, systematic analysis procedures. Long term concerns such as weather conditions affected by climate change have also high impacts, as much as short term arguments. Hence, there is a need for considering life-cycle operations of the building with regard to long term uncertainties throughout the building performance assessments in design process.

In conclusion, deficiencies in systematic approach for design decision support in order to increase energy and environmental performance of buildings in Turkey is projected as the main problem of this study. There is the need for informational assistance in different stages of sustainable design in Turkey, since design decisions are often based on experiments and intuition, rather than quantitative prediction of performance indicators. Furthermore, the insufficiency in evaluating building performance depending on rare computational method usage, as well as lack of interaction between systematic knowledge and building professionals are secondary problems in terms of design decision process.

1.2. Aim, Scope and Objectives of the Study

This thesis mainly aims to test usability of the decision support process assisting architects in early design stages of residential buildings. Assessing the uncertainties in building performance caused by design parameters in terms of determining the most significant parameters on annual energy consumption for heating, cooling and annual operational CO_2 emissions in hot humid climatic region of Turkey is the primary objective of the study.

The performance indicators for energy efficient and environmentally friendly design are selected as annual energy consumption for heating and cooling, and annual operational CO_2 emissions of buildings. The utilization of building performance simulations for increasing design quality, clarifying the impacts of uncertainties on building performance indicators, and sharing systematic information with building professionals during early design stage are the main subjects of this thesis. These aspects are achieved by collecting information about the impacts of selected design parameters on energy and environmental characteristics of the case building.

Energy consumption for heating in housing stock covers around 30% of the total energy consumption of Turkey (Altaş et al. 1994). Accordingly, housing industry plays an essential role for energy efficiency in buildings. It was the reason of selecting the case building as the residential block. It is specified by considering common design properties of existing and ongoing housing projects in İzmir, Turkey. Then, the mid-rise residential building in early stages of design is specified for the case study with help of the selected architectural office, and several discussions with its architect.

The objectives to accomplish the aim of thesis are stated as follows:

- Investigating the integration and importance of building performance practice in early stages of residential building design
- Discovering types of building performance evaluation methods and variety of building performance criteria
- Analyzing the importance of building performance simulations on design processes
- Evaluating the impacts of climate change on building energy and environmental performance characteristics
- Analyzing building performance improvement based design decision support systems
- Revising uncertainty and sensitivity analyses methods integrated with building performance simulations
- Discussing the effects and significance of uncertainty and sensitivity analysis on design decision process
- Synthesizing the correlation between building energy and environmental performance criteria and design parameters, as well as classification of these parameters according to significance levels on performance criteria
- Investigating current status of relation between building performance simulations and the people involved with design process (designers, stakeholders, engineers, clients etc.)
- Revising the presentation techniques of results acquired from the analyses of building performance criteria and relations among design parameters

- Investigating different approaches to test usability of the results, and selecting the appropriate method for creating interaction between systematic knowledge and building professionals
- Assessing the architect's perspectives in terms of building energy and environmental performance simulation, uncertainty and sensitivity analyses, and decision support processes
- Exploring feedbacks of the architect with regard to the information about the most effective parameters on building energy and environmental performance and possible alternatives for improving design decisions

1.3. Research Methodology

There are several methods applied in this thesis to support architects for design decision process in early stages towards improving building performance characteristics. The general structure of thesis research methodology is separated into three parts as pre-processing, simulation, post-processing, and illustrated in Figure 1.3.

The research starts with conducting the literature review to investigate the state of the art in building performance and sensitivity analysis method in design. The insight into building performance analysis tools, building performance indicators, and evaluation of various uncertainty and sensitivity techniques in design practice have been scrutinized in terms of specifying scope and limiting the study. In addition, literature survey was conducted for defining the contributions of this thesis to the existing literature (see Chapter 2).

Three meetings are arranged with Serdar Bolposta, the architect of SRD Architecture and Project Management Office, to conduct the study of design decision support with the building professional. Interviews, questionnaires and presentations are held for each discussion. First meeting was before pre-processing, second interview after the simulation and the last discussion at the end of the post-processing.

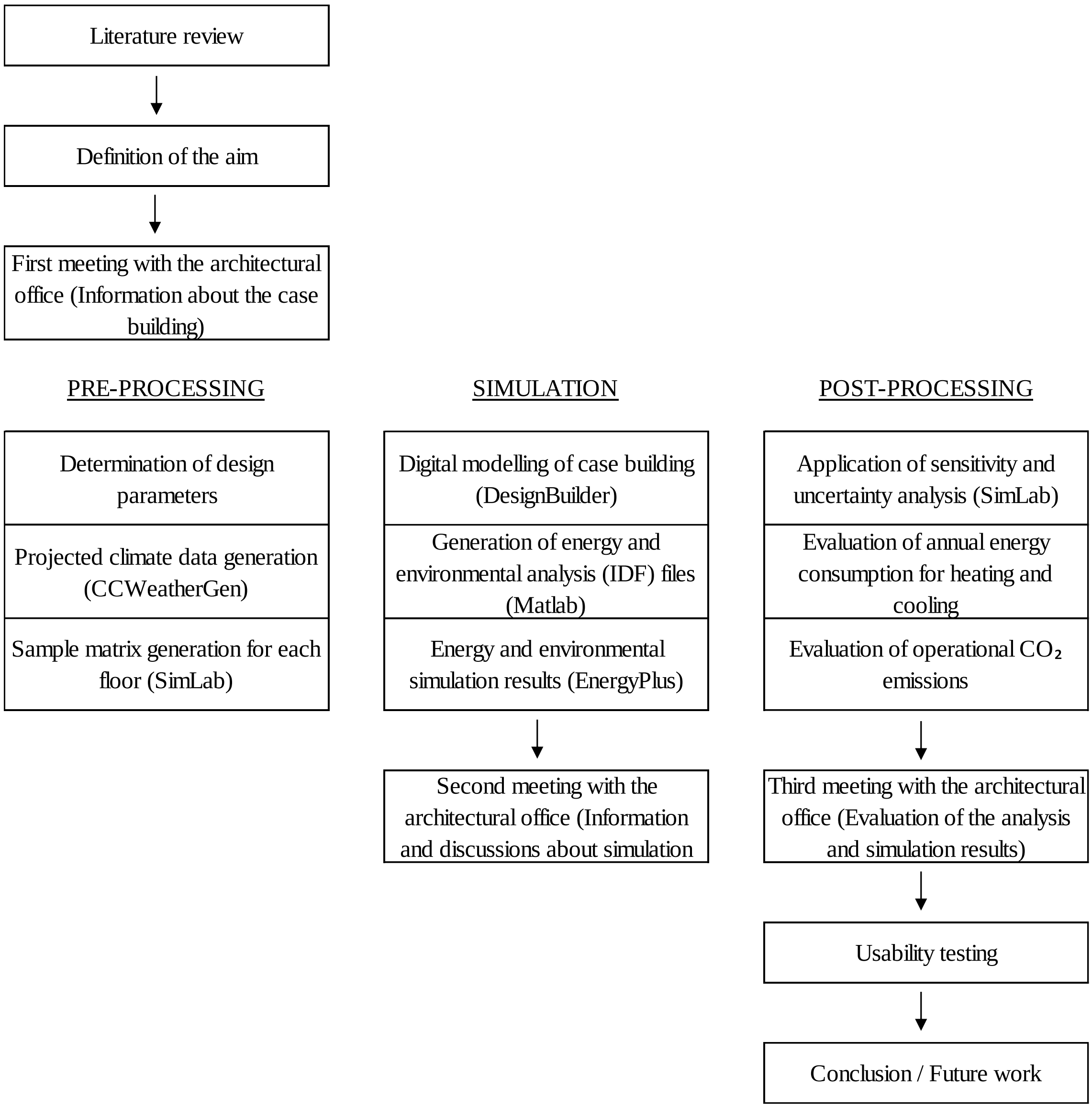

Figure 1.3. Workflow of the research methodology, used in the thesis

Pre-Processing: The design parameters, affecting energy and environmental performance of the building, are specified with the help of literature search and considering current situation of the building. Yet, the parameters related to architect's conceptual design decisions, such as orientation, space organization etc. are eliminated for limiting the number of input parameters.

At the same time, climate projections, possible thermal and environmental behavior of building in near future, are investigated. The climate change weather file generator (CCWeatherGen) has been used for the future climatic data generation, i.e. weather data for the 2020s, 2050s and 2080s. It enables generating climate change weather files ready for use in building performance simulation programs. The underlying weather file transformation routines of this tool are based on the so-called ‘morphing’ methodology for climate change transformation of TRY/DSY weather files. Besides, 400 input sample matrix covering simultaneous variations of design parameters are generated by using SimLab, in order to search for impacts on energy analysis results during sensitivity analysis. SimLab is a free software providing development model for sensitivity and uncertainty analyses (see Section 5.2.).

Simulation: Afterwards, computational modelling of the mid-rise residential block, located in Çiğli, İzmir is created. The digitalization of building is executed by the dynamic performance simulation program, DesignBuilder v.4.2. It is used to generate IDF files, suitable for external simulation environments such as EnergyPlus. Then, the Matlab software is selected for generating IDF files from digital model of the building. The sample matrix collected from the SimLab and two IDF files of the top and intermediate floor exported from DesignBuilder are used in data generation process. The Matlab automatically transforms each sample matrix into files compatible with selected energy analysis program for the next step. The total amount of documentation includes extraction of 200 sample files for each floor (400 sample files for the top and intermediate floors), and 400 different sample files for each climatic condition (see Section 5.3.).

Energy and environmental analyses process is conducted by EnergyPlus v. 8.1.0.009 dynamic simulation modelling program. The simulation outputs, i.e. annual energy consumption for heating and cooling, are organized in the Excel format to calculate annual operational CO_2 emissions, multiplied by specified coefficients in Turkey, for operational values of CO_2 emitted from related power plants.

The second presentation was held after finalizing digital modelling of the case building. This second meeting was in February 10, 2016 with around one hour of briefing composed of 34 slides through PowerPoint presentations. The content of the meeting included brief information about building performance simulation tools, case specific usage of the selected program and uncertainty/sensitivity analyses methods. The feedback is also received in terms of usability of the information.

Post-Processing: The key point of the thesis is accepted as uncertainty and sensitivity analyses to support design quality in terms of building performance. The SimLab program is utilized for uncertainty and global sensitivity analyses by using specified input parameters with output factors as annual consumption for heating, cooling and operational CO_2 emissions. Various graphics which indicate the input-output relations, estimated annual energy consumption characteristics of the building and design decision support scenarios, for now, 2020s, 2050s and 2080s are created in the Excel software.

The most remarkable results of this process are the indication of most sensitive parameters for building performance, changing trends in annual energy consumption for heating and cooling, and CO_2 release of the building in time (recent, 2020s, 2050s, 2080s). Moreover, the rate of improvements in performance indicators and payback periods are calculated for the most effective parameters collected from the simulation and analysis results (see Chapter 6).

The next step is the usability testing of method, both to evaluate analyses results proposed scenarios, and get feedbacks in terms of positive and negative aspects of the entire process. Hence, third meeting is organized with the architect in April 6, 2016. It included the discussions about performance simulation and analyses results, as well as the proposed design support scenarios. Overall discussion lasted around two hours with 21 slides of presentation and a questionnaire of 11 questions. Questionnaire and presentation are conducted over assessment, evaluation of performance simulation results, and proposed design support options, at the end. Ultimately, whole methods and proposals are discussed by a questionnaire including 11 questions. Suggestions are received in terms of usability of the collected information, as well as acceptable aspects of the entire study.

1.4. Limitations and Assumptions

During this study, there have been some limitations and assumptions arising from several sections of the overall methodology of the thesis. Namely, the limitations are caused by determination of design parameters, dynamic building performance software and usability testing processes. Moreover, some assumptions are required in terms of detailing process of digital building model, since the case residential building is in early design stage and not built, yet.

Determination of input parameters are specified according to current design phase of the building. In fact, it was not possible to make direct modifications for every parameter in DesignBuilder dynamic building performance software, specified for the study. For example, window to wall ratio has been one of the design parameters to be eliminated, since the program does not have the direct tool about this feature. Besides, overhang was selected for the shading element as a design parameter instead of blinds. Difficulties in the simulation program DesignBuilder caused integration of overhangs in EnergyPlus, as well.

Simulation phase of the design decision support process includes some limitations and assumptions. Initially, simplifications in floor plans of the building were required because of increasing simulation duration in EnergyPlus. The building is assumed to be unoccupied for the digital model. Besides, thermal properties of the selected floors are arranged by specifying heat exchange as adiabatic to prevent unpredicted energy consumption values.

DesignBuilder is not capable of conducting multiple simulations simultaneously, so that EnergyPlus software is also included. Calculation of operational CO_2 emission properties of the building are handled manually in order to collect more proper results, since DesignBuilder software does not provide the emission factors of Turkey.

Usability testing process of the study contains three meetings only with the architect. The excessive amounts of workloads of the office created restrictions in durations and numbers of the meetings.

1.5. Thesis Outline

The thesis is structured in eight main chapters. The contexts of each chapter are explained as follows:

The first chapter includes the general framework of the thesis. Initially, the state of the art and importance of the study is pointed out. Then, problems related to the area, aim, scope and objectives, and methods used during the research are clarified.

The second chapter presents background of the study, existing research efforts in the analysis, assessment and implications of building energy and environmental performance through professional works. In addition, effects of usability testing with building professionals in terms of design decision support are investigated through previous studies. The problems and deficiencies in the literature are evaluated at the end of this chapter.

The third chapter introduces the issue of performance analysis in design. Overall information is stated with regard to common performance analysis tools, effects of climate change on the performance of buildings, and importance of building performance simulations in design assessment.

The theory related to the subjects of uncertainty and sensitivity is presented in the fourth chapter. An insight is given in different types of uncertainty, sensitivity analyses and various measurement techniques, as well as applications of the analyses in building design area.

In the chapter five, the project selected for this research is evaluated. After describing the mid-rise residential block as the case building, three stages of the model are implemented. Firstly, decisions of input parameters, generation of projected weather files and sampling procedures are executed as pre-processing. Then, digital model of the building is created for energy analyses. Energy and environmental simulations according to four different climate conditions are performed by using the digital model. Finally, the uncertainties and sensitivities of the project are carried out.

Subsequently, the results of the case study focusing on different groups of uncertainties and sensitivities of design parameters in the use of building performance simulation are presented and evaluated in the chapter six.

The chapter seven summarizes the feedbacks gathered from meetings, interviews and presentations with the architect to investigate usability of the study in terms of correlating the systematic knowledge and practical experience of building professionals.

Finally, conclusions and possible further studies are summarized in the chapter eight, as well as presenting recommendations for future challenges in the research era.

CHAPTER 2

LITERATURE REVIEW

The realities of global warming and increasing energy demand have revealed the need for holistic environmental solutions, hence both global and local efforts have accelerated. It is the fact that, huge amount of consumed energy is originated from the built environment. Building design is a complex process; including not only aesthetical issues, but also many factors to be thought in order to meet physical, environmental and user centered requirements. The quality criteria for sustainable building design has a wide range from conventional performance indicators, e.g. material durability, occupant comfort, structural performance, cost efficiency, environmental performance etc., to the most recent subjects such as near zero energy consumption, energy plus structuring, carbon zero buildings/cities etc.

There has been ongoing research for improving the performance of existing and buildings in the design stage by developing and integrating new techniques into building sector. Under the general topic of building energy performance, broad range of research areas exist such as constitution of guidelines, regulations and tools, studies of relation between environmental conditions and existing buildings, retrofits and/or replacement for nonrenewable energy sources, and lower amounts of CO_2 emissions of existing buildings. Actually, these considerations canalized the entire world, especially The European Union (EU) to generate and apply immediate action plans. Many legislative regulations exist, in terms of increasing building performance in existing and new buildings. The Directive on Energy Performance of Buildings (EPBD-2002/91/EC) aims to create a common methodology for evaluating energy performance of the buildings, and set certain standards (EU, 2002). According to these objectives, the member states of EU established the national regulations and building energy certificate procedures. Then, this directive was revised, in terms of achieving zero energy building concept, and published in 2010 with the recall of “EPBD recast” (EU, 2010).

Meanwhile, Turkey has officially taken considerable steps in accordance with the building performance, even though it became widespread for only thermal insulation in buildings in Turkey. Thermal Insulation Requirements for Buildings (Binalarda Isı

Yalıtım Kuralları-TS 825), released in 2000, is the standard proposing the calculation procedure for heating energy consumption of buildings (Turkish Standards Institute, 2008). There had been revisions in the regulations to comply with the EPBD published by the EU. Thus, EPBD (Binalarda Enerji Performansı Yönetmeliği) went into operation in 2008 (The Ministry of Public Works, 2008b). The directive basically aims to define a methodology to calculate the whole energy use of buildings, to label the primary energy consumption and CO_2 emissions of the buildings, to determine the viability of using renewable energy sources, to inspect the heating and cooling systems in the buildings, and to restrict the CO_2 emissions. In accordance with the Regulation in 2008, The Building Energy Performance Calculation Method (Bina Enerji Performansı Hesaplama Yöntemi, BEP-TR) has been developed to evaluate energy consumption for heating and lighting, and classify the building energy ratings, in 2011. According to the regulations, annual energy consumption amounts and CO_2 emission values of entire buildings should be calculated with BEP-TR, and Energy Performance Certificate (EPC) should be defined according to the consumption value classifications. EPC gives general information about a variety of topics, such as building area, energy performance classes, GHGs, and annual energy consumption for heating, ventilation, hot water, and lighting of buildings. Buildings constructed before 1 January 2011 are defined as existing buildings, and those constructed after are defined as new buildings. In the EPC system, the energy classification of buildings is based on five classes, from A to G. Class A refers to the lowest energy consumption and class G refers to the highest energy consumption. The energy performance classification of new buildings has to be at least class C, or better.

The main objective of the report of ‘Climate Change Action Plan 2011-2013’, published by The Turkish Ministry of Environment and Urbanization in 2012, is to participate in fight against climate change and global efforts specified with scientific findings in cooperation with international parties under the specific conditions of Turkey (The Ministry of Environment and Urbanization, 2012). It aims series of actions in terms of increase in thermal insulation applications and use of energy efficient systems in commercial and residential buildings. Developing projects which can provide financial aid for energy efficiency actions, supporting energy efficiency, identification of Energy Performance Certificate of entire existing and new buildings until 2017, to ensure decrease in annual energy consumption at least 10% until 2015, and 20% until 2023, supports for integrated building design approaches, as well as zero carbon buildings (The Ministry of Environment and Urbanization, 2012) are additional aims of the report.

2.1. Building Performance Assessment

The evaluation and improvement of energy and environmental performance require bringing out different outlook into design process of new buildings or retrofits in extant buildings. This primarily involves the assessment of relationship among building design parameters, and energy and environmental performance of the building. Here, ‘performance assessment’ specifies to the qualification of building performance according to these relations. It relies on such performance indicators as energy consumption for heating or cooling, operational CO_2 emissions, cost efficiency, and thermal comfort applied into projects still in design process, or an existing building. The assessment process is formed by previous experiences and usage of design guidelines, as well as the dynamic simulation modelling (DSM) software, aspiring estimation of building performance in early stages of design.

2.1.1. Building Performance Simulation Tools

Building designers use several calculation methods to quantify the performance of buildings. This systematic yet static information functional for increasing design quality manually, until the development of reliable computational simulation tools. The building performance simulation method is conducted by dynamic simulation tools to investigate the relationship between design parameters and performance of the building in detail. Besides, it is capable of examining the correlation between different building design or retrofit parameters and performance indicators, e.g. energy, environment, cost etc., of the building simultaneously in a systematic way. De Wilde (2004) points out that, building performance simulation tools provide design guidance in terms of numerical results, and offer various options for design process, promote awareness between design alternatives in order to provide decision support, as well as optimization of buildings and/ or systems. It is hypothesized that, more efficient use of building simulation programs during design stages would increase the quality of the end result.

All attempts for increasing design and performance qualities of buildings have accelerated the advances in computerized analysis tools. Thus the development of dynamic building simulation tools has ended up with high levels of modelling capability over the last two decades (Ahn et al., 2013). This enables simulation experts to apprise architects with qualified information in which they previously had to depend on experience, use of simplified calculation methods or application of rule of thumb. Therefore, building design has moved from a “craft-based approach” to a process that comprehends advanced technologies (Lawson, 1990). This can be associated with the view that simulation tools should not only be used for final performance validation but as an integrated element of the design process (Augenbroe, 1992, Mahdavi, 1993).

2.1.2. Building Design Parameters

There are several interrelated parameters during lifespan of the building. These parameters include material properties and availability of building surface elements, openings, shadings and structural or operational properties of the buildings. For instance, Morbitzer et al. (2001) classify parameters according to different building design stages as outline, scheme and detailed (Table 2.1.). Outline design stage includes the subjects considered before building construction, while scheme design is the stage that can be controlled within an existing building. On the other hand, more specific building variables, such as mechanical system are categorized under detailed design stage.

Table 2.1. Parameters of different building design stages
(Source: Morbitzer et al., 2001)

Outline Design Stage	**Scheme Design Stage**	**Detailed Design Stage**
Orientation (appraisal) U-values (opaque and transparent) Heat recovery systems Light/heavy construction Air change rate (appraisal) Space usage Glazing area (appraisal) Floor plan depth Fuel type	Glazing area (detailed analysis) Glazing type Shading and/or blinds Blind control Orientation (small adjustments) Air change rate (detailed analysis) Material adjustment in overheating areas Lighting strategy Cooling required: yes/no?	Different heating systems Different heating control strategies Different cooling systems: • Mechanical • Free Different cooling control strategies Different ventilation strategies

Besides, Hopfe (2009) categorizes design parameters as physical, design and scenario parameters in terms of different impacts on performance of the building. ‘Physical’ parameters indicate material properties of the building, ‘design’ involves decisions taken during design stage, while ‘scenario’ is about uncertain characteristics of design such as occupant behavior and climate changes. Diversification of design parameters occurs because of belonging to different phases of buildings’ lifespan and different design approaches of architects.

Initial building performance based researches mostly focused on investigating the impacts of specific design parameters on energy characteristics in terms of heating or cooling consumptions of the existing and new buildings. Most common examples of the building sector are commercial and residential buildings around the world, thus existing researches on building performance generally involve these building types in order to provide more user friendly and energy efficient design solutions. De Wit (1997) investigated the parameters influencing thermal comfort features of an office building in its design stage. He underlined that, convective heat transfer properties of the roof, floors and walls had the most significant effects on thermal performance of building. In addition, parameters with an impact on thermal comfort are the wind reduction factor, the wind pressure coefficient data set, the deviation of local ambient temperature from the meteo-value and the choice of a model for the internal heat transfer coefficients. The effects of uncertainty in the albedo, the modeling of external heat transfer coefficients and the indoor thermal stratification are less effective, but still of importance.

2.1.3. Uncertainty and Sensitivity Analyses

Analyses for energy performance assessment: Sensitivity analysis is designed to assess how the variations in outputs may be apportioned qualitatively and/or quantitatively to the variations in a set of input parameters, which can be concluded as an ‘input-output analysis’ of a simulation model (Wang, 2014) (see Section 4.2.). The demand for including sensitivity analysis into building performance researches have emerged depending on the needs for more accurate results and ability to conduct more sophisticated analysis. Building performance simulation tools for design support and retrofitting are incorporated in uncertainty and sensitivity analyses.

Lam and Hui (1996) examined an existing office building in terms of 60 design parameters under the subject of thermal load and HVAC systems. Annual cooling consumption and electrical demand of the building are selected as performance indicators, i.e. the outputs. They used a simple 'local' sensitivity test and the simulation tool DOE-2 to examine an office model in Hong Kong. As the variation of each design parameter was considered separately, the study could not quantify complex interactions among design parameters. It was concluded that, the annual building energy consumption and peak design loads are sensitive to the measures affecting internal loads, window system, temperature set points and HVAC plant efficiencies. It was also emphasized that, sensitivity of both energy consumption and peak demand showed similar patterns. Tavares and Martins (2007) also used 'local' sensitivity analysis method to examine the influence of each parameter on building performance of a town hall building in Portugal. The study concludes that, important information about the influence of design parameters on building performance can be gathered by sensitivity analysis in early design phases and efficiency of design can be increased. Corrado and Mechri (2009) performed uncertainty and sensitivity analyses in terms of climatic, envelope and building use parameters for a family house in Italy. The analysis indicated that, only 5 factors (indoor temperature, air change rate, number of occupants, metabolism rate and equipment heat gains) out of 129 parameters had influence on energy consumption for heating and cooling of the building. In addition, Hopfe and Hensen (2011) examined three groups of input parameters of an office building; including physical, design and scenario parameters by using uncertainty and sensitivity analyses. This study revealed that, the infiltration rate and room geometry were the most sensitive parameters on energy consumption and thermal comfort of the model.

By moving these researches one step further, Spitz et al. (2012) used three analyses including uncertainty, local and global methods for an experimental house. Local sensitivity analysis is conducted for 139 parameters, then the most influential 10 parameters on air temperature are investigated with the analysis. The global sensitivity analysis narrowed down to 6 influential parameters in their uncertainty band, which are the capacity of electric heating, infiltration, fiberglass thickness, heat exchanger efficiency, internal gains on the ground floor and fiberglass conductivity. Eisenhower et al. (2012) studied more detailed issues than previous researches, so that not only the impact of input parameters, but also the intermediate processes (air handling unit, heating sources, cooling sources etc.) as a decomposition of sensitivity indices are simulated. Namely, the sensitivity decomposition for facility electricity is presented, and sub categories of the subject were also considered to specify the design considerations instead of differentiating entire electrical appliances. Therefore, efficient design approaches would be possible to implement to the building. Table 2.2. at the end of this chapter indicates a general insight of the significance and applications of sensitivity analysis among building design discipline

Analyses for environmental performance assessment: Taking precautions for excessive GHG emissions have gained importance during different design stages or retrofits of buildings. To reduce the energy consumed, the EU legislated EPBD (2002/91/EC) basically states that, each member state should develop a methodology to predict and certificate the energy performance of buildings (EPBD, 2002). Similarly, The Climate Change Act was passed in 2008 to enable UK to reduce its GHG emissions and become a low-carbon economy. It commits UK to reduce emissions by at least 80% in 2050 from 1990 levels. After the Climate Change Act, the governments of northern countries have also set targets on reducing CO_2 emissions as mentioned in EPBD that, all new buildings are required to be nearly zero energy by December 2020. Therefore, the aim is not only to decrease energy consumption but also GHGs in the EU countries within the scope of EPBD. The similar measures are of the concern for Turkey too, since the amount of CO_2 released has increased 133% between the years 1990 and 2012 (TUIK, 2014).

Analyzing building design process, building parameters and energy characteristics of buildings in terms of impacts on CO_2 release have been more common within architectural research fields. Firth et al. (2010) used a new housing stock model developed to predict the CO_2 emissions of existing English housing stock. Local sensitivity analysis is undertaken for dwellings from different ages and types to investigate the effects on predicted emissions of uncertainty in the model’s inputs. The results indicated that, the effects of energy-efficiency measures on CO_2 emissions could be very large. The quality control of complete energy system in new and existing residential buildings is essential, if the national CO_2 targets are to be met. Han et al. (2013) aimed to develop a multi-objective prediction and optimization tool to guide professionals to decide the optimum solutions in terms of the building energy consumption, initial cost, and CO_2 emissions for the early stage of an eco-city/community. Local sensitivity analysis was applied to decide which variables have the greatest influence on each sub-objective function. The effects of walls, roofs, windows and air conditioner (AC) heating/cooling sources on the building energy consumption, incremental initial cost and CO_2

emissions were investigated, as well. All of these analyses indicated that, not only energy performances, but also CO_2 emission values of dwellings have very significant effects on developing different design stage decisions in terms of reaching energy efficient and environment friendly buildings.

Sensitivity analysis for building performance analysis; research in Turkey: The recent studies in Turkey have also followed the similar patterns, and aimed to integrate not only building performance simulations, but also optimization into climate change related decision support and design guides in order to increase the energy efficient and environment friendly buildings. Yıldız et al. (2012) investigated the effects of design parameters on energy consumption for cooling of a theoretical residential building model located in hot humid climate of İzmir, Turkey. Climate data projections for the 2020s, 2050s and 2080s were also included as the external factors in energy performance of the buildings. Global sensitivity analysis was preferred during the analyses, and a design guideline model for professionals was proposed according to the results indicating the most essential design parameters for different time periods. Solmaz (2015) developed a decision support model in terms of determining optimal solutions for evaluation, and improvement processes of building energy performance to decision makers, especially the architects. The research included analyzing the sensitivities of building envelope, properties of transparent surface, and shading elements on energy consumption for heating of an existing school building. Then, the results were evaluated in order to develop a multi-objective optimization tool, which would bring solutions to the complex problems including interrelated, multiple factors, find optimal options, and overcome time consuming difficulties at short notice.

2.1.4. Effects of Climate Change on Building Performance

Climate change and global warming were some of the major challenges which the building sector should tackle with in future. It is feasible to observe various performance characteristics of buildings, so that the design decisions is made by considering longer periods of time. Climate projections as one of the scenario parameters have been part of the building performance simulation tools, as well.

Zmeureanua and Renaud (2008) introduced a method for estimating the potential effect of climate change on heating energy use of existing dwellings. The proposed method was based on the house energy signature that is developed from the historical energy use data. It can be applied to any individual house, by providing the utility bills from the owner, or used by the utility companies. The method was applied to 11 different existing houses. The results conveyed the reduction of heating energy use between 7.9% and 16.9% due to climate change between the 1961–1990 and 2040–2069 periods. De Wilde and Tian (2009) investigated the thermal performance of an office building in UK, then came up with the most influential parameters by using sensitivity analysis in the prediction of overheating and energy use for the time horizons of the 2020s, 2050s and 2080s. The results pointed out that, the most significant input variables were infiltration, lighting gain and equipment gain regarding the uncertainty in predicted heating energy consumption. Collins et al. (2010) explored the possible impacts of heating and cooling systems on gas and electricity consumption, and CO_2 emissions in existing housings up to the 2080s, supposing an extensive uptake of cooling systems. In conclusion, general trends were found, indicating essential sensitivities of ventilation rate, U values, occupant behavior and location. Heating appeared to remain the major load rather than cooling even in the 2080s, based on the projected weather scenarios of UK. Wang et al. (2010) studied the potential effects of climate change on heating and cooling energy requirements of dwellings in five regional climates varying from cold to hot humid characteristics in Australia by combining sensitivity and scenario assessments. In conclusion, the increase in the cooling energy requirement was observed much more than decrease in heating energy requirement, considering the global warming. Besides, it represented a significant increase in the total annual heating and cooling energy requirements in a cooling demand dominated hot or warm climate, and amounts of cooling and heating consumption balance in temperate climate. On the contrary, decrease in heating energy requirement was obtained in a relatively cold temperate climate.

Considering all these researches, significant impacts of climate change on energy requirements is observed within the lifespan of housing stocks (Table 2.2.). Hence, projected weather conditions should be considered as the external factor in different design stages and decision processes.

2.1.5. Uncertainty and Sensitivity Analyses For Design Support

The recent literature on design decision support for architects focuses on the connection of two main study areas: professional experiences gained from previous works with building performance simulations, and decision support information provided by the digital analysis tools. The aim is to increase usage of decision support tools, close the gap between design process and simulation tools, get more feedback from practitioners, and create more practicable models for professional works. Hopfe (2009) suggested using uncertainty and sensitivity analyses as post-processing steps for building simulation, to provide an analysis of energy consumptions for heating and cooling, and overheating/underheating problems for physical and design variables in an existing office building. The result of this research included a prototype simulation based environment that provides add-ons like uncertainty and sensitivity analyses, multi-criteria and disciplinary decision making under uncertainty and multi-objective optimization. The applicability and necessity of implemented prototypes have been verified with the help of conducting usability tests, presentations and an online survey with practitioners. The outcome pointed out that, the presented information enhanced the capabilities of performance simulations and met the requirements in detailed design by providing a better understanding of the results, guidance through design process, and supporting the decision process.

Struck (2012) studied on the utilization of building performance simulation tools with uncertainty and sensitivity analysis methods for conceptual design support. Existing office building in Amsterdam has been used as a case study in order to examine the relations between inputs and outputs, e.g. adaptive temperature limit, energy demands for heating and cooling as the outputs. In addition, climate change scenarios were part of the concerns, as apart from the previous work of Hopfe (2009). The study ended up with developing a prototype simulation tool regarding the extent and content of the design option space. At the end, interviewees have also agreed that, the utilization of simulation tools in the beginning of design process was significant to supplement design experience and knowledge during design decisions. Hence, the quality of results in terms of ability to affect design decisions were investigated, and the accuracy of outcomes were enhanced by working with the professionals. Consequently, the new researches have been promoted by synthesizing and developing the existing studies through communicating and sharing information with professionals on every stage of the process.

2.2. Evaluation: State of the Art on Energy and Environmental Performance Analysis for Design Decision Support

In this section, entire scientific studies handled in this chapter are systematically evaluated. The main purpose is to highlight the associated studies in literature and make them the source of inspiration for the framework of the thesis. First, the literature survey was conducted under two main categories: energy efficiency in buildings and performance analysis in design. Later, building performance indicators and performance analysis models in buildings are investigated. Moreover, some other parameters, highly connected to the framework of the thesis such as building performance analysis tools, and significance of the climate change on building performance were searched to identify some notable studies in the literature.

The literature survey was conducted for the publications published between the years from 1990s until present. It included various information sources, such as books and dissertations as much as articles related to the research era. Accordingly, evaluation of all information collected from the publications is presented. Table 2.2. indicates the general view of the literature survey.

The state of the art on the recent literature reveals that, there are plenty of studies scrutinizing energy performance assessment. The design decision support approaches are also one of the focused topics related to the improvement of building energy performance during design, operation or maintenance stages. Yet, the studies on usage of building performance simulation tools for design evaluation are limited. However, the existing studies mostly focused on the significance of utilizing detailed simulation programs in terms of building energy and environmental performance evaluations (EU, 2010). Even though the utilization of simulation models on the building performance analyses are extensively applied abroad, the amount of studies on this subject are limited in Turkey.

The sensitivity analysis method is perceived as the guide for selecting the most effective design parameters on building performance, and the contributor to building performance improvements. The global sensitivity analysis method is commonly used for the researches of complex performance analyses of different types of buildings in various stages of design process in diverse countries. Unfortunately, sufficient researches for the housing stock in hot-humid climate regions are not conducted in Turkey, especially for early stages of design decisions.

The consideration of global warming and climate change issues are the hot topics observed in the recent studies about decision support and building performance analyses. Energy demands and accordingly environmental performance of buildings may differ depending on the future weather conditions. In addition, the issue of global warming has accelerated lots of investigations focusing on the impacts of building parameters and design decisions over the amount of CO_2 releases arising from the buildings. However, the number of energy oriented studies has been more than environmental performance based researches during building performance analyses for design decision support in Turkey (Lam, 1996; Zmeureanua, 2008; de Wilde and Tian 2009; Firth et al., 2010; Collins et al., 2010; Wang et al., 2010; Struck, 2012; Yıldız, 2012; Han et al., 2013).

Increasing trend of the effort for empowering bridges between theoretical studies and building professionals is observed throughout the existing studies. Usability, efficiency, and accuracy of entire building performance models are evaluated to provide more beneficial guides for decision support. However, lack of communication with professionals, which requires more comprehensive studies is underlined. Thus, the projected design decision support aims to be reliable for using in early building design stages by the architect, and enable to create consciousness about the importance of systematic building design decision approach for the building professional, as well (Almeida et al., 2007; Hopfe, 2009; Struck, 2012).

In conclusion, systematic approaches for design decision support, impacts of climate change on design process, importance of informational assistance in design, analyzing sensitivities of different design parameters on energy and environmental performance of the building, usability testing of the process through communications with building professionals are determined to be more underpinned according to the evaluations of the existing studies (Table 2.2.). Information gathered from the literature about the significance of interventions in early stages of design in terms of improving performance of the building, and impacts of housing sector on energy and environmental problems are also prominent factors affecting selection of the case study for the recent work (Almeida et al., 2007; Hopfe, 2009; de Wilde and Tian, 2009; Hopfe and Hensen, 2011; Struck, 2012; Solmaz, 2015).

Table 2.2. Main characteristics of the studies identified by a systematic literature review

PUBLICATION DATE	AUTHORS	TYPE	COUNTRY	PROJECT PHASE	BUILDING TYPE	ENERGY PERFORMANCE	CLIMATE CHANGE	CO_2 EMISSION	UA/SA	USABILITY TESTING	DESIGN SUPPORT
1996	Joseph C. Lam Sam C. M. Hui	paper	Hong Kong	existing	office building	✓	✓		✓		
1997	Sten de Wit	paper	Netherlands	final design stage	office building	✓			✓		
2007	Paulo Filipe de Almeida Ferreira Tavares Antonio Manuel de Oliveira Gomes Martins	paper	Portugal	early design stage	public building	✓			✓	✓	✓
2008	Radu Zmeureanua Guillaume Renaud	paper	Canada	existing	housing	✓	✓				
2009	Vincenzo Corrado Houcem Eddine Mechri	paper	Italy	existing	housing	✓			✓		
2009	Christina Johanna Hopfe	dissertation	Netherlands	existing	office building	✓			✓	✓	✓
2009	Pieter de Wilde Wei Tian	paper	Netherlands	existing	office building	✓	✓		✓		✓
2010	S. K.Firth K. J.Lomas A. J. Wright	paper	UK	design stage	housing stock	✓		✓	✓		
2010	Lisa Collins Sukumar Natarajan Geoff Levermore	paper	UK	existing	housing stock	✓	✓	✓	✓		
2010	Xiaoming Wang Dong Chen Zhengen Ren	paper	Australia	existing	housing	✓	✓		✓		
2011	Christina J. Hopfe Jan L.M. Hensen	paper	Netherlands	existing	office building	✓			✓		✓
2012	Clara Spitz Laurent Mora Etienne Wurtz Arnaud Jay	paper	France	experimental	housing	✓			✓		
2012	Bryan Eisenhower Zheng O'Neill Vladimir A. Fonoberov Igor Mezi	paper	USA	existing	drill hall	✓			✓		
2012	Christian Struck	dissertation	Netherlands	existing	office building	✓	✓		✓	✓	✓
2012	Yusuf Yıldız	dissertation	Turkey	experimental	housing	✓	✓		✓		
2013	Xu Han Jingjing Pei Junjie Liu Luyi Xu	paper	China	existing	eco-community	✓		✓	✓		
2015	Aslıhan Şenel Solmaz	dissertation	Turkey	existing	school building	✓			✓		✓

CHAPTER 3

PERFORMANCE ANALYSIS IN DESIGN

Building performance analysis enables the prediction of the thermal and environmental conditions in a building through computational model calculations. Performance evaluations get more sophisticated with the help of technological improvements. The more detailed simulations are conducted, the more accurate and real like results can be achieved.

Energy analysis in buildings has improved, and enabled performing more complicated calculations after the 1970s with support of computer based programs. Clarke (2001) assesses the evaluation process of performance analysis methods in four sections, starting from traditional calculations to modern, computerized simulation methods. Initially, implementations were handbook oriented, manually calculated with limited conditions, and far from actual energy performance of buildings in the 1960s and early 1970s. Second generation was less simplified, and attempts to modelling real conditions were seen in spite of many deficiencies in the mid-1970s. Third section included numerical methods, integrated energy evaluations and improved user interface, which were held in the 1980s. Forth section provided intelligent knowledge based, advanced software engineering, which is much easier to use with many sophisticated simulation systems, starting from the 1990s. Throughout the generations, results and investigations have approximated to real conditions, while general structure of the simulation programs has become more complicated.

Actually, contemporary concerns about performance of the buildings is to lower energy demands, and to fulfill environmental benchmarks as much as possible, because real-like performance analysis models in design have become more crucial than before. Apparently, building performance simulation tools are essential parts of the design process in order to manage energy oriented objectives. In addition, developments in available tools, introduction of new analysis programs, development of user-friendly interfaces, or trials for overcoming more complicated data processes are all ongoing attempts to improve the support provided by performance simulations, as well.

3.1. Building Performance Analysis Tools

Building energy performance evaluations are important design supports for professionals. Hence, building simulation tools are extensively employed during building design process, since performance of building gains more significance due to changing thermal regulations and environmental issues all around the world. Simulation tools may be preferred for every stages of design, in order to obtain information about energy performance of the building, enhance thermal comfort of occupants, reduce environmental impact of the structure during its entire lifespan or reduce operational costs.

