SENSITIVITY AND UNCERTAINTY ANALYSIS TO REDUCE COOLING REQUIREMENT OF LOW-RISE APARTMENT BLOCKS IN THE HOT-HUMID CLIMATE REGION OF TURKEY

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ABSTRACT

SENSITIVITY AND UNCERTAINTY ANALYSIS TO REDUCE COOLING REQUIREMENT OF LOW-RISE APARTMENT BLOCKS IN THE HOT-HUMID CLIMATE REGION OF TURKEY

Cooling demand in apartment buildings is an important problem due to the global warming today. Implementing passive design techniques to reduce cooling requirements cannot be possible in dense cities. Therefore, energy performance of apartment buildings usually depends on uncertainties caused by local climate and design parameters such as window size, zone height, features of materials and so on.

The main aims of dissertation are to determine design parameters that have the most impact on the annual cooling energy loads for low-rise apartment blocks in hot-humid climatic region of Turkey, and to evaluate uncertainty in annual cooling loads caused by design parameters and global warming. Global sensitivity and uncertainty analysis methods are performed by using morphology of an existing low-rise apartment block in Izmir, Turkey. The minor aim of thesis is to develop a practical guide to help architects while designing low-rise apartment blocks which have low cooling load located in Izmir. This practical guide was developed by using the results of sensitivity and uncertainty analyses and interviews with architects who have worked on commercial architectural projects in Izmir and are considered to be experts on energy efficiency in buildings.

The results show that the sensitivity of evaluated design parameters and annual cooling energy loads in low-rise apartment blocks varies based on the effect of global warming and floors in the apartment block. In addition, total window area, natural ventilation and solar heat gain coefficient of the glazing based on the orientation have the most influence on annual cooling load of low-rise apartment blocks in hot-humid climates. Furthermore, the developed practical guide is feasible and could be used in design process of low-rise apartment blocks targeted low cooling demand in hot-humid climates.

ÖZET

TÜRKİYE'NİN SICAK NEMLİ İKLİM BÖLGESİNDEKİ AZ KATLI APARTMAN BLOKLARINDA SOĞUTMA GEREKSİNİMİNİ AZALTMAK İÇİN DUYARLILIK VE BELİRSİZLİK ANALİZİ

Günümüzde küresel ısınma nedeniyle apartman binalarında soğutma ihtiyacı önemli bir sorundur. Yapılaşmanın yoğun olduğu şehirlerde soğutma yükünü azaltmak için her koşulda pasif tasarım tekniklerini uygulamak mümkün değildir. Bu nedenle, apartman binalarının enerji performansı, genellikle yerel iklimsel özelliklerden ve pencere boyutu, mekan yüksekliği, malzeme özellikleri gibi tasarım parametrelerinden kaynaklanan belirsizliklere bağlıdır.

Bu nedenle, tezin temel amacı Türkiye'nin sıcak-nemli iklim bölgesindeki az katlı apartman bloklarında soğutma yükü üzerinde en etkili olan tasarım parametrelerini belirlemek ve tasarım parametreleri ile küresel ısınmadan kaynaklanan yıllık soğutma yüklerindeki belirsizliğin değerlendirilmesidir. Global duyarlılık ve belirsizlik analizi yöntemleri İzmir'de bulunan az katlı bir apartman bloğunun plan şeması kullanılarak uygulanmıştır. Tezin ikincil amacı ise İzmir'de mimarların uygun tasarım kararları ile daha az soğutma yüküne sahip az katlı apartman blokları tasarlamak için kullanabileceği pratik bir rehber oluşturmaktır. Bu rehber duyarlılık ve belirsizlik analizlerinden elde edilen sonuçlar ve İzmir'de mimarlık bürosu bulunan enerji verimliliği konularında duyarlı 5 mimarla yapılan mülakatlar sonucunda hazırlanmıştır.

Sonuçlar, incelenen tasarım parametrelerinin hassasiyetinin ve yıllık soğutma yükü miktarının, küresel ısınmaya ve katlara bağlı olarak değiştiğini göstermiştir. Yönlere bağlı olarak toplam pencere alanı, doğal havalandırma ve camların güneş ısı kazanç katsayısı sıcak-nemli iklim bölgesindeki az katlı apartman bloklarının soğutma yükü üzerinde en fazla etkiye sahiptir. Ayrıca, geliştirilen pratik rehber sıcak-nemli iklim bölgesinde yer alan daha az soğutma ihtiyacı olan az katlı apartman bloğu tasarım sürecinde kullanılabilir.

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CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Energy requirements with global warming especially in the building sector are an important issue today because energy consumption caused by the buildings is a big part of the total energy consumption in many countries. For example, in Turkey the building sector is the second largest consumer of energy. Therefore design and retrofitting of buildings in terms of energy efficiency is very important problem for all developed and developing countries. Building sector consists of many types of buildings such as residential, office, health, education, public, and etc. Big part of the fast-growing cities usually consists of apartment buildings that accommodate many people and the number of them can increase depending on population and policies of governments. Thus, apartment buildings have considerable energy saving potential.

The most important factors affecting rate of the energy consumption in buildings is mostly related to design decisions and climatic conditions. Design decisions can change depending on climatic regions which can lead to different set of priorities to be considered during the design process. As an example, Eastern Turkey has long snowy winters that results in a priority on heating requirements, whereas in Western Turkey long hot summers result in peaks of energy consumption for cooling. These kinds of architectural examples designed with respect to local climate conditions already exist in Turkish vernacular architecture. For instance, traditional buildings have heavy thermal mass, small windows and light surface colors to reduce cooling requirements in hot and dry climatic zones.

Though climate is an independent criterion which is impossible to control by the human being, design decisions can easily be changed by designer. However, architects generally have relatively limited information about impact of design decisions on energy performance in design process to be able to design buildings which consume less energy. Therefore, inappropriate or wrong decisions in the early design process of buildings can lead to increased energy requirements. For example in summer especially in hot climates, excessive solar radiation which exposes to building envelope may cause overheating in spaces because of the lack of shading measures or wrong glazing selection. Consequently, energy consumption for cooling can be higher in buildings but a significant amount of energy saving is possible with appropriate design measures in summer. In addition, it is possible to provide appropriate thermal comfort conditions with low energy consumption in buildings by following only simple heat transfer principles and by selecting suitable materials in the early design phase of buildings depending on the local climatic conditions. In other words, architects have to deal with several uncertain design parameters affecting energy performance of buildings during the design process. Some of them are shown in Table 1.1.

Table 1.1. Some parameters affecting energy consumption based on different design stages (Source: Morbitzer et al. 2001)

Predesign	**Schematic design**	**Design development**
Orientation	Windows area	Different heating systems
Floor plan depth	Glazing type	Different heating control strategies
Space usage	Shading and/or blinds	Different cooling systems
Windows area	Blind and/or shading control	Different cooling control strategies
U values for opaque and transparent surfaces	Exact orientation	Different ventilation control strategies
Light/heavy construction	Exact air change rate	
Air change rate	Material selection for overheating surfaces	
Heat recovery system	Cooling required: yes/no	
Fuel type	Lighting strategy	

Integrating and selecting appropriate value of these design parameters depending on the climatic conditions and building types into the early stages of building design is a complex issue because the design team has large degrees of freedom but has not enough information. Therefore, knowledge related to the importance and influence of several design parameters can support the architectural decision-making process for low energy consumption in especially apartment blocks. Apartment blocks are usually designed by architects without taking consultancy from other professionals such as mechanical engineer and etc. Hence owners have to rely on the performance of active components (such as heating, cooling and lighting devices) that are chosen by engineers in the final design stage. Other important point is that design parameters and their suitable values should be defined in the early stages of design, since changes in later stages may not influence energy performance and they cannot be cost effective solutions as well. In other words, although degree of the effort to increase building's energy performance rises, impact of the effort can decrease through late stages of the design process (Figure 1.1).

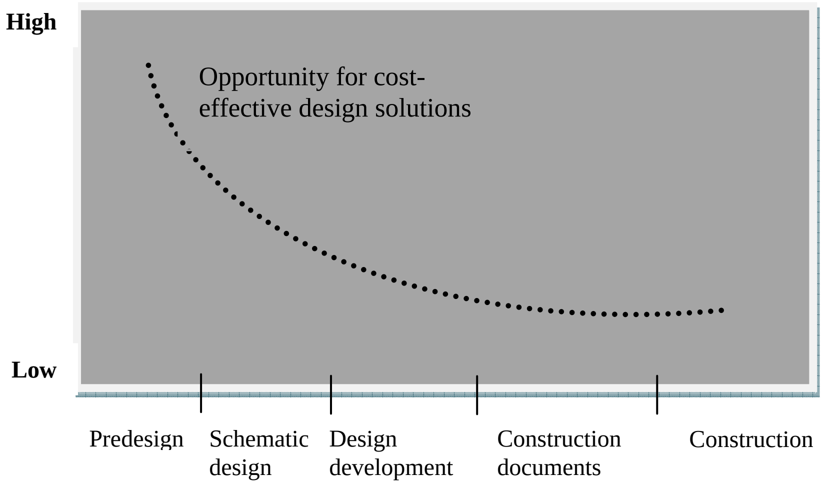


Figure 1.1. Impact of design decisions on building performance
(Source: ASHRAE, 2008)

In the extant literature, there are lots of general information and sources like books related to energy efficient design and strategies to improve building energy performance. However, there are no enough knowledge and source in Turkey for a specific subject, location and climate. For example, there are no any information for characteristic features of building design parameters which have the most impact on annual energy loads and the contribution on the relative energy saving for a local condition and specific building type such as apartment blocks. This kind of information can be a significant opportunity to support architects during the early design process because general design rules that refers usually to massing and orientation of individual buildings. However, optimum orientation and massing cannot always be possible in the most densely built-up cities of Turkey that had a period of unplanned development. In addition, still the planning of an energy efficient environment has not a priority. In other words, in the current practice, the majority of residential buildings are low-rise apartment blocks in the attached or detached order depending on the local master plan decisions, on plots of varying shape and orientation which may not be always possible in terms of energy efficiency. However, an existing research has demonstrated that compensation of the negative effect of these mandatory decisions is possible with other appropriate building design parameters (De Wit, 2001). It can be concluded that important part of the decisions affecting energy consumption in apartment blocks may be related to design parameters. Thus, determining the suitable values of the most significant, i.e., the most sensitive, building parameters can reduce the energy consumption in apartment buildings. In addition, guidelines including this kind of information such as reduction of annual heating or cooling energy for architects can be developed to use them in the early design stages of apartment blocks. In other words, guidelines can be a supporting tool in design process for architects. Thus, this thesis focuses on the effects of building design parameters on annual cooling loads of low-rise apartment blocks for the time periods of today, 2020s, 2050s, and 2080s in the hot-humid climatic region of Turkey and integration of produced knowledge into the architectural practice by developing a practical guide for architects who have studied in Izmir. The special reasons for targeting only cooling loads in low-rise apartment blocks can be summarized as follows:

- Cooling loads is in increase trend because of the climate change. A study projected that 6-7 °C increase in mean outside temperature in west side of Turkey is expected in summer for the time period of 2071-2100 as a result of global warming. The calculated mean maximum temperature will go up 5-6 °C in the east part and 4-5 °C in the rest of the Turkey (Demir et. al. 2007). In general, it can be called that while heating energy demand would decrease, the cooling energy demand would increase in buildings located especially in warming climatic zones of Turkey over time.
- In the hot humid climatic region of Turkey, annual cooling loads are generally more than annual heating loads.

1.2. Aim and Scope of the Work

The main aim of the current dissertation is to determine relative effects of selected design parameters (window area, glazing type, thermal insulation, envelope color, material usage and etc.) on annual cooling energy loads in low-rise apartment blocks located in the hot-humid climatic region of Turkey according to today's local climatic feature and global warming impact (2020s, 2050s, and 2080s). In other words, which design parameter is more effective than another is examined in the dissertation. Consequently, architects can focus on building design parameter(s) which have high impact on annual cooling energy loads during the design process of low-rise apartment blocks and they do not spend most time for robust design parameters. Moreover, other objective of the thesis is to investigate variations in annual cooling energy loads caused by uncertainty in design parameters and global warming, for architects can prefer different values for design parameters and it can change energy consumption rate for cooling. For that reasons, this thesis will mainly discuss building design parameters, impact of global warming, and changing in annual cooling energy loads not the influence of design parameters in terms of energy consumption for heating, ventilating, daylighting. Minor aim of dissertation is to develop a practical guide to integrate results of thesis into the architectural practice and to help architects working in Izmir during the design process of low-rise apartment blocks which consume low energy for cooling. The guide provides practical feasibility and evaluation of the building design parameters into the early design process.

The objectives of the dissertation are to find answers to the following research questions:

- What is the sensitive and robust design parameters affecting annual cooling energy loads in low-rise apartment blocks located in hot-humid climates?
- What is the influence of the global warming on sensitivity of design parameters?
- How will change the annual energy consumption for cooling due to the global warming?
- What kind of tools (book, article, journal, guideline, and magazine) can be used to integrate knowledge into the architectural design process?

1. 3. Research Methodology

Several methods are applied in this dissertation and main research methodology consists of two basic parts (see Figure 1.2). The first part is to determine impacts of building design parameters and variations in annual cooling energy loads under global warming. The second step is the development part of the practical guide with results of the first part.

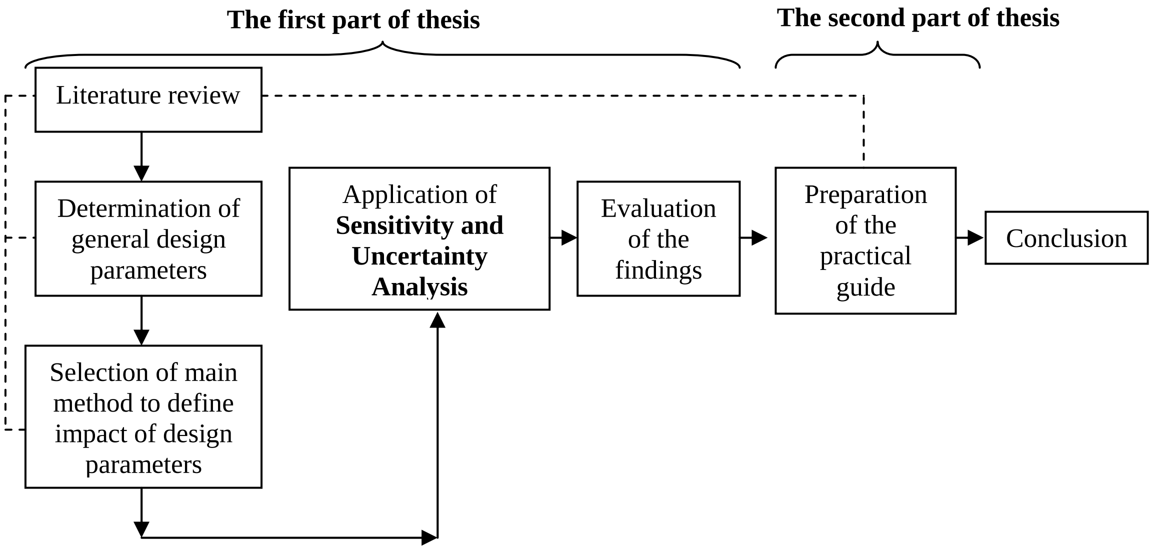


Figure 1.2. The major steps of the research methodology

In the first part, research starts with a general literature review for identification and explanation of design parameters which can affect annual cooling energy loads in residential buildings. In addition, main method and design parameters used in the thesis are selected based on results of the literature review. Design parameters should be concise and simple in terms of architectural practice in Turkey. Furthermore, they should have a respond in the building sector of Turkey.

In order to investigate the impact and relative importance of each selected design parameters on annual cooling energy load, global sensitivity analysis is determined as the main method. It is a powerful technique that enables to ascertain uncertainty in the model output caused by different inputs (Saltelli et. al. 2004). In addition, it investigate the degree to which parameter contribute to variation in outputs from a quantitative point of view. As a result, it provides a straightforward conclusion on the impact of input parameters on output (Mechri et al. 2010). In this thesis, global sensitivity analysis is used to find which design parameter is more important than others for annual cooling energy load. This analysis is applied for the time periods of today, 2020s, 2050s, and 2080s. In this way, influence of climate change on the selected design parameters can be found and we can assess the effect of global warming on sensitivity of building design parameters easily.

Possible annual cooling energy range based on the variety of design parameters is evaluated by using uncertainty analysis technique. In this dissertation, it is assumed that uncertainty in design parameters is caused by architectural decisions. The backbone of this thesis is sensitivity and uncertainty analysis by using Monte Carlo technique with Latin hypercube sampling that is expected to produce information to support early stages of building design process in general. The sensitivity and uncertainty analysis is explained in detail in the Chapter 3.

The second part is the preparation of a practical guide to help architects in design process of low-rise apartment blocks which need less energy for cooling. Thus, this study has been formulated as aware of the importance of sharing academic knowledge as much as findings of the research. For that reason, a significant focus in this part has been given on integration of the results obtained from first section into the architectural design practice in Turkey. The results should be presented in a format that is easily understandable and physically usable by architects. In the literature, there are currently three common formats for this purpose: guidelines, codes, and regulations. Practical guides for architects may be more useful during the building design which has high energy performance by providing information about relative importance of building design parameters in the early stages of design. However, most of the resources cover basic fundamentals of energy efficient building design in terms of mostly active systems. It means that they do not intend to give enough information in terms of architectural perspectives for building design. In addition, for Turkey there are no guidelines for specific subjects such as energy efficient design components and energy efficient building design to reduce heating, cooling, and lighting energy consumption. For that reason, all results of the present research is organized in a coherent format usable in architectural practice by architects.

The second part to develop the practical guide consists of the four steps. (1) Literature review is conducted to analyze the current knowledge about building design parameters and guidelines. (2) Interviews with five architects who is expert on energy efficient building design in Izmir are carried to get idea for structure of the practical guide. (3) As a result of the two steps, information used in practical guide is determined and first draft of the practical guide is constituted. (4) Lastly, mock-up presentations and meetings are performed with four academicians (three architects and one mechanical engineer) who are specialist about energy efficiency in buildings to develop first draft of the practical guide and constitute final draft of the practical guide.

1.4. Thesis Outline

The thesis is structured as follows:

Chapter 2 explains building design parameters which have influence on cooling energy loads in buildings.

Chapter 3 addresses current sensitivity and uncertainty analysis techniques applied with building energy analysis tools.

Chapter 4 presents application of sensitivity and uncertainty analysis by using an existing low-rise apartment blocks located in Izmir. Subsequently, results of the sensitivity and uncertainty analysis together with impact of global warming are evaluated.

Chapter 5 introduces preparation process of the practical guide. In addition, outcomes of the literature review, interview and mock-up presentations and meetings are summarized.

Chapter 6 gives the main conclusions of the thesis and shows future challenges for research effort in this domain.

CHAPTER 2

DESIGN PARAMETERS AFFECTING COOLING LOADS IN BUILDINGS

In the world, approximately 30-40% of all primary energy is consumed in building sector and residential buildings are mostly responsible from relatively high part of the consumed energy in this sector. This consumption is usually caused by heating, cooling, ventilation and lighting purposes.

Features of buildings and local climate are the main factors affecting the amount of the energy requirements. It is known that climate is an independent criterion and impossible to control by human being. However, daily, seasonal, and annual variations in the climate can influence rate of the energy usage in buildings. In other words, there is a direct relationship between the climatic conditions and energy demand. According to the research conducted by the Turkish State Meteorological Service, an increase (4-5 °C) in mean outside temperature is projected in Turkey between 2071 and 2080 because of the global warming. The calculated mean maximum temperatures will go up 5-6 °C in the east and 4-5 °C in the rest part of Turkey. Furthermore, the increase in mean minimum temperatures in the western Turkey will be less than eastern parts. Based on this study, it can be expected that whereas heating loads will decrease, cooling loads will increase in buildings in Turkey (Demir, 2007). Therefore importance of cooling loads will be more than today in warmer regions of Turkey.

Due to the rising cooling loads, dependence of the air-conditioning systems in buildings can increase. Thus, excessive use of active cooling systems can lead to some problem as follows (Santamouris. and Asimakopoulos, 1996):

- Increase of peak electrical energy demand in especially midday in summer season,
- Increase of the possibility of symptoms of flu, muscle pain, asthma, and tuberculosis,
- Increase of dependence on exported fuel,

- Increase of use of fossil fuels which leads to more poisonous gas release , and triggering climate change,

For that reason, specific strategies for design of new buildings and renovation of existing buildings are essential to reduce a significant amount of energy for cooling.

It is possible to improve energy performance of buildings by following simple heat transfer principles and using appropriate material configurations in the early design phase of buildings because decisions taken in these stages have the most impact on energy performance of buildings. Rate of the possible energy saving rates is shown in Table 2.1.

Table 2.1. Potential energy saving rates based on stages of building design process (Source: American Institute of Architects, 1981)

Stages in building design process	**Potential energy saving rate (%)**
Predesign	0-10
Schematic design	40-50
Design development	30-40
Construction documents	0-10
Construction management	0-10
Post-construction	10-20

Another important point is that passive design strategies to reduce energy consumption cannot be applied easily in densely cities because passive solar design strategies can dictate some certain configurations for more benefits. For example, usage of passive heating strategies can lead to narrow building plan with large south facing window (Beggs, 2009) but it cannot be applied every time because of the site conditions. Therefore, decisions about building design parameters in the design process are important and have a deterministic role in terms of energy requirements in buildings. In other words, energy performance of buildings may mostly be related to controllable design parameters which can be changed easily depending on the decisions taken by architects but this uncertainty can lead to large variations in energy demands of buildings.

For that reason, in this chapter selected simple and concise nine main parameters in terms of architectural points of view have been retained as the important variables,

which have impact on cooling loads: building shape/geometry, windows, building materials and their thermal properties, thermal insulation, air infiltration, natural ventilation, zone height, envelope color, and indoor set point temperature. They are explained in the following parts.

2.1. Building Shape/Geometry

Building shape has several significant roles such as energy performance, building’s functionality, and occupant performance (ASHRAE, 2006). The most important one is the impact on energy performance because building shape can influence rate of benefits taken from the local climatic conditions (AlAnzi et al. 2009). Rate of benefits can also change depending on esthetical concern, prevailing winds, natural daylight, shading, ventilation need, acoustical concern and etc. (Thomas, 2006). Conditions for optimum building form in terms of high energy performance can be formulated as minimum energy losses while maximum solar gain in winter, and accepting lower solar radiation in summer (Olgyay, 1962). In addition, the amount of heat gain from the solar radiation and heat loss can change depending on the area of building envelope exposed to outside conditions. Therefore, solar radiation may be minimized with compact building form in cool and hot-dry climates. In hot-humid climates, building shape should be elongated in the east-west direction due to intense solar radiation on the east and west directions (Hirst et al. 1986).