Various building energy simulation tools exist for design, analysis, or modeling. General information about some common building analysis tools for dynamic simulation are explained in this section. Various programs have been chosen in order to give brief information about their capabilities, and six different simulation software are described as follows (EkoYapı, 2012):

Energy 10: It is a building energy simulation tool, focusing on the early design stages of architectural design process for smaller residential or nonresidential buildings. It provides daylighting, passive solar design, low-energy cooling and energy-efficient equipment integration into buildings for higher performance calculations. Whole-building energy analysis can be conducted for around 8760 hours per year including dynamic thermal and daylighting calculations. It is only able to simulate one or two thermal zones, which limits its usage for generally smaller than 1000 m^2 buildings.

EnergyPlus: It is a whole building energy simulation tool that is most widely used by engineers, architects and researchers to model both energy consumption and water use in buildings. Generally, it provides calculations for energy, CO_2, lighting and comfort performances of the building by using hourly weather data. It has plug-ins with different 3D modelling programs, so that multiple programs can work together via user-interfaces.

DesignBuilder: It is a dynamic simulation program, giving opportunities for computing advanced whole-building energy, CO_2, lighting, acoustic and comfort performance, cost analysis, or optimization. It provides heating-cooling calculations over EnergyPlus program by using hourly weather data. The program provides easy to use interface as well as simplifications in HVAC, air flow inputs. One of the disadvantages is complexity of 3D modelling process and difficulties in model detailing process.

Esp-r: It is a Linux based software for building simulations, capable of thermal and visual simulations as well as acoustic calculations. Detailed HVAC and renewable energy system equipment identifications are also possible within the program. Building geometry can be created through CAD environment. The program is suitable for mostly finished designs, or existing buildings, since it requires and gives very detailed information during modelling and simulations. Any model formed by the program can be transferred into various programs, such as EnergyPlus.

e-Quest: It is a building energy use analysis tool, providing detailed comparative analysis of building design and technologies through application of sophisticated building energy use simulations with no need for extensive experience in terms of building performance modeling. It can be used for energy cost, daylighting and thermal calculations. One of the disadvantages is lack of detailed mechanical system equipment.

IES-VE: Integrated Environmental Solutions-Virtual Environment is a program used by design and consultancy companies, for analyzing thermal and energy performance, natural ventilation, daylighting characteristics of buildings, as well as examining energy efficient, passive, renewable strategies. It is a comprehensive program consisting of different modules for whole-building design, optimization and analyses.

In this thesis, DesignBuilder and EnergyPlus programs are selected and integrated for the study. Digital modelling of the building and energy simulation files will be created by DesignBuilder. The program is suitable for late conceptual design stages, as it gives adequate opportunity for detailing the building. Actually, ease of use of the program enables faster data transfers between different programs, and it is practical in terms of generating proper files for EnergyPlus program. Then, EnergyPlus energy simulation tool will be used for running simulations, and collecting energy and environmental performance results of the building.

3.2. Role of Building Performance Simulations in Design Assessment

Design process requires several decisions based on observations from previous design experiences, or rule of thumb. Therefore, design decision support has deficiencies in terms of well-defined knowledge which can be provided by computational experiments. The eligibility of a design option is demonstrated by a number of measurements due to various performance indicators. Efficiency in the results, after applying the design alternatives verifies the acceptability of design support, due to demands addressed in the design framework. Investigations through building performance indicates current situation of the building rather than directing design decisions. Processed knowledge of outcomes help decision makers in terms of carrying the proposed design a step further according to prioritized building performance factors.

The performance analyses enhance energy efficiency and thermal comfort of buildings, since relative or subjective decisions are based on rational results. For instance, they enable creating clear design objectives and focusing on these specific points during performance analysis. Hence, the designer can rationally execute effective project goals by narrowing down the aspects that affect the design assessment.

Building performance simulation (BPS) programs are used to evaluate different aspects about projects, like thermal performance, occupant comfort, dynamic operation scenarios for intelligent buildings and cost efficiency (Augenbroe and Hensen, 2004). Spitz et al. (2012) also investigate the reliability of building performance simulations as well as uncertainties in terms of improving design quality. In fact, it is indicated that, the methods are suitable for overall building design stages, including design, construction, operation, retrofit and optimization phases. In addition, Struck and Hensen (2007) examine the integration of simulation tools into building physics in order to support conceptual stages of design. LEA v. 0.9.1, one of the conceptual design analysis tools, is used to obtain annual cooling demands of a theoretical case building. Then, they revealed the potentials of this method for design support. It is concluded that, the technique is capable of offering rational design knowledge. In addition, Breesch and Janssens (2004) analyze various options about enhancing thermal summer comfort by use of thermal simulation program called Transient System Simulation Program (TRNSYS) and COMIS; multi-zone infiltration and ventilation simulation model. The results give information about more important and effective indicators in terms of thermal mass, which are indicated as false floor and ceiling usage.

It is stated in existing studies that, simulations are integrated into performance based design approach, mostly earlier stages of the design process. Morbitzer et al. (2001) point out that, building simulations play important role for different design phases; especially if the programs provide user friendly interfaces. Besides, the programs are mostly advantageous on the energy and environmental performance of the building in early stages of design, since rapid feedbacks can be provided, and more comprehensive interferences are possible throughout design process. However, current simulation tools are not capable of processing the results into rational design support information acquired by stakeholder or professionals during design assessments. In other words, collected performance indicator outcomes are to be processed in terms of providing data for design support, which will help designers to manage efficient decisions due to previously specified design quality measurements.

3.3. Climate Change as a Performance Indicator

Climate change is the rise in average surface temperatures on Earth. In general, it is primarily due to the use of fossil fuels, which releases carbon dioxide and other greenhouse gases into the air. In fact, global surface temperature change is projected to increase between 1.5-4.8 ºC until the end of 21st century according to the discussions in The Intergovernmental Panel for Climate Change (IPCC, 2014).

There are different projected climate change scenarios of IPCC published by Special Report on Emission Scenarios (SRES). Although assumptions throughout the changes contain more than forty scenarios, four main groups are indicated in the report, as A1, A2, B1 and B2:

The A1 story depicts a world of rapid economic growth, increasing global population until the mid-century and decreasing afterwards, and innovation of different efficient social, cultural or scientific technologies. The A1 scenario is separated into three groups describing variations of technological changes in the energy system. The scenarios are differentiated by their technological priorities, as fossil-intensive (A1FI), non-fossil energy sources (A1T) or a balance between all sources (A1B). The A2 storyline assumes a very heterogeneous world, including self-reliance and protection of local identities, as well as continuously increasing population. In addition, local economic growth and slower technological developments than other scenarios are predicted. The B1 scenario introduces a world with the similar population growth with the A1 scenario. However, it includes rapid fluctuations in economic systems towards an information and service economy, with decreases in material intensity. Besides, the scenario reports increases in the innovation of clean and resource-efficient technologies. The B2 scenario describes a world, where economic, social and environmental sustainability solved locally. Continuously increasing population, with lower amounts than A2, medium rates in economic development and slower technological development than other scenarios are pictured during the B2 story (IPCC, 2000).

Actually, the built environment is also affected by changing weather conditions, such as amount of energy consumed for cooling or heating of residential buildings and thermal comfort of occupants. Therefore, energy efficiency, low carbon solutions and thermal performance in buildings have gained more importance in time. The effects of climate change on building thermal performance and the adaptation of buildings to changing environmental conditions have turned into active research subjects. For example, Zmeureanu and Renaud (2008) represent a method for estimations about potential effects of climate change on the heating energy demands of existing houses. A2 climate scenario is selected in the study, and 1961-1990 and 2040-2069 projections are used as climatic data for calculations. The method, which can be applied to any house, is used in two cases, including a house in Montreal and other eleven houses. The results indicated that, decrease will be observed in heating energy demands of existing residential buildings because of climate change.

In addition, it is indicated in literature that, technological tools are required, in order to analyze the impacts of complicated interactions between the buildings and changing weather conditions. Therefore, related studies in building science mostly contain building performance simulation tools, as well as projected weather generation programs. For instance, De Wilde and Tian (2010) analyze a theoretical office building in UK by employing a probabilistic approach, and explore the use of simulation to examine the climate change impact. The research describes weather conditions for three different 30 year periods; 2020s, 2050s and 2080s. The future weather conditions are generated by The Climate Change Weather File Generator. Thermal performance of the building is studied in terms of annual CO_2 emissions, overheating risk and work performance related to changing environmental conditions. The results pointed out that, climate change causes a slight increase in the annual CO_2 emissions over time, with foreseeable uncertainties in the previsions. Besides, it is found that, different zones on the same floor may represent obvious differences in overheating risk and work performance.

CHAPTER 4

UNCERTAINTY AND SENSITIVITY ANALYSIS BASED DESIGN SUPPORT

Uncertainty and sensitivity analyses may be defined in different ways according to the questions to handle and alternative purposes. Substantially, sensitivity analysis is the study of how the uncertainty in the output of a model or system can be allocated to different sources of uncertainty in its input variables. A related procedure with sensitivity is the uncertainty analysis, which has focus on uncertainty quantification and propagation of uncertainty (MacDonald, 2002). In fact, uncertainty and sensitivity analyses should be associated, since uncertainties are identified in model inputs initially, and uncertainties of output factors of models are measured in accordance with the sensitivity analysis (Saltelli, 2008). They may be performed in different forms depending on the subjects, so that variable methods exist for applying and examining the acquired outcomes of models (Saltelli, 2004).

Uncertainty and sensitivity analyses have become one of the current subjects to be included in building sector, like any other building simulation, energy assessment tools. They are integrated into different stages of architectural design from conceptual phase to construction field, since technological evolution has also taken building sector into another place in terms of offering number of digital programs instead of manual methods for design decisions. They are useful to acquire efficiency in various key points of entire design process; like materials, cost, consumed energy or maintenance. Besides, the more detailed analyses are performed, the more accurate, and efficient results are gathered for improving building design quality. These analysis methods are also integrated in design assessment processes, based on increasing interests in building performance efficiencies, recently.

In this chapter, brief overview of the uncertainty and sensitivity analysis techniques is going to be expressed by giving general information about contents of both methods. Then, evaluation of the analyses within the design process is going to be presented through existing literature in this field.

4.1. Methods of Uncertainty and Sensitivity Analyses

The distinction between ‘sensitivity’ and ‘importance’ of the parameters, i.e. inputs relies on the pursued analysis method (Heiselberg et al., 2009). In fact, uncertainty analysis reveals parameter importance, and sensitivity analysis gives information about parameter sensitivity. An important parameter is also sensitive due to providing significant variability to output, whereas sensitive parameter is not always inevitably important, since it may contribute small amounts of variability to the output.

Uncertainty analysis is used for decision making problems in order to examine the uncertainty of variables. It is a part of the technical process of decision support by means of quantifying relevant uncertainties. Various assumptions, simplifications or calibrations during researches may cause misleading outcomes, as well. Hence, uncertainty analysis utilizes a number of techniques for discovering the reliability of model predictions, accounting for various sources of uncertainty in model input and design.

Uncertainty analysis is applied into different branches of research fields, such as physical or numerical experiments or modelling. In fact, evaluation of the uncertainties of measurements in physical experiments is the main purpose of analysis. Inaccuracy or obscurity in methodology, equipment or contradictory situations may occur during experimental setup or execution process. Experimental uncertainty estimations require evaluating confidence levels of the results. Furthermore, the analysis of numerical experiments and models involve multiple approaches according to main objectives of the study. In fact, the more complicated or complex models are analyzed, the higher uncertainty range and model input uncertainty take place during experiments.

Sensitivity analysis is also a method mostly applied together with the uncertainty, which may be conducted for a number of purposes in different research areas such as finding out the influence of input parameters on outputs of simulation models, eliminating insignificant factors from following models, and examining the validity of project setups by comparing digital and physical model results. Sensitivity analysis can be performed by a large number of approaches, according to differences in calculation process, input-output relation and complexity of the project. Commonly used methods, distinguished by the different sensitivity measures to be calculated, will be presented in this section, such as screening, local and global sensitivities.

Screening methods are one of the most common ways of dealing with the complicated models. The purpose is to identify which input parameters are affecting significantly the output uncertainty in sophisticated models, rather than specifically quantifying the sensitivities. The model may also be preferred for preliminary analyses to eliminate ineffective variables before applying a more detailed analysis to the remaining model. In addition, the method is called as one-parameter-at-a-time (OAT) since the effect of input parameters are investigated by differentiating each parameter one by one, while the others are fixed. The standard value is used to control the performance comparison. Generally, two extreme values are preferred on both sides of the standard value, for each input factor. The distinction between the outcome acquired by using the standard value and the extreme values are compared, to decide which input variable is more sensitive to output variables (Heiselberg et al., 2009; Hamby, 1994).

Local sensitivity methods usually depend on OAT approach in terms of measuring the influence of parameters, while the values of each input factor is evaluated in turn, as well. It addresses sensitivities locally, since the specific parameters are investigated instead of considering the relation between overall parameters. Actually, it is preferred for comparing the impacts of different parameters separately. Parameter sensitivity estimation is conducted by calculating the ratio of differences between results acquired by using extreme values of the input parameters. This ratio is called 'sensitivity index' (SI) and calculated by using the equation (3.1.).

$$SI = \frac{Emax - Emin}{Emax} 100\% \tag{3.1}$$

The minimum and maximum output values are defined as E_{max} and $E_{min.}$ Therefore, if the sensitivity index extends to specified critical rates after variations in whole range of input parameters, the parameter is accepted as sensitive. However, interaction between parameters is not considered, while input-output correlation is accepted as linear during analysis period.

Global sensitivity methods imply the observation of output variables by considering the interaction between input parameters at the same time. In other words, it is a process of deciding certain amounts of variations for each parameter, creating different samples including different values of each input parameter simultaneously, then analyzing the model by using overall samples. At the end, decisions about parameter sensitivity are provided by observing the results collected from interrelated input variations. In general, global sensitivity analysis considers the variation ranges of input factors, then allocates the output uncertainty to the input factor uncertainty. This kind of method is beneficial for more complicated models, if many factors have impact on output, and they are dependent on other parameter changes.

The general process of sensitivity analysis is summarized in six main stages as follows (Heiselberg et al., 2009; Hamby, 1994):

1) Defining the problem that needs to be answered by the results of the analysis, determination of output factors, and input parameters
2) Primary execution of screening analysis in order to prioritize more sensitive parameters while eliminating ineffective factors
3) Probability density function assignment for each specified input parameter
4) Selecting the proper random sampling method to form the input matrix
5) Investigating the output distribution by using generated input matrix
6) The output variable evaluation and specifying the relative significance of each input-output relationship

Sensitivity analysis process starts with defining the properties of input and output variables. If necessary, screening analysis is conducted to decrease the number of input variables by prioritizing more sensitive factors. Then, proper probability density function is assigned for each uncertainty source, in terms of considering the probability pattern that the parameters are assumed to follow. This method is conducted by three techniques mostly; as uniform, normal and lognormal distributions.

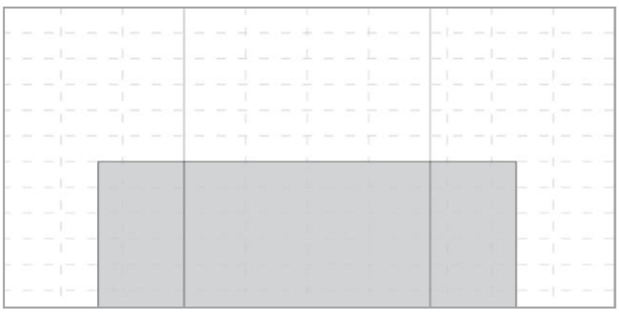

Figure 4.1. Uniform Distribution

The uniform distribution, visualized in Figure 4.1., is the simplest way to apply when all of the outcomes have equal probabilities of occurring. It is mostly used for conditions, where there are multiple possible outcomes, but no information to make a conclusion assuming, one outcome is more likely than the others. In other words, the uniform parameter distribution assesses the occurrence of all parameters between the minimum and maximum values as equally.

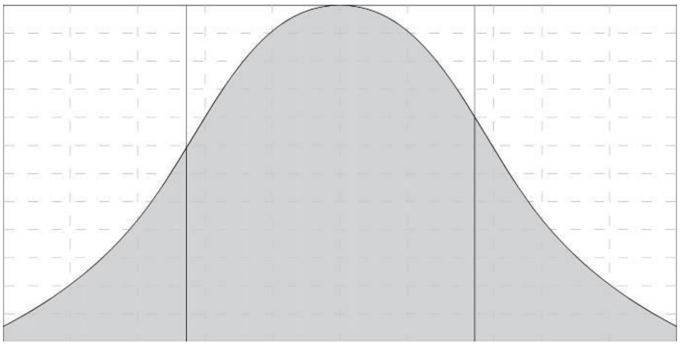

Figure 4.2. Normal Distribution

The normal distribution is a symmetrical pattern, as shown in Figure 4.2. It has several characteristics that makes it more preferable. Firstly, it can be fully characterized by only the mean and the standard deviation, thus it decreases the time spent for estimation, and calculation process. Secondly, the probability of occurrence for any value can be gathered by knowing the number of standard deviations that differentiate the value from the mean deviation. Negative values are not possible for the input parameters in normal distribution. Therefore, it is preferred in some cases to avoid infeasible values.

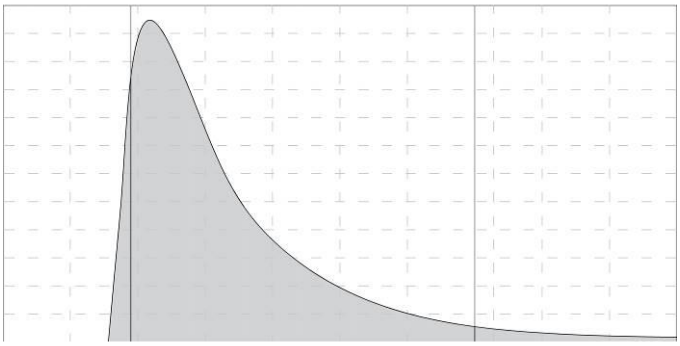

Figure 4.3. Lognormal Distribution

Figure 4.3. shows that, log-normal distribution is a continuous, one-tailed probability distribution of a random variable whose logarithm is normally distributed. It occurs if selected variables are independent, and equally-distributed in the same way that a normal distribution results. It is usually described in terms of the log-transformed

variable, using parameters as the expected value, or mean of its distribution and the standard deviation. It is the statistical application of the multiplicative outcomes of many independent and positive random variables.

After defining the probability density functions of each parameter, proper random sampling method selection has importance in terms of forming an input matrix. Actually, sampling of input variables enables investigating input-output distributions, and evaluating uncertainties globally. There are different types of statistical sampling methods: simple random sampling, Monte Carlo analysis and Latin Hypercube Sampling (LHS) are some of the most commonly used methods (Hamby, 1994).

Simple random sampling follows a process of choosing individuals from a larger set of possibilities. Selection is made randomly with every individual having the same chance in each point of sampling process. It has advantages of eliminating classification errors, as well as necessity of minimum knowledge about the population. On the other hand, possibility of missing the outliers, extreme points of the distribution create disadvantages in larger or complex cases.

The Monte Carlo analysis method uses random quantities for sampling through a probability distribution. It requires large amounts of samples for estimating an input distribution, in particular. It is especially used for outlining the process of translating model input uncertainties into uncertainties of model outputs. This method consists of uncertainty configuration process by using probability distributions of input parameters, since the inputs of the model, and output variables have uncertainties. However, it generally creates some errors related with the complicated systems, but if greater number of random samples are selected, reliability of the results increase. Macdonald et al. (1999) state that, the Monte Carlo method should be carried out to analyze all input parameters combined for giving an overall range, in case of complex parameter interactions in comprehensive models.

The LHS is one of the stratified sampling types. It includes dividing members of the variations into uniform subgroups before sampling. It differentiates from the Monte Carlo method with regard to the amount of iterations needed for approximating the sampled values into input distributions, because less iterations are adequate for this sampling method. It can be applied to multiple variables, and commonly used for variance reduction when the Monte Carlo methods are used to estimate population statistics from a known population to reach a correct random distribution. Therefore, it is often used for the Monte Carlo integration in different analysis schemes. The validity of this method is also investigated by a number of different researches. For instance, Lomas and Eppel (1992) investigated the performance of three sensitivity analysis methods (differential sensitivity analysis, the Monte Carlo analysis and stochastic sensitivity analysis) on different building energy programs. The study pointed out that, both differential sensitivity and the Monte Carlo analyses have generated similar results and could be applied to different thermal programs, whereas stochastic sensitivity analysis was complex to implement.

Afterwards, generation of output parameter values according to each input parameter or sample matrices takes place, by conducting selected simulation tools for models, properly. Different methods may be followed, depending on the focused study areas. Ultimately, the selected output variables need to be evaluated in order to specify the relative sensitivity of each input-output relation. Great number of approaches exist for this data transformation in terms of rank, regression and correlation approaches. For instance, Sobol index and Fourier Amplitude Sensitivity Testing (FAST) as variance based analysis methods, while Spearman Coefficient (SPEA), Standardized Regression Coefficient (SRC) and Standardized Rank Regression Coefficient (SRRC) are used for rank transformation techniques.

Variance based analysis methods allocate model output variations into model input variations within a probabilistic approach. They are favorable for nonlinear relations or if there is a need for interrelated sensitivity calculation of entire input data sets. For example, Sobol index considers the interaction between each input parameter, as well as associating the effect of each input on output variance. Additionally, FAST is another variance based technique, using global sensitivity analysis approach. FAST is similar to Sobol index in terms of the procedure used for representing the impacts of input variables. Although, FAST is a model independent technique, the difference between FAST and Sobol methods is the requirement of additional multidimensional integral calculations. FAST is preferred for calculating sensitivities than other variance-based global sensitivity analysis methods via Monte Carlo integration. Nevertheless, the calculation by FAST is generally limited to the sensitivities referring to first order sensitivity indexes.

Regression analysis techniques are based on estimating the relationships between variables, specifically the impact of one variable on another. In regression analysis, the covariates are continuous, whereas they are a discrete set of groups in analysis of variance. In fact, standardized coefficients are used in this method, so that linear regression is considered for accurate calculations. Therefore, this technique is mostly beneficial for the models with linear relations. One of the subcategories of regression analysis, SPEA is calculation of the correlation between paired variables in a nonparametric way. It examines the intensity of monotonic relation between two variables. In other words, the relation shows a continuity, as the independent variable increases or decreases, while the remaining variable follows the same pattern as it was before. Moreover, SRC and SRRC are also linear regression analysis methods, considering the intensity of correlation between outputs and independent input variables. SRRC is preferred in the case of monotone but non-linear rank based models. Actually, SRC evaluates the degree of linearity of the model, while SRRC focuses on the degree of monotonicity of the components (Saltelli et al., 2008).

4.2. Design Support Through Uncertainty and Sensitivity Analyses

Building designers need to consider how a specific design decision would affect the performance of the building and its components (Trinius et al., 2005). The communities working on building performance simulations and analyses have examined different ways of combining the various domain calculations in an attempt to better represent the behavior of buildings, and to produce better designs over the last 30 years (Macdonald, 2002). At the same time, simulation tools have evolved in terms of ability to model in detail and applicability, but the integration of building performance simulation tools into design process is still limited at some points. However, it could provide significant amounts of data to improve building design quality.

Such complex models require considerable amounts of information to describe buildings detailed enough. This may cause open-ended, undefined situations during simulation or analysis process. In fact, difficulties through non-linear relations of large amount of parameters, or uncertainties about correlations between building parameters and energy/ environmental characteristics of the building are some of the challenges in simulation programs. Uncertainties are inevitable in design process, because of possibility of missing key points in building design, unknown future design decisions, or various possibilities of different occupant behaviors. Hence, opportunities of complex considerations about variables during numerical analysis have importance on preventing lack of information, and provide support for decision makers. Actually, Hopfe and Hensen (2011) indicate that, the efficient integration of uncertainty analysis in building performance analysis for design assessment and quality assurance is beneficial for providing information about the reliability and impact of design variables, according to the entire design decisions, and performance of the building.

A number of studies investigate the opportunities provided by uncertainty and sensitivity analysis methods through further researches. For example, Spitz et al. (2012) focus on evaluating the uncertainties of simulation results along with the design periods. The aim is to compare digital and measured data in terms of investigating the reliability of the simulations and measurements. Indoor air temperature of the building is selected as the output factor. Uncertainty, local and global sensitivity analyses are used for the study of a low-energy house in Paris. Ten parameters are selected as the most influential inputs on the air temperature, after eliminating less significant variables among 139 parameters. As a result, it is pointed out that, outcome was reliable in terms of comparison between simulated and measured data for air temperature of ground floor, while results of the first floor of the building were different. In conclusion, it is pointed out that, the integration of building performance simulations and uncertainty, sensitivity analyses can be used during overall design stages.

Consequently, it is also favorable to point out the most influential and important parameters on selected building performance indicators (heating, cooling, electricity, CO_2 emissions and cost) for developing more efficient design possibilities or offering solutions that can improve the design quality. It is possible to determine the most effective parameters on performance of the buildings, as well as providing assistance for focusing on the specific points of design process, by means of uncertainty and sensitivity analyses. In other words, uncertainty and sensitivity integration into building performance simulations and decision assessment is capable of providing an evidence based design support for professionals and customers, as well as architects themselves.

4.3. Parametric Inputs of Uncertainties in Design

Many complicated factors are associated with the relation between building and its environment. Hence, not only the building itself, but also a great number of intrinsic and external factors (occupant, weather, location etc.), and interaction between overall parameters need to be considered as parts of the building design process. Therefore, there is a need for detailed thinking about the most important factors for more accurate inferences with their properties. It can be provided by making some parameter classifications, so that misleading generalizations are prevented while clarifying the uncertainties and correlations between the building performance and input parameters. Because, assuming that all factors are equal may cause many deceptions during building analysis process. For example, thermal properties of building materials may be strict, while occupancy schedule within the building needs scenario assumptions. Therefore, there may be major distinctions between different input parameter characteristics. If both factors are investigated at the same time, possibility of making incorrect assumptions according to the output values may result in much worse design qualities.

De Wit (1997) has proceeded one of the early examples of researches considering the importance of categorization of uncertainties in input parameters before the analysis process. In the study, two separate categories were mentioned, as design specifications (building shape, materialization of the building, etc.) and test (scenario) conditions (climate time series, occupant behavior, control set point, etc.). In addition, the benefits of integrating this classification into simulation, performance and the building design stages is also pointed out. Afterwards, more detailed classifications have come out by evaluating physical and design characteristics of the building separately. Then, three categories have been developed specifically as physical, scenario and design parameters (Hopfe and Hensen, 2011).

Physical parameters are generally identified as the standard inputs of thermal simulations. Physical characteristics of different wall, floor, roof materials like thickness, density, specific heat capacity are the members of this category. Modifications in material properties are one of the main factors affecting the building performance. Differences and possible variations in design decision process are categorized as design parameters. They depend on decisions of the architect or client.

Different interventions on design parameters are possible in each building design phase. For instance, building geometry and orientation are initial decisions that need to made in early stages of design, while it is more accurate to focus on shading implementations, or building color (e.g. reflectance, solar absorption) afterwards. Hence, design decision support due to uncertainty and sensitivity analyses of these parameters are also capable of improving the performance of the building. Various intervention possibilities for different cases would be available after analyzing design parameters.

Variations in scenario conditions have different characteristics than physical and design parameters in terms of affecting the building throughout its entire lifespan. In addition, it is essential to examine the scenarios separately from other variables. Analysis of uncertainties in scenario parameters is beneficial for monitoring future behavior of the building, as well as the building robustness. Scenarios indicate occupant based variations, lighting control patterns, environmental and climatic factors (climate change etc.), which are not dependent on certain rules and more likely to be proposed by the assumptions of architect, or decision maker for future conditions. Internal and external variables are also the subcategories of scenario parameters. Internal parameters involve building operations, namely internal heat gains from the equipment, occupant behavior, whereas climatic conditions cause uncertainties in external parameters. Interactions between these variables and the building are totally distinct from other categories. In fact, uncertainties in design and physical parameters usually investigated by normal distribution assumptions for analysis process. However, scenario parameters have random occurrence patterns. Instead of making general assumptions, individual models of variations are needed to be created by keeping former scenarios constant.

CHAPTER 5

APPLICATION OF BUILDING PERFORMANCE SIMULATION

The building performance simulation and analysis processes contain different stages, and generalized into three main subjects, namely pre-processing, simulation and post-processing (Figure 5.1.). In general, pre-processing includes selection of input parameters to be analyzed in terms of effects on energy and environmental performance of the building, generation of future climate conditions as one of the input variables and preparation of sample files consisting of input parameter variations. Then, digitalization of the building, generation of energy simulation files, performing simulations and compilation of the results are included in the simulation topic. Finally, post-processing is the part, where entire outcome, collected from the process is analyzed by uncertainty and sensitivity analysis tools. Detailed information of each step is explained in the following sections.

In this chapter, utilization of building performance simulations, before uncertainty and sensitivity analyses stages are presented. The aim of this chapter is to describe general process of the digital modelling and quantification of annual energy consumption for heating and cooling as well as annual operational CO_2 emissions. The mid-rise residential building in early design stage, located in hot-humid climate region, İzmir is selected, and simulations are applied for different time periods including recent, 2020s, 2050s and 2080s. Firstly, the conceptual and thermal characteristics of the building is explained in detail. Secondly, digitalization of the building is clarified comprehensively. The application of the building performance simulations, before uncertainty and sensitivity analyses are conducted, is the last stage presented in this chapter.

Case Study

↓

Pre-Processing

- Input parameter decisions for the top and intermediate floors

- Weather file generation for 2020s, 2050s, 2080s (CCWeatherGenerator)

- 200 sample matrix generation for each floor (SimLab)

↓

Simulation

- Digital modelling of case building (DesignBuilder)

- 200x2x4 EnergyPlus file generation of model (Matlab)

- 200x2 energy simulation for each climate prediction (EnergyPlus)

- Annual energy consumption for heating and cooling and CO_2 emission (output) compilation (Excel)

↓

Post-Processing

- Uncertainty and sensitivity analysis of outputs (SimLab)

Figure 5.1. Visualization of the project simulation process

5.1. Description of Case Building

Energy consumption for heating in housing stock covers 30% of the total energy consumption of Turkey (Altaş et al., 1994). Accordingly, housing industry plays an important role for energy efficiency in buildings. It was the reason of selecting the case building as the housing block. Therefore, the case building is searched by considering common design properties of existing and ongoing housing projects in İzmir, Turkey. Then, the mid-rise residential building in early stages of design is specified for the case study with help of the architectural office, and several discussions with the architect.

The ground floor of the mid-rise building is designated for commercial use, and upper levels for housing units. The location of the block is in Çiğli district, İzmir, with 38.5°N latitude, 27. 02°E longitude and 1.2 m elevation above sea level, as well as 60° directed to north. In addition, Figure 5.2. indicates that, distance from green areas and open-air spaces around the building increase the exposure to local climatic factors e.g. sun, wind, as well. The general description describes the decisions; architect has already taken during conceptual design process.

Figure 5.2. Plot of the land in Çiğli, İzmir with the surroundings

The climatic conditions for the studied area are hot, humid in summer and rainy in winter, as a representation of the Mediterranean climate. Hence, the proximity to the Aegean Sea makes summer and winter relatively temperate. Summers are hot and dry in contrast to mild and rainy winters, as well. In fact, July-August are the hottest months of summer, and January-February are the coldest of winter. The average maximum temperature is around 38°C during summer period, whereas the average minimum ones in winter vary between 0°C and -3°C. Besides, the annual mean temperature is approximately 17.9°C, while the mean relative humidity is around 65% (Turkish State Meteorological Service, 2015).

Figure 5.3. Site plan of the residential building

The residential block has a prismatic shape with larger surfaces in north-west and south-east elevations as indicated in Figure 5.3. Moreover, window-wall ratios are also considerably high, which could cause major heat gains and losses from the building envelope. The selected building is a seven storey dwelling, where the main entrance is rotated to south-west. The building has twelve flats with 767.88 m² total floor area in each residential level. Besides, floor-to-ceiling height is 2.80 m, while ground floor is 4.21 m. The total height is 21.49 m along with walkable flat roof on top (Table 5.1.).

Table 5.1. Technical information about the case building

Site Details	Location	Latitude	38.52
		Longitude	27.04
	Elevation Above Sea Level (m)		1.2
Building Specifications	Site Orientation (°)	North Axis	60
	Number of Floors		Basement + 7 floors
	Ground Floor Area (m²)		692.33
	Housing Floor Areas (m²)		767.88
	Floor Height/Ground (m)		4.21
	Floor Height/Upper (m)		2.88
	Total Building Height (m)		21.49
	North-West Elevation Surface Area (m²)		300.86
	South-East Elevation Surface Area (m²)		300.86
	North-East Elevation Surface Area (m²)		974.36
	South-West Elevation Surface Area (m²)		974.36
	North-West Elevation Opening Area (m²)		243.96
	South-East Elevation Opening Area (m²)		243.96
	North-East Elevation Opening Area (m²)		722.76
	South-West Elevation Opening Area (m²)		684.51
	North-West Elevation Window-Wall Ratio (%)		81.09
	South-East Elevation Window-Wall Ratio (%)		81.09
	North-East Elevation Window-Wall Ratio (%)		74.18
	South-West Elevation Window-Wall Ratio (%)		70.25

Technical drawings of the building are presented within Figure 5.4. and Figure 5.5. The plan drawings indicate that, the commercial spaces are located symmetrically on ground level and main entrance in the middle. Furthermore, there are twelve housing units on each floor, aligned around a central hall. The units have one bedroom and a living room facing outside in every plan schema. On the other hand, bathrooms, entrance halls and kitchens are the spaces with blind facades, except for kitchens of the corner units.

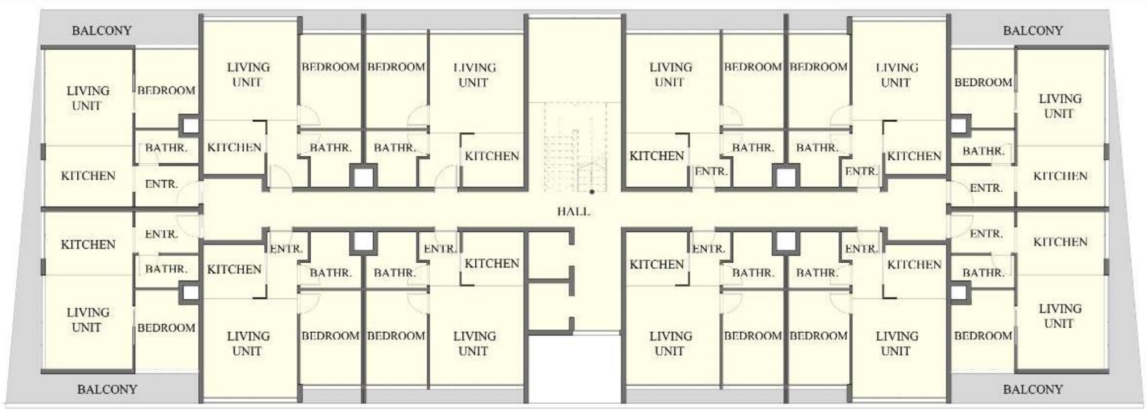

Figure 5.4. Typical schematic plan of the residential floor

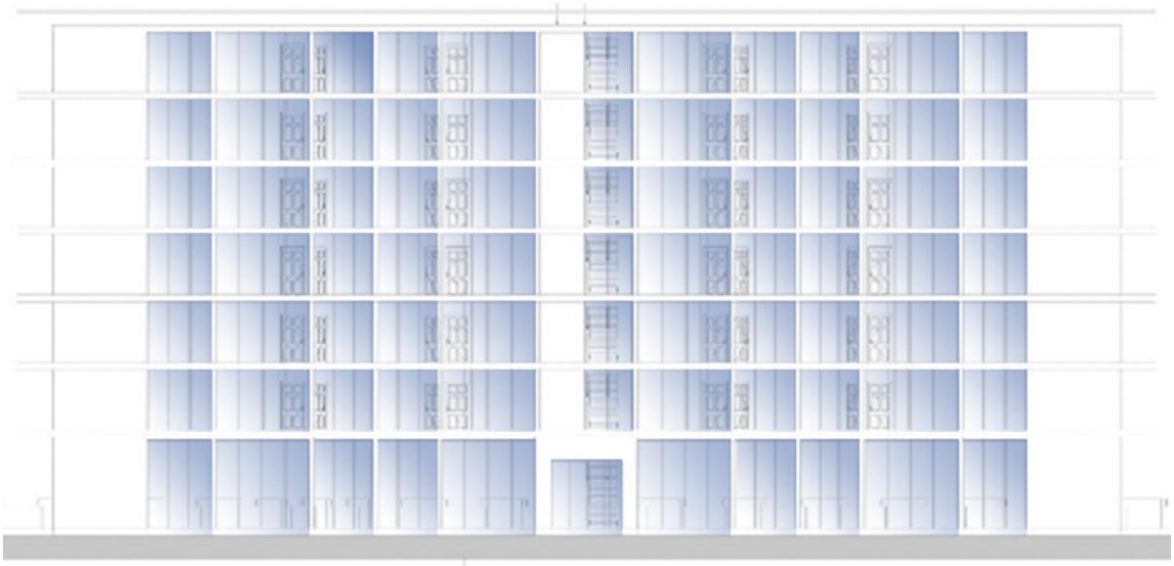

Figure 5.5. South west elevation of the building

The specifications about the building envelope and thermal properties of the materials are elaborated in terms of external walls, floors, roof, partitions and openings. In fact, they are discussed with the architect, and arranged according to the initial decisions taken during preliminary design.

Table 5.2. Thermophysical properties of the building components defined by the architect

BUILDING COMPONENTS	POSITION	LAYER NAME	THICKNESS (m)	CONDUCTIVITY (W/m.K)	SPECIFIC HEAT (J/kg.K)	DENSITY (kg/m³)	U VALUES (W/m².K)	THERMAL ABSORPTANCE	SOLAR ABSORPTANCE	VISIBLE ABSORPTANCE
	OUTERMOST	Artificial stone tile	0.02	1.2	840	2000		0.9	0.6	0.6
EXTERIOR WALL		EPS Expanded Polystrene	0.03	0.04	1400	15		0.9	0.6	0.6
		Brickwork (inner leaf)	0.195	0.3	840	1000	0.61	0.9	0.7	0.7
		Plaster (coarse)	0.02	0.72	840	1860		0.9	0.6	0.6
	INNERMOST	Gypsum plaster	0.01	0.4	1000	1000		0.9	0.5	0.5
	OUTERMOST	Gypsum plaster	0.01	0.4	1000	1000		0.9	0.5	0.5
INTERIOR FLOOR / GENERAL		Plaster(coarse)	0.01	0.72	840	1860		0.9	0.6	0.6
		Hollow concrete block	0.32	0.62	840	1040	0.985	0.9	0.6	0.6
		Cement screed	0.05	1.4	650	2100		0.9	0.6	0.6
		Kapron	0.005	0.035	1400	40		0.9	0.6	0.6
	INNERMOST	Flooring layer	0.012	0.14	1200	650		0.9	0.78	0.78
INTERIOR FLOOR / WET CORE	OUTERMOST	Gypsum plaster	0.01	0.4	1000	1000		0.9	0.5	0.5
		Plaster(coarse)	0.01	0.72	840	1860		0.9	0.6	0.6
		Hollow concrete block	0.05	0.62	840	1040	1.23	0.9	0.6	0.6
		Cement screed	0.05	1.4	650	2100		0.9	0.6	0.6
	INNERMOST	Ceramic tile	0.015	1.2	850	2000		0.9	0.6	0.6
	INNERMOST	Gypsum plaster	0.01	0.4	1000	1000		0.9	0.5	0.5
		Plaster(coarse)	0.01	0.72	840	1860		0.9	0.6	0.6
		Hollow concrete block	0.35	0.62	840	1040		0.9	0.6	0.6
		Cast concrete	0.04	1.4	650	2100		0.9	0.6	0.6
FLAT ROOF		Cement screed	0.04	1.4	650	2100	0.452	0.9	0.6	0.6
		Bituminous membrane sheet	0.006	0.23	1000	1100		0.9	0.87	0.87
		XPS Extruded Polystrene	0.04	0.03	1400	35		0.9	0.6	0.6
		Cast concrete	0.04	1.4	650	2100		0.9	0.6	0.6
	OUTERMOST	Ceramic tile	0.015	1.2	850	2000		0.9	0.6	0.6
	OUTERMOST	Gypsum plaster	0.01	0.4	1000	1000		0.9	0.5	0.5
PARTITION WALL 1		Plaster(coarse)	0.02	0.72	840	1860		0.9	0.6	0.6
		Brickwork (inner leaf)	0.195	0.62	800	1700	0.985	0.9	0.7	0.7
		Plaster(coarse)	0.02	0.72	840	1860		0.9	0.6	0.6
	INNERMOST	Gypsum plaster	0.01	0.4	1000	1000		0.9	0.5	0.5
	OUTERMOST	Gypsum plaster	0.01	0.4	1000	1000		0.9	0.5	0.5
PARTITION WALL 2		Plaster(coarse)	0.02	0.72	840	1860		0.9	0.6	0.6
		Brickwork (inner leaf)	0.195	0.62	800	1700	1.541	0.9	0.7	0.7
		Plaster(coarse)	0.02	0.72	840	1860		0.9	0.6	0.6
	INNERMOST	Gypsum plaster	0.01	0.4	1000	1000		0.9	0.5	0.5
	OUTERMOST	Generic clear	0.004							0.8
EXT. GLAZING		Air gap	0.012				2.725			
	INNERMOST	Generic clear	0.004							0.8
DOORS		Wooden door	0.035	0.19	2390	700	2.25	0.9	0.5	0.5

Initially, the construction technique planned to be used is reinforced concrete skeleton system (Table 5.2.). In fact, the exterior walls and partitions are designed to be made of hollow brick, while building envelope is to be covered by thermal insulation layer. The material of floors is selected as hollow tiles, i.e. hollow clay tile and reinforced with steel framing, overlaid with wooden parquet in common use spaces, as well as ceramic tiles for wet cores. Furthermore, the building consists of hollow brick internal partitions and thermally insulated exterior walls. The glazing units are composed of 4 mm clear double-pane glasses with a 12 mm air cavity. In addition, wooden framed doors are selected for the openings of interior spaces.