Building shape can be generally defined with the following parameters:

- The compactness ratio: the ratio of the amount of the surface area to building volume,
- Building shape factor: the ratio of the amount of the surface area to conditioned floor area of building,
- Aspect ratio: the ratio of the building length to building weight.

2.2. Windows

Windows have several tasks in buildings to provide visual and auditory contact with outside, natural ventilation and daylighting. In addition, the following factors should be considered while designing windows because they take solar radiation into the space and provide lower thermal barrier according to thermal features of opaque walls. Thus it can cause high heat gain or loss per unit area compared to opaque walls (Athienitis and Santamouris, 2002; Moss, 1997):

- Net heat transfer: it happens by conduction, convection and long-wave radiation. Rate of net heat transfer changes also based on window area.
- Net transmitted solar radiation: some part of the solar radiation enters in the space directly with diffuse or beam solar radiation. A little part of the incident solar radiation is absorbed by the windows and its rest enters in the space as infrared radiation or by convection.
- Daylighting effectiveness: it is important in terms of energy cost for lighting and visual comfort. Therefore, daylighting factor which is the ratio of illumination at the point of work plane is to be considered during the window design.
- Acoustic performance: it is related to noise transmission from outside to inside.

Window’s form and area should be determined based on the above parameters. Furthermore, the amount of the heat loss and gain can change based on the window area, frame and thermo physical properties of glazing. In addition, glazing used in windows can lead to positive contribution for heating and cooling requirements in buildings according to the glazing types and climatic characteristics of locations. At the same time, window frame has a significant role in energy performance of buildings based on thermal conductivity of frame. Therefore, windows and its area is a critical design issue for architects, which provide opportunity to improve energy efficiency (Bouchlaghem, 1996). A study showed that different window area according to orientation can be used to increase energy performance of buildings if energy efficient glazing is used (Hassouneh et al. 2010). In terms of natural ventilation, the effect of the window size mostly changes based the ventilation type. If there is one window on one wall in the space, window size has little effect on air velocity.

Another critical point is that small inlet and larger outlet on windows are more beneficial to increase air flow rate. It should also not be forgotten that wind direction is one of the effective parameter on air velocity as well as window size (Givoni, 1976).

2.3. Building Materials and Their Thermal Properties

Selection of materials in buildings is a significant task for design team because the heating or cooling requirements and thermal comfort conditions in buildings are affected by their thermal properties, thickness, and location. For that reason, thermal properties of building components and their impacts on energy performance should be known by architects. Two basic features of building components determine the heat flow in buildings and have high effect on energy performance. They are thermal resistance and thermal capacity. Moreover, the main thermal features of building materials can be defined by thermal conductivity, density and specific heat. Thermal conductivity is one of important properties of building materials because it is ability of materials to conduct heat energy. Another significant feature is the specific heat capacity which influence rate of the heat transfer through in and out of a building. Specific heat for a material is the amount of heat required to change the temperature of a unit volume by one degree (Givoni, 1976). Therefore, high dense materials such as brick, earth, and concrete can hold large quantities of heat but low dense materials can hold small quantities of heat. Thermal properties of some materials are summarized in Table 2.2. In addition, building surfaces absorb and reflect solar radiation depending on materials. Thus, the following properties related to radiation should also be considered during the design process (Givoni, 1998):

- Absorptivity: the fraction of the striking radiation absorbed at the surface.
- Reflectivity: the fraction of the striking radiation reflected away.
- Transmittance (for glazing): the fraction of the striking solar energy transmitted through indoors from glazing.
- Emissivity: the capacity of a surface to emit long-wave radiation.
- Solar heat gain coefficient: measure of amount of the solar radiation blocked by glazing.

Emissivity and reflectivity of some materials are shown in Table 2.3.

Table 2.2. Thermal properties of some materials
(Source: Indian standards, 1996)

Building materials	Density (kg/m^3)	Specific heat (kJ/kg-K)	Conductivity (W/mK)
Brickwork	1820	0.88	0.811
Brick	1731	0.88	0.750
Dense concrete	2410	0.88	1.740
Calk	2420	0.84	1.800
Slate	2750	0.84	1.720
Reinforced cocncrete	1920	0.84	1.100
Brick tile	1892	0.88	0.798
Cement mortar	1648	0.92	0.719
Cement plaster	1762	0.84	0.721
Cinder concrete	1406	0.84	0.666
Gypsum plaster	1120	0.96	0.512
Gas concrete	500	0.84	0.160
Wood	480	1.68	0.072
Plywood	640	1.76	0.174
Soil	2240	0.84	1.740
EPS	34	1.34	0.035
Glass wool	189	0.92	0.040
Rock wool	150	0.84	0.043
XPS	35	1.4	0.034
Bims block	500	0.96	0.29

Table 2.3. Emissivity and reflectivity of some materials
(Source: Indian standards, 1996)

Building materials	Emissivity	Reflectivity
Bright aluminium	0.20	0.80
Concrete (new)	0.60	0.40
Concrete (old)	0.75	0.25
Asphalt paving	0.90	0.10
Pale brass	0.60	0.40
Shinny brass	0.30	0.70
Brick	0.70	0.30
White portland cement	0.40	0.60
Reinforced concrete	0.65	0.35
White marble	0.45	0.55
Aluminium grey	0.50	0.50
White	0.30	0.70
Brown	0.70	0.30
Red	0.70	0.30
Green	0.70	0.30
Black	0.90	0.10
Paper white	0.30	0.70
Dark stone	0.90	0.10
Galvenized new steel	0.55	0.45
Galvanized old steel	0.70	0.30
Red roof tile	0.70	0.30
Clourless roof concrete	0.65	0.35

2.4. Thermal Insulation

Thermal insulation which is the first strategy for energy conservation can be expressed as a material which is used to decrease heat flow through a building component based on its thermal conductivity and thickness. In other words, use of the thermal insulation decreases heat flux in the building envelope. Thus, thermal insulation in the proper place of the building envelope such as external wall and roof is a kind of barrier to reduce heat losses in the winter and heat gains in summer. For example, performance of corrugated iron roof with polystyrene, radiant barrier, fibber glass and no insulation was investigated with an experimental study. As a result, heat flux in unventilated roof was minimized by using polystyrene material (Soubdhan, 2005). In a different study made by Bojic and Yik (2005), approximately 38% of annual cooling load was saved by applying thermal insulation on external envelope and indoor walls of 12-storey residential building in Hong Kong. In another experimental study, performance of 14 different roof types was evaluated and best results were obtained from insulated version of roofs. Other roof types obtained high performances were ventilated and terrace roof (Özdeniz and Hançer, 2005). In addition, benefits from thermal insulation and its economic value can vary according to the building type and its function, climatic features, type of the insulation material, insulation cost, energy cost saved (Al-Homoud, 2004).

2.5. Air Infiltration

Air infiltration can be defined as the flow of air through gaps and cracks in the building fabric. Uncontrolled air infiltration can increase the amount of the heat loss in winter because warmer air from inside is displaced through the outside from some points of building envelope. If the indoor space is cooler than the outside, hot air can enter in the indoor spaces in summer and it can lead to high cooling demand. In the buildings which have enough thermal insulation, air infiltration can be dominant factor for heat loss (Oughton and Hodkinson, 2008). Other disadvantages of air infiltration are moisture problems, acoustic control, thermal comfort and hygiene consequences (Elmroth and Levin, 1983). Rate of the air infiltration can change based on the air tightness of the building and wind driving forces across the building envelope. For that reason, insulation continuity and construction process of buildings is important. Some measures to succeed insulation continuity and airtightness in buildings can be summarized as follows (Government report, 2008):

- Provide simple form to built right,
- Reduce the number of different types of construction,
- Pay carful attention to design of junctions,
- Develop the most appropriate details for junctions,
- Reduce penetrations into the thermal envelope,

2.6. Natural Ventilation

Natural ventilation in buildings is one of the common passive methods for cooling. Ventilation is also necessary for fresh air in buildings but it should be controlled every time since excessive air flow rate can lead to unwanted heat gain or loss. Thus windows should be designed to take fresh air into the space (Figure 2.1).

Figure 2.1. Window to provide controlled fresh air

Natural ventilation with correct position of indoor spaces to reach air flow until the desired point can contribute to coolness and thermal comfort conditions (Allard, 1998). Natural ventilation can be defined as transport of low temperatures with air flow. Moreover, enough air flow rates help to reject excessive heat from human surface by increasing convection coefficient (Çakmanus and Böke, 2001). One of the important points is that effectiveness of natural ventilation can change according to climatic conditions. For example, though natural ventilation has enough benefit in tropical and temperate climates, it does not have enough potential in terms of coolness in subtropical regions (Haase and Amato, 2009).

The speed of air movement in buildings mainly changes depending on the pressure difference between internal and external spaces. Pressure difference can occur due to the temperature difference inside and outside of building. Wind can also cause a natural pressure difference and it can be provided with a fan as mechanically (Athienitis and Santamouris, 2002).

There are various methods used in buildings to provide natural ventilation such as cross flow ventilation, single-sided ventilation, passive stack ventilation, wind towers and atrium ventilation according to the places of fenestration (Figure 2.2) (Dickson, 1998). In addition, it is possible to increase indoor air speed naturally by using the solar chimney. For instance, a study indicated that indoor air speed can be increased as regardless of outdoor wind speed with solar chimney. Therefore, this system may be appropriate for the regions having high amount of solar radiation and low external wind speed (Macias, 2009). In an another study, air exchange rate in a room (27 m^3) which varies between 2 and 5.6 ach was obtained by using the solar chimney and it was found that air exchange rate can change based on amount of solar radiation, gap between absorber and glass surface and size of input/output gap (Mathur et al. 2006). In hot and humid climates, the effectiveness of a solar chimney can be increased by adding water spraying mechanism on the roof (Chungloo and Limmeechokchai, 2007). Cooling with natural ventilation can be assessed under two headings as day and night ventilation in buildings. During the daytime, comfort conditions can be provided with natural ventilation depending on air flow rate. A sense of coolness as psychological may be created with direct air flow even when indoor temperature is 34 °C. Furthermore, evaporation rate in human skin can be increased with high air velocity and a sense of comfort can be obtained. Therefore, spaces in buildings should be designed to allow continues air flow into the deep points of indoor spaces easily and to obtain high air velocity in spaces which human density is high. In a research, thermal comfort conditions in three buildings which have different geometry and 1-1.5 m/s wind velocity were investigated (1:1, 1:1.44 and 1:1.7 dimensional ratios) by using the FLUENT 6.2 program for Kayseri. According to the results, thermal comfort conditions could be provided with rectangular form, but it was also seen that square form had less potential than rectangular form. In addition, optimum geometric form in Kayseri was found to be 1:1.7 for optimum thermal comfort conditions provided with natural ventilation (Ayata and Yıldız, 2006).

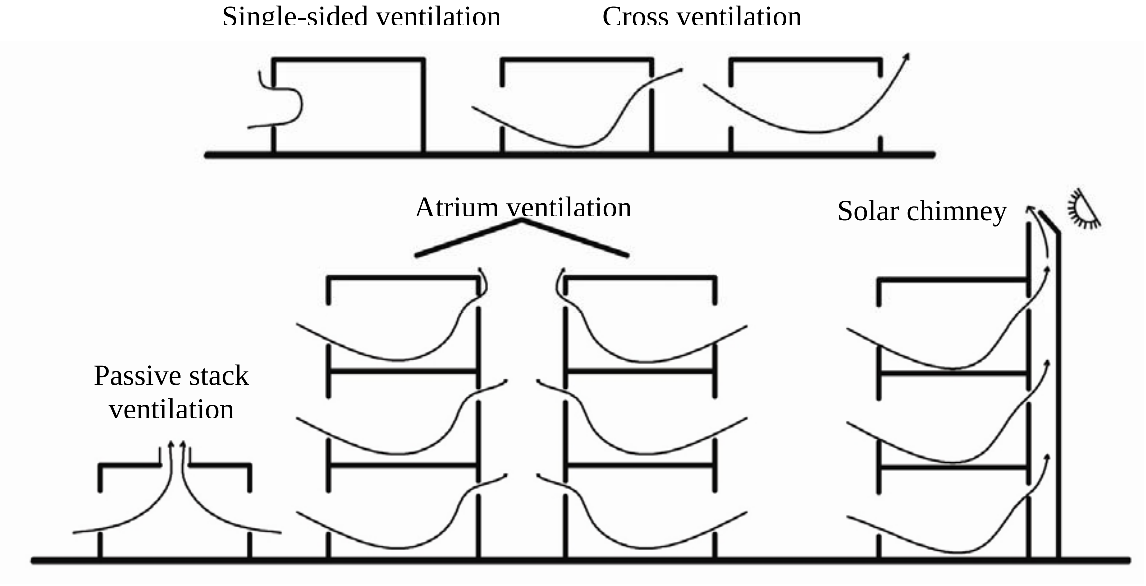


Figure 2.2. Passive methods to provide natural ventilation

Night cooling is another type of natural ventilation to reduce indoor temperature with air flow provided during the night when the external temperature is lower than the internal temperature. Benefit from night cooling can change based on thermal storage capacity of buildings. Natural ventilation at night can lead to following effects in buildings (Kolokotroni and Aronis, 1999):

1. Reduction of peak temperatures,
2. Reduction of temperature throughout day and especially in the early hours of day,
3. Reduction of slab temperatures,
4. Creation of a time lag between external and internal peak temperatures.

Coolness can be stored in wall, floor, ceiling and even in rock beds or water tanks designed for these purposes. Under appropriate conditions, it can be stored during the a few hours in building mass, a few days in bed rock, seasonal in soil, a few hours or months in water and daily or seasonal in phase change materials (Santamouris and Asimakopoulos, 1996). In other words, buildings which have enough thermal mass can keep low temperature for the next day but windows should be close. If coolness is stored out of the building, cool air can also be used as pre-cooling for active cooling systems.

The performance of night cooling is generally affected by air flow rate, climatic conditions, capacity of thermal mass and internal heat gains (Artman, 2008). In a building which has high thermal mass, well insulation, enough shade, windows closed during the day, internal temperature can be reduced 35-40% with night ventilation depending on external air temperature (Artman, 2008). According to a study made in 2001, 54% energy was saved in a 3-storey office building located in a city which average outside temperature is 35 °C and relative humidity is 80% with natural ventilation provided between the hours of 21.00-8.00 (Keskin, 2001). In another study made in Malaysia, the peak air temperature was decreased 2.5 °C with night ventilation (Kubota, 2009). Although night cooling has big energy saving potential depending on climate conditions, it has some disadvantages such as moisture and condensation control is necessary especially in humid regions. Other problem is that especially in the city center cooling potential of night ventilation is affected from increasing external temperature and reduction in air speed due to the heat island effect and global warming (Santamouris, 2007). Therefore, local climatic features should be examined in details during the early stages of building design.

To calculate cooling potential of night ventilation, various methods have been developed. In one study, potential of night ventilation based on local climatic features is determined depending on the temperature oscillations in the free-running buildings. According to this method, the night cooling potential in northern part of Europe is more than other regions and it is enough alone in only a small part of the southern Europe (Ghiaus and Allard, 2006). Artmann et al. (2007) found by using degree-day approach

with climate data taken from 259 meteorological stations in Europe that North Europe has high potential in terms of night cooling. However this potential is affected by climate change over time. For instance, according to another study potential of night ventilation will reduce based on the climate change scenarios at the end of 21 century in Europe (Artmann et al. 2008).

Reduction of cooling loads in buildings is also possible with ventilated roof. Ciampi et al. (2005) calculated that over the 30% of energy can be saved with ventilated roof designed correctly in summer.

As a result, the advantages and disadvantages of natural ventilation can be summarized as follows (Liddament, 1996):

Advantages:

- Easy applicable for many types of buildings,
- Inexpensive in terms of implementation and maintenance cost according to other cooling methods,
- High air speed can be obtained with enough open areas,
- Short uncomfortable times can be tolerated in warm conditions,

Disadvantages:

- Insufficient control can cause excessive ventilation rate,
- Not suitable in locations which have excessive voice and dusty,
- Security problem,
- Not suitable in severe climatic regions,
- Filtration of incoming air is usually not easy.

2.7. Zone Height

Zone height directly affects volume of the space and it determines the size of cooling and heating space. Floor height should be minimized for low energy consumption depending on architectural and technical considerations because air-conditioned volume is a main parameter for the amount of the energy consumption in buildings.

2.8. Envelope Color

Color of external surfaces and properties of coverings determine solar radiation rate absorbed and reflected from building envelope. Thus absorptivity and albedo value of materials is important in terms of energy performance of buildings. Albedo can be defined as reflectivity ability. Absorptivity and albedo value of some materials used in external surfaces are shown in Table 2.4.

Table 2.4. Absorptivity and albedo values of some color
(Source: Yu et. al., 2008)

Color	**Absorptivity**	**Albedo**
Bare cement plaster	0.65-0.80	0.10-0.35
Dark	>0.90	0.05-0.10
Grey	0.65-0.85	0.15-0.35
Red, reddish-brown, green	0.70-0.80	0.20-0.30
White	0.10-0.30	0.70-0.90

It is clear that though light colors reduce absorption rate of solar radiation, dark colors increase the amount of absorbed solar radiation. This directly affects surface temperature of building envelope and indirectly affects energy demand for cooling or heating and thermal comfort conditions in buildings. For example, while reflectance rate of roof was 26%, this ratio was increased up to 72% with white coatings. As a result of this, 125 kWh annual energy savings was achieved (Akbari, 2003). In another study, the reflectance ratio of a roof increased from 0.2 to 0.6 and 0.85 sequentially. Internal maximum temperature reduced between 1.2 °C and 3.3 °C depending on local climatic features (Synnefa et al. 2007). In a similar research, when lightweight roof was painted with white color and polyurethane material was applied, the reduction in cooling loads was calculated as 20% (Han et al. 2009). Furthermore, the surface temperature of tiles can be reduced 4 °C in the daytime and 2 °C at night by using reflective coatings in hot summer (Synnefa et al. 2006). Performance of the building envelope can also be increased by using the thermo coatings. Usage of thermo coatings provides advantages in winter and summer, since thermo coatings reduce the surface temperature by showing a resistance against the solar radiation in summer and increases surface temperature by absorbing solar radiation in winter (Karlessi et al. 2009).

Use of light colors, reflective or thermo coatings is also very important in urban areas. In this way, heat island effect in cities may be reduced. Heat island effect can be described as a general result of urbanization activities, and therefore the average air temperature in city centers can be higher than surrounding rural areas in general. Although it has positive effects in terms of heat demand in the winter, it causes significant increases in cooling loads in summer in especially warm regions. For instance, the cooling loads in the city center in London are higher than 25% in rural areas because of heat island effect. However, the heating load is less than 22% (Kolokotroni et al. 2007). The most significant feature of this kind of materials does not require extra implementation cost in buildings.

2.9. Indoor Set Point Temperature

Level of set point temperatures for heating and cooling can affect the quantity of energy consumption in buildings positively or negatively (Wan et al., 2009). High fluctuations of set point temperature in a space can increase heating or cooling energy loads and can lead to uncomfortable conditions. Therefore they should be maintained the same level according to thermal comfort conditions. However, temperatures which people feel comfortable can change individually or based on the activity level, clothing, time of the day, physical and emotional state of people and etc. (Hoen, 1987).

CHAPTER 3

UNCERTAINTY AND SENSITIVIY ANALYSIS METHODS APPLIED BY USING BUILDING ENERGY ANALYSIS PROGRAMS

There are several methods to apply uncertainty and sensitivity analysis in literature. While uncertainty analysis determines the possible variations in the outputs of the model due to uncertainties in the input(s) (SIMLAB, 2004 and Ruijven et al. 2010), sensitivity analysis determines the level of impact of input(s) on the selected output(s) (Heiselberg et al. 2009). Sensitivity analysis can be used for several reasons (Marzban, 2011): (1) definition of the inputs which affect the outputs, (2) the rank the inputs in some order of importance, (3) reducing the number of inputs, (4) model tuning.

Uncertainty can be categorized as either aleatory or epistemic. Aleatory uncertainty is the natural randomness in the behavior of the system under study. It is also called as variability, stochastic uncertainty, irreducible uncertainty and Type A uncertainty. This type uncertainty cannot be reduced by increasing level of knowledge. Epistemic uncertainty is due to the lack of knowledge about usually the suitable value in the context of a specific implementation (Swiler and Giunta, 2007). Thus, the rate of this type of uncertainty can be decreased by enhancing essential information but sometimes it cannot be possible because of the time and resource limitations, technological infeasibility, or sociopolitical restraints (Ayyub and Klir, 2006). In addition, basic objective of uncertainty analysis can be sorted as understanding of the effect of uncertainties, calibration, simplification and validation of a model, showing compliance of the system with an explicit criterion, and comparison of relative performance and optimization of operation of the system (de Rocquigny., Devictor., Tarantola, 2008). General uncertainty during the building simulation can be originated from (De Wit, 1995):

- Lack of specification of the system,
- Simple modeling of complex physical process,
- Division of more complex geometry into simpler geometry and time step,

- Outdoor climatic conditions and occupant behavior.

In this section, uncertainty and sensitivity analysis methods are summarized under four groups as local, screening, global and variance based-techniques which can be applied by using building energy analysis programs because these are already well documented in literature.

3.1. Local Methods

One of the easy and cheapest methods is local sensitivity analysis. It can also be called as one-at-a-time sensitivity measure. Main rule is to change one parameter at a time while keeping the others fixed. Aim is to quantify the change in output corresponding to change in input (Hamby, 1994). Local techniques can be used if there is a linear correlation between inputs and outputs to define the singular effect of selected input parameters on the calculated performance indicator (Struck, Hensen, and Kotek, 2009).

3.2. Screening Methods

The prior step of uncertainty and sensitivity analysis is to use screening methods if there are tens or many inputs which will be evaluated. Main objective of the screening methods is to eliminate input(s) which have a negligible impact on output(s) to focus on the most important input(s) (de Rocquigny, Devictor, Tarantola, 2008). Another advantage of the screening is to simplify the complexity of models by removing less effective or irrelevant input(s), is to increase the accuracy of model predictions, is to reduce computer time for simulations and is helpful to modify the structure of the existing model (Saltelli et al. 2004). Various screening methods are available in literature. In this part, only some methods used in thermal simulation of buildings are investigated. Thus, Morris method and several sensitivity coefficients are considered as common techniques. The requirements which should be met by screening methods used in building simulation can be summarized as follows (De Wit, 1997):

- Flexibility to make it useful for building designs with several simulation models,
- Easy applicability,

- Use the available knowledge of the model to obtain maximum economy.