Actually, Turkey is separated into four climatic zones according to TS 825 in order to specify different heat transfer coefficient (U value) limitations for building components of the envelope. Therefore, the U value of exterior walls and external floors with 0,70W/m²K, 0,45W/m²K with roofs, windows having U value of 2,4W/m²K and internal partitions with 0,8m²K/W R value are the maximum rates specified for the climate zone of İzmir. In fact, U values of exterior walls and roof defined by the architect are 0,61W/m²K and 0,452W/m²K in this study. In addition, U values of interior floors are designated as 0,985W/m²K and 1,23W/m²K depending on different functions, as well as partition walls having 0,985W/m²K and 1,541W/m²K U values. Thermophysical properties of the building components are defined in consistent with Thermal Insulation Regulations in Buildings (TS 825, 2008). The conductivity, specific heat, density, thermal, solar, visible absorptance and calculated U values of the constituents are demonstrated in Table 5.2.

5.2. Pre-Processing

There are a number of design, physical and scenario uncertainties effecting the energy and environmental performance of buildings as indicated in the Chapter 4.3. The parameters of these categories are specified for the case study, according to the interview conducted with the architectural office.

The architect has brought the project into a certain level during design process by following the regulations and client's requests. Therefore, a number of parameters have been disregarded such as building dimensions and floor height in terms of design decisions about configuration of the building form. In addition, design parameters are mostly selected by concentrating on building components, such as building envelope, internal partitions, floors and roof.

Accordingly, 45 design parameters are selected for three groups of inputs; as design, physical and scenario variables. The maximum and minimum values depending on thermal and physical characteristics of input parameters are specified due to the common materials used for walls in the building sector in Turkey (Table 5.3.). For example, concrete, adobe, hollow brick, autoclaved aerated concrete (AAC) and solid brick are the materials considered for exterior walls.

The roof and intermediate level variables are studied separately, with regard to diverse thermal performance of different levels. The material thickness and conductivity of thermal insulation material for roof are additionally different than the intermediate floor, in terms of design and physical parameters.

Different thermal responses of facade orientations are also considered during parameter selection process. Table 5.3. indicates that, north-east (N-E), north-west (N-W), south-east (S-E) and south-west (S-W) elevations are studied individually, due to positioning of the building. Besides, annual energy consumption performance includes acclimatization (heating and cooling, except ventilation) characteristics of the building. Remaining energy consumption factors such as lighting, electrical appliances, elevator and services are excluded from calculations.

Only, the effects of climate change are investigated as the scenario parameter. Since the scenario parameters require separate modelling than design and physical variables, and accurate results can be gathered in terms of the effects of climate change; this section is going to be analyzed individually. Hence, the simulations of each time period is going to be conducted by fixing remaining variables.

Table 5.3. Input parameters for the top and intermediate floors of case building

PARAMETER TYPES	PARAMETERS			UNITS	MIN. VALUE	MAX. VALUE
DESIGN PARAMETERS	Color (Reflectance)	Exterior Wall	NE Facade	-	0,1	0,9
			NW Facade	-	0,1	0,9
			SE Facade	-	0,1	0,9
			SW Facade	-	0,1	0,9
	Air Infiltration Rate			ach	0,3	4
	Shading Device Angle (Horizontal)		NE Facade	°	0	90
			NW Facade	°	0	90
			SE Facade	°	0	90
			SW Facade	°	0	90
PHYSICAL PARAMETERS	Thermal Insulation Material Thickness	Exterior Wall	NE Facade	m	0	0,2
			NW Facade	m	0	0,2
			SE Facade	m	0	0,2
			SW Facade	m	0	0,2
		Interior Floor		m	0	0,1
		Roof (Additional for top floors)		m	0	0,2
	Conductivity of Thermal Insulation Material	Exterior Wall	NE Facade	W/m.K	0,03	0,05
			NW Facade	W/m.K	0,03	0,05
			SE Facade	W/m.K	0,03	0,05
			SW Facade	W/m.K	0,03	0,05
		Interior Floor		W/m.K	0,03	0,05
		Roof (Additional for top floors)		W/m.K	0,03	0,05
	Exterior Wall Material Thickness		NE Facade	m	0,19	0,4
			NW Facade	m	0,19	0,4
			SE Facade	m	0,19	0,4
			SW Facade	m	0,19	0,4
	Density of Exterior Wall Material		NE Facade	kg/m³	300	2400
			NW Facade	kg/m³	300	2400
			SE Facade	kg/m³	300	2400
			SW Facade	kg/m³	300	2400
	Specific Heat Capacity of Exterior Wall Material		NE Facade	J/kg.K	750	1000
			NW Facade	J/kg.K	750	1000
			SE Facade	J/kg.K	750	1000
			SW Facade	J/kg.K	750	1000
	Conductivity of Exterior Wall Material		NE Facade	W/m.K	0,1	2,5
			NW Facade	W/m.K	0,1	2,5
			SE Facade	W/m.K	0,1	2,5
			SW Facade	W/m.K	0,1	2,5
	U Value	Window	NE Facade	W / m²K	0,8	3,5
			NW Facade	W / m²K	0,8	3,5
			SE Facade	W / m²K	0,8	3,5
			SW Facade	W / m²K	0,8	3,5
	Solar Heat Gain Coefficient	Window	NE Facade	-	0,3	0,85
			NW Facade	-	0,3	0,85
			SE Facade	-	0,3	0,85
			SW Facade	-	0,3	0,85
SCENARIO PARAMETERS	Generated Weather Data (2020s, 2050s, 2080s)					

Initially, the climate change world weather file generator (CCWorldWeatherGen) is selected to generate climate change weather files for the residential building located in İzmir, Turkey. CCWorldWeatherGen is a program used for projected weather data generation of various locations around the world by using existing climate change scenarios, which creates files ready to use in building simulation programs at the end. The program acquires weather conditions of specified regions, and generates probabilistic weather files according to the projected A2 scenario (see Section 3.2.). The existing weather file of İzmir (TUR_Izmir.172180_IWEC.epw) is provided from website of the program, and used for weather data generation. Hence, three different probabilistic weather files of İzmir are obtained for overlapping 30-year time periods of the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). Generated weather files show changes in climate characteristics of İzmir over time. For instance, Figure 5.6. indicates that, global solar radiation of İzmir will increase around 5% by the 2080s.

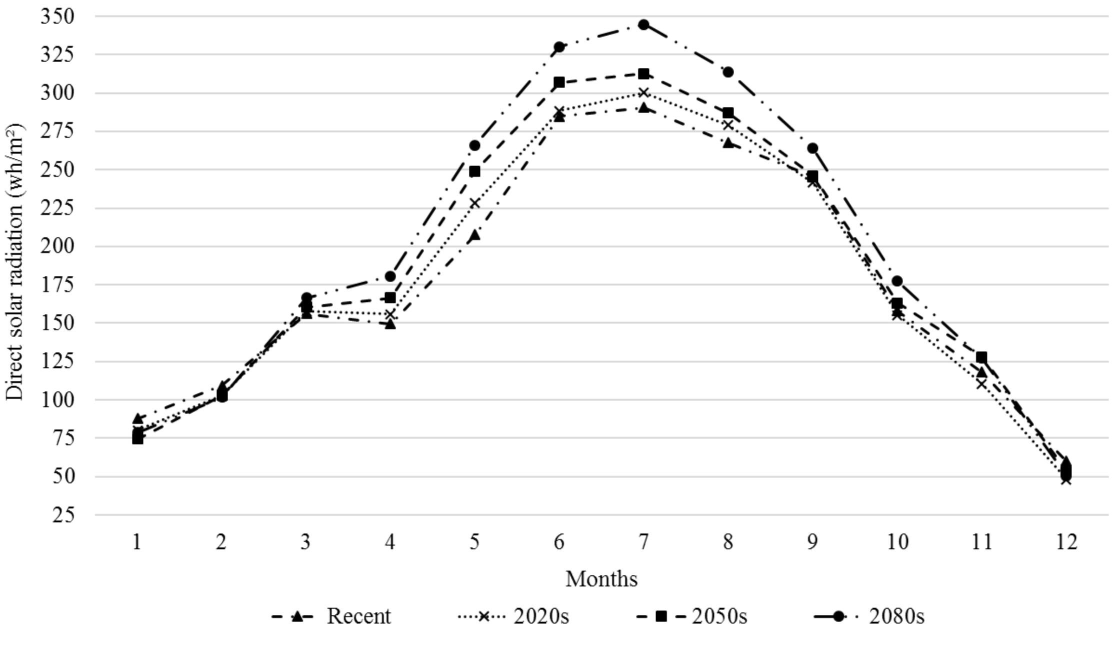

Figure 5.6. Monthly direct solar radiation for present, 2020s, 2050s, and 2080s in İzmir

The minimum and maximum values of each parameter are entered into SimLab sensitivity analysis program. SimLab is a software providing free development model for sensitivity and uncertainty analyses (https://ec.europa.eu/jrc/en/samo/simlab). It is a professional tool to use and exploit global uncertainty and sensitivity analysis techniques. It enables implementation of a number of global sensitivity analysis techniques. The first step of analysis process requires generation of sample files. In that way, design and physical parameters are combined simultaneously during sample generation process, while projected weather data as the scenario parameter is going to be handled discretely.

LHS is selected as the statistical sampling method, which includes dividing members of the parameters into uniform subgroups before sampling. It is mostly used to construct computer experiments, and Monte Carlo integration (see Section 4.1.). The minimum number for conducting LHS is indicated as two third of the number of parameters. In that case, requirement for the study is 68 samples at least. However, 200 samples are generated by using SimLab, in order to obtain more accurate results from the analyses. In addition, the number of samples is determined regarding to similar examples in the existing literature (Heiselberg et al., 2009; Hopfe et al., 2013). Namely, 200*43 sample matrix for the intermediate and 200*45 sample matrix for roof floors are generated in the program. Finally, entire sample matrices are saved into an Excel worksheet for creating energy simulation files.

5.3. Simulation

Digital modelling of the case building is provided by the simulation software, DesignBuilder v4.2. The program is a dynamic simulation modelling tool, which is able to execute building energy, CO_2, lighting and comfort performance analyses. Annual energy consumption for heating and cooling calculations are conducted through EnergyPlus algorithms within the program.

Generally, there are two different approaches in digital modelling for thermal simulations. The first method includes simplifications through real project by separating whole project into zones, so that complexity of the model decreases as well as the time spent for simulations. The second approach is modelling of the whole building according to entire information in a detailed way. This method contains more complexity than the previous model, and takes more time for simulations. However, the results present more accurate information. In this study, the digital model is simplified in order to accelerate simulation process, and decrease the model complexity by zoning method.

There are certain steps followed, during modelling of the building. Initially, model simplification is conducted by grouping corner flats into two zones (zones 1 and 4) due to similar thermal responses. Another four zones (zones 2, 3, 5 and 6) are created by joining attached flats between the circulation zone and corner apartments. Finally, entire floor leads up to six zones including living units and a zone for circulation (zone 7), which formation is the same for remaining residential floors (Figure 5.7.). Then, the plan drawings of the residential and commercial ground floors are generated and simplified in the AutoCAD program. The ground floor plan is not included into thermal calculations since occupancy, thermal behavior and space organization creates additional uncertainties for energy performance of the building. Therefore, only external borders of the space are designated in the program. On the other hand, residential floor of the building is formed according to the drawings collected from the architect and simplified zones.

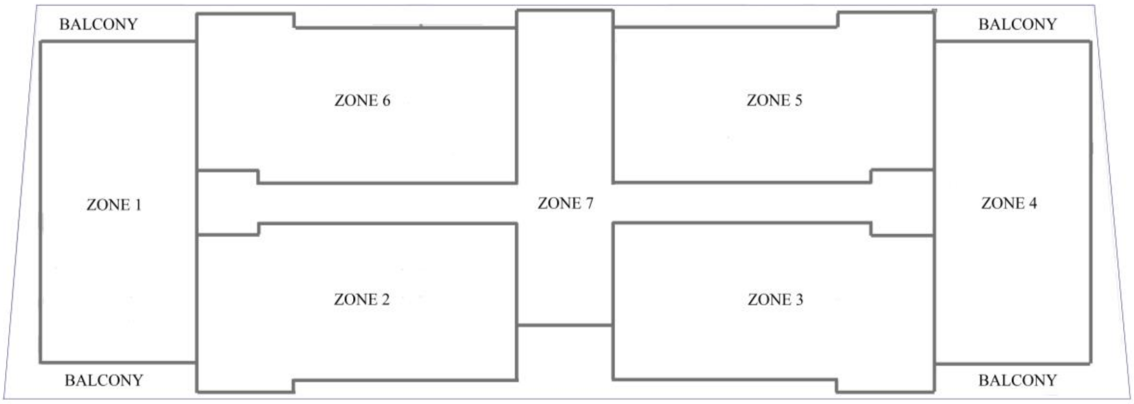

Figure 5.7. Simplified zone information of the building simulation model

Afterwards, 2-D drawing of the building is exported into DesignBuilder, and modelled three dimensionally. The materials constituting building envelope, partitions, as well as openings and their thermophysical properties are assigned in reference to Table 5.2. At the same time, natural gas in terms of heating and electricity for the cooling are denoted as part of the building HVAC system. Besides, the building is assumed to be unoccupied, since the model contains combined functions within simplified zones, and the building is still in design phase. Hence, activities are not indicated for zones in order to avoid increasing uncertainty as well as possibility of errors. The flats are assumed to be heated by host system, and there would be no heat transfer between floors. Therefore, the floors are assumed to be adiabatic. Then, landscape arrangement and surrounding buildings are investigated, and added into the simulation model. Thermal properties of ground, water, or exterior environment materials are assigned. Two different versions of the simulation model are created, indicating the top floor and intermediate floor. In fact, the intermediate floor is selected as fourth floor of the building, since it is located in between. Then, model for the top floor is created, and thermophysical properties of materials are designated additionally (Figure 5.8.). Finally, two different files are created by exporting both digital models in order to be used for energy simulations.

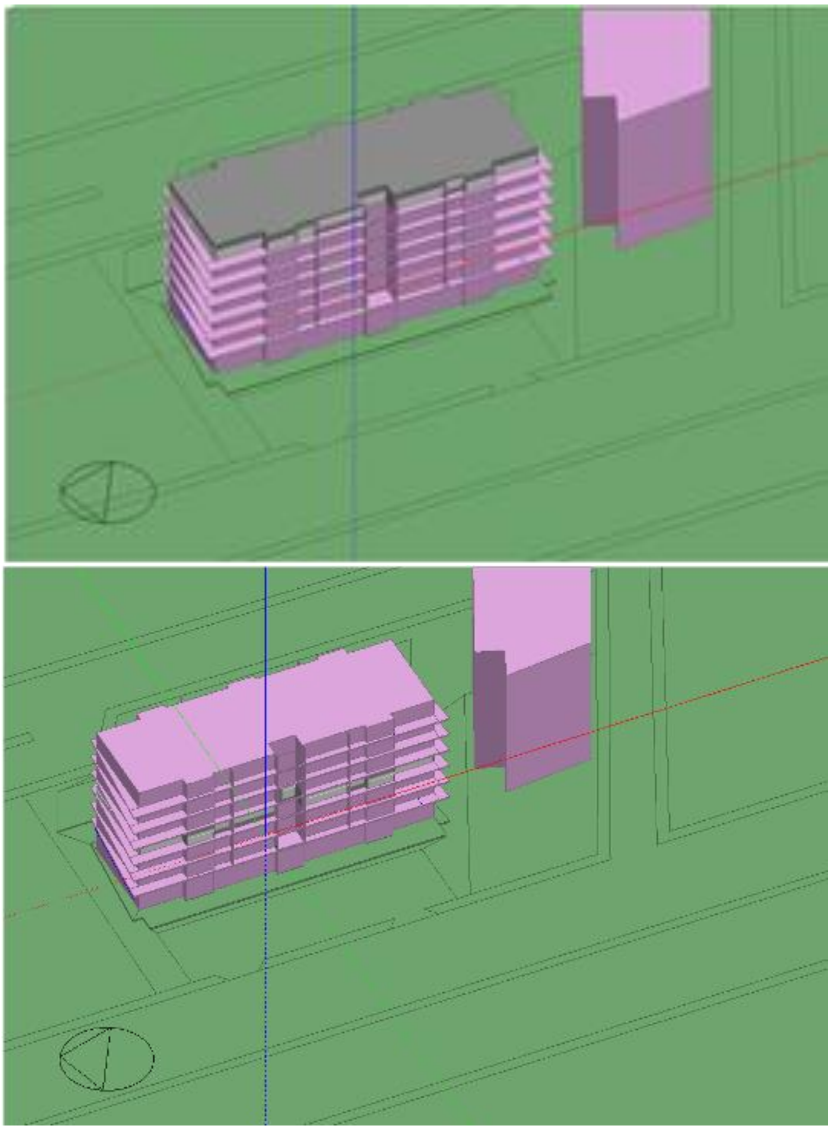

Figure 5.8. Visuals from the digital building simulation models

Energy simulations are held by EnergyPlus 8.1.0.009 software. EnergyPlus input data files (IDF) are created by using previously generated sample matrices by SimLab and the digital base model by DesignBuilder, then saved as Excel worksheets. IDF files are obtained by assigning material properties indicated in sample matrices to the base model. That process is automatically driven by a computer code written in Matlab program, then total 400 IDF files are created for the intermediate and top floors, indicating entire input parameter combinations assigned. In conclusion, IDF files are collected by allocating the values in generated sample matrices into text-based EnergyPlus files, and all IDF files are executed through a repetitive process.

Annual energy consumption for heating and cooling of the building and annual operational CO_2 emissions are specified as output parameters for the sensitivity analysis. Therefore, EnergyPlus simulations are held for annual energy consumption for heating and cooling. The energy consumption results are collected for heating and cooling separately by EnergyPlus. Then, annual operational CO_2 emissions are calculated by acquired annual total energy consumption values. For this step, results are generated from 200 IDF files including combinations of different values of building input parameters for each floor. There are two digital models of the mid-rise residential block consisting of the top floor and intermediate floor. Hence, 400 IDF files are used. Then, they are simulated to calculate outputs for each climatic data representing the present, 2020s, 2050s and 2080s, separately.

Initially, specific weather data is assigned, and IDF files are simulated by EP-Launch.exe interface of EnergyPlus program for the thermal simulations. EnergyPlus provides simultaneous iterations for multiple input files. After this step, the program automatically simulates each input file in turn, and gives results in different EnergyPlus extension files. This iterative process is called group energy simulation in the program. 1600 output files are collected in response to 200 input files for each floor and climatic data (present, 2020s, 2050s, 2080s). Afterwards, another computer code generated by Matlab is used to collect outcomes from each output file, assign them automatically to selected Excel files, and save each file individually. As a final step, annual CO_2 emissions are calculated manually in order to have more accurate results adapted to Turkey, by using sum of annual heating and cooling consumption values. Total annual energy consumption values are multiplied by CO_2 emission factors specified in regulations on the energy performance of buildings; as 0.234 kg/kWh for the natural gas and 0.819 kg/kWh for the electricity. In conclusion, input sample matrices and building performance simulation results are collected during simulation stage. Following process requires the investigation of the relations between input parameters, and energy and environmental performance of the building.

5.4. Post-Processing

Post-processing section includes the examination of input and output parameter correlations. Uncertainty and sensitivity analyses are conducted in order to observe energy and environmental performance of the building in time, and the most important design parameters on building characteristics.

Uncertainty analysis is used for decision making problems in order to examine the uncertainty of variables. It is a part of the technical process of decision support by means of quantifying relevant uncertainties. Various assumptions, simplifications or calibrations during researches may cause misleading outcomes, as well. Hence, uncertainty analysis utilizes a number of techniques for discovering the reliability of model predictions, accounting for various sources of uncertainty in model input and design. Experimental uncertainty estimations require evaluating confidence levels of the results. Uncertainties in energy and environmental performance of the building according to climate scenarios are examined by SimLab program. EnergyPlus simulation results are exported into program and frequencies and mean values of energy consumption and emission properties of the building are collected from the program.

The impacts of input parameters are evaluated by using sensitivity analysis method. Statistical analysis program, SimLab is used for sensitivity analysis. Initially, the sample files are exported, in terms of providing information about ranges of the input parameters. Then, generated Excel model output files, created by using EnergyPlus simulation results of annual energy consumption for heating and cooling, and operational CO_2 emissions are assigned into the program.

The Monte Carlo method is selected for the configuration process. Monte Carlo procedure is the analysis of building models by substituting a range of probability distributions for any factor that has uncertainty. By using probability distributions, variables can have different probabilities of different outcomes (Section 4.1.). Probability distributions are much more realistic for describing uncertainty in variables. In addition, uniform probability distribution is assigned for each parameter, so that all values have equal chances of occurring. Besides, it requires only defining the minimum and maximum values of parameters. After specification of input and outputs, regression based sensitivity analysis method is selected. In this study, Standardized Rank Regression Coefficient (SRRC) is determined as an indicator to identify the sensitivity of each design parameter, which is based on a non-linear relation between the output and input parameters (Helton et al., 2006). Eventually, sensitivity analysis is conducted in order to clarify the most effective design parameters on energy and environmental performance of the building.

Uncertainty and sensitivity analyses results are evaluated through annual heating, cooling, total energy consumptions as well as annual operational CO_2 emissions. Besides, the most sensitive parameters are indicated according to annual total energy consumption results.

CHAPTER 6

UNCERTAINTY AND SENSITIVITY ANALYSIS FOR DESIGN SUPPORT

The total 1600 EnergyPlus simulation results will be explained in terms of uncertainties and sensitivities in this chapter. The input parameters and the simulation results are entered into SimLab program, then the analysis results are collected. Uncertainties in energy and environmental performance of the building according to different climate conditions will be studied in the first section, in order to find out the possible impacts of global warming. Then, the sensitivity analysis results will be presented. The most effective parameters on performance of the building will be specified. In this section, each parameter will have the importance value between -1 and 1, where the negative sign points out that, the output parameter value (annual energy, annual operational CO_2 emissions) will decrease when there is an increase in input parameter value. On the contrary, the positive numbers point out the direct proportion of the input parameter value and the model output. In fact, values higher than 0.9 are indicated as very effective, while useless regression model implies the values below 0.1 for the output variable (Saltelli et al., 1993). Therefore, input parameters having the absolute values higher than 0.1 will be considered as more influential design variables, as others, having values less than 0.1, will be classified as ineffective on increasing or decreasing annual energy consumption and environmental emissions.

The evaluations will be visualized by histograms and explained with the statistical values to demonstrate the uncertainties and sensitivities of different parameters in terms of annual heating, cooling consumption and annual total energy consumption as well as annual operational CO_2 emissions in four different climatic conditions.

6.1. Uncertainty Analysis Results

6.1.1. Uncertainties of Outputs at Present

Annual heating energy consumption frequencies: The range of possible annual heating energy consumption together with the frequency of each interval for the intermediate and top floors at present are represented in Figure 6.1. The annual heating consumption range varies between 17.5 and 39.7 kWh/m² for the intermediate floor, while it is between 22.5 and 42.4 kWh/m² for the top floor. In addition, amount of annual energy consumption for the intermediate floor is less than the top floor. Extreme differences are not observed for the annual heating consumptions between the intermediate and top floor. The most frequent annual heating consumption is 28.7 kWh/m² for the intermediate floor, while it is 33.2 kWh/m² for the top floor. The frequency and ranges of annual heating consumption indicate alterations in terms of levels of the building. Mean values of annual heating consumption are 27.9 kWh/m² for the intermediate level and 32.7 kWh/m² for the top level.

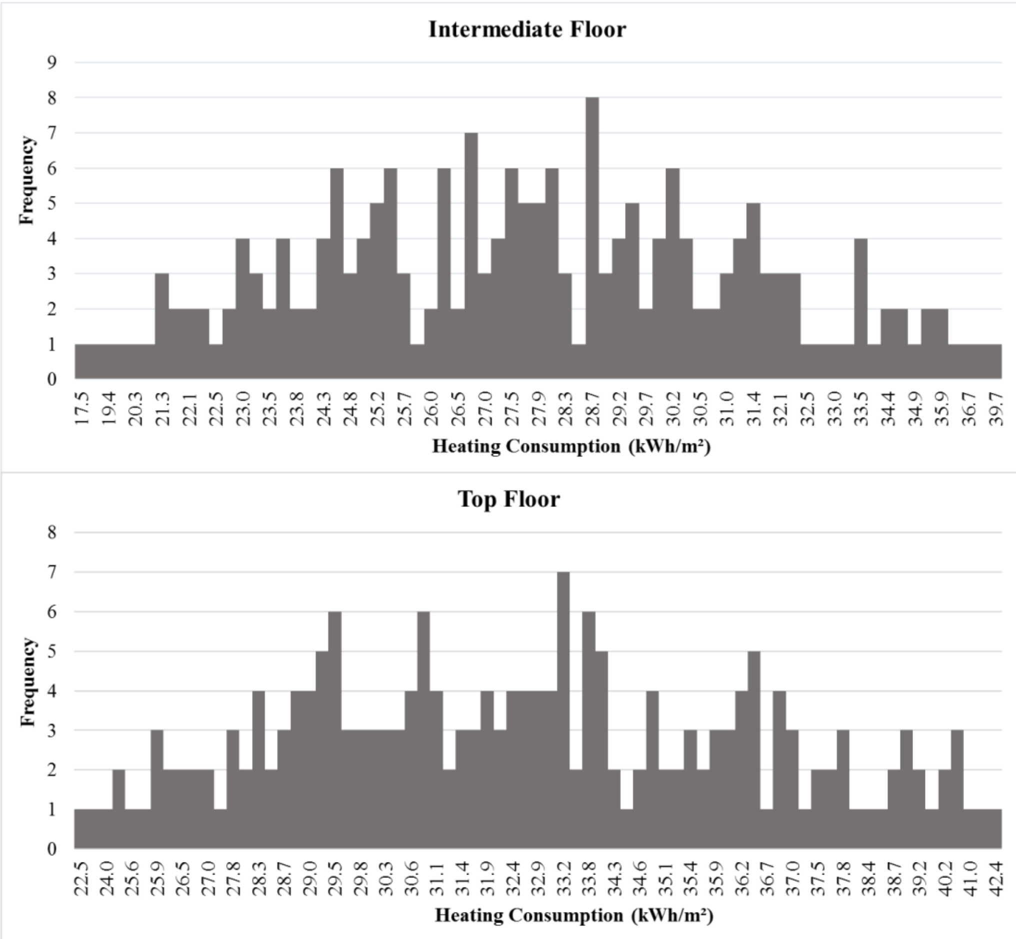

Figure 6.1. Uncertainties of annual heating consumption at present

Annual cooling energy consumption frequencies: The range of possible annual cooling energy consumption as well as the frequency of each interval for the intermediate and top floors at present are visualized in Figure 6.2. The range of annual cooling consumption between minimum and maximum values is broader than annual heating consumption. For instance, the difference between min and max values for annual heating consumption indicates 22.2 kWh/m² for the intermediate floor, and 19.9 kWh/m² for the top floor. On the other hand, it is around 32.9 kWh/m² for the intermediate floor, while the top floor reveals 24.3 kWh/m² difference. Similarity between the minimum annual heating and cooling consumption amounts for the intermediate floor is observed, while maximum values show difference because of higher cooling consumption, which is around 49.7 kWh/m². It is also indicated that more amount of energy is needed for cooling than heating, since the mean value of cooling consumption is around 31.7 kWh/m² for present. The minimum cooling consumption is also similar between the intermediate and top floors, although the top floor requires less amount of energy than the intermediate floor in terms of maximum values. Mean values of the top floor annual cooling consumption is around 28.1 kWh/m². The most frequent consumption is seen around 23.5, 24.9 and 28.9 kWh/m² for the top floor, while it is around 26.5 kWh/m² for the intermediate floor.

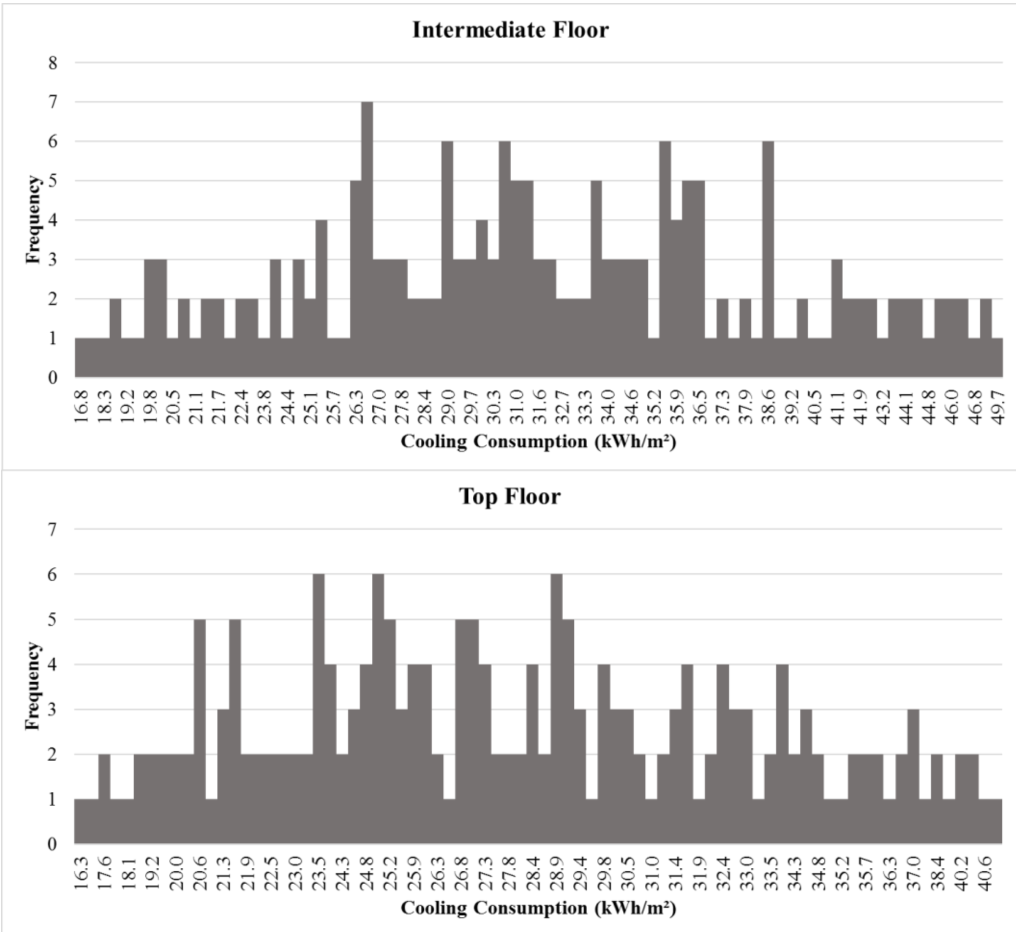

Figure 6.2. Uncertainties of annual cooling consumption at present

Annual operational CO_2 emission frequencies: The possible annual operational CO_2 emissions are between 22.2 and 44.8 kg CO_2e/m^2 for the intermediate floor, while they are indicated as 23.0 and 39.5 $kgCO_2e/m^2$ for the top floor. It is demonstrated in Figure 6.3. that, minimum values are very similar for both floors. However, maximum emission value for the intermediate level is much higher than upper level. In fact, the amount of operational CO_2 released increases due to higher cooling consumption values of intermediate floor. Mean values of operational CO_2 emissions are 32.9 $kgCO_2e/m^2$ for the intermediate floor, 30.6 $kgCO_2e/m^2$ for the top floor. Therefore, it is possible to observe decreases in emission amounts of the upper floors of studied mid-rise residential block.

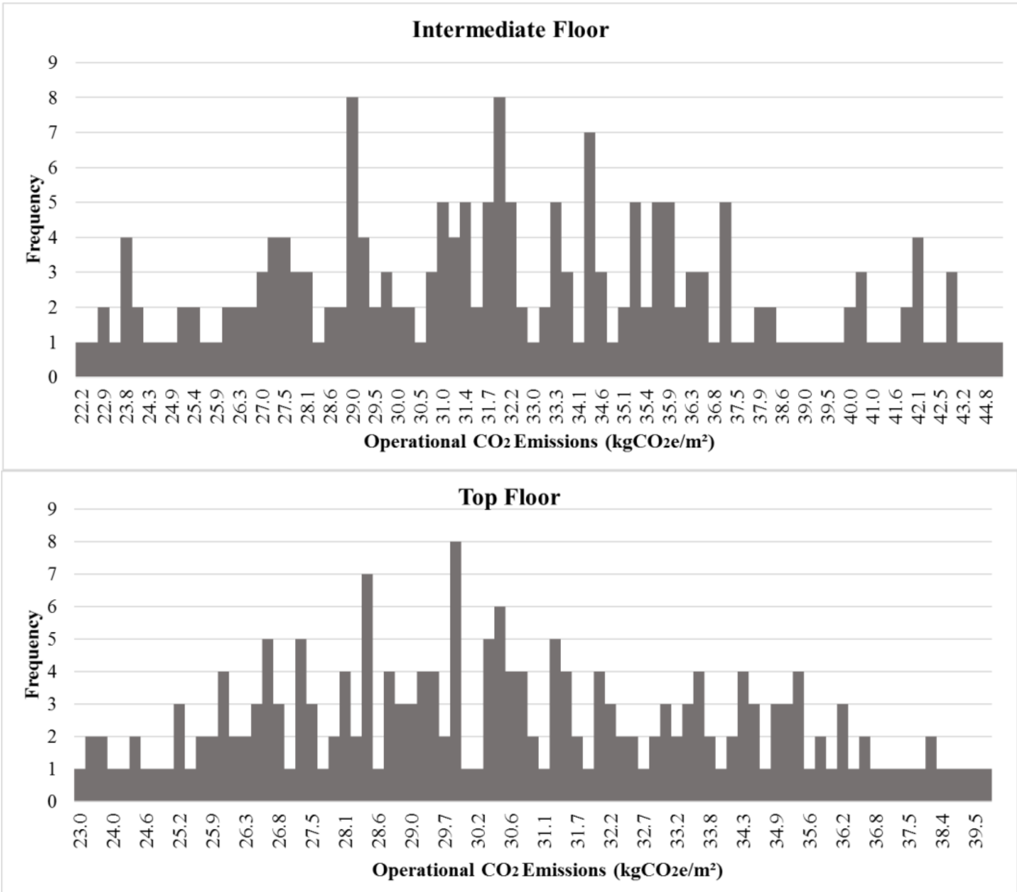

Figure 6.3. Uncertainties of operational CO_2 emissions at present

6.1.2. Uncertainties of Outputs in the 2020s

Annual heating energy consumption frequencies: The difference between maximum and minimum values of annual heating consumption decreases in the 2020s with reference to recent values, for both levels. Annual heating energy consumption is between 14.8 kWh/m² (around 3.0 kWh/m² less than present) and 33.7 kWh/m² (around 6.0 kWh/m² less than present) for the intermediate floor, while it is 19.4 kWh/m² (3.0 kWh/m² less than present) and 36.2 kWh/m² (6.0 kWh/m² less than present) for the top floor (Figure 6.4.). In terms of mean energy demand, the intermediate floor needs lower amount of energy with 24.1 kWh/m² for heating. The mean energy consumption takes place on the top floor with 28.4 kWh/m². The most frequent values for annual heating consumption is 25.0 kWh/m² for the intermediate floor and 25.5, 28.0, 28.7, 29.5 and 31.3 kWh/m² for the top floor.

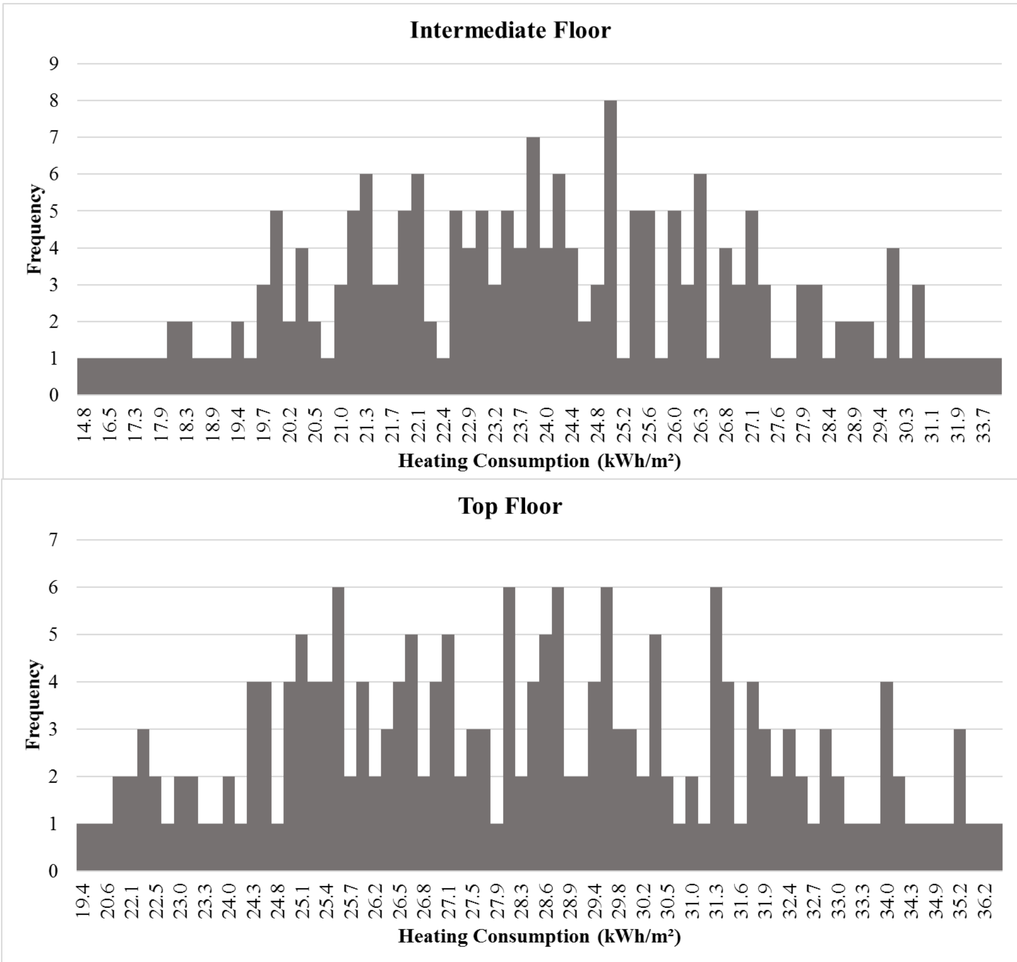

Figure 6.4. Uncertainties of annual heating consumption in the 2020s

Annual cooling energy consumption frequencies: The observable increase in annual cooling consumption for both levels shows up, when it comes to the 2020s. The values change between 23.7 and 57.1 kWh/m² for the intermediate floor, while it is between 23.8 and 50.5 kWh/m² for the top floor (Figure 6.5.). The most frequent annual cooling consumption is 38.3 kWh/m² for the intermediate floor and it is 33.0 kWh/m² for the top floor, which are relatively higher than previous year energy consumption values. The differences between maximum and minimum values of annual cooling consumption stays the same with recent results.