One of the common screening methods is Morris method which is also called one-at-a-time (OAT) method. It determines which input(s) are negligible, linear and additive, and nonlinear or involved in interactions with other inputs. Main advantage of the method is related to the number of the model needed for assessment (Campolongo and Saltelli, 1997) but a disadvantage of the method is that uncertainty analysis is not possible because it does not use the probability density functions to create inputs (De Wit, 2001). Inputs are selected in the input range of variation. Sensitivity of the inputs is related to the elementary effects of inputs. Results in Morris method are showed on a graphic including the sensitivity indices; mean (μ) and standard deviation (σ). The mean evaluates total impact of the input on the output. The standard deviation predict the ensemble of the input's influence, they are nonlinear due to the interactions with other inputs (Saltelli et al. 2008).

Another screening technique is to use sensitivity coefficients which can be used as a measure of the sensitivity in the fields of mathematics and engineering to reduce the number of inputs. After determining a limit value for sensitivity coefficient, inputs which are under the limit value can be admitted as negligible parameters for further evaluations. In the building energy simulation, influence coefficient (IC) is usually used and is defined as the partial derivatives of output and input (Lam and Hui, 1996):

$$IC = \frac{change \quad in \quad output}{change \quad in \quad input} = \frac{\partial OP}{\partial IP} \tag{3.1}$$

Equation (1) can be used for one step change. The following equation can be used for two sets of data:

$$IC = \frac{\Delta OP}{\Delta IP} = \frac{OP_1 - OP_2}{IP_1 - IP_2} \tag{3.2}$$

Where OP: the output, IP: the input, OP_1 and OP_2: the output values, IP_1 and IP_2: corresponding input values.

For more sets of data, the influence coefficient can be defined as the slope of the regression straight. Other types of the sensitivity coefficient are as follows (Lam and Hui, 1996, Heiselberg et al. 2009):

$$IC = \frac{\Delta OP \div OP_{BC}}{\Delta IP \div IP_{BC}} \tag{3.3}$$

$$IC = \frac{\Delta OP \div OP_{BC}}{\Delta IP} \tag{3.4}$$

$$IC = \frac{\Delta OP \div (\frac{OP_1 + OP_2}{2})}{\Delta IP + (\frac{IP_1 + IP_2}{2})} \tag{3.5}$$

$$IC = (\frac{\Delta OP}{\Delta IP}) \div (\frac{OP}{IP}) \tag{3.6}$$

$$IC = \frac{E_{\max} - E_{\min}}{E_{\max}} \tag{3.7}$$

Where OP_{BC} and IP_{BC}: base case values of output and input respectively, IP_1 and IP_2: two values of input, OP_1 and OP_2: two values of output corresponding input, OP and IP: mean values of output and input, E_{max} and E_{min}: maximum and minimum output values.

Equation (4.2) is used for only one step change. It cannot be used multiple sets of data.

3.3. Global Methods

Global sensitivity analysis investigates the effects of all the inputs at once.
In other words, it can be used to quantify the influence of uncertain input parameters on the response variability of a model (Griensven, 2006). General steps to apply global methods on a model can be summarized as follows (Saltelli, 2004):

- Determine the objective of your study and consequently identify the output(s) as answers of your question(s),
- Decide input(s) which you would like to use in your study,
- Assign an appropriate probability density function to each input,
- Choose a uncertainty and sensitivity analysis method,
- Generate the input sample depending on a selected method,
- Calculate the output(s) based on the generated inputs,
- Analyze the output(s) and evaluate the results.

Monte Carlo analysis (MCA) is used for sensitivity and uncertainty analysis because the sensitivity of selected parameters can change based on the interactions and effects of all parameters, and the minimum number of simulations is sufficient to apply this method (Heiselberg, 2009). MCA uses random input(s) produced based on the some techniques and probability density functions for evaluation of uncertainty and sensitivity. There are several sampling techniques in literature such as random sampling, stratified sampling importance sampling, and Latin hyper-cube sampling (LHS). Random sampling works by creating a random number and scaling it to the target variable with its probability density function. Stratified sampling can be defines as grouping members of the population into the subgroups before creating sampling (Macdonald, 2009). Importance sampling is to select a good distribution supporting the important values (Yon and Goldsman, 2006). LHS is very common sampling technique used with MCA, for it is possible to evaluate a large amount of uncertainty and sensitivity with a relatively small number of samples due to its efficient stratification properties (Helton et al. 2006). Another powerful aspect of LHS is that it integrates the desirable points of simple random sampling with a multilevel, highly fractionated fractional factorial design. However, unlike simple random sampling, the size of a LHS cannot be increased by producing additional inputs as the new sample including the original LHS and the additional sample inputs will not have the structure of an LHS (Sallaberry, Helton and Hora, 2008).

In this approach, every input as a source of uncertainty should have a probability density function. Thus appropriate probability function must be defined for each input. The common probability density functions used in building simulation are summarized as follows (Montgomery and Runger, 2003; Macdonald, 2002):

- Discrete distribution: it defines the probabilistic features of a random variable which takes on a set of values that are discrete and can be parametric or non-parametric (Figure 3.1).

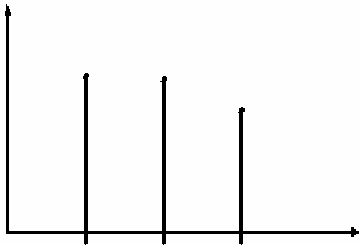


Figure. 3.1. The discrete distribution

- Normal distribution: it is very commonly used distribution in several models, which is also called the Gaussian distribution (Figure 3.2). The normal distribution can be defined by using its mean and standard deviation. Mean shows the center of the probability function. Standard deviation is the square root of the variance which is a kind of measure of the dispersion in the function. It is mostly appropriate for measured physical data.

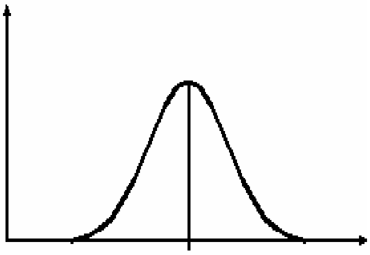


Figure 3.2. The normal distribution

- Log-normal distribution: it is a kind of probability distribution of a random variable whose logarithm is normally distributed (Figure 3.3).

  This type of distribution cannot produce negative values. The Log-normal distribution can be defined by using its standard deviation median which is the middle value in a probability distribution.

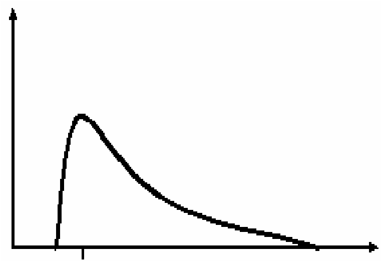


Figure 3.3. The log-normal distribution

- Triangular distribution: it is a kind of continuous probability distribution and can be defined with minimum value, maximum value and mode which is the value happening mostly or frequently in a distribution (Figure 3.4). If experts think that a value c belonging to [a, b] is the best estimate, a triangular distribution could be used. The difference from the uniform distribution is that the likelihood of a value x belonging to [a,b] increases linearly as x approaches c [c].

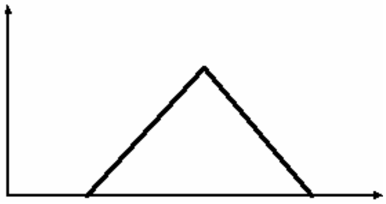


Figure 3.4. The triangular distribution

- Uniform distribution: The probability of the variable takes a value between a and b, which a shows possible minimum and b shows possible maximum value (Figure 3.5). Moreover, all values have the same probability to happen. It can be assigned for inputs which poorly defined and only minimum and maximum values are known.

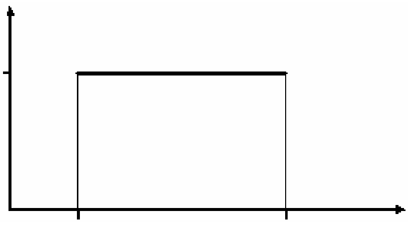


Figure 3.5. The continuous uniform distribution

If the selected value is between the defined minimum and maximum values, a uniform probability density function is a reasonable choice because a value outside of minimum and maximum values is not possible.

MCA is also useful for building thermal simulation and it can be implemented for both uncertainty and sensitivity analyses (Breesch and Janssens, 2010). Thus, in this study MCA with LHC is preferred for all analysis.

MCA can be expressed with the following formulae, where *N* is the number of samples, and *i* is the number of input parameters (Hopfe, 2009):

$$E(Y) = \frac{1}{N}\sum_{i=1}^{N} y_i \tag{3.8}$$

$$V(Y) = \frac{1}{N-1}\sum_{i=1}^{N} [y_i - E(Y)]^2 \tag{3.9}$$

The prospective value E and the variance V of the output Y are predicted with the above expressions. MCA is a so-called black box approach; extra code modification is not necessary. One of the important points is that there is a difference between simulation and Monte Carlo Analysis. Simulation is a direct record within computing terms of a natural stochastic process. MCA is to obtain solution for non-probabilistic problems by using probabilistic techniques (Kalos and Whitlock, 2004).

If samples are generated based on LHC method, selection of the sensitivity indicator is important process because it is necessary for the evaluation of sensitivity of input(s). There are several sensitivity indicators in literature. Regression and correlation based techniques to assess results of the global sensitivity analysis is very common and easy applicable. Different types of regression and correlation approaches are also available depending on LHC method. They are the Pearson Product Moment Correlation Coefficient (PEAR), Spearman Coefficient (SPEA), Partial Correlation Coefficient (PCC), Partial Rank Correlation Coefficient (PRCC), Standardized Regression Coefficient (SRC), and Standardized Rank Regression Coefficient (SRRC). They have different features depending on whether the relationships between input and output parameters are linear or non-linear. For example, while PEAR is suitable for linear models, SPEA is preferred for non-linear models. SRC measures the linear impact of each input variable, while PCC provides a sensitivity analysis of systems that excludes the impact of correlations between input parameters (SIMLAB, 2004).

3.4. Variance-Based Methods

Variance-based sensitivity analysis is based on generated samples. Thus Monte Carlo analysis can be applied. Variance-based methods are generally well practice for tackling settings and focuses on the questions which of the input variables variances influence the model output variance at most? and which of input variables has to be known more accurate to reduce the output variance? (Schwieger, 2011). Some interesting characteristics of variance-based methods are as follows (Saltelli et al. 2008):

- Independent sensitivity measure from model,
- Capturing capacity for the impact of the full range of variation of every input,
- Capacity to tackle groups of inputs,
- Appreciation of interplay influencing among inputs.

However, the most important disadvantage of variance-based methods is that prediction of the sensitivity coefficients takes too much time because of the essential many model realizations (Ratto et al. 2007). One of the significant variance-based methods is Fourier Amplitude Sensitivity Test (FAST). It can be used to define the contribution of singular inputs to the expected value of the output variance by using first order sensitivity index and allows the computation of the fraction of the variance of an output of model to every input (Mokhtari and Frey, 2005).

An important feature of FAST is that assessment of sensitivity can be conducted independently for every parameter by using one simulation since all the parameters in a Fourier expansion are mutually orthogonal (Chan, Saltelli, Tarantola, 1997). In addition, it can also useful for uncertainty analysis. Another variance-based method is Sobol's method which is depending on total sensitivity indices. Total sensitivity indices (TSI) can be calculated with the sum of all the sensitivity indices including all the interaction effects of these inputs. In other words, there are three input factors: x, y, z and TSI of the input factor x is S(x) + S(xy) + S(xz) + S(xyz) (Frey, Mokhtari, Zheng, 2004).