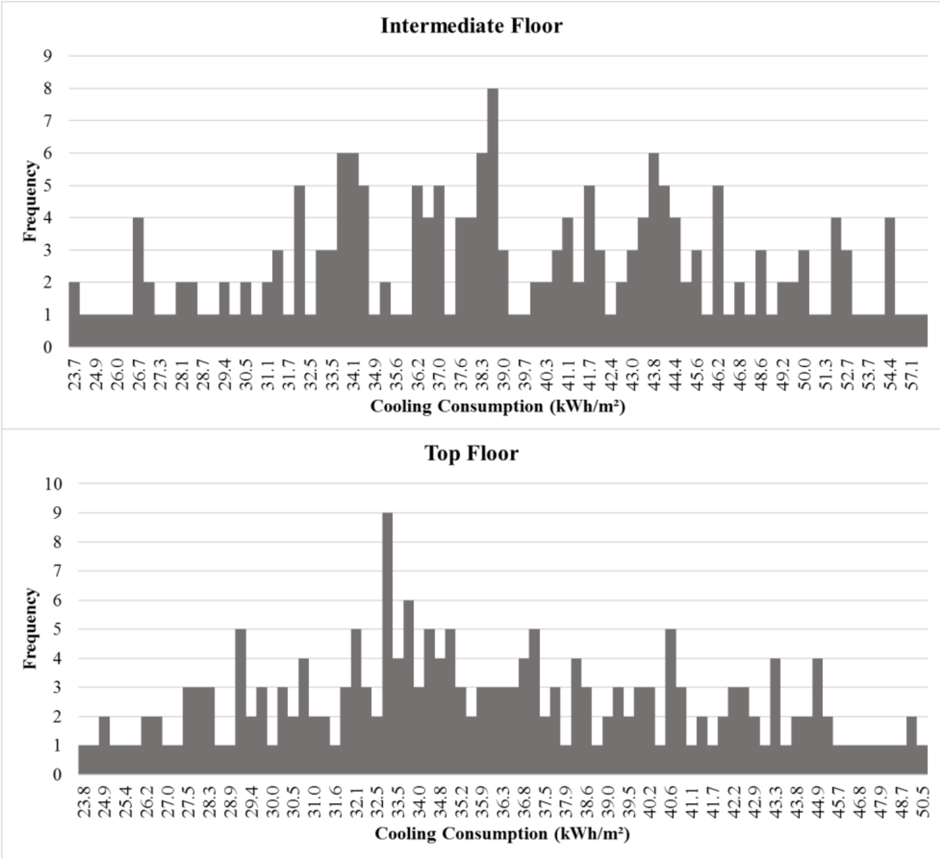

Figure 6.5. Uncertainties of annual cooling consumption in the 2020s

Annual operational CO_2 emission frequencies: The consumption values differ between 26.5 and 50.6 kgCO_2e/m² for the intermediate floor, while the minimum value is 27.6 kgCO_2e/m², and the maximum value is 46.5 kgCO_2e/m² for the top floor (Figure 6.6.). There is an increase in emissions for both floors in the 2020s with reference to recent results. The difference between minimum and maximum values is higher for the intermediate floor than the top floor. The trend of decrease in emission values for upper floors continues for the 2020s similar to recent results. Mean operational CO_2 emission values of the intermediate and top floor are 38.1 and 36.2 kgCO_2e/m² respectively. The intermediate floor emission values are higher than the top floor. The most frequent results of the intermediate floor are 36.0, 36.6 and 38.5 kgCO_2e/m², while they are 33.5, 35.0 and 36.1 kgCO_2e/m² for the top floor.

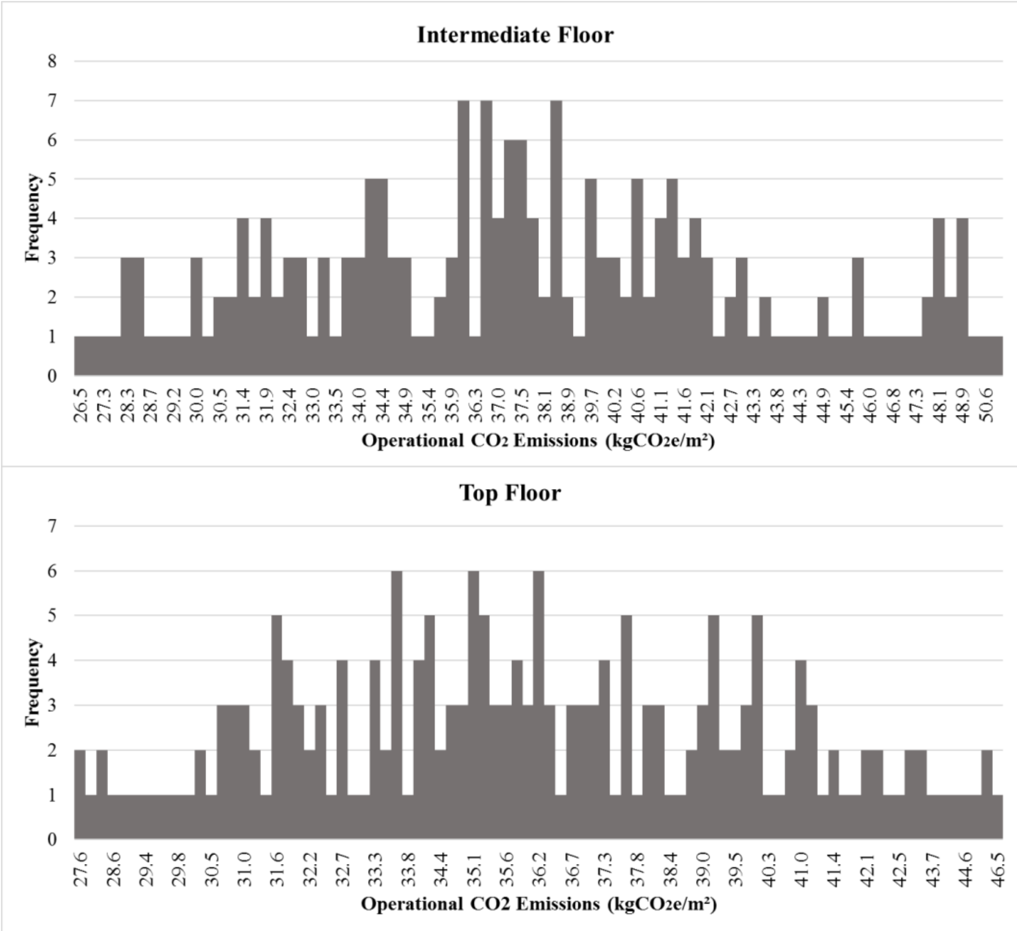

Figure 6.6. Uncertainties of operational CO_2 emissions in the 2020s

6.1.3. Uncertainties of Outputs in the 2050s

Annual heating energy consumption frequencies: Annual heating consumption changes between 12.0 and 29.0 kWh/m² for the intermediate floor, besides it is between 16.0 and 30.8 kWh/m² for the top floor, in the 2050s (Figure 6.7.). For both levels, around 4.8 kWh/m² decrease is observed in comparison with recent values. The most frequent heating consumption value is 20.1 kWh/m² for the intermediate level and 24.9 kWh/m² for the top floor. The top floor requires more energy for heating than lower levels, as it was the same in previous time periods. The difference between minimum and maximum energy consumption also decreases over time. For instance, around 22.2 kWh/m² difference is observed for the intermediate floor annual heating consumption at present, while it declines to 17.5 kWh/m² in the 2050s.

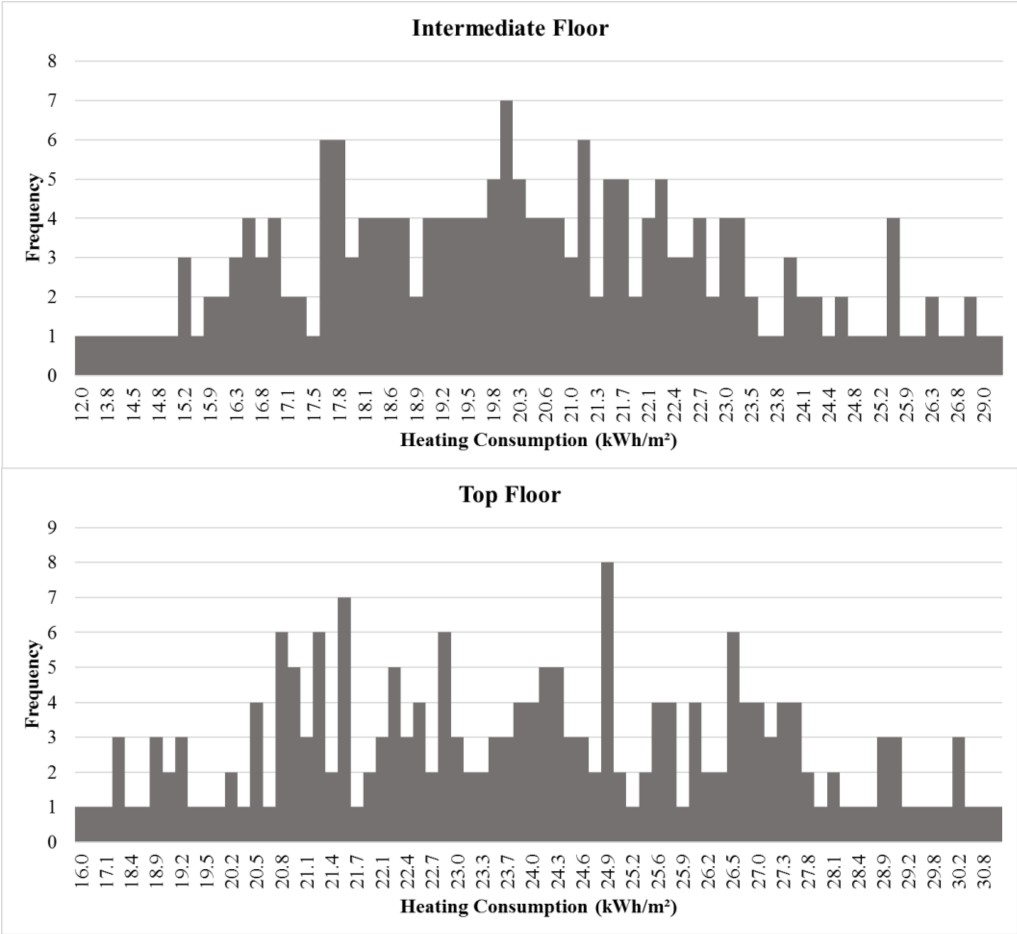

Figure 6.7. Uncertainties of annual heating consumption in the 2050s

Annual cooling energy consumption frequencies: Frequencies and distribution of annual cooling consumption values in the 2050s are represented in Figure 6.8. It is indicated that, the energy demands of intermediate floor change between 31.1 and 67.1 kWh/m², while it is between 32.1, 58.6 kWh/m² for the top floor. The range between minimum and maximum values remains the same with previous years, which is approximately 17.5 kWh/m². The most frequent annual cooling consumption amounts are 46.9 and 52.1 kWh/m² for the intermediate floor and 40.8 kWh/m² for the top floor. This indicates that, higher amounts of cooling energy is needed for the intermediate floor than the upper level.

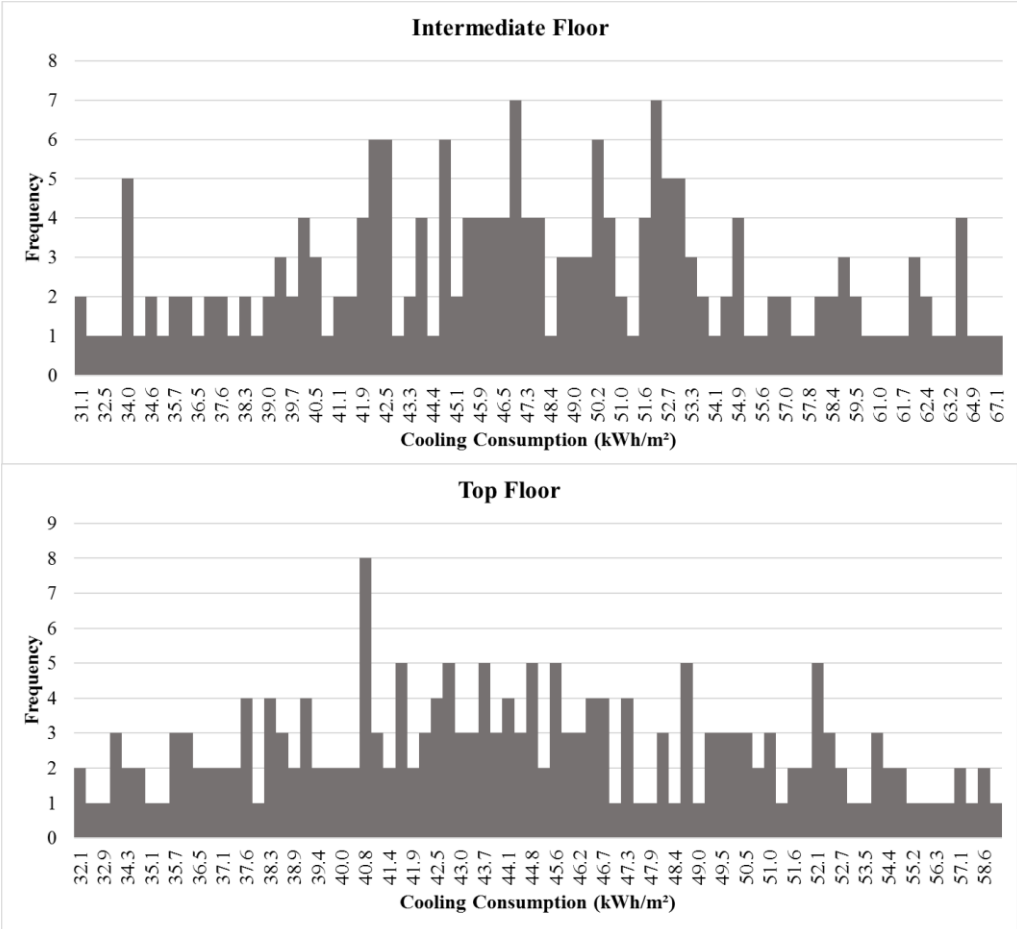

Figure 6.8. Uncertainties of annual cooling consumption in the 2050s

Annual operational CO_2 emission frequencies: Annual operational CO_2 emission frequencies are pointed out for the intermediate and top floors in the 2050s (Figure 6.9.). The minimum and maximum emission values are 31.4 and 58.6 $kgCO_2e/m^2$ for the intermediate floor, while they are 32.7 and 52.4 $kgCO_2e/m^2$ for the top floor. In addition, the most frequent emission values are 42.5 for the intermediate level, while 36.2 and 41.2 $kgCO_2e/m^2$ for top level. Mean values of both floors are 44.1 and 42.2 $kgCO_2e/m^2$ for the intermediate and top floors. In other words, the intermediate floor causes more carbon equivalent emissions than upper floors.

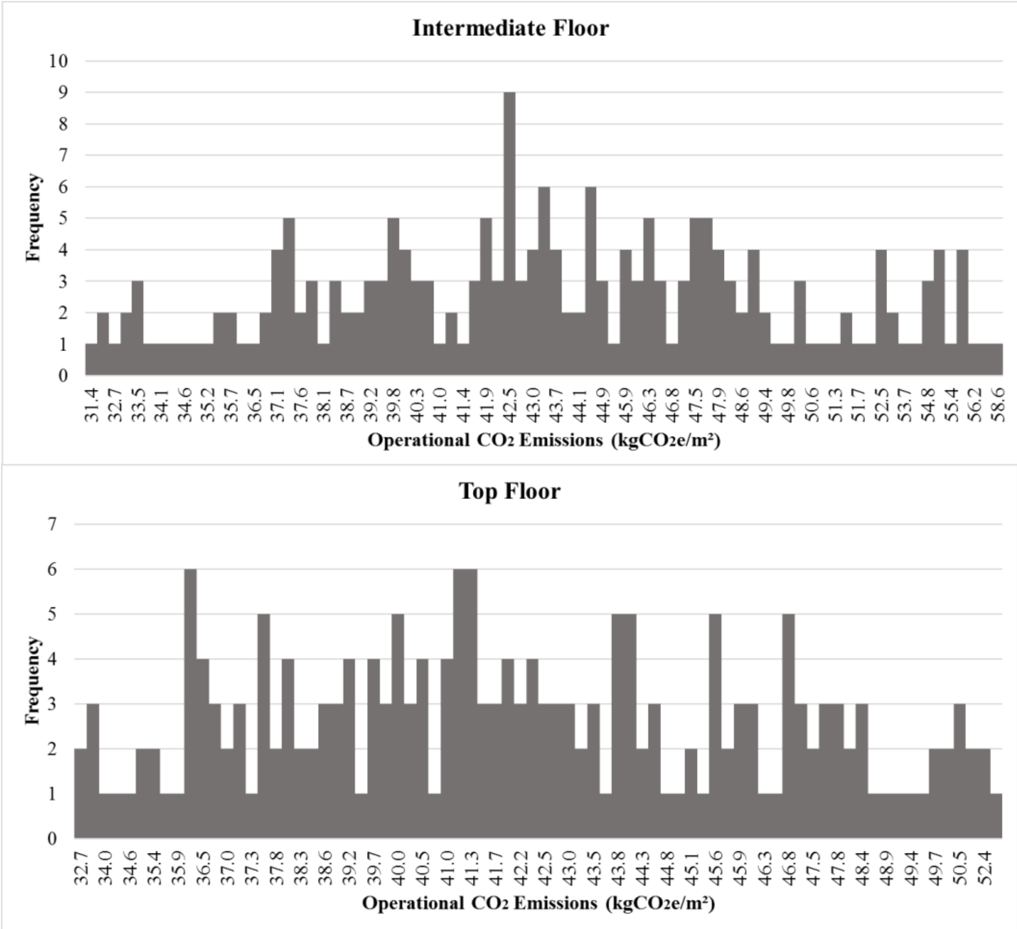

Figure 6.9. Uncertainties of operational CO_2 emissions in the 2050s

6.1.4. Uncertainties of Outputs in the 2080s

Annual heating energy consumption frequencies: Annual heating consumption trend is between 8.5 and 23.2 kWh/m² for the intermediate floor, and it is between 11.7 and 24.8 kWh/m² for the top floor, in the 2080s (Figure 6.10.). The mean values for annual heating consumption of the intermediate and top levels are 15.7 and 18.3 kWh/m², respectively. Namely, annual heating consumption is still higher for upper levels than intermediate floor. Difference between the minimum and maximum results also stay similar to recent values, which is around 14.0 kWh/m². The most frequent energy demand is 16.0 kWh/m² for the intermediate floor, whereas they are 16.8 and 17.5 kWh/m² for the top floor.

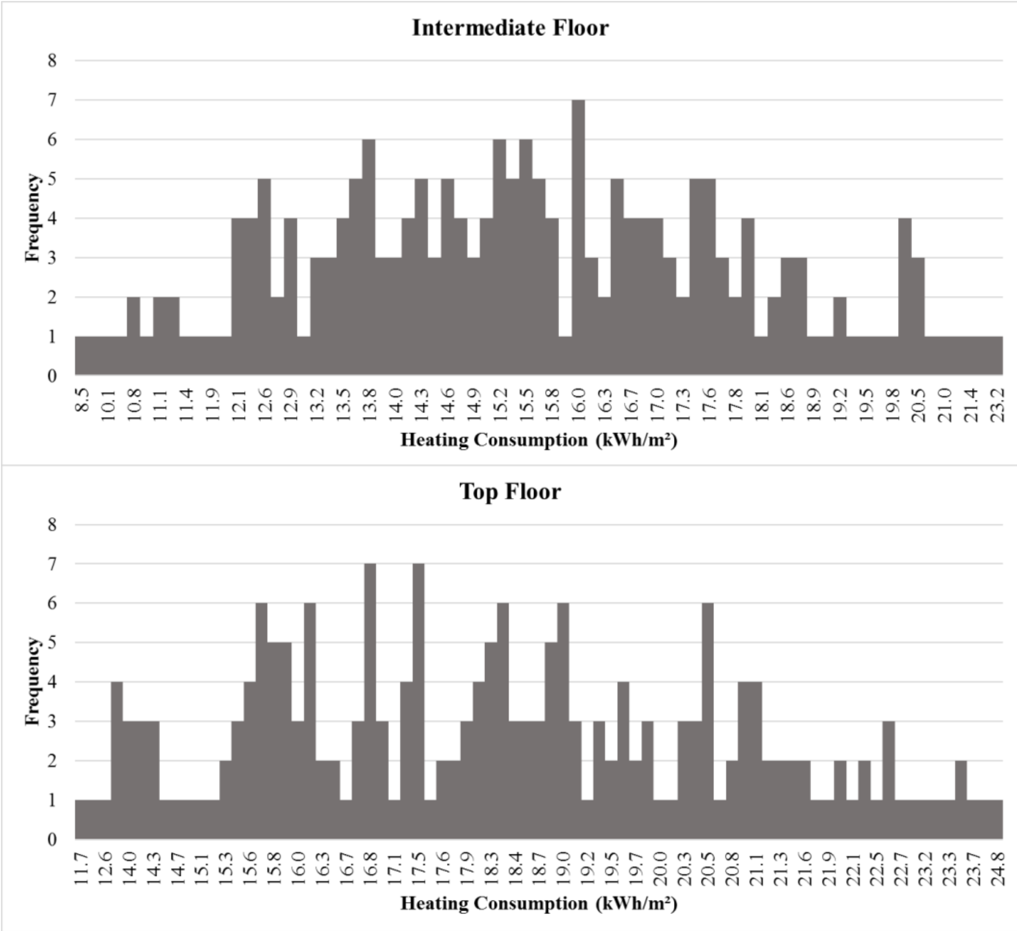

Figure 6.10. Uncertainties of annual heating consumption in the 2080s

Annual cooling energy consumption frequencies: The intermediate and top floor annual cooling consumption range is around 42.7, 81.7 kWh/m² and 44.4, 74.6 kWh/m² in the 2080s (Figure 6.11.). The range between minimum and maximum values of energy consumption increase, in comparison with the one of annual heating consumption. Moreover, the difference is around 20.6 kWh/m² for the top floor in the 2050s, while it increases to 30.2 kWh/m². It means that, changes in cooling consumption also increase in time. The mean value of the intermediate floor annual cooling consumption is 62.0 kWh/m² (95% higher than the present value), and it is 59.2 kWh/m² (45% higher than the present value) for the top floor. The most frequent cooling consumption is 59.8 kWh/m² for the intermediate level, while it is 57.3 kWh/m² for the top floor.

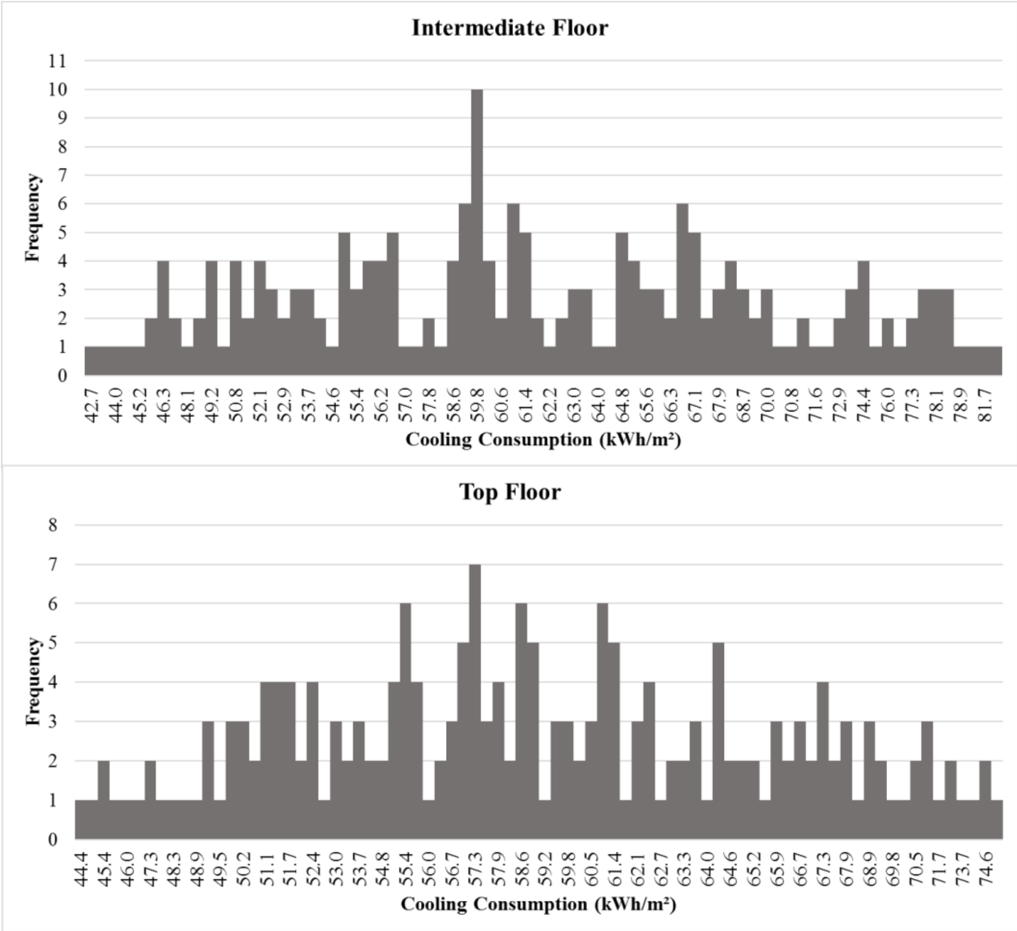

Figure 6.11. Uncertainties of annual cooling consumption in the 2080s

Annual operational CO_2 emission frequencies: Annual operational CO_2 emissions for the intermediate and top floor in the 2080s are presented in Figure 6.12. Namely, the intermediate floor emission value ranges between 39.7 and 71.0 kg CO_2e/m², while the top floor values are between 41.3 and 64.6 kg CO_2e/m². Mean emission values are 54.3 kgCO_2e/m² for the intermediate floor, 52.7 kgCO_2e/m² for the top floor. The most frequent emission value is 52.2 kgCO_2e/m² for the intermediate level, and they are 50.2 and 51.2 kgCO_2e/m² for the top level.

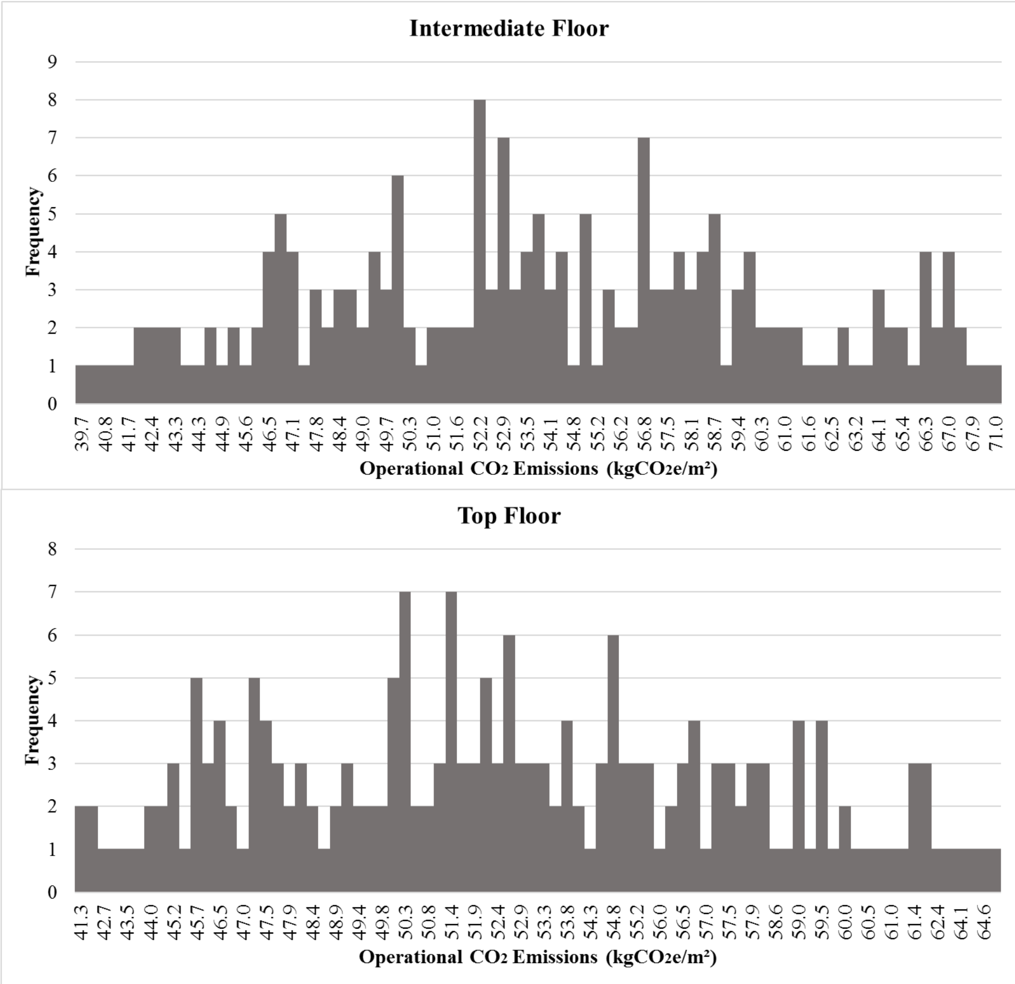

Figure 6.12. Uncertainties of operational CO_2 emissions in the 2080s

6.1.5. Evaluation of Uncertainty Analysis Results

The purpose of the uncertainty analysis is to support the design process by providing additional information about the impacts of input variables, and to observe uncertainties about different climate scenarios. Investigating the influence of the uncertainties of inputs on the outputs. Therefore, indication of the analysis results about the general trend of the energy and environmental performance of the building within different time periods are explained in this section. Important information about the uncertainties of output parameters due to changing design variables and projected weather conditions are numerically visualized by the analysis results, as well.

All selected input parameter properties have been varied simultaneously in order to cover uncertainties in outputs of the presented building. Then, the uncertainties of annual energy consumption for heating and cooling, and annual operational CO_2

emissions in changing climate conditions are analyzed according to the building performance simulation results. Simulations have clarified the uncertainties about the impacts of global warming on annual energy consumption and CO_2 emissions of different floors. Hence, the evaluation of uncertainties is conducted by examining the annual mean heating, cooling, operational CO_2 emissions and annual total energy consumption values.

Initially, both floors follow the similar performance patterns throughout the years (Figure 6.13. and Figure 6.14.). Annual mean values of heating consumption represent similar trend lines for both floors, which indicate significant amounts of decrease from present to the 2080s. Declines in annual heating consumption point out the effects of global warming, as well as changes in thermal behavior of the building. In addition, recent annual heating consumption of the top floor is higher than the intermediate floor. It is caused by more amounts of heat loss through the roof of top floor, compared to the losses of the intermediate floor. However, there has been so severe decrease in annual heating consumptions of the intermediate floor throughout the years. It is also observed that, the amount of annual heating consumption of top floor gets higher than intermediate floor in the 2080s. Besides, there is an increase in the mean values of annual cooling consumptions from present to the 2080s, which is around 30 kWh/m² for both floors. The necessity of more energy for cooling in order to fulfil occupant comfort within the building is also appeared during the analysis of climate change.

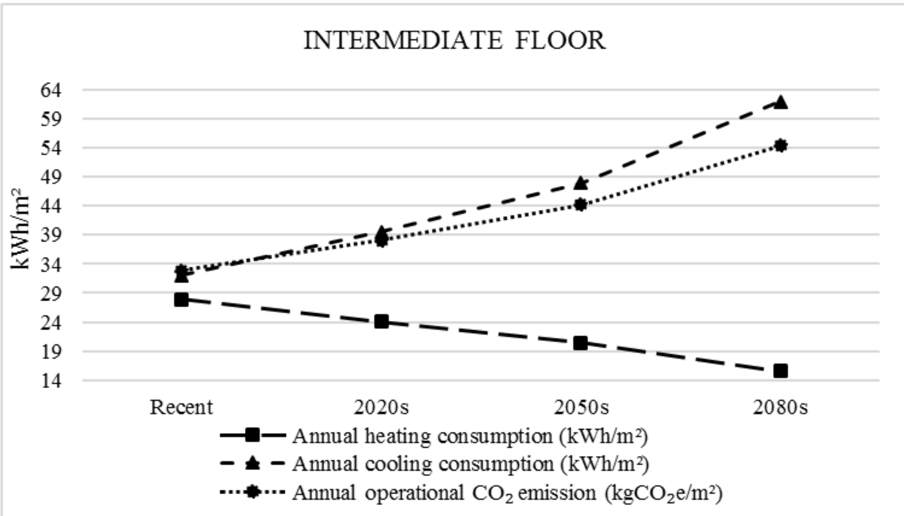

Figure 6.13. Annual performance properties of the intermediate floor

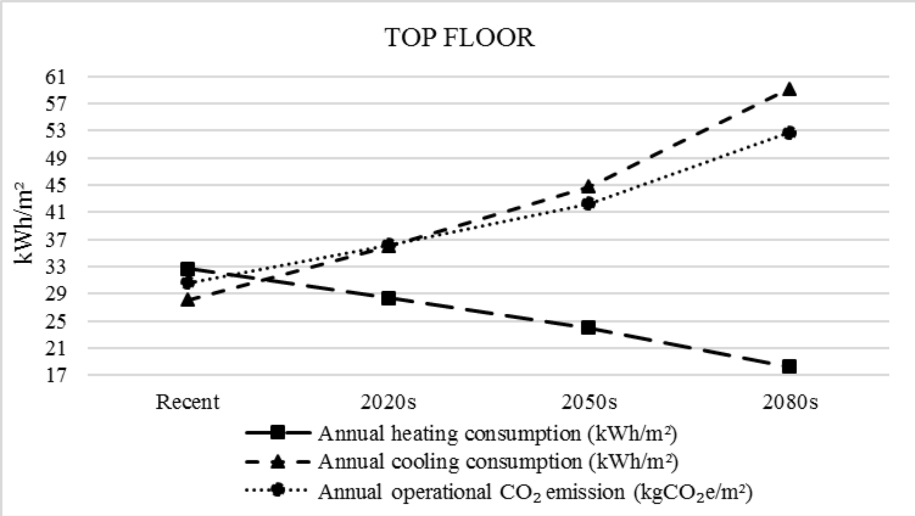

Figure 6.14. Annual performance properties of the top floor

Annual heating and cooling consumptions are balanced between the 2020s and 2050s for the top floor (Figure 6.14.). Although energy consumption for cooling on the intermediate floor is higher than heating, starting from recent years (Figure 6.13.). The changes in heating and cooling requirements of the building visualize the increases in heat gains arising from the effects of global warming.

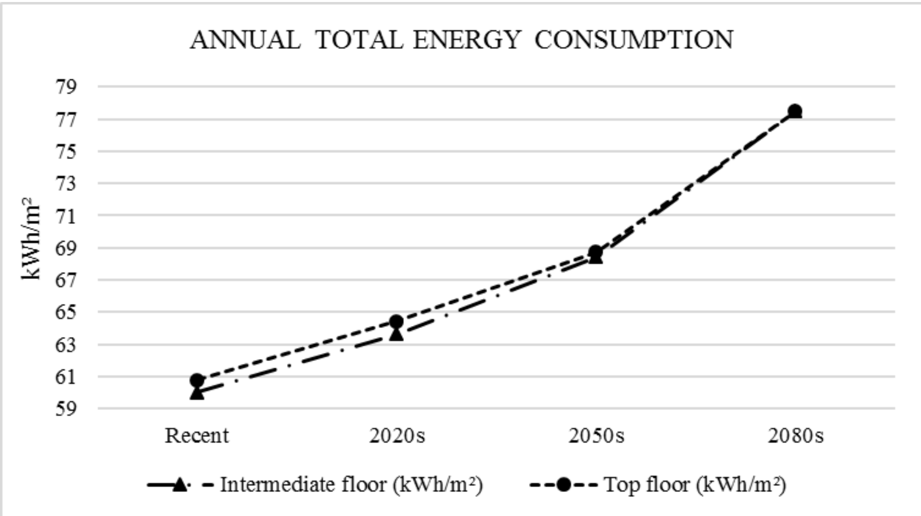

Figure 6.15. Annual total energy consumption comparison of different floors

Both floors consume similar amounts of energy per year within the years. However the energy needed for the top floor is higher at present, the energy consumption values of both floor start getting closer to each other starting from the 2050s, as shown in Figure 6.15. Besides, annual total energy consumptions of the building have shown significant amount of increase from recent years to the 2080s. For example, the intermediate floor consumes around 60 kWh/m² per year at present, although it is around 78 kWh/m² per year in the 2080s, with 29.2 % increase (Table 6.1.). It means that, if precautions are not taken during early design stages, energy performance of the building would show substantial decrease. The energy class specifications of the buildings in Turkey are determined by using the annual energy consumption and CO_2 emissions released per square meter in Turkey. The energy class specifications of the building will be below the acceptable labels (see Chapter 2).

It is also concluded that, the major changes in annual heating and cooling consumption correlations of the building have huge impacts on the environmental characteristics of the case building. The amount of CO_2 emissions from the intermediate level has always been slightly higher than the top level from present to the 2080s. Besides, huge amounts of increases are observed in operational CO_2 emissions until the 2080s. For instance, the recent mean CO_2 emission value is around 30 $kgCO_2e/m^2$ for top floor, then it shows around 72% rise until the 2080s. The results indicate that, the more temperature rises, the more carbon equivalent gases are released to the atmosphere from the studied residential block, located in hot-humid climate.

Table 6.1. Ratio of changes in annual performance characteristics of the building, compared to the recent values

Ratio of Annual Changes in Uncertainties (%)	Intermediate Floor			Top Floor		
	2020s	2050s	2080s	2020s	2050s	2080s
Annual Heating Consumption	-13.6	-26.7	-44.2	-13.1	-26.7	-44.2
Annual Cooling Consumption	23.3	49.5	93.1	28.2	59.3	110.7
Annual Operational CO_2 Emissions	15.9	34.3	65.2	18.1	37.8	72.0
Annual Total Energy Consumption	6.1	14.0	29.2	6.0	13.1	27.4

It is indicated that, the effect of annual cooling consumption is more than the annual heating consumption on operational CO_2 emissions of the building, since the amount of energy needed for cooling always increases, while heating consumption shows reduction when compared to recent values (Table 6.1.). In other words, excessive raises in energy consumption for cooling creates higher electricity oriented operational CO_2 emissions, even though the heating diminishes.

6.2. Sensitivity Analysis Results

6.2.1. Sensitivities of Input Parameters at Present

Sensitive parameters for annual heating energy consumption: The most important parameter affecting annual heating consumption of the building is the solar heat gain coefficient (SHGC) of windows located on S-W facade of the building, for both the intermediate and top floors at recent climate conditions (Figure 6.16.). The sensitivity value of S-W window SHGC is -0.65 for the intermediate and top floors. The value is negative, because the annual heat gain through windows will increase by selecting windows with higher SHGC values. Hence, the annual heating consumption of the building will decrease. The time of exposure to the sun is the highest on S-W facade. The second important parameter is also SHGC of windows located on N-E facade of the building with a value around -0.4 for both levels. The third and fourth important parameters are U values of windows for N-E and S-W facades. The importance values of these parameters are around 0.35 and 0.29, for both levels. These results mean that, the annual heating consumption of the building will decrease, if the windows with lower U values are selected, since the less the U value is specified, the lower heat loss would be observed in the building. The fifth important parameter, window SHGC of S-E facade has -0.22 sensitivity value for the top floor, whereas the thermal insulation thickness of S-W and N-E exterior walls are sensitive for the intermediate floor which have the similar, -0.174 value of importance. The most remarkable point about the results of annual heating consumption is that, the most important parameters are related with the building envelope, and placed in physical parameters category. According to these results, S-W and N-E facades of the residential block are more significant than the others in case of attempts for decreasing the annual heating consumption of the building.

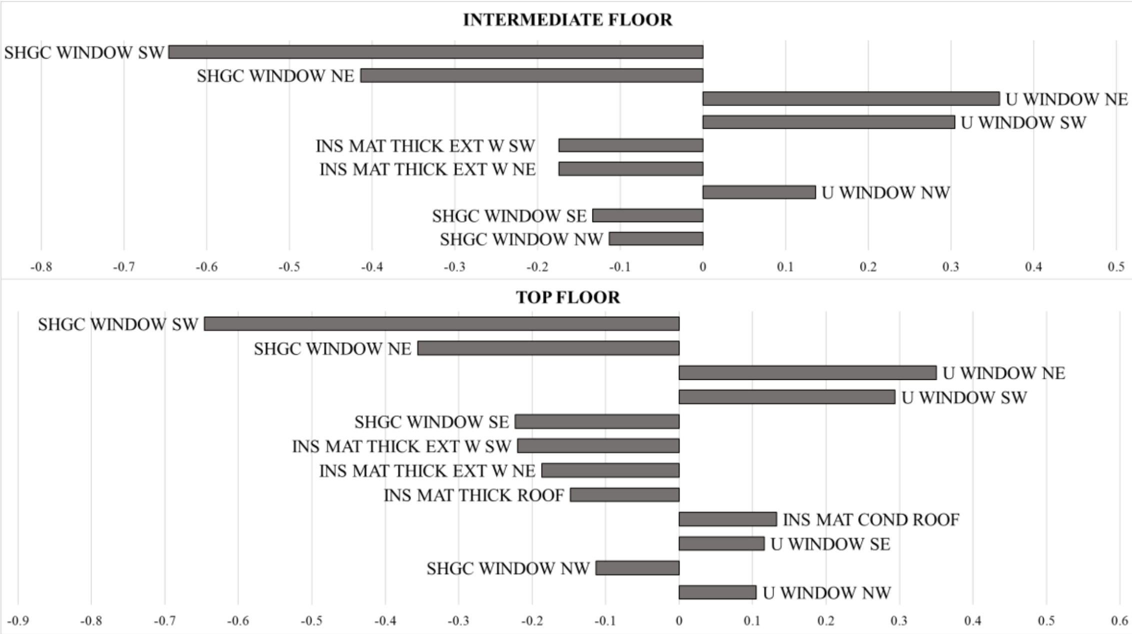

Figure 6.16. Sensitive parameters for annual heating consumption at present

Sensitive parameters for annual cooling energy consumption: The first and second important parameters of the top and the intermediate floors, affecting building annual cooling consumption are S-W and N-E window SHGC values, which is similar to annual heating consumption results (Figure 6.17.). Actually, if the SHGC values of windows are increased, the cooling consumption of both levels is going to increase depending on huge amounts of heat collected inside, since the building envelope has wide opening areas along each facade. Sensitivities of the parameters are around 0.7 and 0.6, which are remarkable numbers in terms of significance, indeed. The third and fourth effective parameters for annual cooling consumption of the block are window SHGC on S-E and N-W facades with around 0.2 and 0.15 values. These factors are followed by U values of S-W and N-E facade windows located on the top floor. The intermediate floor only has window U value of N-E facade with around -0.1 sensitivity value, as the fifth important parameter. In fact, the most effective parameters on annual cooling consumption are mostly related to the transparent surfaces of the building envelope similar to the annual heating consumption sensitivities. The resemblance between energy performance of the intermediate and top floors is still noticeable with regard to recent annual cooling consumption results.

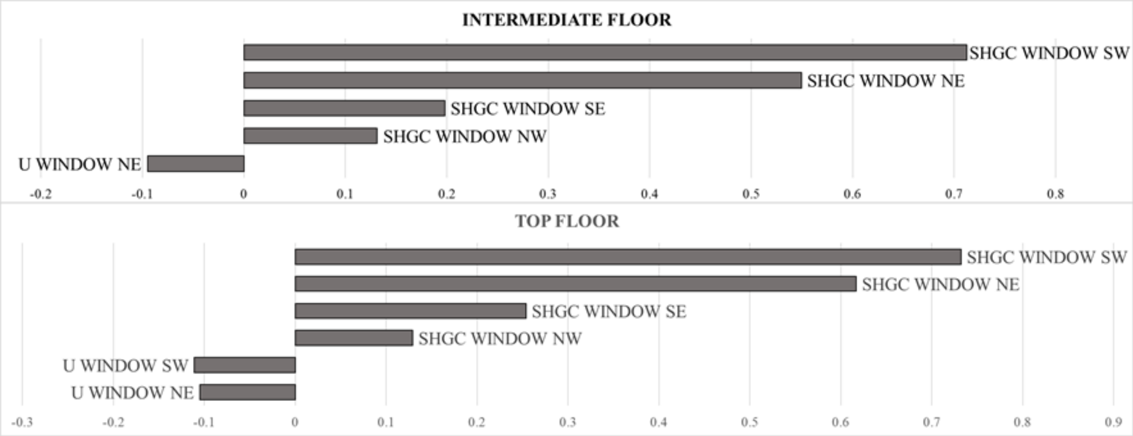

Figure 6.17. Sensitive parameters for annual cooling consumption at present

Sensitive parameters for annual operational CO_2 emission: The most important parameters for annual CO_2 emission of the building are also window SHGC of S-W, N-E, S-E and N-W facades (Figure 6.18.). Window SHGC of S-W and N-E facades are around 0.7, while the other two parameter sensitivity values are around 0.2. The remaining design factors are all under 0.1 value, so that the transparent surfaces of building envelope are the factors to be taken into consideration for improvements in environmental performance of the building. The sensitivity is on the positive side, since the decreases in window SHGC values would also cause lower amounts of CO_2 emission from the residential block.

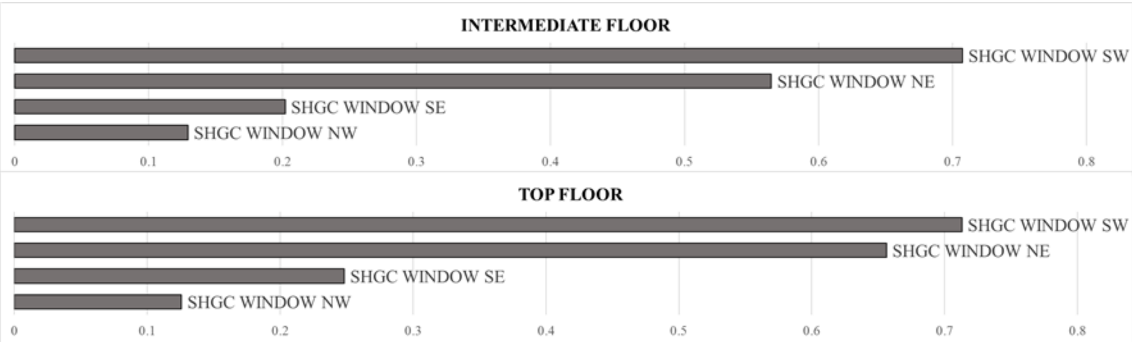

Figure 6.18. Sensitive parameters for annual operational CO_2 emission at present

6.2.2. Sensitivities of Input Parameters in the 2020s

Sensitive parameters for annual heating energy consumption: The window SHGC value of S-W facade is the most important factor for both floors in terms of annual heating consumption in the 2020s (Figure 6.19.). It has -0.65 sensitivity coefficient, which is much higher than the following N-E facade window SHGC with -0.4 importance value. Both parameters have negative sensitivity values, which indicates that increasing SHGC values will cause higher heating consumption during winter period. The third and fourth significant factors are U values of N-E and S-W facade windows which have around 0.3 SRRC values. Exterior wall insulation material thicknesses of S-W and N-E facades are the fifth and sixth important parameters for the intermediate floor, whereas they are behind SHGC value of S-E façade windows for the top floor. The results represent that, the physical parameters would still be important for annual heating consumption in the 2020s. Small differences on the importance of input parameters are seen between the intermediate and top levels, when time period has changed from present to the 2020s, as well. Transparent surfaces of the building would be considered firstly, during design decisions in terms of increasing building performance.

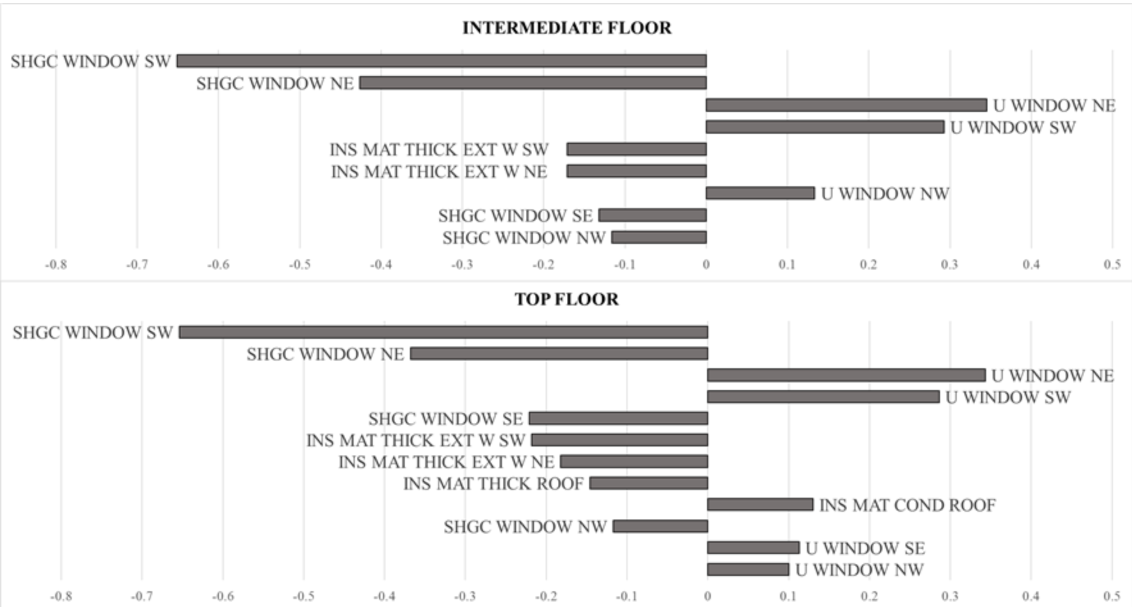

Figure 6.19. Sensitive parameters for annual heating consumption in the 2020s

Sensitive parameters for annual cooling energy consumption: Window SHGC of S-W facade is the most prominent parameter for annual cooling consumption of the top and the intermediate levels, in the 2020s with around 0.7 sensitivity value (Figure 6.20.). The second important parameter is window SHGC value of N-E facade, and it has around 0.6 sensitivity coefficient, while S-E and N-W facade window SHGC values are the third and fourth important factors with around 0.2 and 0.12 sensitivity coefficient values. Window U values are under 0.1 sensitivity value; thus they are omitted. However, it is conveyed that the transparent surfaces are still significant for the annual cooling consumption performance of the building.

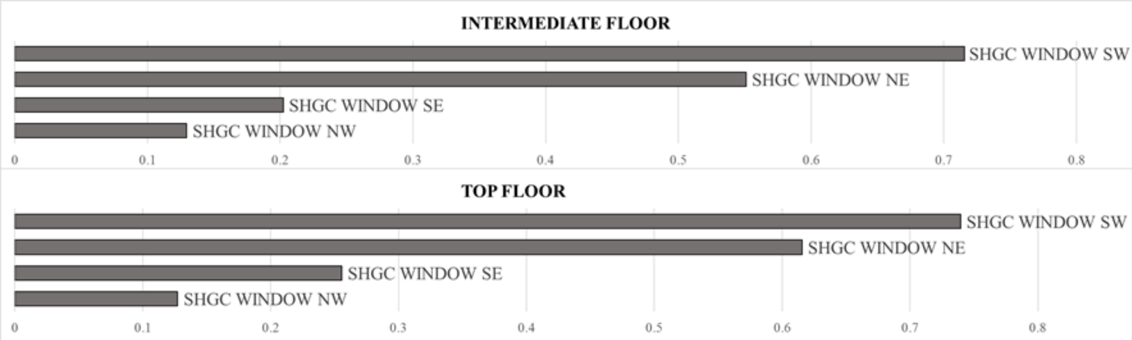

Figure 6.20. Sensitive parameters for annual cooling consumption in the 2020s

Sensitive parameters for annual operational CO_2 emission: Window SHGC value of S-W facade is the most significant parameter for annual operational CO_2 emissions of the top floor, and it has 0.72 sensitivity coefficient (Figure 6.21.). SHGC value of N-E facade window is the second effective factor for the top floor, with 0.65 sensitivity coefficient. The second and third sensitive variables are window SHGC values of S-E and N-W facades, which have lower sensitivity than the previous parameters, with 0.25 and 0.12 coefficients. The same importance levels are also valid for the intermediate floor results, but the importance coefficients are different than the top floor values. In fact, the higher numbers of the intermediate floor indicate that, the changes in window properties would be more effective than the top floor in terms of operational CO_2 emission performance of the building. The window SHGC of S-W and N-E facades have 0.7 and 0.56 sensitivity coefficients, while S-E and N-W facades have 0.2 and 0.14 values for the intermediate floor. It is indicated that, the attempts for decreasing annual CO_2 emissions would be possible by selecting windows with lower SHGC values for S-W facade openings of the building.

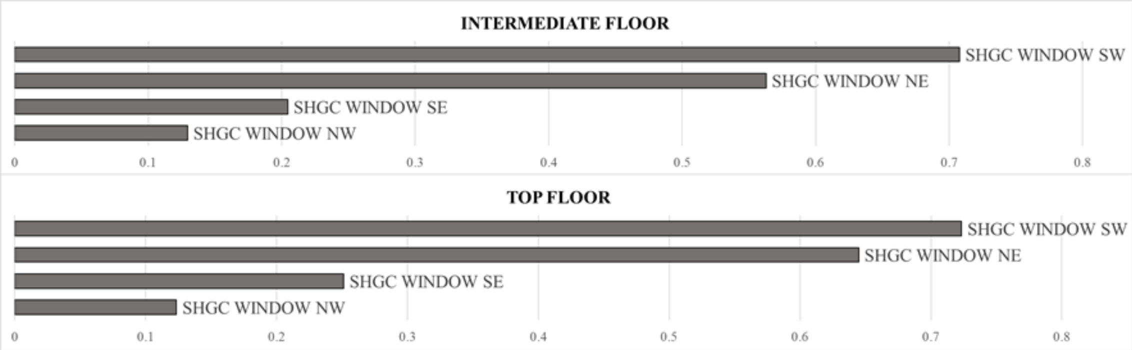

Figure 6.21. Sensitive parameters for annual operational CO_2 emission in the 2020s

6.2.3. Sensitivities of Input Parameters in the 2050s

Sensitive parameters for annual heating energy consumption: The sensitivity coefficient of S-W facade window SHGC is similar to the previous climatic scenarios, which is around -0.66 for the intermediate and top floors in the 2050s (Figure 6.22.). N-E facade window SHGC value is the second important parameter for annual heating consumption for both levels of the building with around -0.4 sensitivity rate. Window U values of N-E and S-W facades are also the third and fourth important parameters, after the previous indicators. The sensitivity coefficients are indicated as 0.34 and 0.28 for the physical characteristics of transparent surfaces.

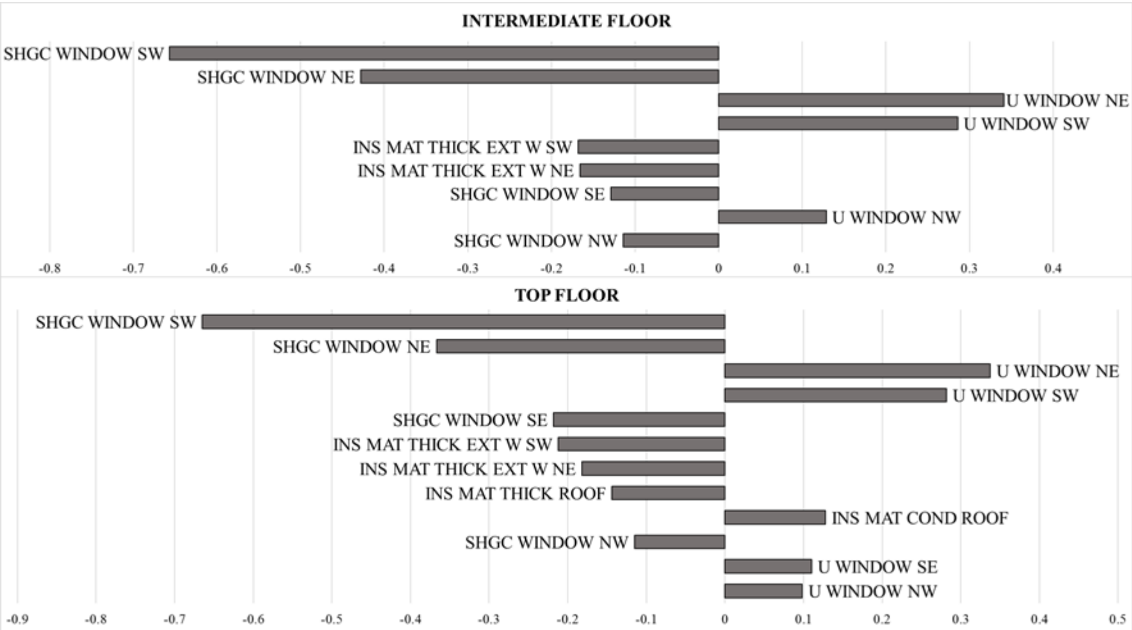

Figure 6.22. Sensitive parameters for annual heating consumption in the 2050s

Sensitive parameters for annual cooling energy consumption: The most effective parameter for annual cooling consumption of the intermediate and top floors is again the window SHGC value of S-W facades, which is specified with around 0.75 sensitivity coefficient value. Remaining important parameters with higher importance coefficients than 0.1 are window SHGC of N-E, S-E and N-W facades in terms of annual cooling consumption in the 2050s (Figure 6.23.).

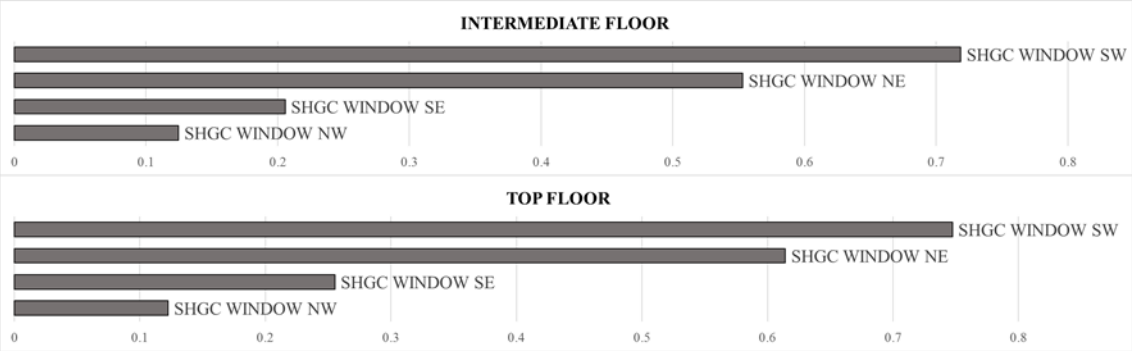

Figure 6.23. Sensitive parameters for annual cooling consumption in the 2050s

Sensitive parameters for annual operational CO_2 emission: Annual operational CO_2 emissions of the building (for the intermediate and top floors) is mostly effected by the same parameters of annual cooling consumption sensitivity results of the 2050s. Hence, the physical features of transparent surfaces are still the most essential parameters for environmental design issues in the 2050s. Different thermal responses of facades are presented in Figure 6.24., and the window SHGC of S-W facade is the most effective parameter for operational CO_2 emission performance of the building.

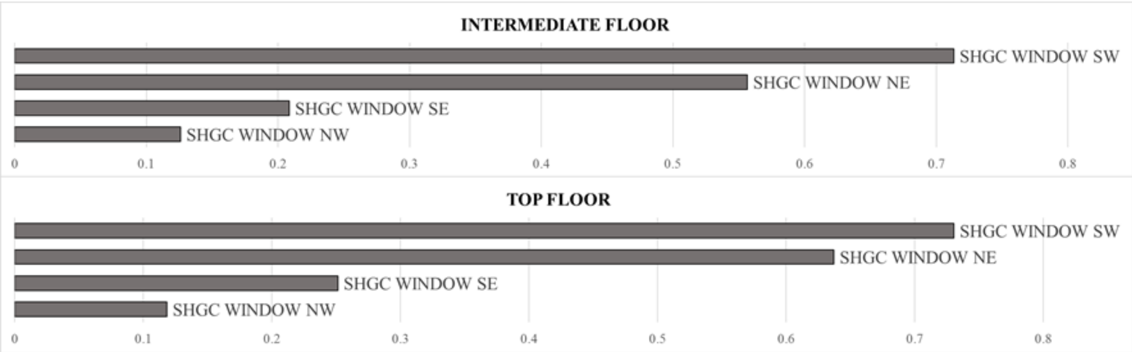

Figure 6.24. Sensitive parameters for annual operational CO_2 emission in the 2050s

6.2.4. Sensitivities of Input Parameters in the 2080s

Sensitive parameters for annual heating energy consumption: The window SHGC values of S-W facade is the most important parameter in terms of annual heating consumption of the building for the intermediate and top levels in the 2080s. The sensitivity coefficients are around -0.67. It has negative value, since the more SHGC value of windows increase, the less energy for heating is required for the building. The window SHGC of N-E facade is the second important parameter with around -0.4 for both floors. The third and fourth sensitive factors are the window U values of N-E and S-W facades. Transparent surfaces of the top floor are worth to mention in terms of window SHGC of S-E facade, while the insulation material thickness of exterior walls on S-W and N-E facades are more sensitive for the intermediate floor. Insulation material thickness and conductivity are also another significant factors for the top floor with around -0.15 and 0.12 sensitivity coefficients. Even though, the windows would be considered in case of building annual heating performance improvements, insulation material properties of the roof would also be examined thoroughly (Figure 6.25.).

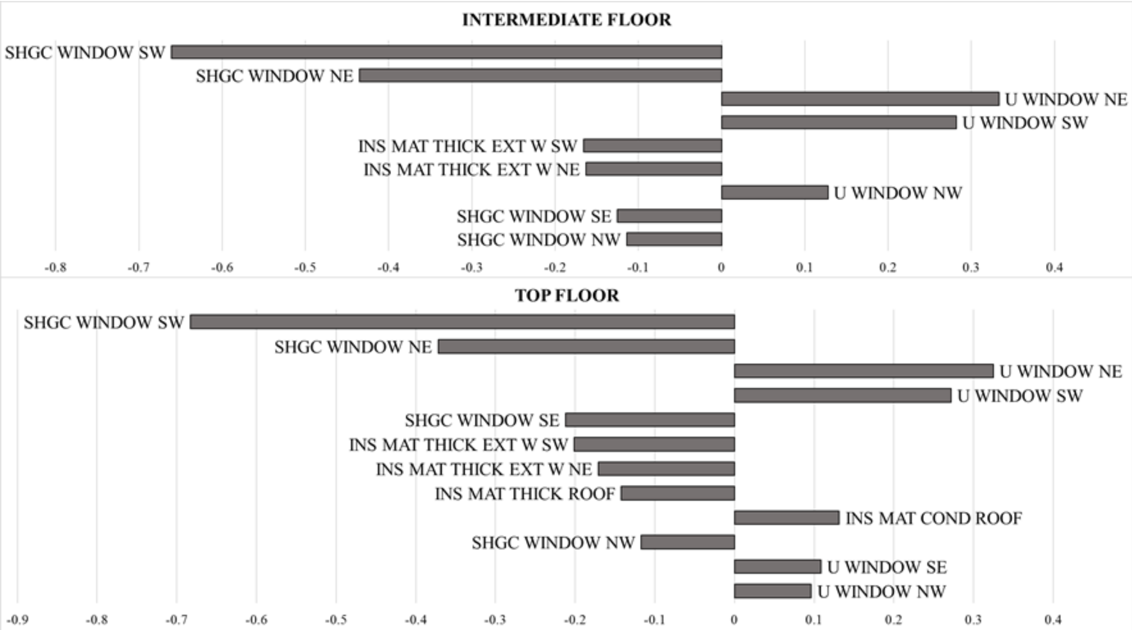

Figure 6.25. Sensitive parameters for annual heating consumption in the 2080s

Sensitive parameters for annual cooling energy consumption: The S-W window SHGC value is indicated as the most important parameter for annual cooling consumption in the 2080s, which is similar to the results of previous climate conditions. Actually, it is shown in Figure 6.26. that, the importance value of the variable is about 0.75 for the top and intermediate floors of the building. Following important parameters for both levels are the SHGC values of windows for N-E, S-E and N-W facades. It is presented in the results that, the transparent surfaces, especially window SHGC characteristics are still very effective for the energy performance characteristics of case building. In addition, the positive sensitivity coefficient of parameters indicate the lower SHGC values of windows may also decrease the annual cooling consumption of the building.

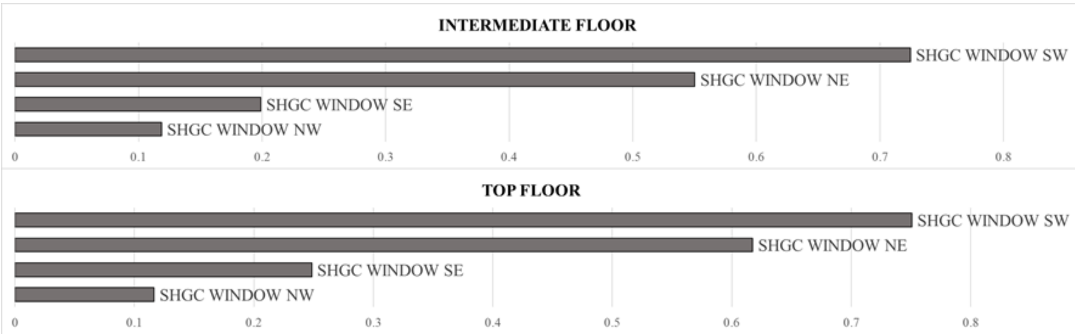

Figure 6.26. Sensitive parameters for annual cooling consumption in the 2080s

Sensitive parameters for annual operational CO_2 emission: The most sensitive parameter for both levels is the S-W facade window SHGC value with around 0.73 sensitivity coefficient, in terms of annual operational CO_2 emissions in the 2080s (Figure 6.27.). The window SHGC values of N-E, S-E and N-W facades are the following sensitive parameters for both levels, which have sensitivity coefficients higher than the limit of 0.1. Resemblance with the annual energy consumption sensitivities is also observed that, the operational CO_2 emission characteristics of the building are mostly affected by the transparent surface properties.

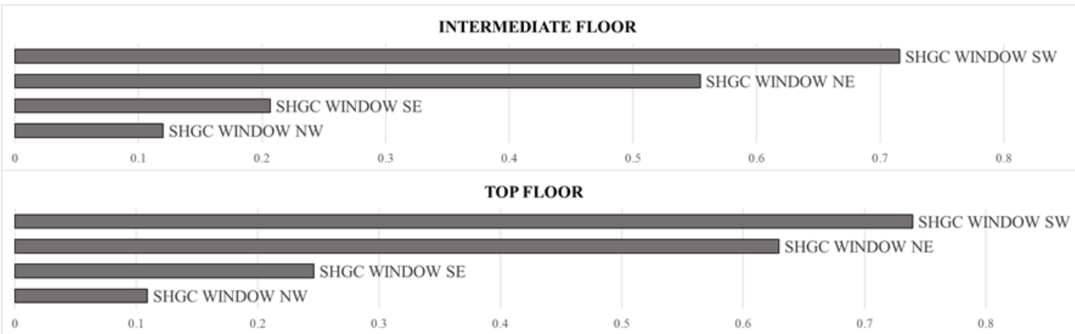

Figure 6.27. Sensitive parameters for annual operational CO_2 emission in the 2080s

6.2.5. Evaluation of Sensitivity Analysis Results

The results derived from the simulations and the analyses of the model are evaluated comprehensively. The aim is to simplify the outcomes, create the close connection between the massive information and practicality in professional life, so that more readable, case specific and application oriented approaches would be provided to the architects in practice. Hence, energy and environment oriented simulations, uncertainties of simulation outputs, sensitivities of the parameters and possibilities in supporting the early design process are discussed with the architect.

After the evaluation of uncertainty analysis results was performed, the performance simulation results have also been utilized for the sensitivity analysis in order to observe the relation between the outcomes and the input parameters. Various charts were created to explain the importance of different parameters throughout the Chapter 6. The importance values (SRRC) of the parameters are required to be higher than absolute value of 0.1 in order to be accepted as the sensitive. The design parameters with lower levels of importance than the absolute value may be eliminated by the decision maker (Saltelli et al., 1993). Among 43 parameters for intermediate and 45 for top floor, few parameters have passed the boundary conditions. Hence, the most sensitive variables are listed for proposing better design decision options separately for the intermediate and top floors.

The most prominent parameters are related to the transparent surfaces of the building envelope, since the floors consist of extended openings on exterior walls (Table 6.2. and Table 6.3.). The building has the widest elevation are on N-E and S-W facades with 974 m^2. In fact, the highest amount of opening area is placed on the N-W and S-E facades (81%), followed by N-E (74%) and S-W (70%) facades.

Annual energy consumption of the top floor includes insulation material conductivity for the roof, instead of SHGC value of north-west facade of the building as one of the effective parameters on energy performance of the building, which differs from the intermediate floor results.

The most sensitive parameters for energy consumption for annual heating and cooling are SHGC values of windows on S-W, N-E, S-E and N-W facades, respectively. The same order of sensitivity is valid for following years.

Environmental performance of both floors is affected by same parameters at most, as SHGC values of transparent surfaces on different facades. The sensitivity of same parameters is prominent for future climate scenarios, as well.

Table 6.2. Visualization of the most sensitive parameters for the intermediate floor

INTERMEDIATE FLOOR	RECENT	2020s	2050s	2080s
HEATING CONSUMPTION	SHGCWindowSW SHGCWindowNE UWindowNE UWindowSW	SHGCWindowSW SHGCWindowNE UWindowNE UWindowSW	SHGCWindowSW SHGCWindowNE UWindowNE UWindowSW	SHGCWindowSW SHGCWindowNE UWindowNE UWindowSW
COOLING CONSUMPTION	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW
OPERATIONAL CO_2 EMISSIONS	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW
TOTAL ANNUAL ENERGY CONSUMPTION	SHGCWindowSW SHGCWindowNE SHGCWindowSE UWindowNE	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW

Table 6.3. Visualization of the most sensitive parameters for the top floor

TOP FLOOR	RECENT	2020s	2050s	2080s
HEATING CONSUMPTION	SHGCWindowSW SHGCWindowNE UWindowNE UWindowSW	SHGCWindowSW SHGCWindowNE UWindowNE UWindowSW	SHGCWindowSW SHGCWindowNE UWindowNE UWindowSW	SHGCWindowSW SHGCWindowNE UWindowNE UWindowSW
COOLING CONSUMPTION	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW
OPERATIONAL CO_2 EMISSIONS	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW	SHGCWindowSW SHGCWindowNE SHGCWindowSE SHGCWindowNW
TOTAL ANNUAL ENERGY CONSUMPTION	SHGCWindowSW SHGCWindowNE UWindowNE InsMatCondR	SHGCWindowSW SHGCWindowNE SHGCWindowSE InsMatCondR	SHGCWindowSW SHGCWindowNE SHGCWindowSE InsMatCondR	SHGCWindowSW SHGCWindowNE SHGCWindowSE InsMatCondR

Proposals of design decision support scenarios: Building performance is not only affected by multiple design parameters, but the interaction among these variables are also involved with building operations. Consequently, it gets significant to examine the interaction among each input parameter, and relation between input and performance indicators, in order to obtain further knowledge about more significant parameters on building performance. Therefore, decisions for energy and environmental performance based design should have been made in terms of highlighting the most effective design parameters peculiar for each project. Besides, energy efficient and environmentally friendly design process requires more knowledge, when compared to conventional methods. Multiple design parameters should be handled simultaneously through an integrated design process, which requires a systematic knowledge.

The specification of the most sensitive parameters on energy and environmental performance of the case building has provided overall systematic and scientific knowledge for creating different design support scenarios. Since the SHGC values of windows were the most important factors on annual energy consumption and operational CO_2 emissions of the building, available products for the window panes in Turkey have been searched and selected. Five types of windows are determined for the study. Specific characteristics and thermal properties of the windows are explained in the table (Table 6.4.). Window glass type differentiations are conducted by changes in the glass type, number and thickness of the layers. Therefore, three types of double and two types of triple glasses are selected for the scenarios. The standard glass, namely base case, includes two clear float layers with the 12 mm air gap. The other double glass window is with one layer of low-e coated clear float (Ecotherm), and clear float with solar low-e coating (Ecosol). In addition, the triple glasses also vary depending on the coating properties of outer layer, which are covered with low-e and solar low-e filters. The thermal properties of the glasses belong to the specified values of product company i.e. Trakya Cam in Turkey (Trakya Cam, 2015).

The sensitivity analysis results indicate that; thermal effects of the windows have showed variations according to different facades of the building. In fact, S-W and N-E facade window SHGC values have turned out to be the most important parameters for energy and environmental performance of the building. Hence, three main energy simulation scenarios are created for design decision support, by focusing on transparent surfaces of different orientations.

Table 6.4. Technical information about the selected glass types

No	Glass Types	Glass /air gap / glass thickness (mm)	SHGC Values	U Values (W/m^2K)
1	Standard glass (Clear float + Air gap + Clear float) (Base case)	4+12+4	0.75	2.9
2	Clear float + Air gap + TRC Ecotherm	4+12+4	0.55	1.6
3	Clear float + Air gap + Ecosol	4+12+4	0.44	1.6
4	LowE + Air gap + Clear float + Air gap + LowE	4+12+4+12+4	0.48	0.9
5	Solar LowE + Air gap + Clear float + Air gap + LowE	4+12+4+12+4	0.39	0.9

Five types of windows are applied to the S-W, N-E facades and entire transparent surfaces of the intermediate and top floors, separately. Then, annual total energy consumption calculations for each climate scenario and possible financial returns of different glass types according to the recent total energy saving values are investigated through the building performance simulations. Only the glass types are changed per each model, while the other parameters are kept constant during simulations. The standard double glass (number 1 in Table 6.4.) is selected as the base case for the building. The comparison of suggested glass types with the base case is used for energy saving estimations. Unit prices of selected glass types, in 2015, are used for the financial return calculations. The payback period is computed by using the equation (6.1.). Investments and cash flows of suggested and standard glasses are the components of the equivalence.

$$Payback\ Period = \frac{Investment\ for\ suggested\ glass - Investment\ for\ standard\ glass}{Cash\ flow\ for\ suggested\ glass - Cash\ flow\ for\ standard\ glass} \quad (6.1.)$$

Scenario 1: The first scenario includes the variations in transparent surfaces of S-W facade for the intermediate and top floors. The results of annual total energy saving and financial returns of the building with regard to the performance simulations for S-W facade window variations of the intermediate and top floors at present are indicated in the table (Table 6.5.). The possible total energy saving ratios depending on the changes in glass types with reference to the future energy characteristics of the building are presented, as well (Table 6.6.).

The DesignBuilder simulations convey that, significant amounts of decrease in energy are obtained by changing only the type of S-W facade window pane. For instance, selecting double glass with one clear float layer and one layer of coated glass with low-e filter (Ecosol) (number 3 in Table 6.4.) on the intermediate floor, creates around 8% of annual total energy saving, when compared to the standard double glass. In fact, the difference between the prices of two variations is also estimated to be financially returned by around seven years (Table 6.5.). Major differences between the annual total energy savings of different window scenarios are not observed, whereas the financial charges of triple windows are much higher than the double layered glasses.

Table 6.5. Energy and financial effects of window scenarios on S-W facade at present, compared to standard glass (base case)

NO	GLASS TYPES	Thickness (mm)	Intermediate Floor Total Energy Gain	Financial Return	Top Floor Total Energy Gain	Financial Return
2	Clear float+ TRC Ecotherm	4+12+4	6%	5 years	4%	8 years
3	Clear float + Ecosol	4+12+4	8%	7 years	5%	11 years
4	LowE + Clear float +LowE	4+12+4+12+4	7%	23 years	5%	38 years
5	Solar LowE + Clear float +LowE	4+12+4+12+4	9%	22 years	6%	36 years

Table 6.6. Annual total energy saving ratios of S-W window variations with reference to future climate scenarios

NO	GLASS TYPES	Thickness (mm)	2020s Intermediate Floor Total Energy Gain	2020s Top Floor Total Energy Gain	2050s Intermediate Floor Total Energy Gain	2050s Top Floor Total Energy Gain	2080s Intermediate Floor Total Energy Gain	2080s Top Floor Total Energy Gain
2	Clear float+ TRC Ecotherm	4+12+4	6%	4%	7%	5%	7%	6%
3	Clear float + Ecosol	4+12+4	8%	5%	9%	6%	10%	8%
4	LowE + Clear float +LowE	4+12+4+12+4	7%	5%	8%	6%	9%	7%
5	Solar LowE + Clear float +LowE	4+12+4+12+4	9%	6%	10%	7%	11%	9%

Scenario 2: The second window scenario contains the modifications in the N-E facade openings of the intermediate and top floors. The outcomes of building

performance simulations according to the application of different glasses are presented for recent time period and the future climate scenarios (Table 6.7. and Table 6.8.). The highest amount of annual total energy saving ratio is provided by the triple glass with solar low-e layer (number 5) as 9% for the intermediate, and 7% for the top floor, while financial returns require 24 and 30 years, respectively. At the same time, double glass with solar low-e coating (number 3) has 8% annual total energy saving ratio, which is similar to triple glasses, but requires only 8 years of payback period. The energy performance of the intermediate floor is not affected excessively by the applications of the scenario for future climate conditions, and similar outcomes are acquired from the simulations. However, energy performance characteristics of the top floor are more dependent on projected global warming conditions than the intermediate floor. For instance, thermal properties of the intermediate floor show similarity between the 2020s and 2050s, while the total energy saving ratios of the top floor show around 1% change for all window variation scenarios.

Table 6.7. Energy and financial effects of window scenarios on N-E facade at present, compared to standard glass (base case)

NO	GLASS TYPES	Thickness (mm)	Intermediate Floor Total Energy Gain	Financial Return	Top Floor Total Energy Gain	Financial Return
2	Clear float+ TRC Ecotherm	4+12+4	5%	6 years	4%	8 years
3	Clear float + Ecosol	4+12+4	8%	8 years	6%	10 years
4	LowE + Clear float +LowE	4+12+4+12+4	7%	27 years	6%	34 years
5	Solar LowE + Clear float +LowE	4+12+4+12+4	9%	24 years	7%	30 years

Table 6.8. Annual total energy saving ratios of N-E window variations with reference to future climate scenarios

NO	GLASS TYPES	Thickness (mm)	2020s Intermediate Floor Total Energy Gain	2020s Top Floor Total Energy Gain	2050s Intermediate Floor Total Energy Gain	2050s Top Floor Total Energy Gain	2080s Intermediate Floor Total Energy Gain	2080s Top Floor Total Energy Gain
2	Clear float+ TRC Ecotherm	4+12+4	5%	4%	5%	5%	6%	5%
3	Clear float + Ecosol	4+12+4	8%	6%	8%	7%	8%	7%
4	LowE + Clear float +LowE	4+12+4+12+4	7%	6%	7%	6%	7%	6%
5	Solar LowE + Clear float +LowE	4+12+4+12+4	9%	7%	9%	7%	9%	8%

Scenario 3: The third scenario is the alteration of entire openings on the intermediate and top floors, so that five different glasses are designated to each facade, and the building performance is investigated according to the variations. Brief information about the effects of different glass applications on energy and economic performance of the building for recent time period is presented in Table 6.9. The most efficient energy performance is provided by triple glass with solar low-e coating, with 18% total energy saving ratio, when compared to the standard double glass. It is followed by double glass with solar low-e layer (number 3) with 17% lower energy consumption ratio on the intermediate floor. On the other hand, financial returns of these options are radically different: solar low-e coated double glass (number 3) requires 9 years, while triple glass (number 5) needs 30 years for balancing the financial difference between the standard glass price. Annual total energy savings of the top floor are lower than the intermediate floor with around 6% difference for each glass variation. The higher amounts of total energy saved from the intermediate floor makes window material selections during early design stages of the building more influential than the top floor, in terms of energy and economic perspectives.