3.5. Evaluation of Existing Studies About Uncertainty and Sensitivity Analysis in Buildings

There are various studies in literature about uncertainty and sensitivity analysis related to improvement of energy performance of buildings in general. Several studies are mostly regarding to find most effective parameters in terms of building energy consumption. Uncertainty and sensitivity analysis are also used to assess accuracy of performance of different building simulation tools. In these days, some researchers have explored how to change impact of design parameters on energy performance under the global warming. As an example, Gustafsson (1998) used a sensitivity analysis method to find suitable building energy retrofitting options. De Wit (2002) evaluated several uncertainties related to building performance and their influence on design decisions in general. Also, de Wilde (2004) developed a strategy to select energy saving building components. It consists of the following steps:

- Definition of an option space, relevant functions, specification of performance indicators, prediction of performance for all options and all performance indicators, evaluation of predicted performance and selection of the most desirable option,
- Application of existing building energy simulation tools,
- Use of a support environment providing a mechanism.

The most effective parameters on thermal comfort with natural night ventilation (single sided and cross) were found by using sensitivity analysis and uncertainty caused by parameters was determined by Breesch and Janssens (2005).

As a result, internal heat gains, air tightness and wind pressure coefficients were determined as the most effective parameters on thermal comfort conditions in offices. Hyun et al. (2008) investigated uncertainty in forecasting of natural ventilation rates in high-rise apartment buildings by using the Monte Carlo method with Latin Hypercube Sampling. It is found that uncertainty analysis process is very helpful and propagated uncertainty is very effective factor on the airflow rates. Mara and Tarantola (2008) implemented Analysis of Variance (ANOVA) based global sensitivity analysis to thermal model of a building to show global sensitivity analysis gives helpful information for both decision makers and users during the preparation of thermal model of a building and its improvement. Lam et al. (2008) analyzed energy usage of 10 air-conditioned office buildings in subtropical Hong Kong and sensitivity of 10 design parameters were investigated with a simulation program. As a result, it is stated that set point temperatures, electric lighting and chiller have relatively high energy saving potential. Heiselbert et al. (2009) determined what design parameters contribute significantly to sustainable building design with a case study from Denmark. Corrado and Mechri (2009) investigated influence of 129 input data grouped as climatic data, envelope data and building use data on energy rating of a dwelling in Turin, Italy. The results showed that only less than 10 input data has considerable impact on the energy rating uncertainties. In a study, uncertainty affecting thermal conductivity of 18 common insulation materials selected from different European manufacturers was examined (Dominguez-Munoz et al. 2009). Mechri et al. (2010) evaluated uncertainty in heating and cooling energy requirements depending on possible design variables by implementing the ANOVA approach which is based on the variance of an output caused by different input variables. The study showed that suggested approach is helpful for architects to predict which design variable has more contribution to the building energy performance. Dominguez-Munoz et al. (2010) analyzed inputs for the assessment of their influence on the peak cooling load by using a global sensitivity analysis method. It revealed the most influential inputs as the characterization of the building internal mass, the convection on internal surfaces and the maximum internal and solar gains. Kusiak, Li, and Zhang (2010) examined uncertainty propagation of a building thermal model by using with Monte Carlo simulation. Heiselberg et al. (2009) stated that definition of the most important parameters by using sensitivity analysis techniques is helpful to improve design alternatives to develop building performance.

Importance of design parameters under the climate change can be investigated by using the sensitivity and uncertainty analysis methods. De Wilde and Tian (2009) defined the significant factors which can lead to uncertainty in the prediction of overheating and energy consumption for the time periods of 2020, 2050 and 2080 in office buildings. The results showed that important factors leading to uncertainties for forecasting heating energy consumption are infiltration, lighting gain, and equipment gain. For cooling energy consumption and over heating, the most important factors for 2020 and 2050 are heat gains from lighting and equipment. In addition, de Wilde and Tian (2010) also studied on a theoretical office building to define key design parameters in terms of energy consumption and variations in importance of key design parameters under global warming.

Calibration of building simulation tools and their performance evaluation are also possible with uncertainty and sensitivity analysis. Struck et al. (2009) compared performance of different four simulation tools with uncertainty and sensitivity analysis methods and it was shown that these techniques is capable to support simulation tool diagnostics for improving.

CHAPTER 4

APPLICATION OF UNCERTAINTY AND SENSITIVITY ANALYSIS

This section presents application of the uncertainty and sensitivity analysis to determine the most effective building design parameters and to analyze variations in annual cooling energy loads depending on uncertainties caused by selected design parameters in low-rise apartment buildings in Izmir located in hot-humid climate for the time periods of today, 2020s, 2050s and 2080s. Therefore, firstly, selected existing typical low-rise apartment building is defined. Secondly, basic climatic features of Izmir are shown and climatic data are produced for 2020s, 2050s, and 2080s. Then the uncertainty and sensitivity analyses are applied. Lastly results are evaluated.

4.1. Base-Case Building

A 10-storey apartment building is selected as a reference building to implement the uncertainty and sensitivity analyses. The reference building which is located in Narlıdere/Izmir (Figure 4.1) is representative of the low-rise apartment blocks to be constructed in the near future in Izmir, and thus its location and orientation are not fixed (Figure 4.2).

The building has a rectangular base (23.3 m and 24.6 m) and consists of four flats in each story. The height of each flat is 3 m and the total height of the apartment building is 30.7 m. The area of the flats is approximately 130 m^2, which gives a total cooled floor area of 520 m^2 for each storey. The apartment building satisfies all minimum mandatory conditions defined in TS 825-Thermal Insulation Regulation in Buildings (2000). Therefore, the external walls are composed of a 20–mm-thick outer layer of plaster, a 30–mm-thick thermal insulation layer (XPS), a 190–mm-thick layer of hollow brick and a 15–mm-thick inner layer of plaster with an overall U-value of 0.606 W/m^2K.

The overall U-values of the ceiling, ground floors and roof are 0.42 and 0.65 W/m^{2}K and . The windows consist of low-e glazing glass panes with an overall U-value of 2.76 W/m^{2}K. The existing building is heated with geothermal energy and flats are cooled with individual air-conditioner.

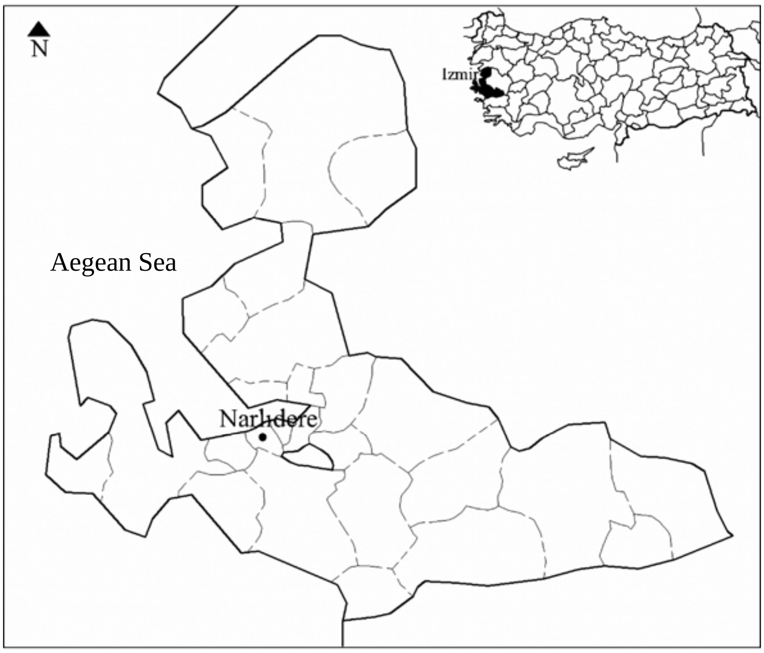


Figure 4.1. Location of case area in Izmir in Turkey

Annual cooling energy load of selected low-rise apartment block was calculated by using EnergyPlus 5.0.0. EnergyPlus is released in 2001 and consists of best features of BLAST and DOE2 (Crawley et al., 2004). It is developed to calculate mainly energy for heating and cooling which is essential to provide thermal comfort conditions with HVAC systems and energy consumption in primary plant equipments. The most important features of EnergyPlus can be summarized as follows (EnergyPlus, 2011):

- User-defined time steps for the interaction between zones and HVAC systems,
- Simultaneous and integrated solution,
- ASCII text file for weather, input and output data,
- Heat balance technique for thermal loads,
- Developed ground heat transfer model,
- Combination of heat and mass transfer,

- Several thermal comfort models such as Fanger,
- Developed calculations for fenestration,
- Anisotropic sky model to calculate diffuse solar radiation on tilted surface.

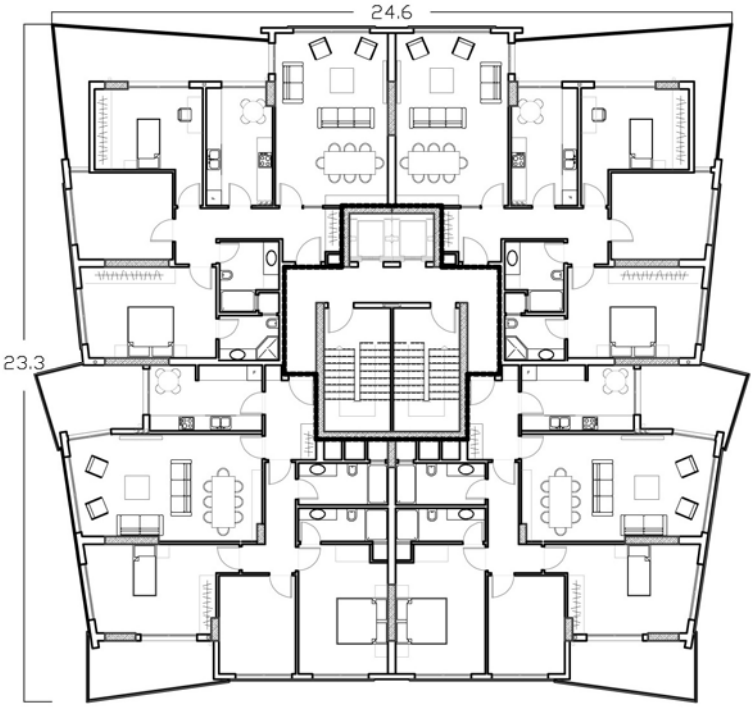


Figure 4.2. Typical floor plan of selected apartment block

EnergyPlus program is selected because it is a powerful and validated tool. In addition, format of input and output are open source code, txt. Thus they can be exported and imported easily to the different softwares. Inner performance of EnergyPlus was also tested by applying BESTEST procedure. This procedure was designed to examine inner performance of energy analysis tools. It consists of different predefined cases to investigate different capabilities of tools. In this study, BESTEST Case 600 which has lightweight construction was selected. It consists of the one zone with two windows on south façade (Figure 4.3). Thermal properties and layer of external wall, ground floor, roof and window are shown Table 4.1 and 4.2. Infiltration rate is accepted as 0.5 and constant. Internal gains are constant and 200 W (60% radiative, 40% convective, 100% sensitive, and 0% latent). Lastly, HVAC system works when inside temperature drops below 20°C to heat and rises above 27°C to cool. Results taken from EnergyPlus is within limits represented in BESTEST procedure (Judkoff and Neymark, 1995). Thus, it can be used in this study.