In addition, the effects of future climate scenarios on energy conservation properties of different glasses are examined, and increases in total energy saving ratios are observed, which points out the importance of design decisions for long term performance characteristics of the building. In fact, taking precautions on openings increase the effective operation of the building in future. For instance, usage of the double glass with solar low-e layer (number 3) provides 18%, 20% and 22% energy savings during the 2020s, 2050s and 2080s for the intermediate floor.

Table 6.9. Energy and financial effects of window scenarios for all facades at present, compared to standard glass (base case)

NO	GLASS TYPES	Thickness (mm)	Intermediate Floor Total Energy Gain	Financial Return	Top Floor Total Energy Gain	Financial Return
2	Clear float+ TRC Ecotherm	4+12+4	13%	7 years	9%	10 years
3	Clear float + Ecosol	4+12+4	17%	9 years	11%	15 years
4	LowE + Clear float +LowE	4+12+4+12+4	15%	30 years	10%	47 years
5	Solar LowE + Clear float +LowE	4+12+4+12+4	18%	30 years	12%	47 years

Table 6.10. Annual total energy saving ratios of window variations for all facades with reference to future climate scenarios

NO	GLASS TYPES	Thickness (mm)	2020s Intermediate Floor Total Energy Gain	2020s Top Floor Total Energy Gain	2050s Intermediate Floor Total Energy Gain	2050s Top Floor Total Energy Gain	2080s Intermediate Floor Total Energy Gain	2080s Top Floor Total Energy Gain
2	Clear float+ TRC Ecotherm	4+12+4	14%	10%	15%	12%	16%	13%
3	Clear float + Ecosol	4+12+4	18%	13%	20%	15%	22%	18%
4	LowE + Clear float +LowE	4+12+4+12+4	17%	12%	18%	14%	20%	16%
5	Solar LowE + Clear float +LowE	4+12+4+12+4	20%	14%	22%	17%	25%	20%

Evaluation of scenarios: It is significant to consider the future energy performance properties in addition to the recent design qualifications of the building. The effects of specific design parameters in future would also be considered for providing guidance for early design decisions.

For instance, specified triple glasses have 0.9 W/ m²K, and double glasses have 1.6 W/ m²K U values, while SHGC values are around 0.4 and 0.55 for selected glass types. Transparent surface limitations of TS 825 regulations in Turkey are only related with U values of the window panes in terms of energy performance of the buildings. However, the amount of annual total energy saving changes only 1% in spite of huge difference between U values for the residential building. These simulations clarify the importance of SHGC values of windows and the effects of applications of different glass types on different facades for the building energy performance characteristics.

It is possible to find many examples explaining the significance of SHGC values as much as U values of windows, in building energy performance regulations of various countries or organizations. For instance, Passive House Institute US (PHIUS) is the organization, focusing on high-performance passive building principles, and the mainstream market energy performance standards. The criteria specified for different climatic zones of the organization focus on overall window U values, center of glass U values, south, north, east and west facade SHGC values separately (PHIUS, 2016). Therefore, reconsidering the regulations in Turkey, and focusing on SHGC of windows as much as U values would be an option for improving the energy performance of buildings, as well.

CHAPTER 7

USABILITY TESTING IN DESIGN PROCESS

Usability testing supplies the feedback about positive or negative aspects, deficiencies of the product performance in the market. It requires specific participants; such as experts, developers or other professionals to work with the proceeding model, or the final product about its functionality. Field observations and surveys may be used to obtain user opinions. Testing techniques may include verbal dialogues and questionnaire protocols (Struck, 2012). Preston (2009) also mentions a number of methods for usability testing on different levels of the studies. Usability testing is integrated into design process in terms of increasing communication for developing the design quality. Usability testing is not only a technique used in user-centered interaction model to evaluate the architectural design process, but also helps to measure the usability, or ease of use of specific building design issues in architecture discipline.

It is essential to test the usability of the overall results evaluated in the study with design professionals. Therefore, usability testing process includes feedbacks for pre-processing stages, simulation phase, evaluations about uncertainty and sensitivity analyses for design support and the analyses results, in this study.

7.1. Usability Testing for Design Decision Support of a Residential Building in Hot-Humid Climate

The usability testing of thesis is conducted with SRD Architecture and Project Management Office, located in İzmir. The entire process is carried out by communicating regularly with the architect Serdar Bolposta, starting from the case study selection until the evaluation of final design support options. Interviews, observations and questionnaires were selected, and applied as usability testing methods for the current thesis.

The main aims were to:

- Observe possibility of using the systematic results of this study in early design stages for improving the building performance

- Test applicability of computational methods for evaluating building performance
- Get feedbacks before finalizing the research and assess the effects of the study on professional life
- Test applicability of proposed design decision support process for early design stage

Initially, interviews and observations were executed with the architect on each meeting, by presentations and asking questions. Then, the questionnaires are delivered to collect the opinion of the architect about entire stages of the performance based design decision support study, and accumulate explicit and standardized feedbacks, so that the data would also be processed easily.

The usability testing process involves series of meetings, composed of PowerPoint slides explaining the subjects in general terms, and questionnaires to measure existing knowledge of the architect, credibility of the presentation, and usability of given information in professional life. Totally three different meetings are carried out with the architect to examine the pre-process, simulation and post-processing stages of the study separately.

The questionnaire and presentations are prepared in Turkish. The presentations are enriched by visuals, such as screenshots from digital model of the building and tables indicating the analysis results. They were not only presentations, but also mutual discussions in terms of clarifying the arising questions of the architect. Besides, the questionnaires were composed of open ended, and yes or no questions, mostly. The questionnaires were handed out as hardcopies, so that they were filled in the time of meetings. The questionnaire process was integrated with interview, since the answers were discussed in order to broaden up information and ideas of the architect about the questions.

The first meeting was held before pre-process stage of the study, in June 23, 2015, and lasted around two hours of presentation with 14 slides and a questionnaire with 18 questions.[1] The focus was on existing viewpoint of the architect about specified subjects, such as the significance of different design elements, sustainability in architecture and the effects of climate change on building design. They are presented by the PowerPoint slides. The meeting also included the specification of case project for

[1] For the PowerPoint slides and questions of the first meeting, see Appendix C.1., Appendix C.2., Appendix B.1.

the thesis, and questions in order to evaluate general knowledge, and opinions of the architect about the significant points of design process of this study, relation among energy, environmental performance and design issues around the world and Turkey. In addition, climate change scenarios, and their relation with the architectural design were examined by the architect as inherent part of the questionnaire. The selection of residential case building was discussed at the end of this meeting.

Secondly, another presentation was held after finalizing digital modelling of the case building. The meeting was in February 10, 2016 for around one hour of briefing with 25 slides.[2] Information about building performance simulation tools and case specific usage of the selected program are formed the main structure of the second meeting. It also included explanation of uncertainty and sensitivity analysis methods and their correlation with building design, as well as the integration with performance simulations. The functions and different application methods of building simulation programs and the DesignBuilder as the selected dynamic modeling software were clarified by the visuals and technical explanations at the beginning of the presentation. Simulation modelling stages and the critical points about detailing within DesignBuilder were explained during the presentation. Afterwards, SimLab statistical analysis program, as preferred for the current study, was explained in terms of data processing methods, possible results that are available within the program, and the main stages followed to analyze parameters related to the case building. Current knowledge and changes in the architect's opinions at the end of the meeting are evaluated according to the responses collected from the interview.

The third meeting was arranged in April 6, 2016 for the presentation and another questionnaire. Overall discussion lasted around two hours with 8 slides of presentation and a questionnaire of 11 questions.[3] It included the discussions about performance simulation, analysis processes and the results, as well as proposed design support options for the case building. Overall stages of building simulation and the results of uncertainty and sensitivity analyses were presented by visualizing performance characteristics of the building, the most sensitive parameters, possible design decision support scenarios for building materials according to the available products in the market, and estimated payback periods depending on the improvements in the specific parameter, i.e. SHGC values of windows. Feedback on the last meeting subjects in

[2] For the PowerPoint slides of second meeting, see Appendix C.3., Appendix C.4.
[3] For the PowerPoint slides and questions of last meeting, see Appendix C.5., Appendix B.2.

terms of listing the results after analysis stage, evaluation and reliability of the outcome and possible economic effects of changes in design are summarized in this section. The results of these three sessions are represented in the following sections.

7.1.1. Feedbacks on the Pre-processing Phase

Initially, the architect was asked to select ten factors out of twelve which are influential design parameters in building projects of his office, and prioritize them according to the importance sequence. The environmental components (land usage, sunlight, orientation) were determined as the most significant factors for the projects/buildings. The insulation material usage, construction costs, user comfort conditions, and selection of natural material are chosen as the following factors. The last three factors are the solar protection in buildings, proportion of construction and green spaces, and compliance with the extant built context, respectively.

The following questions were about the architect's approach to the concept of sustainability in architecture. Five of the twelve keywords were to be selected in order to configure the essential concepts in terms of sustainability in environment and/or buildings. Hence, healthy buildings, natural material usage, architectural policies, correlation between architecture, society and economy are the key concepts for the architect. The architect stated that, common knowledge about sustainability has not been settled extensively among architectural professionals in Turkey yet, even though there are few attempts for bringing thermal properties of buildings to a certain level by the revisions in building regulations in Turkey. Acquiring environmentally adapted buildings have been defined as the main advantages of sustainability in buildings.

Lastly, the questions about climate change have revealed the insufficient knowledge of the architect about global warming and its possible effects on architecture. Moreover, necessity of considering future climate conditions during design process needs to be seized comprehensively by investors according to the collected answers, as well.

After the initial questionnaire, brief information about energy and environmental performance based decision support and climate change issues was given by the PowerPoint presentation, covering different projected climate scenarios, possible impacts on architectural design process, and usage of future climate scenarios in building performance simulations.

Following the briefing, the second questionnaire was held to receive opinions of the architect about climate change and possible effects on architectural practice. Respondent underlined that, the projected climate scenarios and their possible effects on architecture are accepted to be correct partially. Actually, it is mentioned that there might be some exaggerations and misleading about the climate change, with regard to the concerns of some investors about creating a new commercial market. On the other hand, developments in building envelope oriented measures during the architectural design process depending on the changes in climate was mentioned as one of the important points to keep in mind, because of its possible effects on entire lifespan of the building. Besides, it is pointed out that if the legal sanctions about improving building performance are imposed commonly in Turkey, the number of conscious investors and clients would also increase in time. Hence, designing environment friendly and durable buildings to upcoming weather conditions might be designed within collaborative platforms. At the end of the questionnaire, architect’s ideas about relation between climate change and architectural design changed in terms of taking the issue more seriously.

7.1.2. Feedbacks on the Simulation Phase

The second meeting was held just after the completion of modelling, simulation and result assessment processes. After the presentation, the explanations were found enough and informative in terms of creating a general knowledge about simulation process. The respondent stated that, the ability to provide systematical data about many variables in short notice by using digital modelling instead of experimental setups is the advantage of building performance analysis programs. On the other hand, detailed information requirements for building modelling, complicated interfaces, impracticability of the programs have been perceived as the negative sides of simulation software tools.

The interview underpins that, the possibility of using DesignBuilder simulation program for the rest of the design projects of the office was very low with regard to the challenges in ease of use. In addition, there has been some suggestions and ideas about building simulation tools at the end of meeting. It was pointed out that, increasing similarities between the performance simulation tools and widespread digital drawing programs in terms of visualization of workspace, taskbars, interfaces etc. can be beneficial for offering more user friendly tools for professionals. The popularity and use of these programs increase in Turkey, as well. Another proposal was about the organization of workshops, presentations and/or lectures to the design offices for introducing and presenting the developments in computational analyses and simulation tools, and advantages of providing variety of knowledge about different stages of design.

7.1.3. Feedbacks on Uncertainty and Sensitivity Analyses for Design Support

Integration of uncertainty and sensitivity analyses with design support was an appreciated procedure to be used for improving design quality according to the second meeting. The third meeting provided some additional suggestions, and issues for future studies in terms of improving the usability and efficiency of the analyses.

The potential of detailing the project and analyzing comprehensively in terms of performance characteristics were beneficial points of the process according to the discussions during presentation. Sensitivity analysis of different design parameters had been considered as another essential subject, since it can be applied to each stage of design. Another appreciation was about reliability of the analysis results. Even though, it was admitted that, the results are worth integrating into design process, the difficulties in handling the SimLab statistical analysis software and interpretation of the results had been regarded as obstacles of the design support process.

During the third meeting, the interview was also carried about the importance of presenting results, regardless of any specific software. The sensitivity and uncertainty analyses graphs were appeared to be very abstract and hard to understand, when the visualization and explanation methods of tools were represented. The respondent underlined that, the attention should be paid while selecting understandable forms of presenting sensitivities of the model, i.e. bar charts indicating regression coefficients (the longer the beam, the bigger the influence), since there is a need for background knowledge about statistical terms and characteristics of case specific model to understand the presented data. For instance, comprehending the differences between positive or negative regression values and the limit values of sensitive parameters were perceived as the most complex subjects to understand throughout the entire presentation. It was suggested that, presentations of the results should clarify the simulation and analysis data in order to derive information easily for design decision support.

7.1.4. Feedbacks on the Analyses Results

Pointing out the parameter sensitivities, energy and environmental performance of the case building with the help of uncertainty and sensitivity analyses, and the illustration of different financial returns depending on the various window choices were perceived as the beneficial approaches to confront the main purpose of the study.

The respondent mentioned that, orientation of the building, focusing on each facade separately, and information about the material choices had been very beneficial information to improve the energy and environmental quality of project or future works. Especially, explanations would guide decisions about window types of the case building. The architect appreciated validity of the results, and accepted the possibility of presenting experiment values during meetings with the employer or other professionals. However, assessing the operational CO_2 emissions as one of the performance indicator was perceived as controversial for the architect. Whilst operational CO_2 emissions were important for design stages, it is thought to be negligible for clients in Turkey. Actually, cost efficiency and short term profits are the most important issues for stakeholders who are responsible from the finance and/or construction of the project, i.e. contractor, client, rather than design quality, user comfort or environmental concerns. Therefore, the need for informing them about sustainability, energy and performance efficiency in buildings were also pointed out as critical issues.

According to the respondent's point of view, architects may have difficulties in practice for conducting the analysis process, or comprehending the results because of insufficient technical knowledge. At that point, interpretation of the outcomes and making proposals about transparent surfaces to the architect was accepted as practicable for future projects in terms of providing more detailed considerations about early stages of design. Integration of climate change scenarios, building performance analysis tools and sensitivity analysis was admitted as beneficial for building design. Specifically, the respondent underlined that, the possibility of designing environment friendly building, lower amounts of energy consumption, decreases in operational CO_2 emissions during life cycle of the building are main advantages of the analysis procedure.

7.2. Conclusion

The usability testing method provided information about positive and negative perceptions of the architect about the proposed decision support process. Changes in the approaches of the respondent to specified design related subjects are also observed. The proposed decision support was accepted to be applicable for early design stages of the residential building. The effectiveness of the study is perceived as usable for design process of the case building. It is also stated that, the support system helps creating consciousness about the importance of systematic design decision approach for building professionals.

Brief information about the case specified analysis procedure was used for the evaluation of user feedback, as well as project efficiency throughout three discussions with the project partner. The feedback on the entire study was collected to discuss correlating climate change scenarios with design process, usage of building performance simulation tools, as well as integrating uncertainty and sensitivity analyses into building performance assessment during the meetings and the presentations.

Consideration of climate change for early design stages was one of the subjects, and feedback was very positive in terms of increasing awareness and carrying design quality one step further. Even though, most of the projects are designed by only focusing on short term paybacks, it would be included into noncommercial projects as one of the factors significant for environment and user friendly buildings in the long term. It was emphasized that, global warming and climate change issues are inevitable incidents all over the world, which needs to be included in building design decision process, as well. Then, the applicability of building performance analysis tools in early design stage was evaluated, and some deficiencies were pointed out in terms of ease of use, whereas importance of integrating building simulations into design was appreciated.

Following discussion was about testing the efficiency of correlation between performance analysis tools and design process. It was pointed out that, the opportunities of saving time during design stages by computational performance analyses was indicated as very high, and the simulation procedure presentation took into account in terms of comprehensibility. It was discovered that, the uncertainty and sensitivity characteristics of performance factors were very useful statistics to support conceptual design. They had high potential to add value to the design process. The architect pointed out the importance of developing this process into a template, to be available for the future projects. However, it was also pointed out that, analysis programs need to be more user friendly, so that the design teams in the architectural offices would be able to use similar methods in certain projects. Supplementary computational assessment during early design stage was favorable to specify the suitable design alternative and numeric validity. Besides, importance of starting overall energy efficient and environment friendly building applications from commercial buildings is also emphasized, specifically.

Finally, it can be summarized that, the analysis process and numerical results fulfil the expectations for conceptual design stage of the residential building. Provided design support process is highly beneficial for the building professional and they are all approved to be applicable and important for early design stages of the selected building.

CHAPTER 8

CONCLUSION

8.1. Concluding Remarks

Increasing energy demands, global warming and depletion of resources around the world, raised concerns about taking precautions in built environment. It has become clear that, the building sector is in need of efficient, sustainable solutions that are related with the occupant, the economy and the environment. Energy efficient building design approaches search for solutions to provide lower amount of energy and source usage by managing occupant comfort and low cost appliances simultaneously. The challenges of efficiency and sustainability force building professionals to evaluate design strategies and technologies to eliminate deficiencies of the conventional methods, such as complicated mechanical systems and extensive use of energy for thermal comfort. These evaluations or decisions taken with the rule of thumb may not provide the best solutions in case of insufficient knowledge.

The lack of systematic approach for decision support through conceptual design stage, need for informational assistance for architects in terms of building performance characteristics of their projects, focusing on short term solutions instead of long term interactions between the building and environment, and use of conventional design methods during selection of determinative building performance characteristics are some of the major problems faced throughout the design process. These insufficiencies remark the subjects need to be revised in the design process in terms of building performance analyses and miscommunication between theoretical academic knowledge and the building professionals. All of these considerations canalized the entire world to make immediate action plans. Turkey has also taken considerable steps in accordance with the building performance, even though these precautions are behind the actions of northern countries. The evaluation and development of building energy and environmental performances require bringing out new strategies in order to increase thermal characteristics of the building during design or retrofit phases. The process involves assessment of the relationship between building design parameters and energy and environmental performance of the building.

In this study, annual energy consumption and operational CO_2 emissions are evaluated, based on a mid-rise residential block located in hot-humid climate, İzmir, Turkey. Contemporary client preferences and increases in buildings with transparent envelope were the reasons for selecting this residential building type. Initially, digital modelling of the residential block is conducted. The input parameters and possible minimum and maximum limits of the parameters are specified. Samples are generated by changing parameter values simultaneously, then performance simulations are executed. The most important design parameters for decreasing annual energy consumption and operational CO_2 emissions of the building are investigated by using simulation results. In addition, variations in performance of the building due to the uncertainties in design parameters and the impacts of climate change are studied according to the 2020s, 2050s, 2080s projected weather data. Simulations provided information about the energy and environmental performance of the top and intermediate floors.

The results showed that, both floors follow similar performance patterns throughout the years. Annual heating and cooling consumptions balance between the 2020s and 2050s, although equalization in the top floor values are behind the intermediate floor. After the 2050s, accelerated increase in annual cooling consumption is also observed, depending on the effects of global warming. In addition, it is presented that, both floors consume similar amounts of annual total energy within the years. However, average total energy consumption of the top floor is mostly higher than the intermediate floor. Besides, the amount of energy needed for the entire building shows substantially rises from recent years to the 2080s. If necessary precautions are not taken during different stages of the design, energy classification of the building would get lower because of decreasing energy and environmental performance characteristics.

Proceeding stage of the evaluations includes the information collected from sensitivity analysis of the building. Performance simulation results were used for the analysis process, in order to observe the relation between the performance indicators and the design parameters. It is pointed out that, the most important parameters are related with the transparent surfaces of the building envelope, since the floors consist of extended glass area on exterior walls. Namely, SHGC values of S-W and N-E facade windows are found to be the most significant variables, followed by S-E and N-W facades in terms of energy and CO_2 performance of the building for present and future weather conditions.

The specification of the most sensitive parameters on energy and environmental performance of the building provides data for creating different design support scenarios. Three main energy simulation options are created, i.e. the application of five different glass types on transparent surfaces of S-W, N-E and entire facades of the intermediate and top floors. It is revealed that, significant amounts of decrease in energy use is obtained by changing only S-W facade windows. Major differences between annual total energy savings according to different window types are not observed, whereas financial charges of the triple windows are much higher than the glasses with double layers. The outcomes of the building performance simulations according to the modifications in N-E facade openings of the intermediate and top floors showed that, the highest amount of annual total energy saving is provided by solar low-e layered triple glass with the need for around 30 years of financial feedback. However, double glass with solar low-e coating also provides mostly same amount of annual total energy saving with triple glasses, but only 7 years of payback needed. Moreover, improvements in energy properties of the intermediate floor are not affected significantly by future climate scenarios, and similar simulation outcomes are observed for different periods, while energy saving fluctuations of the top floor are more related with the projected global warming. The last scenario is regulated as the alteration of entire openings on the intermediate and top floors. The most efficient energy performance is obtained by the triple glass with solar low-e coating followed by the double glass with solar low-e layer for the intermediate floor. On the other hand, financial returns of these options are radically different, as triple glass requires much more additional years compared to the solar low-e coated double glass. Annual total energy savings of the top floor are lower than the intermediate floor for each glass variation.

Giving priorities to the intermediate floor for material selections (transparent and solid surface materials) during design stages is more influential than the top floor variations in terms of energy, environmental and economic perspectives. Besides, developments in openings improve the performance effectiveness of the building for future, since the increase in annual total energy saving is observed during following years. To understand the effects of specific design parameters in the future are critical for providing guidance for early design decisions, since it is significant to consider the future energy performance properties additionally to recent characteristics of the building.

Annual total energy savings change around 1% in contrast to huge differences among the U values of the window scenarios. However, TS 825 regulations in Turkey are only related with U values of the windows in terms of limitations in energy performance of the buildings. The study clarifies the importance of SHGC values of windows for the residential building. Hence, carrying out a broader study to observe the impact of SHGC values on energy performance may cause reconsidering the regulations in hot humid climatic regions of Turkey. Then, it may lead to focus on window SHGC as much as U values, similar to the regulations of many organizations and countries, and it would be beneficial for enhancing the performance of buildings in our country.

The proposed design decision support options aim to assist the building professional to perceive the importance of building performance simulations, and improve building design qualities starting from early stages of design. Additionally, feedbacks on the analysis process, evaluation of the results and proposed design scenarios are investigated. Initially, the fulfilment of the requirements of building performance analysis in early design stage was evaluated, and some deficiencies are pointed out in terms of ease of use. Efficiency of performance analysis tools and their integration to design process are tested by questionnaires. In fact, the potential of analyses to reduce the amounts of design trials is indicated as time-efficient. Besides, the numerical input on parameter sensitivities are accepted as very useful statistics to support conceptual design, and have high potentials to add value to the early design process. It can be assessed that; additional design support is highly beneficial for the building professional. However, it is also pointed out that, analysis programs need to be more user friendly, so that design partners would be able to make analysis of each project without any need for expertise in the field.

Guidance during early design stage was beneficial for deciding suitable design alternative, which is also verified by simulations. It is indicated that, entire analysis process is more effective for evaluating the core services of the small scale constructions. To sum up, the analysis process, outcomes and the proposed design scenarios fulfil the expectations of the architect for early design stages of the case building. They are all accepted as applicable and important to be integrated in design process of the case building.

One of the main contribution of this thesis to the extant literature is to evaluate energy and environmental performance, simultaneously. Consideration of changes in performance characteristics of the building according to climate change is also another important contribution for the studies focusing on buildings in Turkey.

In conclusion, the results obtained in this study can provide more consciousness for the building professionals about the significance of systematic design decision approach in early design process of the mid-rise residential block in hot-humid climate. In addition, it is possible to apply similar processes to different design stages, as well as various types of buildings. The importance of integrating building simulation into design process can be perceived by the building professionals as the necessity, not an option for creating sustainable buildings.

8.2. Future Challenges

For the future of the current study, integrating uncertainty and sensitivity analyses with different optimization tools would be beneficial to provide optimal solutions during design process, according to the feedbacks. For instance, if the client is more focused on financial issues, or future characteristics of the building, researches may be narrowed down to specific subjects. This can provide more detailed information for building professionals.

In this thesis, the shading element is selected as the overhang during decisions of design parameters. Replacing these components with blinds would be more effective for thermal calculations. Window to wall ratio is also another essential design parameter for the performance characteristics of the building, especially for the case building, since it has significant amount of transparent surfaces. These two variables can be included as inputs for the simulations. Then, if they come out to be significant factors on building performance characteristics, additional design scenarios may be offered for a better performing building.

The use of double skin facade with natural ventilation would be another physical input parameter which may be integrated into the sensitivity analysis. Combining different orientations with investigation of occupant controlled operational costs would also be investigated to provide additional design options and decision support to the architect for the case building.

The operational CO_2 emission characteristics of the building are the only environmental factor observed during simulations. Embodied carbon footprints of materials may also be specified as another performance indicator, while examining input parameters. Hence, more comprehensive outcomes may be revealed, in terms of environmental impact of the building.

The uncertainties of input parameters on annual energy consumptions and operational CO_2 emissions are observed during analysis process. Uncertainty analyses are acquired depending on the physical, and design variables together. However, they might be handled separately, since uncertainties due to physical, design or scenario input parameters have different impacts on the outcome. Therefore, more comprehensive and detailed results may be acquired in case of decomposition in input parameters.

The study contains one architect and one case building for the analyses and the discussions, whereas increasing the number of building professionals and buildings involved with the study could provide more outcome to observe different factors effecting proposed design decision support process in this thesis.

Life cycle assessment of the residential building would also bring the study a step further by utilizing environmental impacts associated with entire lifespan of the block, from cradle to grave, and help creating broader outlook on environmental concerns.

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APPENDIX A

DETAILED SENSITIVITY ANALYSIS RESULTS

Sensitivity analysis results of both floors, and different climate scenarios in terms of the relation between overall input parameters, annual heating/cooling energy consumption, operational CO_2 emissions, and annual total energy consumptions are presented comprehensively. Two different levels of the building are analyzed separately as the intermediate and top floors. The sensitivities of 43 input parameters for intermediate floor and 45 input parameters for top floor on energy and environmental performance of the mid-rise residential building located in hot-humid climate, İzmir, Turkey are visualized for the present, 2020s, 2050s and 2080s.

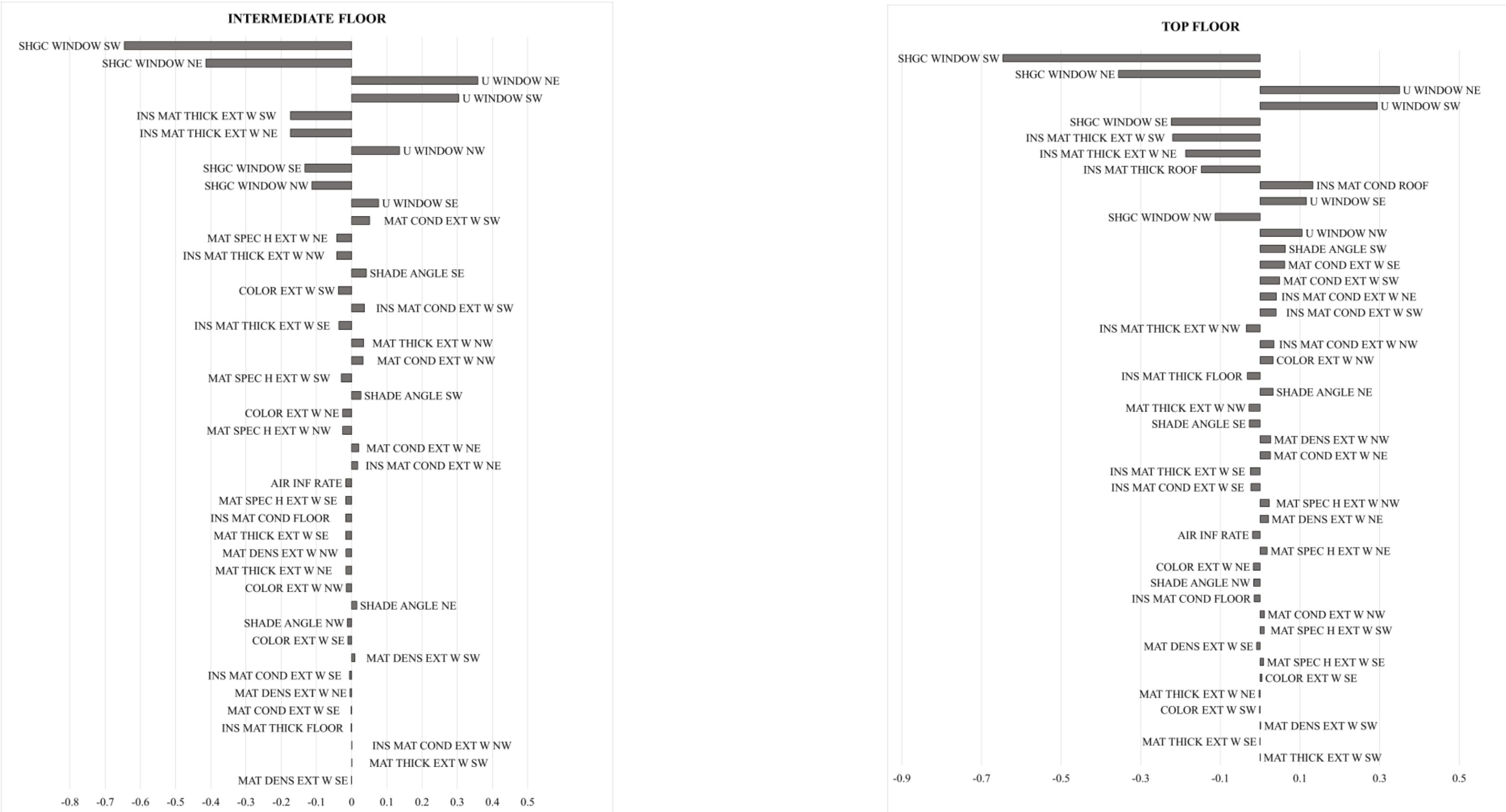


Figure A.1. Sensitive parameters for annual heating consumption at present a) intermediate floor b) top floor

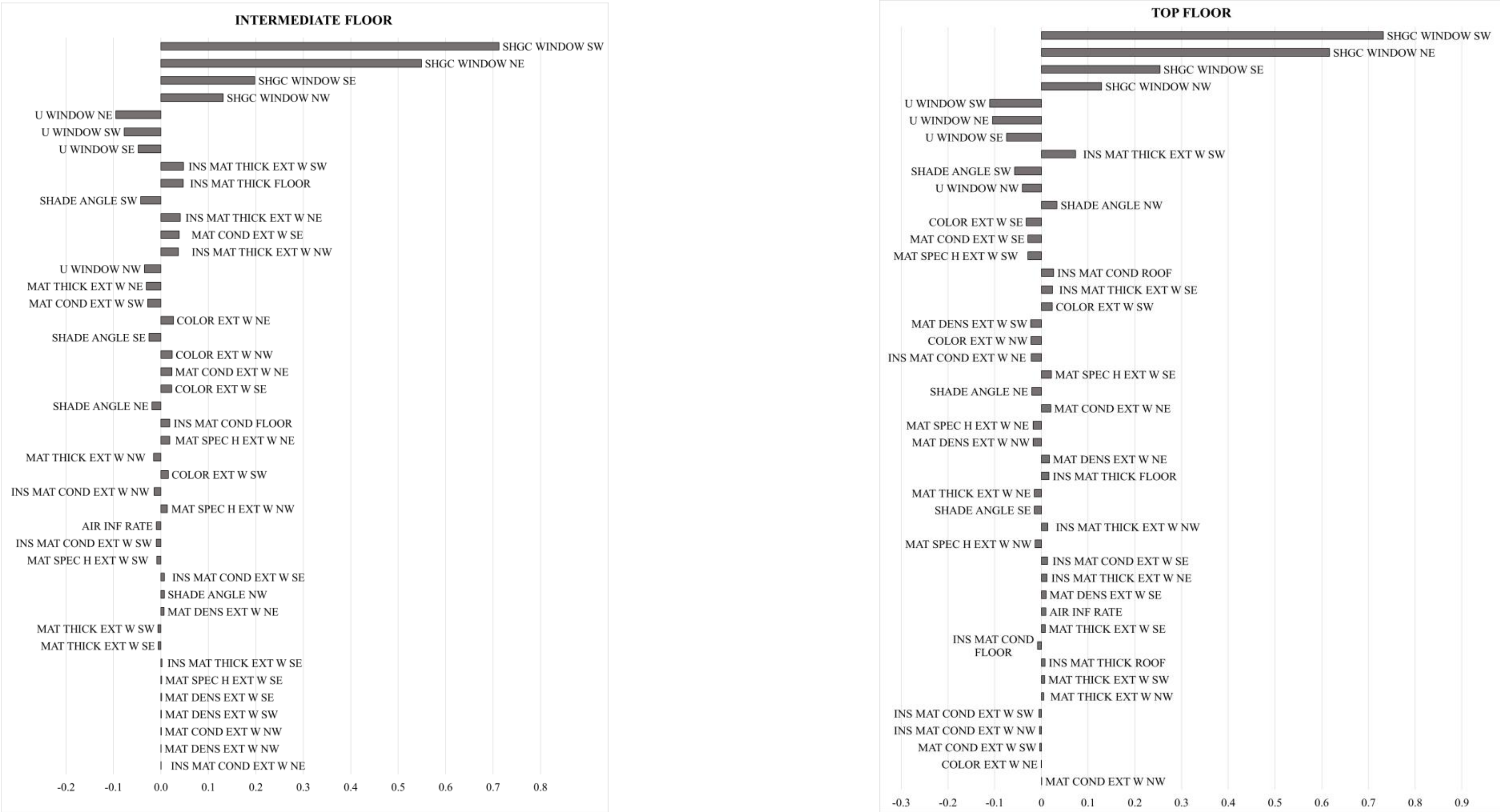


Figure A.2. Sensitive parameters for annual cooling consumption at present a) intermediate floor b) top floor

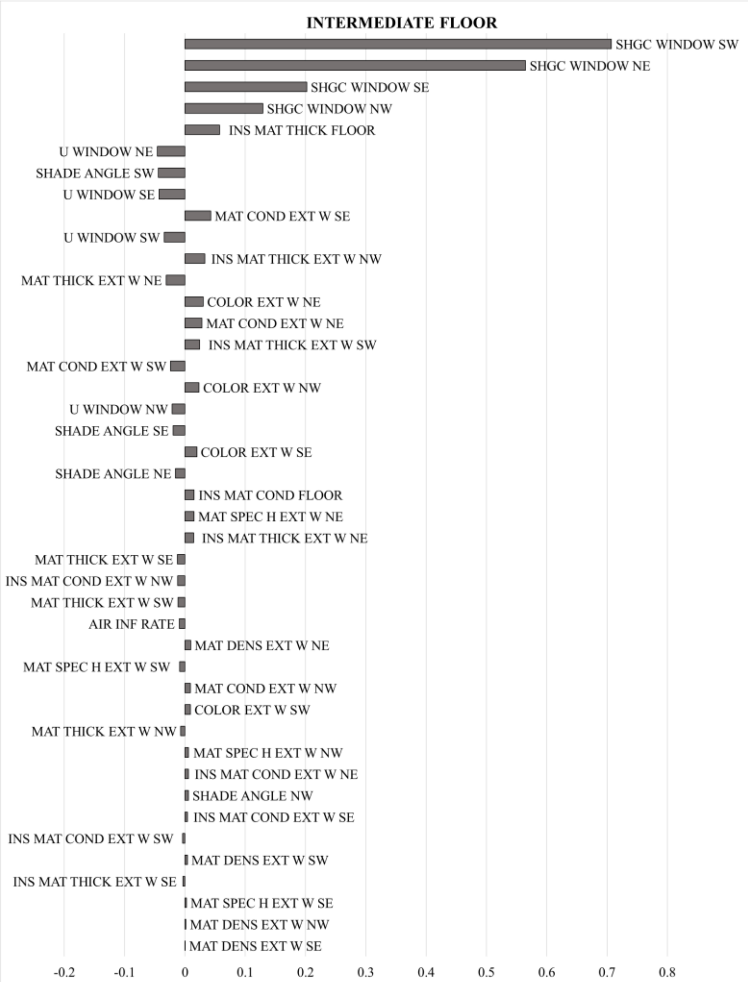


Figure A.3. Sensitive parameters for annual operational CO_2 emission at present a) intermediate floor b) top floor

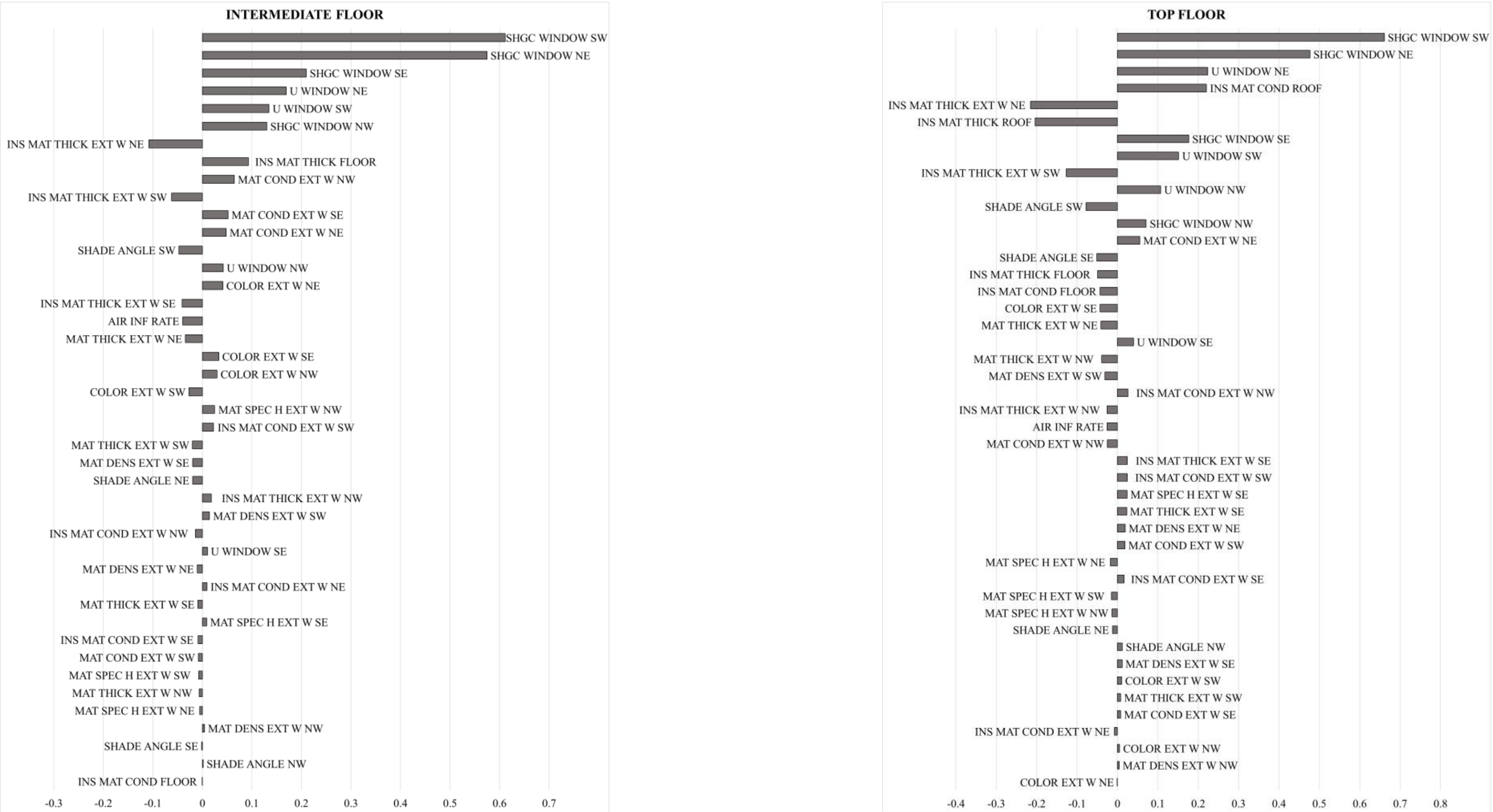


Figure A.4. Sensitive parameters for annual total energy consumption at present a) intermediate floor b) top floor

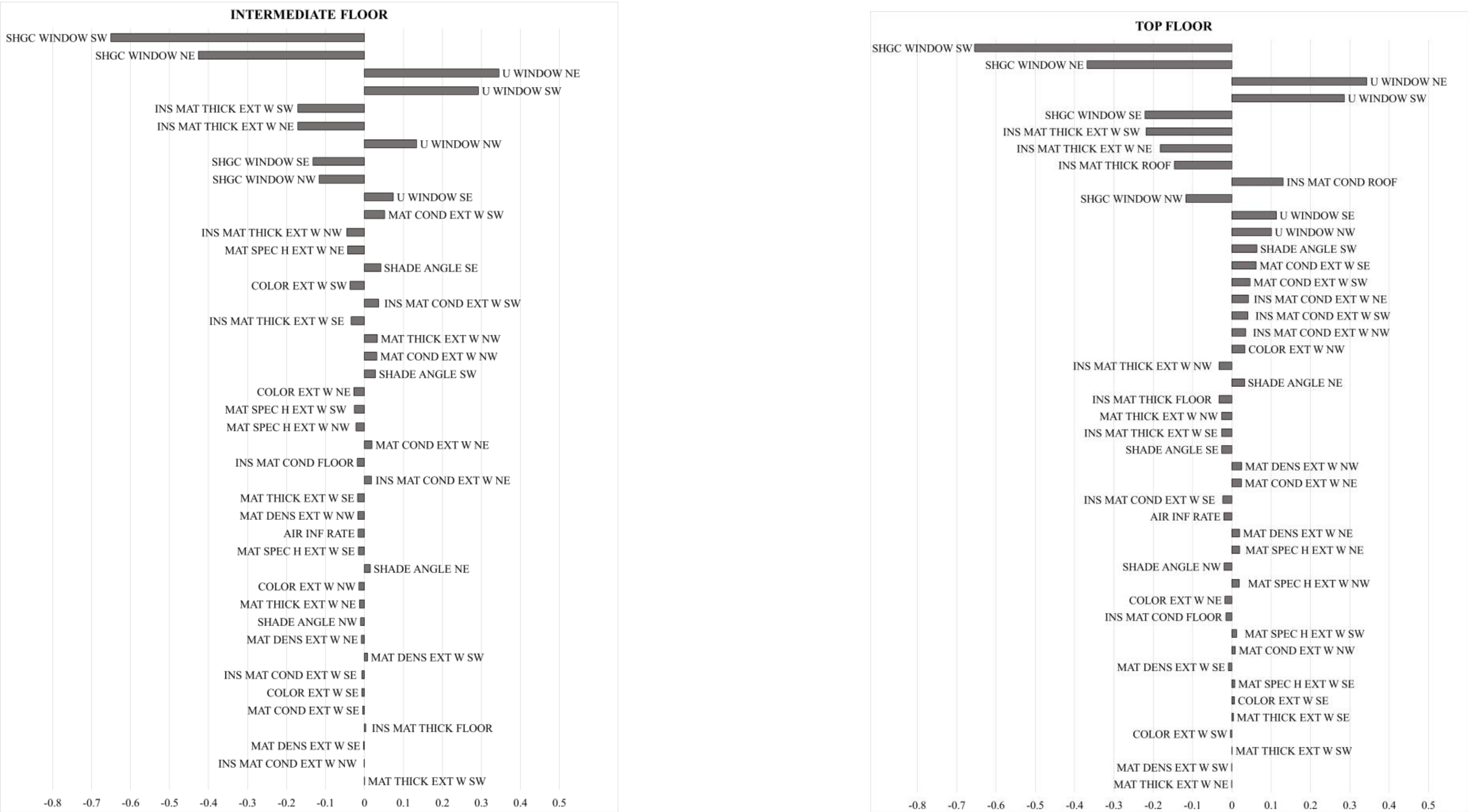


Figure A.5. Sensitive parameters for annual heating consumption in the 2020s a) intermediate floor b) top floor

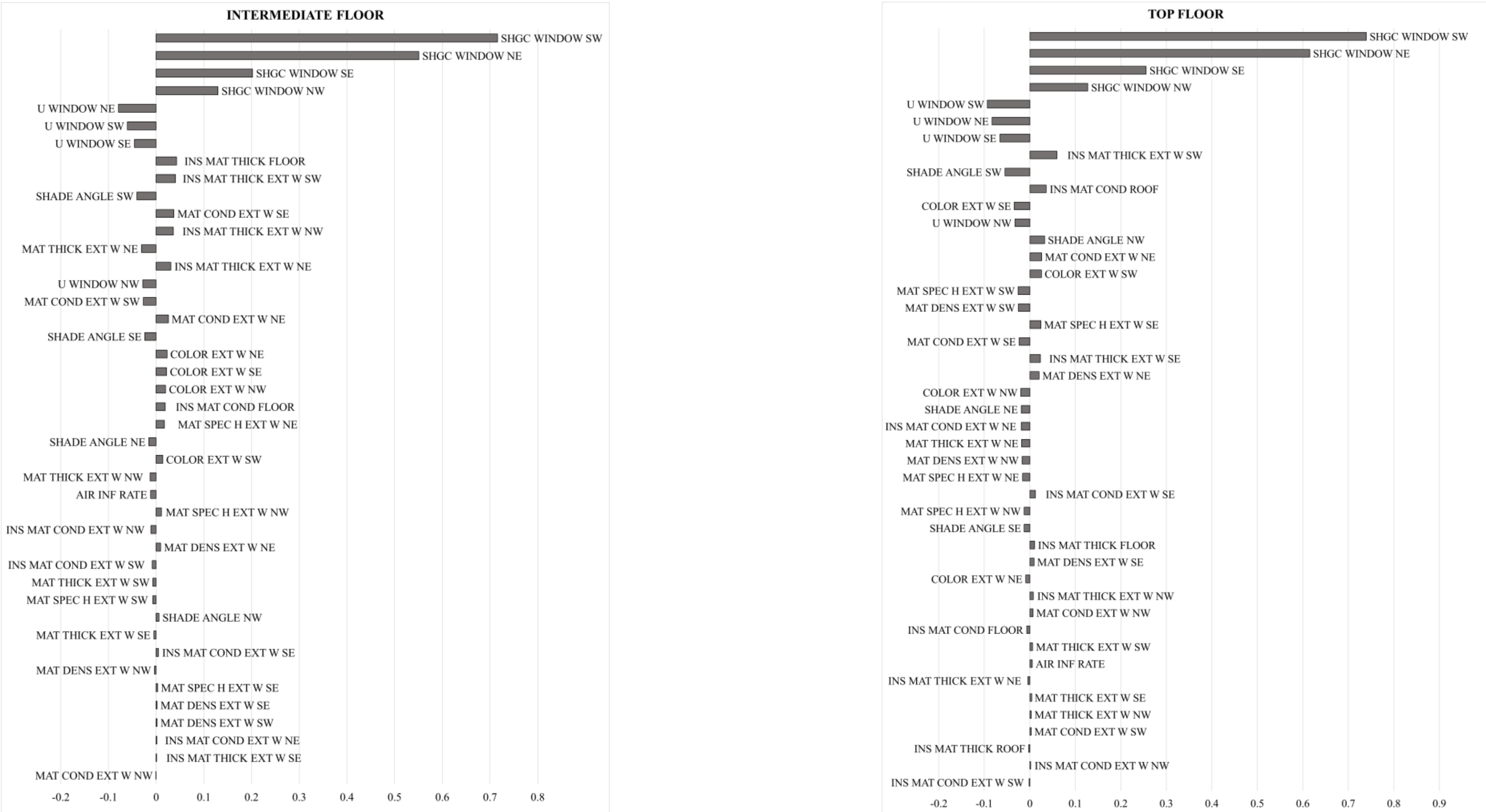


Figure A.6. Sensitive parameters for annual cooling consumption in the 2020s of a) intermediate floor b) top floor

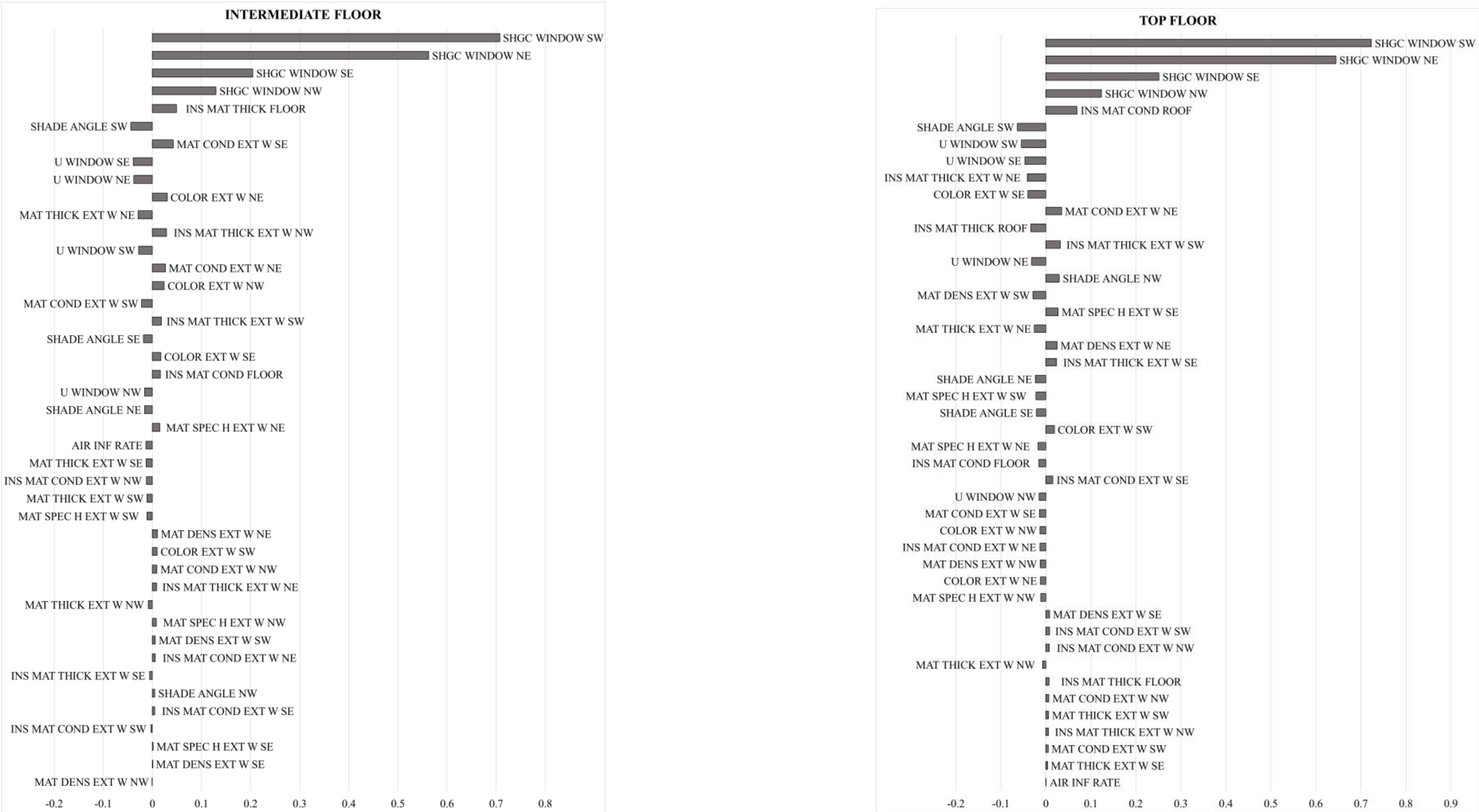


Figure A.7. Sensitive parameters for annual operational CO_2 emission in the 2020s a) intermediate floor b) top floor

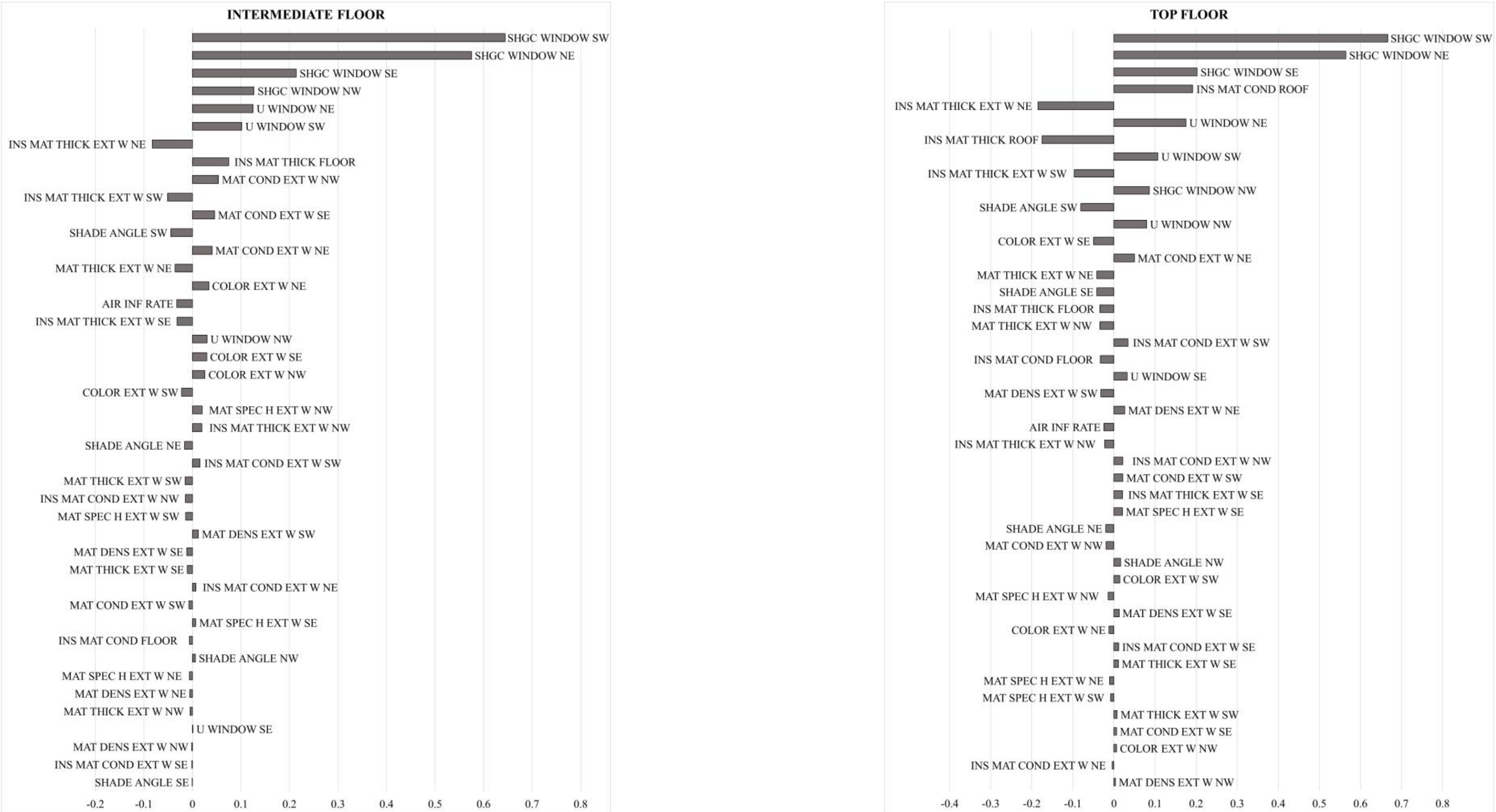
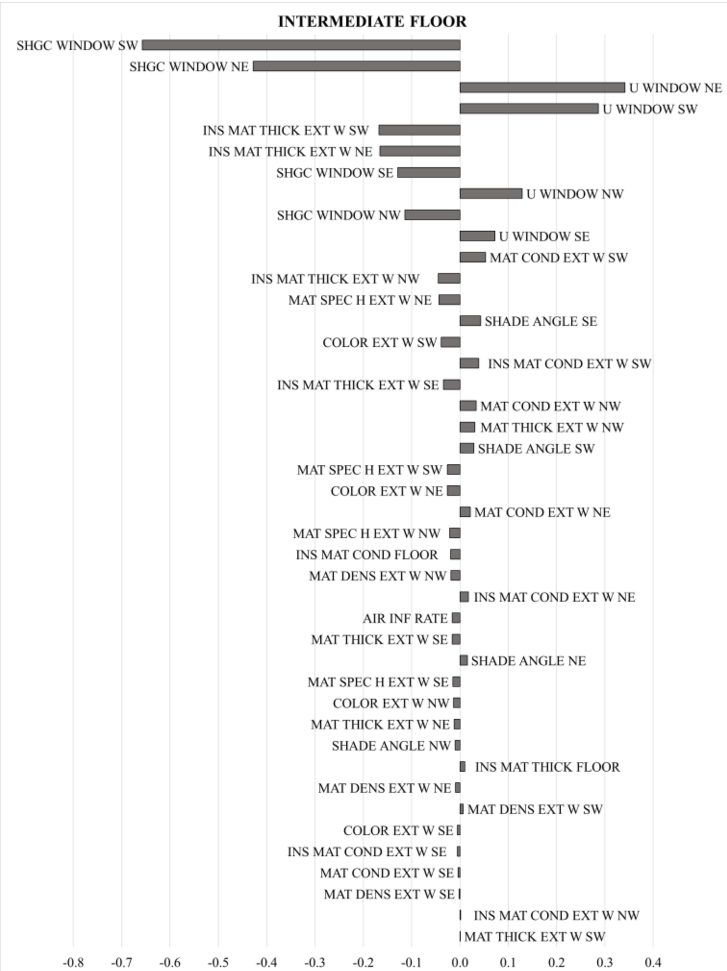


Figure A.8. Sensitive parameters for annual total energy consumption in the 2020s a) intermediate floor b) top floor



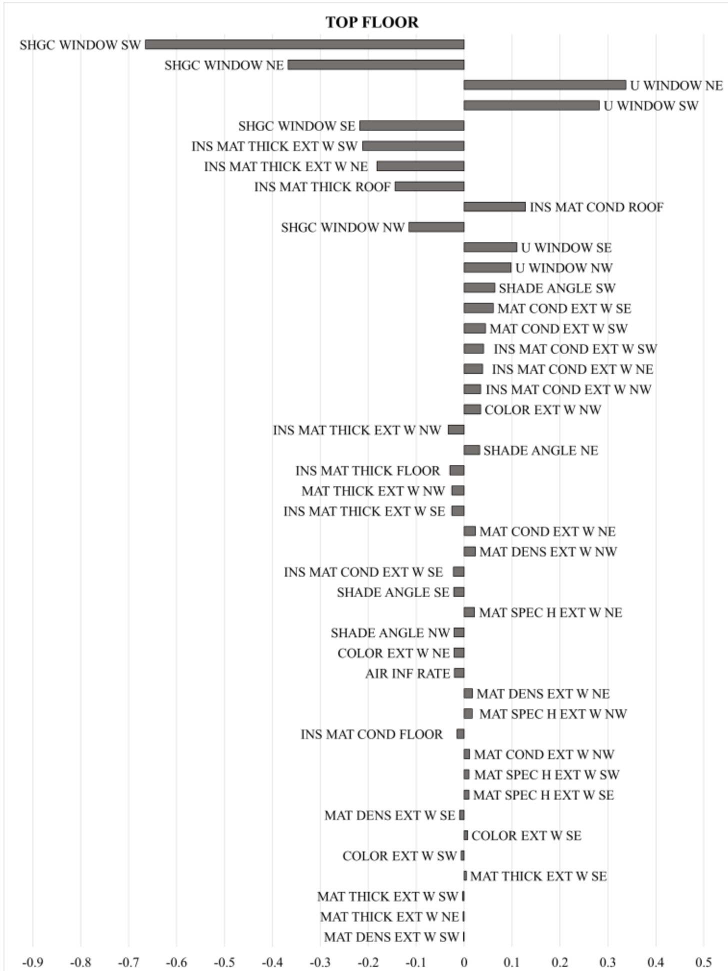


Figure A.9. Sensitive parameters for annual heating consumption in the 2050s a) intermediate floor b) top floor

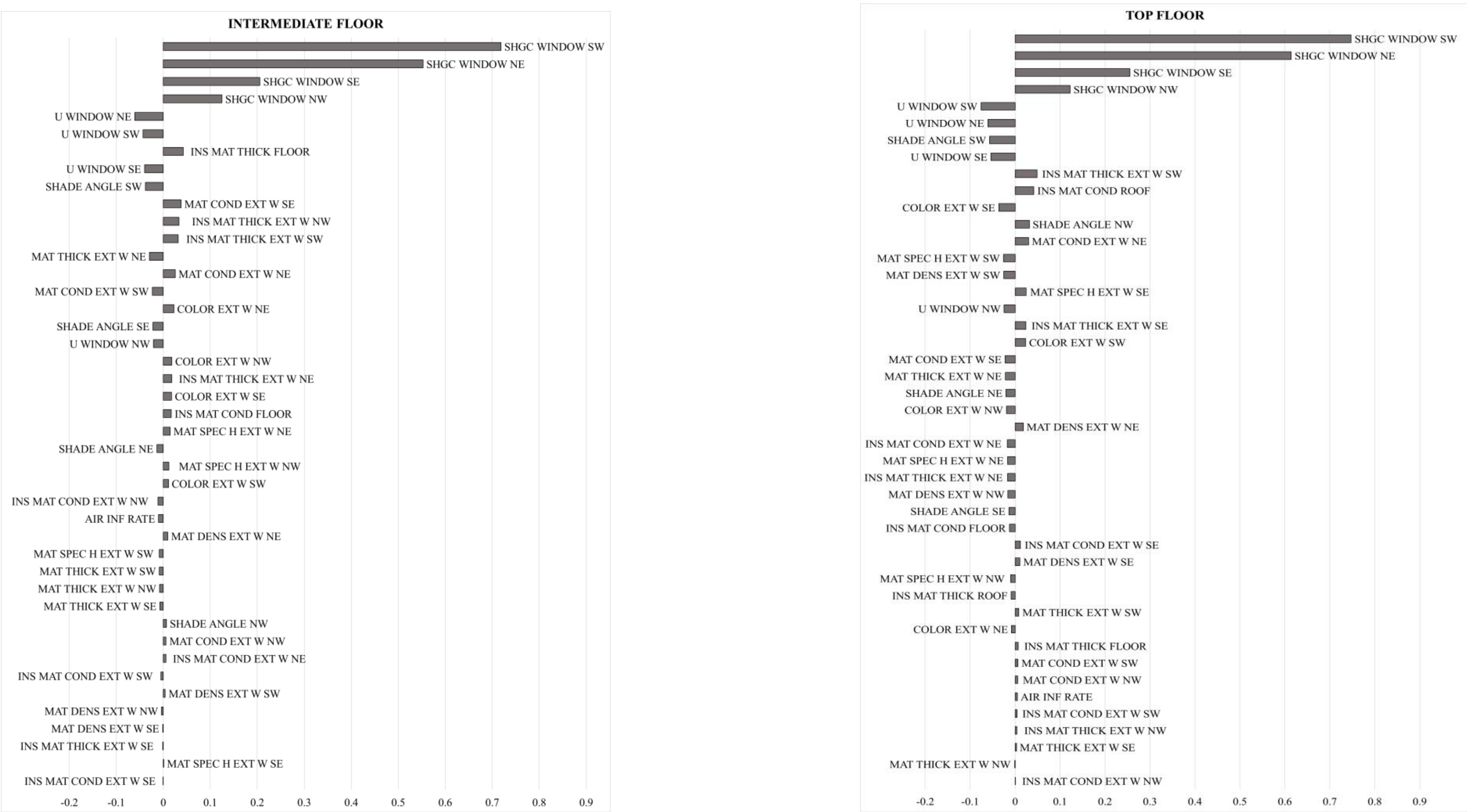


Figure A.10. Sensitive parameters for annual cooling consumption in the 2050s of a) intermediate floor b) top floor

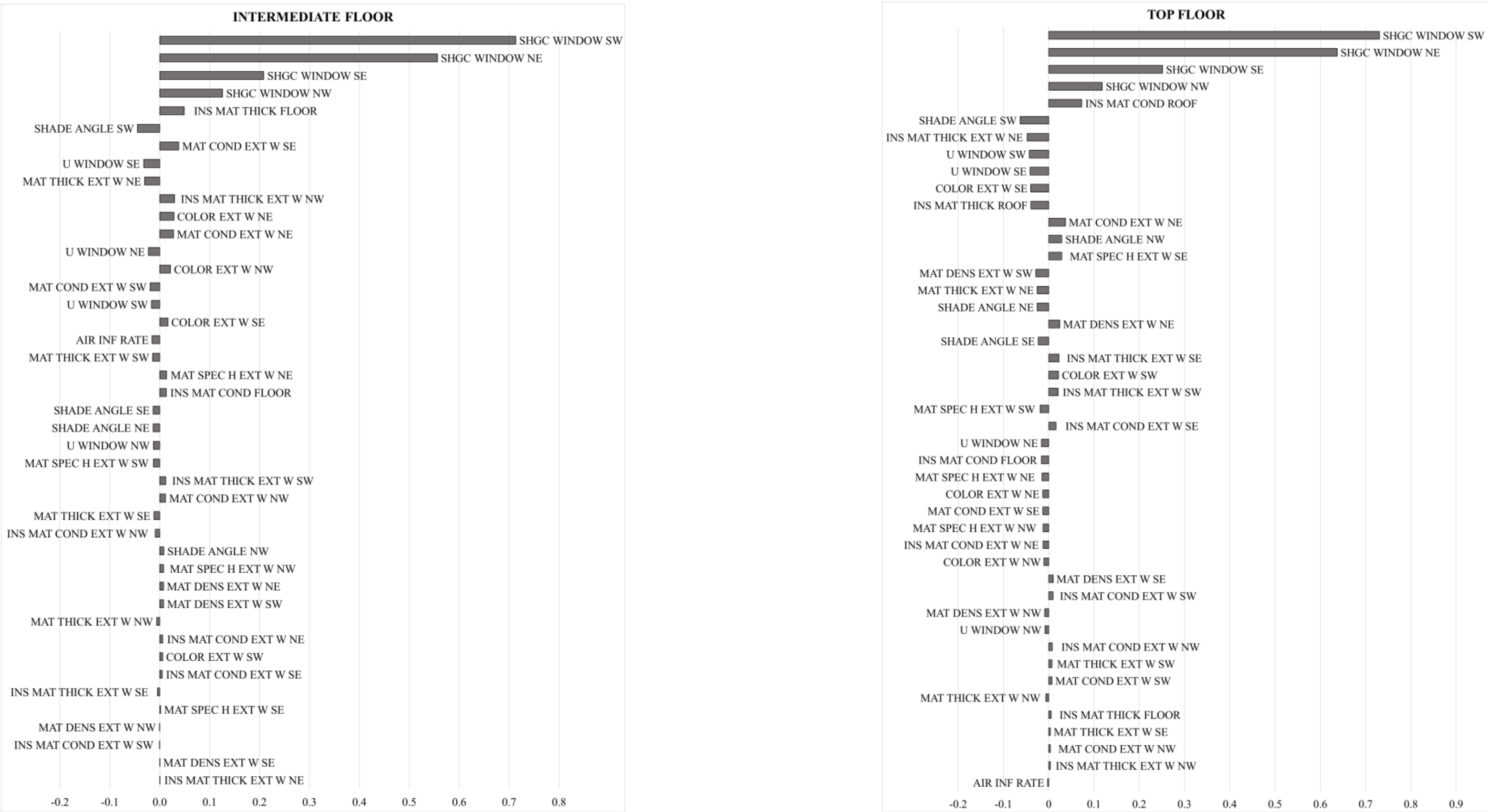


Figure A.11. Sensitive parameters for annual operational CO_2 emission in the 2050s a) intermediate floor b) top floor

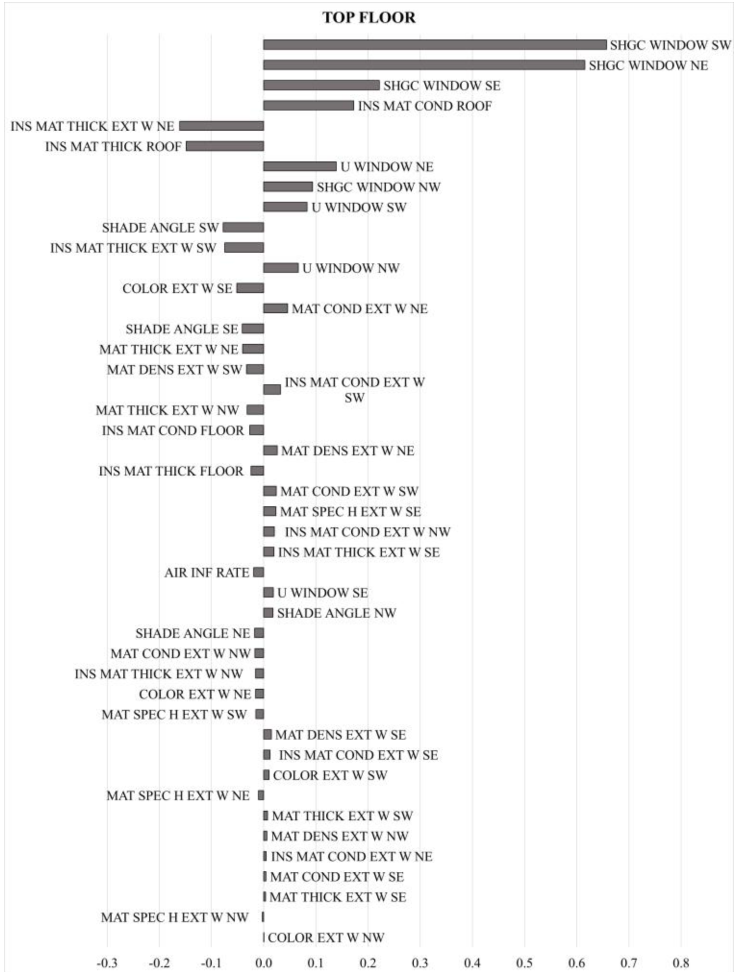


Figure A.12. Sensitive parameters for annual total energy consumption in the 2050s a) intermediate floor b) top floor

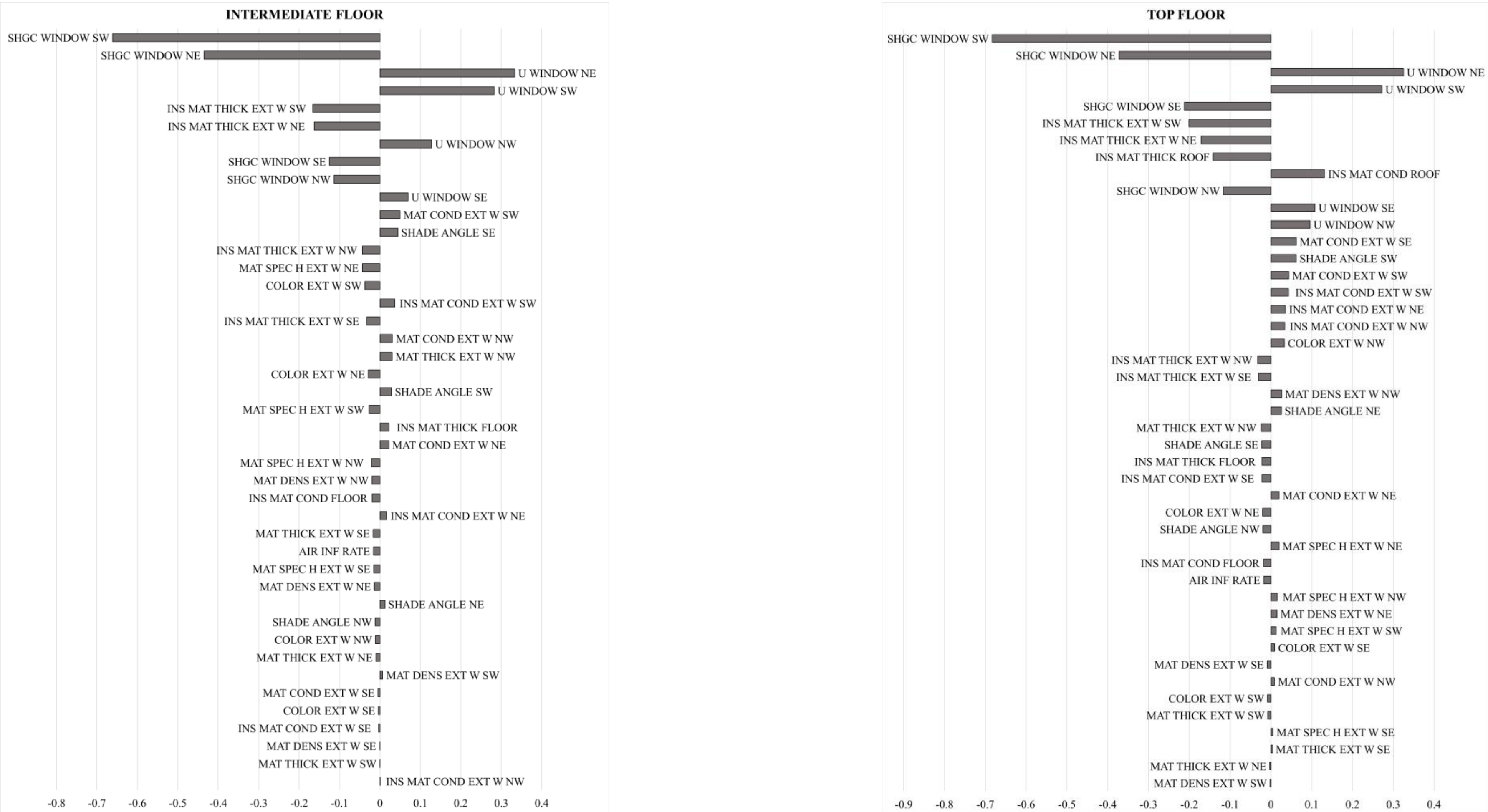


Figure A.13. Sensitive parameters for annual heating consumption in the 2080s a) intermediate floor b) top floor

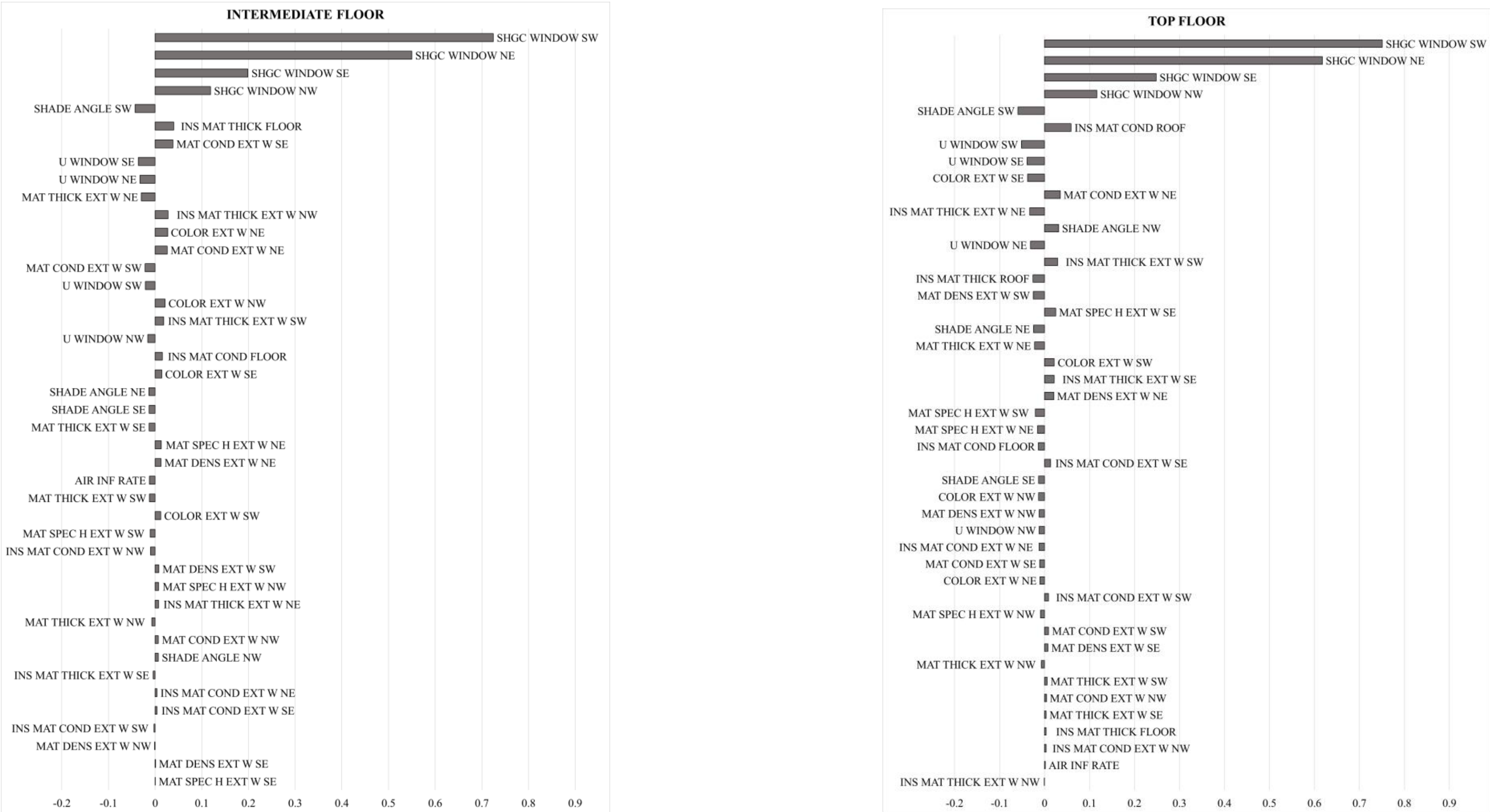


Figure A.14. Sensitive parameters for annual cooling consumption in the 2080s a) intermediate floor b) top floor