Table 4.1. Thermal properties and layer of external wall, ground floor and roof (Source: Judkoff and Neymark, 1995)

External wall	**λ (W/mK)**	**Density (kg/m^3)**	**Cp (J/kgK)**	**Thickness (m)**
Plasterboard	0.16	950	840	0.012
Fiberglass quilt	0.04	12	840	0.066
Wood siding	0.14	530	900	0.009
Ground floor	**λ (W/mK)**	**Density (kg/m^3)**	**Cp (J/kgK)**	**Thickness (m)**
Timber flooring	0.14	650	1200	0.025
Insulation	0.04	-	-	1.003
Roof	**λ (W/mK)**	**Density (kg/m^3)**	**Cp (J/kgK)**	**Thickness (m)**
Plasterboard	0.16	950	840	0.010
Fiberglass quilt	0.04	12	840	0.1118
Roof deck	0.14	530	900	0.019

Table 4.2. Thermal properties of window (Source: Judkoff and Neymark, 1995)

Property	**Value**
Number of glass	2
Glass thickness	3.175 mm
Air gap thickness	13 mm
Conductivity of glass	1.06 W/mK
Conductance of each glass pane	333 W/m^{2}K
Density of glass	2500 kg/m^3
Specific heat of glass	750 J/kgK
Solar heat gain coefficient	0.787

3D-thermal model of selected low-rise apartment block was generated by using DesignBuilder v2.2.5.004. DesignBuilder is a comprehensive interface of EnergyPlus. Then thermal model was exported to EnergyPlus 5.0.0 and necessary modifications were made. Thermal model consists of three storeys representing the ground, intermediate and top floors since every floor has a different energy performance.

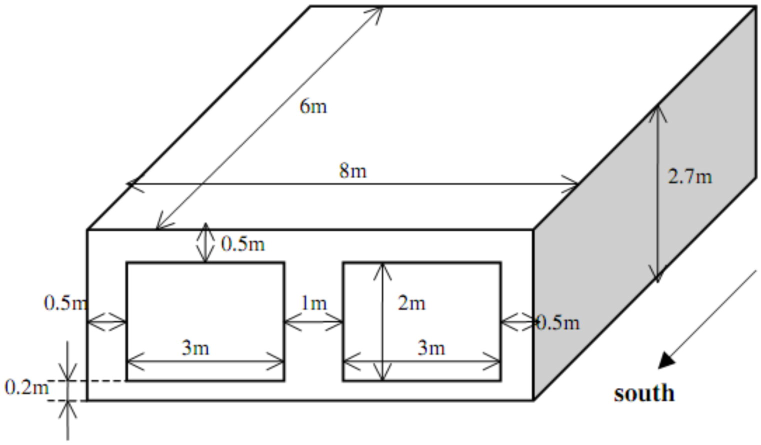


Figure 4.3. BESTEST: case 600

In addition, it is admitted that there is no any temperature difference between the floors. In other words, overlap surfaces are modeled as adiabatic, for reference building has central heating system and geothermal energy is used for heating. Cooling is provided by a split air conditioner in every flat, but it is assumed that the reference building has a central system for cooling in the present study because defining a schedule for individual cooling or heating system based on the behavior of occupants who live in different flats is not an easy task. As a result, in thermal model energy gains and losses take place from external walls, windows and ground in ground floor. It happens only from external walls and windows in intermediate floor. In top floor, it is from external walls, windows and roof. Furthermore, all features related to location such as latitude, longitude, orientation are defined in EnergyPlus.

4.2. Climatic Features of Izmir for the Time Periods of Today, 2020s, 2050s and 2080s

Izmir is located on the Aegean sea coast of Turkey (38 ° 25' North latitude and 27 ° 09' East longitude) and Izmir’s climate can be classified as hot-humid climate: winter season is warm and summer season is hot and humid (Fig. 4.3).

The mean annual temperature is around 16.08 °C. The minimum average temperature usually occurs in January (5.7 °C) and maximum mean temperature occurs in July (33 °C). The monthly minimum, mean, and maximum temperatures are represented in Figure 4.4. The annual mean relative humidity is approximately 64.58%.

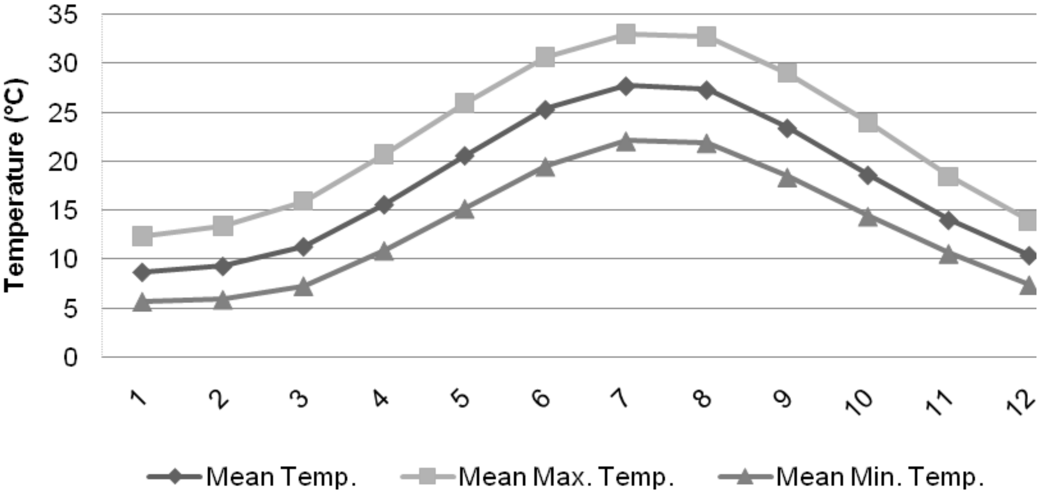


Figure 4.4. Monthly mean temperature in Izmir (1938-2003)
(Source: Adnan Menderes Meteorological Station, 2007)

Building energy analysis tools make dynamic calculations (time dependent) and thus they need hourly climatic data. Therefore, Typical Meteorological Year 2 (TMY 2) for Izmir was used in this study. Instant climatic data is not preferred, for it only shows climatic conditions belonging to selected time such as 2011 for Izmir. However, TMY2 represents general climatic conditions of Izmir because it consists of collection of monthly weather series belonging to different year. In addition, it is very common data to evaluate general energy performance of buildings (Belcher, Hacker and Powell, 2005).

To evaluate impact of global warming on building design parameters and annual cooling energy loads, the future hourly-climatic data is necessary. For that reason, three different climatic data for Izmir was developed by using the UK Handley Center’s third generation coupled atmosphere-ocean global climate model (HadCM3). This model allows investigating the rate of climate change and its impact (Johns, 2003). It composes of different projections based on the envisaged future gas emissions.

A2 scenario is used for this study since appropriate data is provided from only data produced based on A2 scenario. Main concept of this scenario is heterogeneous world with continuously increasing global population and regionally oriented economic growth which is more fragmented and slower than in other storylines (Nakicenovic, 2006). The projection for Izmir were made based on the averaged results of A2a, A2b and A2c experiments for four grid points closest to the selected city, Izmir to constitute hourly weather data for 30-year time periods of 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). All weather data files (TMY) were generated based on ‘morphing’ approach by using The Climate Change Weather File Generator (CCWorldWeatherGen) (Jentsch, Bahaj and James, 2008). It is a tool to generate climate change weather files in different locations to use in building energy analysis programs. The morphing approach is combination of present-day weather information data and results of climate change models. It also has three advantages: weather series used as baseline climate is reliable. Ended weather sequence is probably meteorologically consistent. Lastly, spatial downscaling is achieved because of the present day weather information which is generated from a real location (Belche, Hacker and Powell, 2008). Figure 4.5-6-7 shows the monthly mean temperature, relative humidity and direct solar radiation for Izmir used in all simulations for the time periods of today, 2020s, 2050s and 2080s. It is clear that while annual mean temperature and daily solar radiation increase, relative humidity decreases over time. In other words, the annual mean temperature will increase approximately 4 °C and the solar radiation will increase only 5% but the relative humidity will decrease 10% by the 2080s in Izmir.

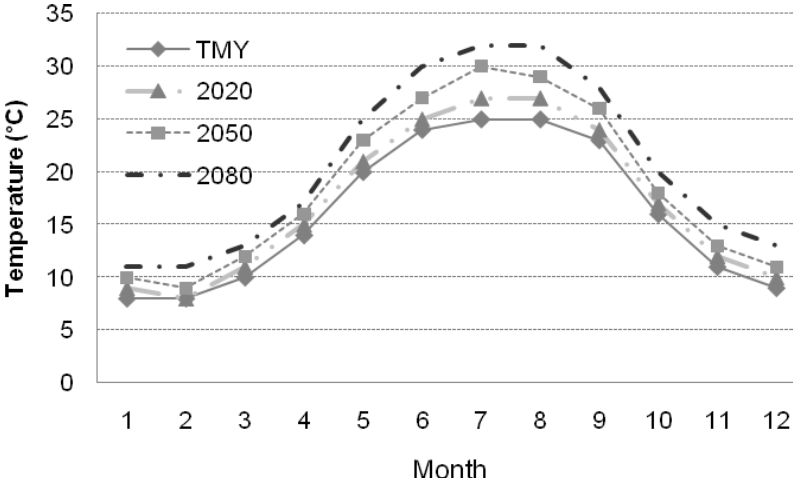


Figure 4.5. Monthly outdoor temperature for present, 2020s, 2050s, and 2080s in Izmir

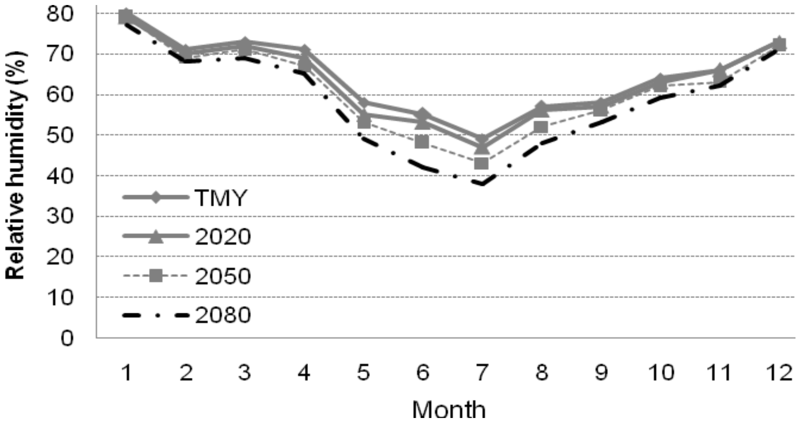


Figure 4.6. Monthly relative humidity for present, 2020s, 2050s, and 2080s in Izmir

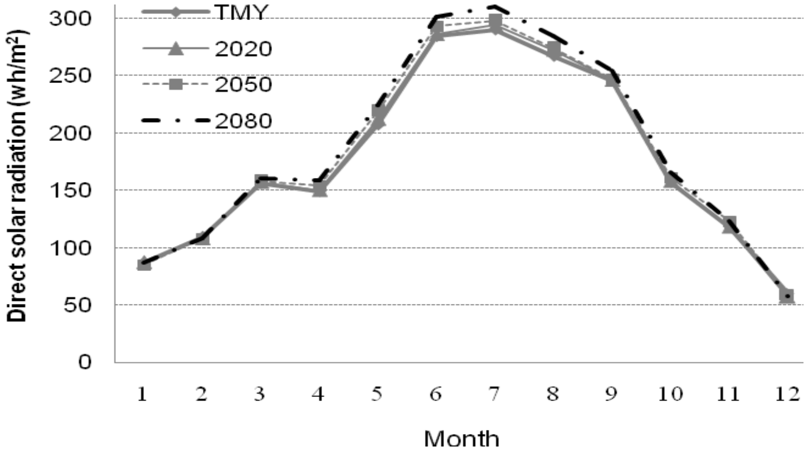


Figure 4.7. Monthly direct solar radiation for present, 2020s, 2050s, and 2080s in Izmir

4.3. Steps of Uncertainty and Sensitivity Analysis

To start sensitivity and uncertainty analysis, firstly objective of study should be established. Then, output parameter(s) which is essential to answer problem questions is determined. In addition, which input parameter(s) will be in the analysis is decided. After selecting inputs, suitable density distribution function for each input should be defined depending on literature review. Later a sensitivity analysis method is selected and a sample matrix for inputs is generated. Lastly, model output is analyzed (Saltelli et al., 2004). Steps to perform uncertainty and sensitivity analysis and programs were shown in Figure 4.8.