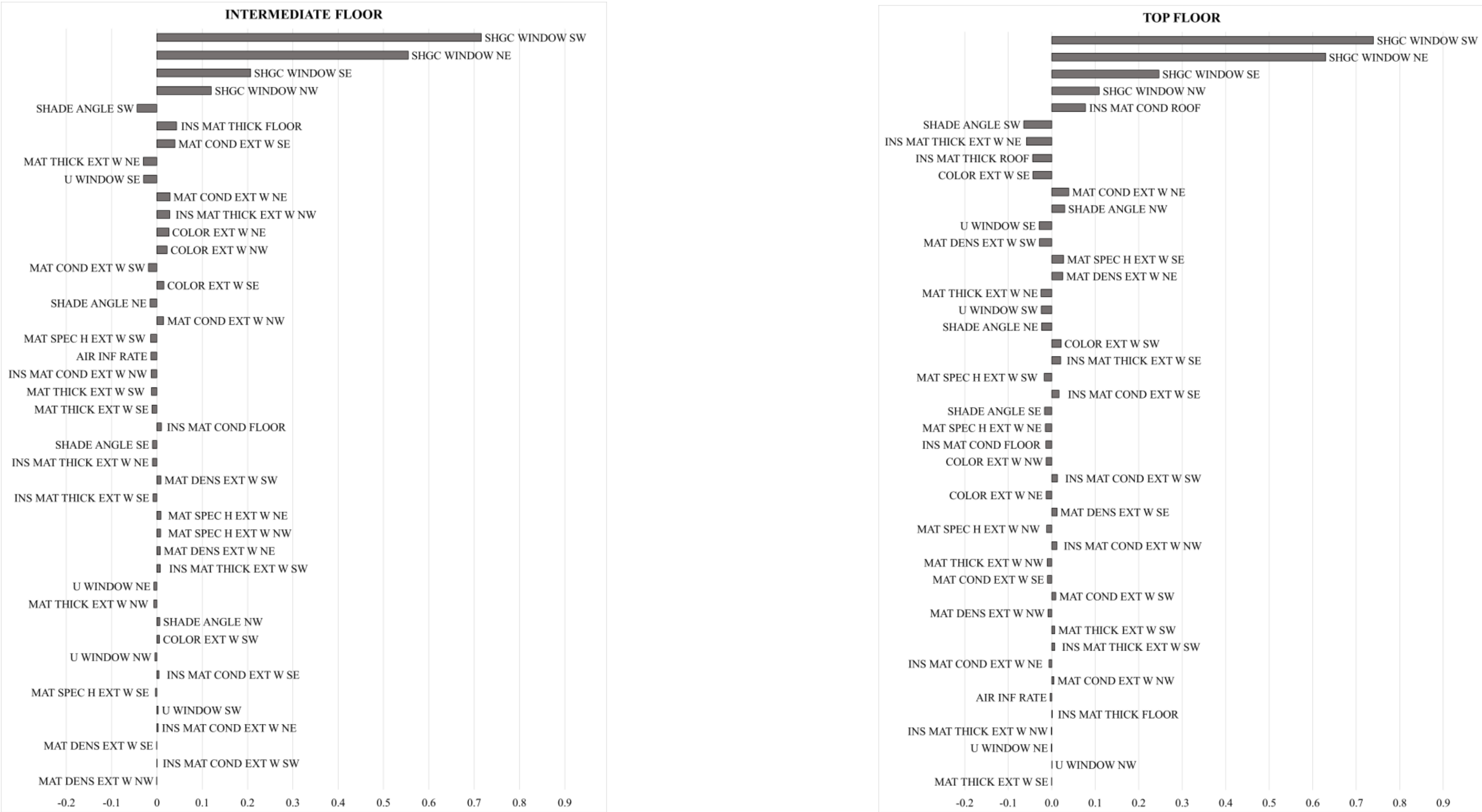
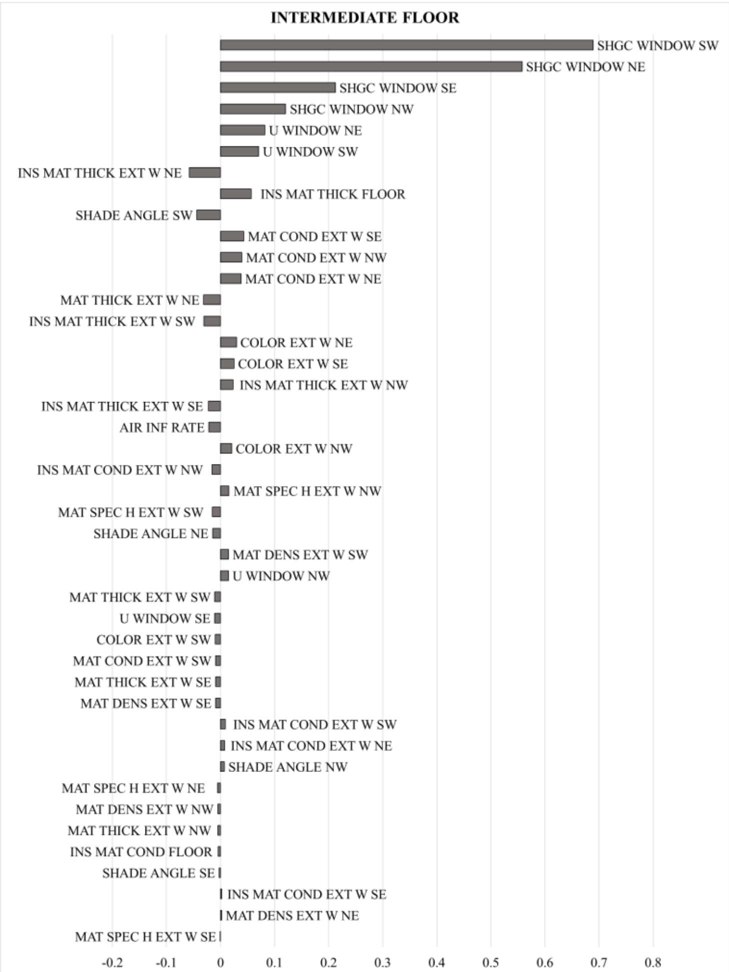


Figure A.15. Sensitive parameters for annual operational CO_2 emission in the 2080s a) intermediate floor b) top floor



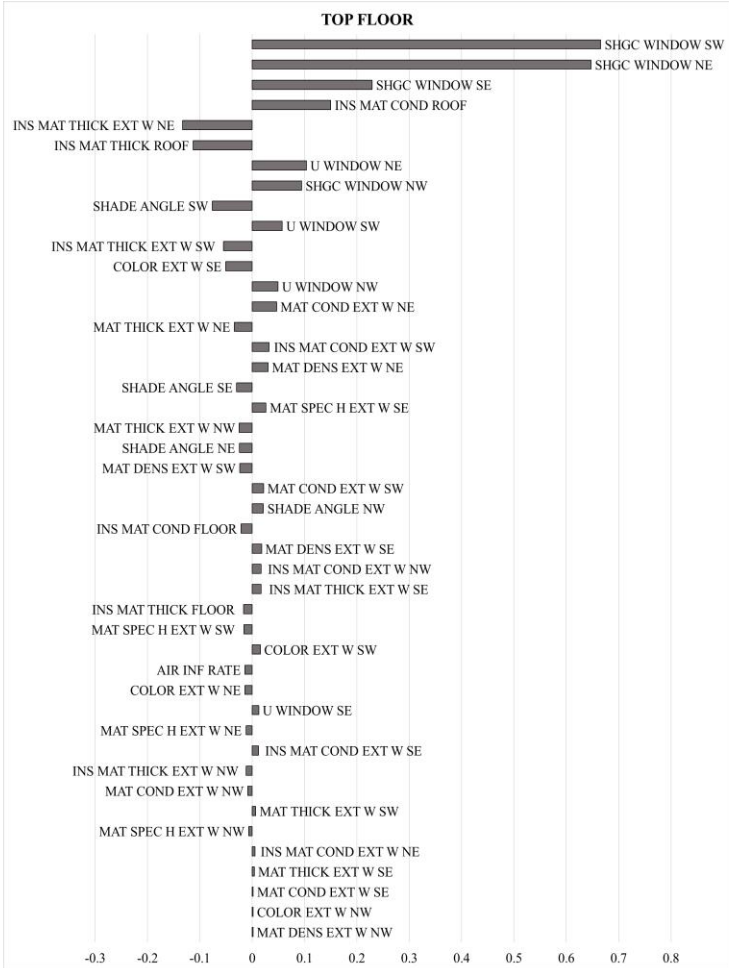


Figure A.16. Sensitive parameters for annual total energy consumption in the 2080s a) intermediate floor b) top floor

APPENDIX B

QUESTIONNAIRES

B.1. Questionnaire 1

1. Projelerinizde/yapılarınızda uyguladığınız aşağıda sıralanan 32 konuyu öncelik sırasına göre belirleyiniz. Lütfen en fazla 10 seçenek belirleyiniz. Derecelendirme 1'den 10'a dek yapılabilir (1 en fazla önemli ilke, 10 en az önemli ilke).

Arsa-arazi kullanımı

Mevcut flora ve faunayı dikkate alma

Yapılaşma/yeşil alan oranı

Yönlenme

Mekân organizasyonunda iklimsel verileri dikkate alma

Güneş ışığından yararlanma

Güneşin etkilerinden yapıyı koruma

Yenilenebilir kaynaklardan enerji elde edilmesi

Yapılı çevreyle ilişki kurma

Proje alanındaki toplumsal yapı

Yapı maliyeti

Yapının çevresel maliyeti

Yapının kullanım maliyeti

Yalıtım

Konfor koşullarını sağlama

İnsan sağlığına ve iç hava kalitesine dikkat etme

Yapı malzemelerinin çevresel etkisini dikkate alma

Yerel malzeme kullanımı

Doğal malzeme kullanımı

Geri dönüştürülmüş ve/veya geri dönüştürülebilir malzeme kullanımı

Malzemenin üretim enerjisini dikkate alma

Yapı atıklarının atılması ve yeniden değerlendirilmesi

Yağmur suyundan yararlanma

Su tasarrufu için önlem alma
Enerji verimli aydınlatma
Doğal havalandırmaya olanak sağlama
Mühendislik hizmetlerinden yararlanma
Kültürel farklılıkları dikkate alma
İnsanla ilgili bedensel/sağlık koşullarını dikkate alma
Yerel bitki kullanımı
Yeşil çatı/duvar uygulaması
Bina otomasyon sistemleri

2. Sürdürülebilirlik kavramı yaşanılan mekânla/binayla ilgili olarak aklınıza ne getiriyor? Lütfen aşağıdaki seçeneklerden en fazla beşini işaretleyiniz.

Sağlıklı yapı
Bina otomasyonu
Bina sertifikasyonu
Doğal malzemelerle yapılmış yapı
Meslek politikaları
Uluslararası ilişkiler ve mimarlık
Enerji etkin bina
Enerji verimli yapı
Mimarlık ve toplum
Mimarlık ve ekonomi
Doğa dostu yapı
Peyzaj
Diğer (Lütfen belirtiniz)

3. Dünyada çevre üzerinde üretilen güncel politikalardan haberdar olabiliyor musunuz?

Evet Hayır

4. Bir önceki soruya yanıtınız evet ise bir örnek verebilir misiniz?

……

5. Türkiye'de çevre üzerine üretilen yasa ve yönetmeliklerden haberdar olabiliyor musunuz?

Evet Hayır

6. Bir önceki soruya yanıtınız evet ise bir örnek verebilir misiniz?

……

7. Sizce sürdürülebilir yapı yapmanın avantajları nelerdir?

……

8. Sizce sürdürülebilir yapı yapmanın önündeki engeller nelerdir?

……

9. İklim değişikliği ve etkileri ilgili konulardan haberdar mısınız?

Evet Hayır

10. Bir önceki soruya yanıtınız evet ise etkilerinden birkaç örnek verebilir misiniz?

……

11. İklim değişikliğinin mimari tasarım sürecini etkileyeceğini düşünüyor musunuz?

Evet Hayır

12. Bir önceki soruya yanıtınız evet ise etkilerinden birkaç örnek verebilir misiniz?

……

13. İklim değişikliği konusu ile ilgili yapılan açıklamaların bilgilendirici ve faydalı olduğunu düşünüyor musunuz?

Evet Hayır

14. Gelecekte öngörülen iklim değişikliği senaryolarını doğru buluyor musunuz?

Evet Hayır

15. Gelecekte öngörülen iklim değişikliği senaryolarını doğru buluyorsanız, mimarlıktaki olası etkilerine inanıyor musunuz?

Evet Hayır

16. Önceki soruya cevabınız evet ise olası etkilerinden bir örnek veriniz.

……

17. İklim değişikliği senaryolarının, devam etmekte olan ya da ilerleyen zamanlarda yapacağınız projelerdeki kararlarınızı etkileyici bir faktör olduğunu düşünüyor musunuz?

Evet Hayır

18. Önceki soruya cevabınız Evet/Hayır ise nedenlerini kısaca açıklayınız.

……

B.2. Questionnaire 2

1. Sunum öncesinde bina simülasyon programları ile ilgili genel bir bilgiye sahip miydiniz?

Evet Hayır

2. Bina simülasyon programları ve kullanımı ile ilgili yapılan açıklamalar yeterli ve bilgilendirici miydi?

Evet Hayır

3. Design Builder programı görsel açıdan anlaşılabilir ve kullanıcı kolaylığı sağlayabilir düzeyde mi?

Evet Hayır

4. Önceki soruya cevabınız Evet ise, bina simülasyon programlarından projelerinizde faydalanmayı tercih eder misiniz?

Evet Hayır

5. Hassasiyet analizi programı olarak SimLab, görsel açıdan kolay anlaşılabilir ve kullanıcı dostu olma konularında yeterli mi?

Evet Hayır

6. Hassasiyet analizleri doğrultusunda elde edilen sonuçları tasarım sürecinizde göz önünde bulundurur musunuz?

Evet Hayır

7. Önceki soruya cevabınız Evet ise, sunumda belirtilen bina enerji simülasyonu ve analiz yöntemlerinin, projelerinizle ilgili hangi ihtiyaçlarınızı karşılayabileceğine inanıyorsunuz?

…..

8. Analiz sonuçları, işveren/müşteri veya diğer profesyoneller ile yapılan görüşmelerde temel alarak kullanılabilecek özelliklerde sayılabilir mi?

Evet Hayır

9. Bütün çalışmalar sonucunda, bina tasarımı ile ilgili elde edilen sonuçların, gelecekteki projelerinizde tasarım sürecine destek olabilecek düzeyde olduğuna inanıyor musunuz?

Evet Hayır

10. İklim değişikliği hakkındaki senaryoları da içine alarak, bina performans simülasyonu ve hassasiyet analizi yöntemlerinin bütünleşmiş şekilde kullanılmasını faydalı buluyor musunuz?

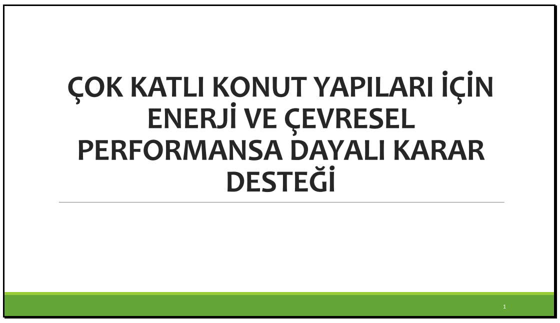
Evet Hayır

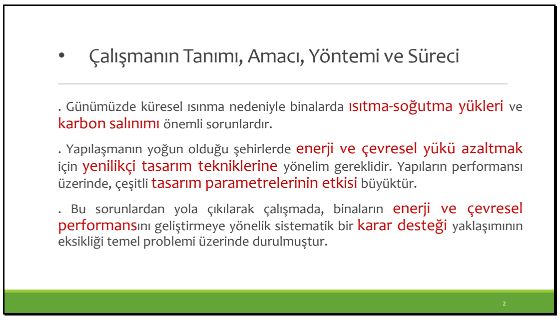
11. Önceki soruya cevabınız Evet ise, bütünleşmiş kullanımın profesyonel alanda ne gibi faydalar sağlayabileceğini kısaca açıklayınız.

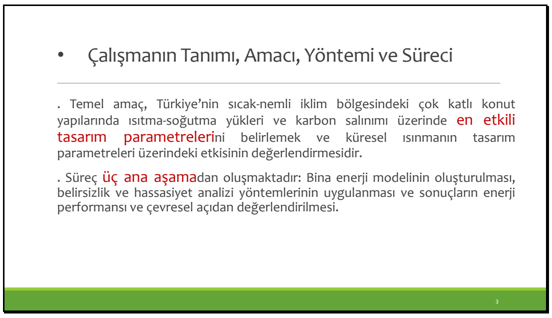
APPENDIX C

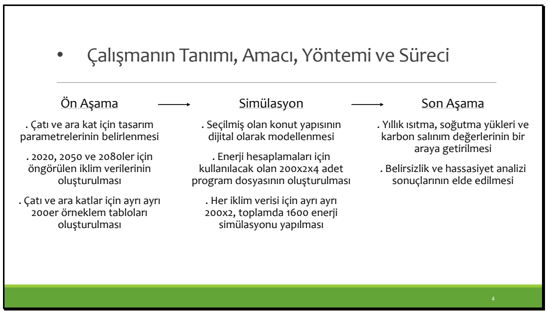
PRESENTATIONS

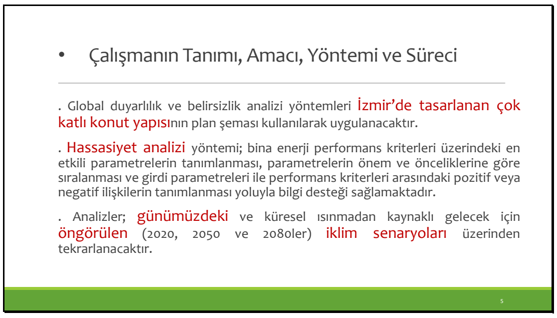
C.1. Presentation 1

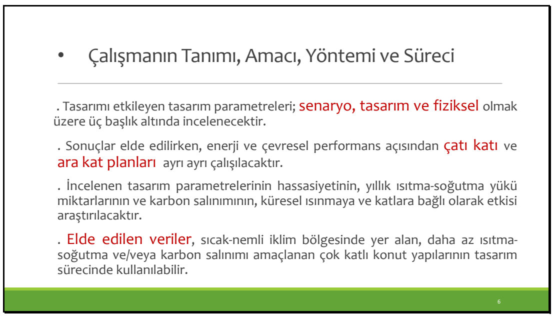




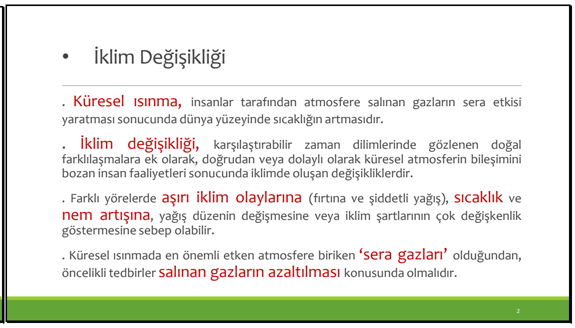


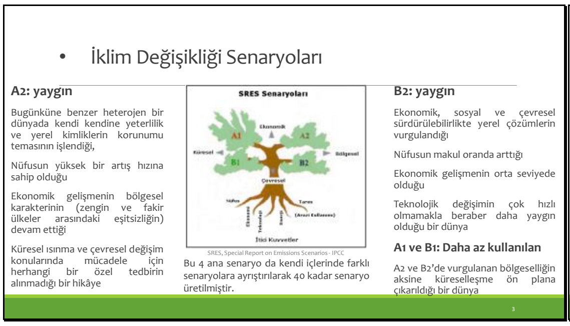


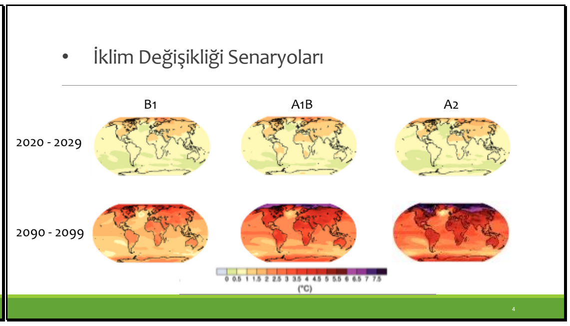


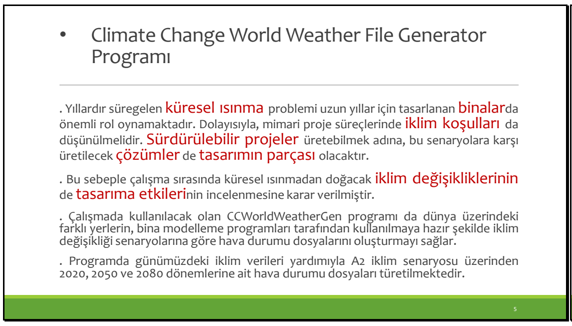


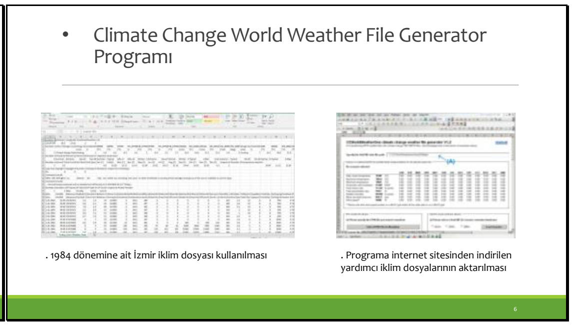
C.2. Presentation 2

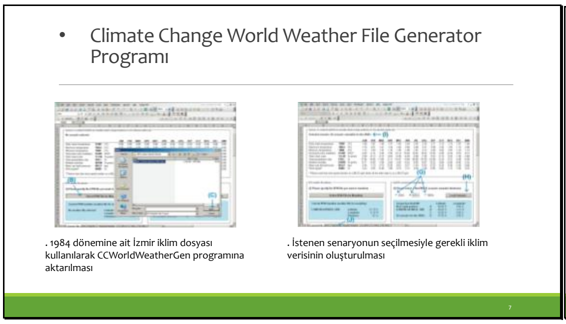


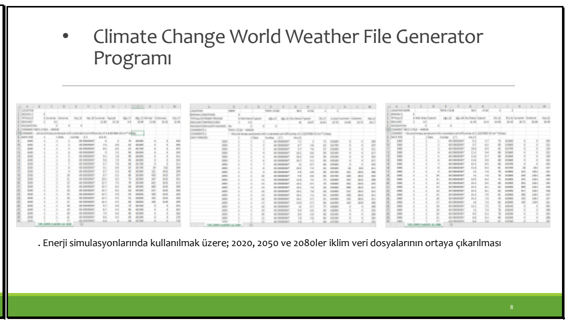




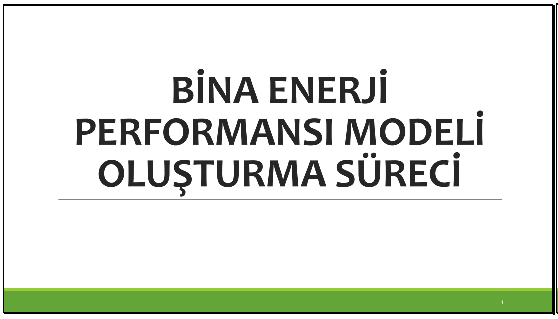


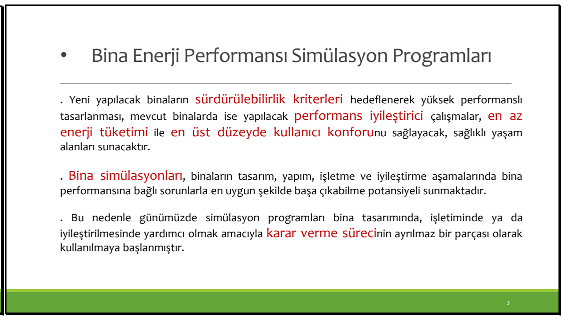


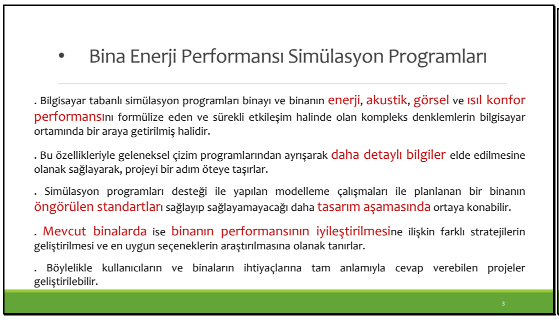


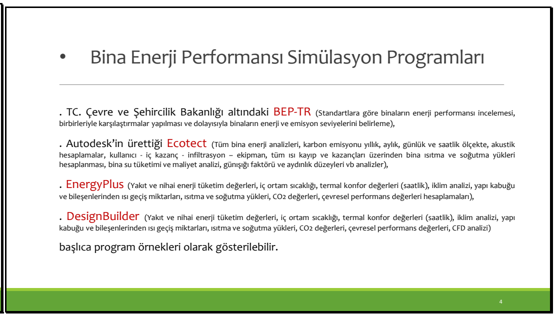


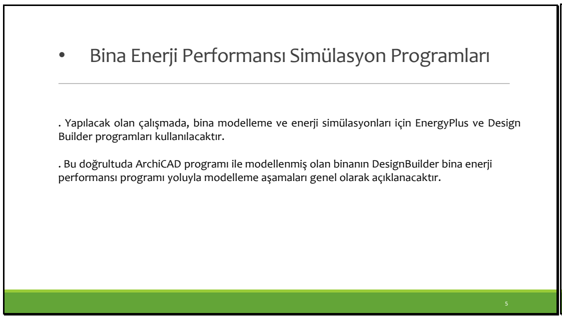
C.3. Presentation 3

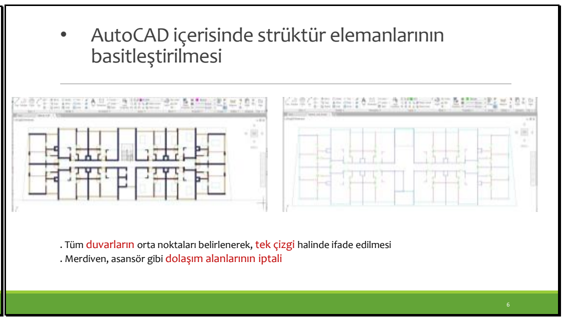


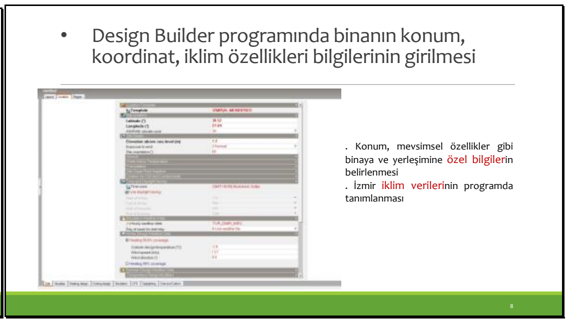


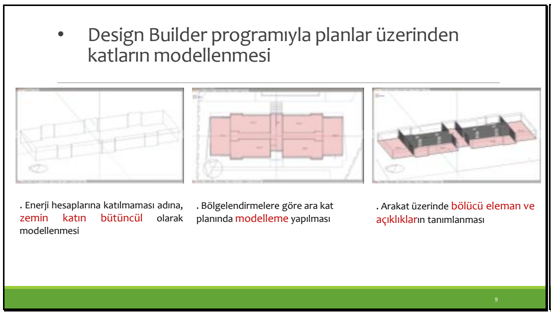


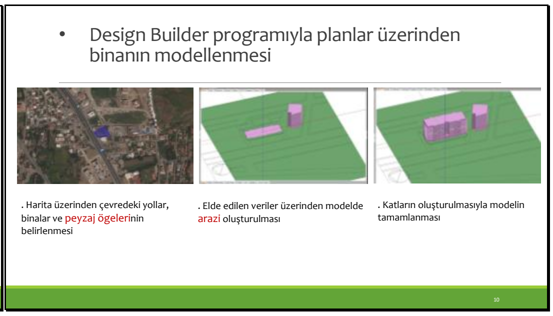


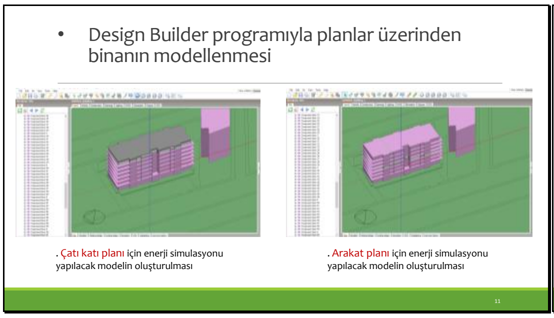


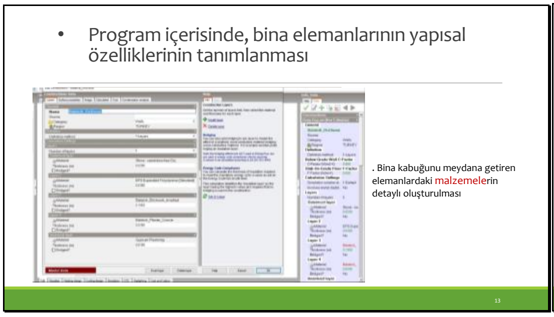


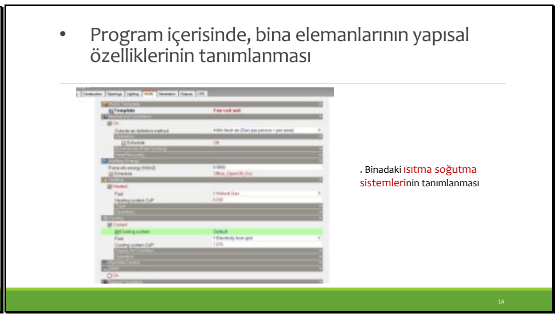




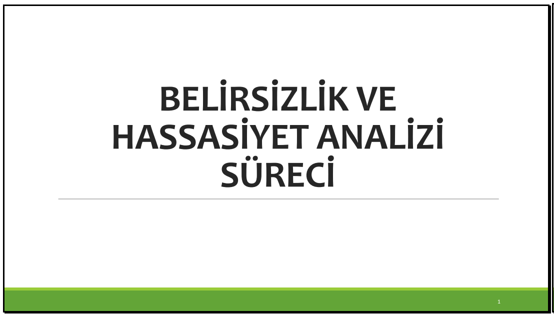


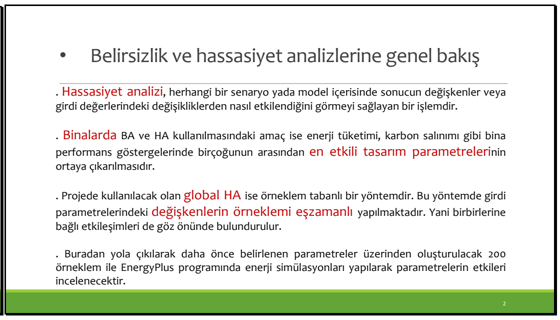




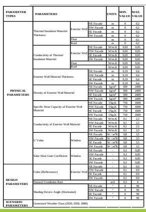


C.4. Presentation 4





- Tasarım parametrelerindeki belirsizliklere karar verilmesi

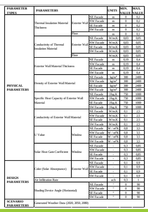


ÇATI KATI ve ARA KAT ÇALIŞMALARINDA;

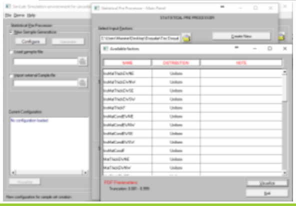
. Tasarım sürecinde etkili olan parametreler, bu konudaki belirsizliklere ve çalışmada kullanılacak olanlara karar verilmesi

. Piyasada bulunabilen ve yönetmeliğe uygun malzemelerin belirlenmesi

. Belirlenen malzemeler ile yönetmeliklerden yola çıkarak parametrelerin alabileceği değer aralıklarının belirlenmesi

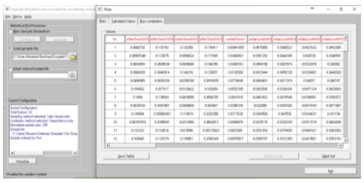


- Tasarım parametrelerinin programa aktarımı



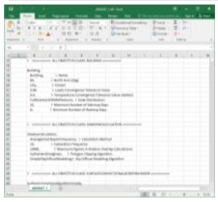
. Belirlenen parametreler ve değer aralıklarının SimLab programına aktarılması

- Örneklem dosyalarının oluşturulması



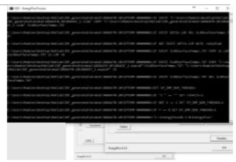
. SimLab yardımıyla, belirtilen parametre aralıkları doğrultusunda iki yüzer adet çatı katı ve ara kat simülasyonlarına gerekecek örneklemlerin oluşturulması

- Enerji analizi dosyalarının oluşturulması



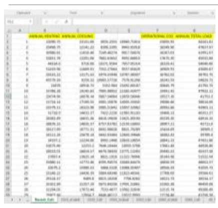
. Oluşturulan örneklem dosyaları kullanılarak EnergyPlus programında enerji analizi yapmak için gerekli olan, binanın bilgilerini ve parametre değişkenlerini içeren 200er adet .idf dosyasının elde edilmesi

- EnergyPlus ile enerji simülasyonu



. Çatı katı ve ara kat için oluşturulan .idf dosyalarının EnergyPlus programına yüklenerek simülasyonu

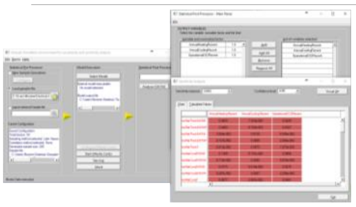
- Enerji perfomansı ve karbon salınımı verileri



. Yapılan simülasyonlar sonucunda her örneklem için binanın yıllık ısıtma, soğutma yüklerinin ortaya çıkarılması

. Türkiye'deki yönetmeliklerde kabul edilen karbon salınım katsayıları (doğalgaz ve elektrik için) kullanılarak binanın her örneklem için yıllık operasyonel karbon salınımının hesaplanması

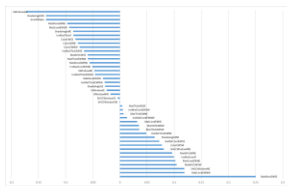
- Hassasiyet analizi



. Girdi ve çıktı dosyalarının Excel ile SimLab programına uygun hale getirilmesi

. Veriler üzerinden hassasiyet analizlerinin yapılması

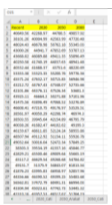
- Parametrelerin ayrıştırılması



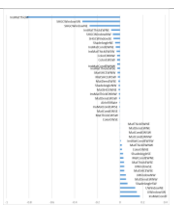
2050 Arakat Yıllık Karbon Salınımı

. Bina performansını etkileyen yıllık enerji tüketimi ve karbon salınımı üzerinde en etkili parametrelerin belirlenmesi

- 2020, 2050, 2080 yıllarının incelenmesi



Arakat Toplam Yıllık Enerji Tüketimi Sonuçları



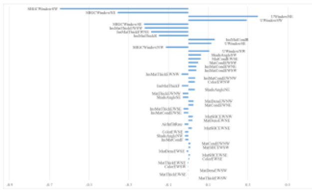
2080 Arakat Yıllık Isıtma Yükü Hassasiyet Analizi Sonuçları

. Simülasyonların, elde edilen bina performansı sonuçlarının işlenme sürecinin, girdi-çıktı dosyaları üzerinden yapılan hassasiyet analizlerinin; 2020, 2050 ve 2080 yıllarına ait iklim verileri kullanılarak tekrarlanması

C.5. Presentation 5

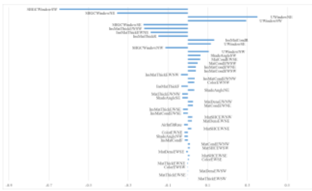
HASSASİYET ANALİZİ SONUÇLARI

- Günümüze ait yıllık çatı katı ısıtma yüklerinde en etkili parametreler



. Hassasiyet analizi sonucunda elde edilen parametrelerdeki etki sıralamasının görselleştirilmesi

- Günümüze ait yıllık çatı katı ısıtma yüklerinde en etkili parametreler



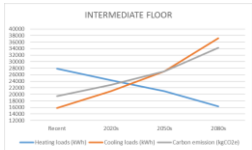
. Pozitif(+) değere sahip olan parametreler azaldıkça; yıllık ısıtma yükü azalma gösterir

. Negatif(-) değere sahip olan parametreler arttıkça; yıllık ısıtma yükü azalma gösterir.

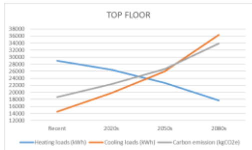
(+) parametre ↓ yıllık ısıtma yükü ↓

(-) parametre ↑ yıllık ısıtma yükü ↓

- Çatı ve ara katlarının yıllık enerji ve çevresel yükleri

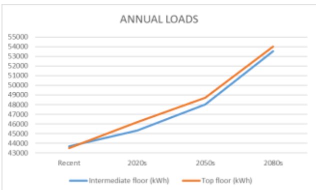


Ara kat yıllık enerji ve çevresel yükleri



Çatı katı yıllık enerji ve çevresel yükleri

- Çatı ve ara katların yıllık toplam enerji yükleri



- Ara ve çatı katlardaki performans üzerinde en etkili parametreler

INTERMEDIATE FLOOR	RECENT	2020	2050	2080
HEATING	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW
	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE
	UWindowNE	UWindowNE	UWindowNE	UWindowNE
	UWindowSW	UWindowSW	UWindowSW	UWindowSW
COOLING	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW
	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE
	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE
	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW
CARBON	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW
	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE
	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE
	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW
TOTAL	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW
	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE
	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE
	UWindowNE	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW

TOP FLOOR	RECENT	2020	2050	2080
HEATING	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW
	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE
	UWindowNE	UWindowNE	UWindowNE	UWindowNE
	UWindowSW	UWindowSW	UWindowSW	UWindowSW
COOLING	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW
	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE
	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE
	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW
CARBON	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW
	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE
	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE
	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW	SHGCWindowNW
TOTAL	SHGCWindowNE	SHGCWindowNE	SHGCWindowNE	SHGCWindowSW
	SHGCWindowSW	SHGCWindowSW	SHGCWindowSW	SHGCWindowNE
	UWindowNE	SHGCWindowSE	SHGCWindowSE	SHGCWindowSE
	InsMatCondR	InsMatCondR	InsMatCondR	InsMatCondR

- Arakat ve çatı katlardaki performans üzerinde en etkili parametreler

ISITMA YÜKLERİNDE (Çatı ve arakat)

. Pencere SHGC Güneybatı (-)
. Pencere SHGC Kuzeydoğu (-)
. Pencere U değeri Kuzeydoğu (+)
. Pencere U değeri Güneybatı (+)

YILLIK TOPLAM ENERJİ YÜKLERİNDE (Arakat)

. Pencere SHGC Güneybatı (+)
. Pencere SHGC Kuzeydoğu (+)
. Pencere SHGC Güneydoğu (+)

SOĞUTMA VE KARBON YÜKLERİNDE (Çatı ve arakat)

. Pencere SHGC Güneybatı (+)
. Pencere SHGC Kuzeydoğu (+)
. Pencere SHGC Güneydoğu (+)
. Pencere SHGC Kuzeybatı (+)

YILLIK TOPLAM ENERJİ YÜKLERİNDE (Çatı)

. Pencere SHGC Kuzeydoğu (+)
. Pencere SHGC Güneybatı (+)
. Pencere SHGC Güneydoğu (+)
. Çatı yalıtım malzemesi iletkenliği (+)

- En etkili parametere olan pencere SHGC değeri ile ilgili örnekler

TRAKYA CAM	Cam Kalınlığı	SHGC Değerleri	U Değerleri	2015 FİYATLARI	TOPLAM ENERJİ KAZANCI (ARAKAT) (standard çift cama göre)	Mali Geri Dönüşler	TOPLAM ENERJİ KAZANCI (ÇATI) (standard çift cama göre)	Mali Geri Dönüşler	2020ler TOPLAM ENERJİ KAZANCI (ARAKAT) (standard çift cama göre)	Mali Geri Dönüşler	2020ler TOPLAM ENERJİ KAZANCI (ÇATI) (standard çift cama göre)	Mali Geri Dönüşler
Standard Çift Cam	4+4	0.75	2.9	39.40TL								
	6+6	0.71	2.8									
Isıcam Sinerji (Ecotherm+Renksiz düzcam)	4+4	0.55	1.6	48.00TL	%13	7 yıl	%9	10 yıl	%14	6 yıl	%10	8 yıl
	6+6	0.54	1.6									
Isıcam Konfor (Ecosol+Renksiz düzcam)	4+4	0.44	1.6	54.40TL	%17	9 yıl	%11	15 yıl	%18	8 yıl	%13	11 yıl
	6+6	0.43	1.6									
Isıcam Sinerji 3+ (LowE+Düzcam+LowE)		0.48	0.9	83.75TL	%15	30 yıl	%10	47 yıl	%17	26 yıl	%12	37 yıl
Isıcam Konfor 3+ (Solar LowE+Düzcam+LowE)		0.39	0.9	90.15TL	%18	30 yıl	%12	47 yıl	%20	25 yıl	%14	36 yıl