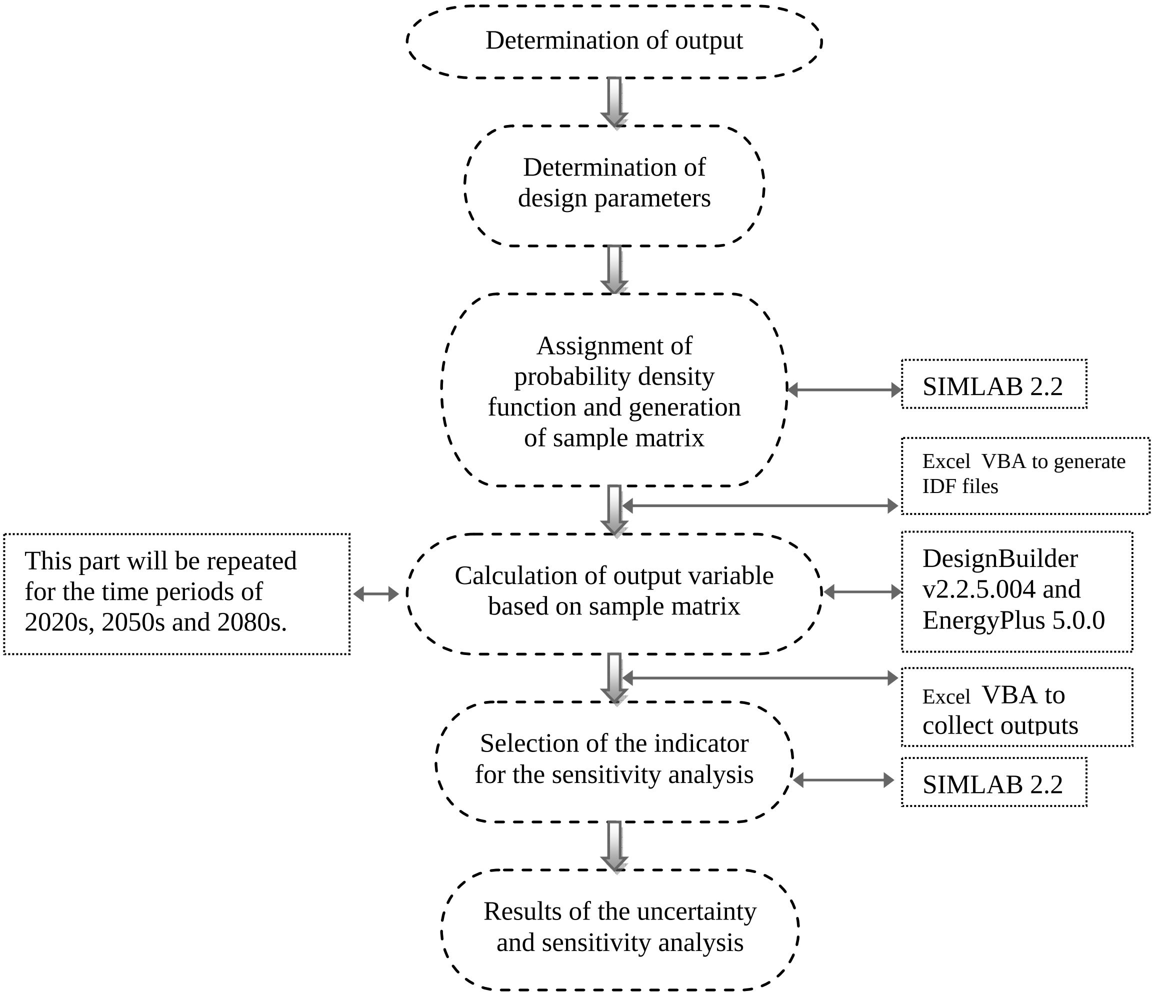


Figure 4.8. Steps for application of uncertainty and sensitivity analysis and tools used in this process

4.3.1. Determination of Output Variable

The aim of the analysis should be determined because the output(s) can be defined based on this objective. Cooling requirement in summer is the main issue in the present study. Thus the annual cooling energy load is selected as the output variable because this is also a significant and common indicator for the level of energy consumption in buildings which have active systems.

4.3.2. Determination of Input Parameters

In this study, uncertainty caused by building design parameters is admitted as epistemic. Epistemic uncertainty means a lack of knowledge about the suitable value in the context of a specific implementation. It is also called as state of knowledge uncertainty, subjective uncertainty, reducible uncertainty, and Type B uncertainty (Swiler and Giunta, 2007). In terms of design practice of buildings in Turkey, epistemic uncertainty in building design parameters arises from decisions by architects, design team and occupancy. For example, set point temperatures can change easily in spaces because information about their optimum values and their effects on energy consumption are lack or poorly known. However, this type of uncertainty can be reduced with more research to increase understanding. For that reason, nine simple and concise building design parameters in terms of architectural points of view in Turkey are selected and they are assumed to be main variables that influence the annual cooling energy loads in low-rise apartment buildings. They are also parameters that can be controlled by architects easily:

1. Building shape (defined width building with and length),
2. Window to external-wall area,
3. Thermo-physical properties of building materials,
4. Thermal insulation,
5. Air infiltration,
6. Natural ventilation,
7. Envelope color,
8. Set point temperature,
9. Zone height.

Then, 34 sub-parameters are derived from nine major design parameters to support architectural decision-making process for reducing cooling energy loads of low-rise apartment buildings. They are the length and width of the low-rise apartment block; the zone height; the set point temperature for cooling; the air infiltration rate; the natural ventilation rate; the window areas in the South, North, East, West directions; the U-value and solar heat gain coefficient (SHGC) of the windows based on orientation; the thermal conductivity of the external wall; the thermal conductivity of the thermal insulation material on the external wall, roof and ground; the specific heat of the external wall; the thickness of the thermal insulation on external wall depending on the orientations; the thickness of the thermal insulation on the roof and ground; the color of the external wall based on the orientation and the color of the roof. The main difficulty with increasing the number of the selected building design parameters in this study is mostly related to limitations of building energy analysis tool, EnergyPlus because each selected design parameter should be defined with one value in selected program.

4.3.3. Assignment of the Probability Density Function and the Generation of a Sample Matrix

Third step consists of two sub-steps. First one is to assign appropriate probability density functions to the 34-derived building design parameters. The probability density functions, which can affect the results of the sensitivity and uncertainty analysis, were assumed to be uniform for all parameters represented in Table 4.3. In this probability function, all values have the same possibility to happen (De Wilde and Tian, 2009)

Table 4.3. Design parameters: their probability density functions and ranges

Design parameters	**Unit**	**Probability density function**	**Min. value**	**Max. value**
Length of building	m	Continues uniform	12	22
Width of building	m	Continues uniform	12	22
Set point temperature for cooling (Cooling set point t.)	°C	Continues uniform	24	26
Air infiltration rate (Air infilt.)	ach	Continues uniform	0.5	2
Natural ventilation rate (Natural vent.)	ach	Continues uniform	0.5	4
Windows area: south	%	Continues uniform	5	90
Windows area: north	%	Continues uniform	5	90
Windows area: east	%	Continues uniform	5	90
Windows area: west	%	Continues uniform	5	90
U-value of window on South (U value: window-south)	W/m^{2}K	Continues uniform	1.1	2.9

(Cont. on next page)

Table 4.3. (Cont.)

Design parameters	**Unit**	**Probability density function**	**Min. value**	**Max. value**
U-value of window on North (U value: window-north)	W/m^2K	Continues uniform	1.1	2.9
U-value of window on East (U value: window-east)	W/m^2K	Continues uniform	1.1	2.9
U-value of window on West (U value: window-west)	W/m^2K	Continues uniform	1.1	2.9
SHGC of window on South	-	Continues uniform	0.28	0.75
SHGC of window on North	-	Continues uniform	0.28	0.75
SHGC of window on East	-	Continues uniform	0.28	0.75
SHGC of window on West	-	Continues uniform	0.28	0.75
Color of external walls on South (Color: ext. wall-south)	-	Continues uniform	0.1	0.9
Color of external walls on North (Color: ext. wall-north)	-	Continues uniform	0.1	0.9
Color of external walls on East (Color: ext. wall-east)	-	Continues uniform	0.1	0.9
Color of external walls on West (Color: ext. wall-west)	-	Continues uniform	0.1	0.9
Color of roof (Color: roof)	-	Continues uniform	0.1	0.9
Space height	m	Continues uniform	2.6	3
Specific heat of external wall	J/kg-K	Continues uniform	800	990
Thickness of thermal insulation on external walls on South (Thickness: ins-ext. wall-south)	m	Continues uniform	0.01	0.2
Thickness of thermal insulation on external walls on North (Thickness: ins-ext. wall-north)	m	Continues uniform	0.01	0.2
Thickness of thermal insulation on external walls on East (Thickness: ins-ext. wall-east)	m	Continues uniform	0.01	0.2
Thickness of thermal insulation on external walls on West (Thickness: ins-ext. wall-west)	m	Continues uniform	0.01	0.2
Thickness of thermal insulation on roof (Thickness: ins-roof)	m	Continues uniform	0.01	0.2
Thickness of thermal insulation on ground (Thickness: ins-ground)	m	Continues uniform	0.01	0.2
Thermal conductivity of external wall (Thermal conduct.:ext. wall)	W/mK	Continues uniform	0.15	2.1
Thermal conductivity of thermal insulation on external wall (Thermal conduct.:ext. wall ins.)	W/mK	Continues uniform	0.028	0.052
Thermal conductivity of thermal insulation on roof (Thermal conduct.: roof ins.)	W/mK	Continues uniform	0.028	0.052
Thermal conductivity of thermal insulation on ground (Thermal conduct.: ground ins.)	W/mK	Continues uniform	0.028	0.052

The minimum and maximum values for each parameter are essential for the definition of continuous uniform probability density functions. Therefore, minimum and maximum values are determined depending on the availability in architectural practice and technical limitations in Turkey’s building sector. For example, min. value (0.028 W/mK) and max. value (0.052 W/mK) were determined for thermal conductivity of thermal insulation used on external wall. It means that in Turkey an architect can prefer the best thermal insulation material which has the minimum thermal conductivity value with 0.028 and also an architect can use a thermal insulation material which has the worst thermal conductivity value with 0.052. In other words, they have only chance to select thermal insulation material which has thermal conductivity value changing between 0.028 W/mK and 0.052 W/mK.

The upper and lower values for design parameters were interpreted as a central 95% confidence interval, and all parameters were considered to be independent from any aesthetic concern, energy performance and compulsory legal regulations. This interpretation is important for evaluating and quantifying the significance and impact of the parameters.

The second step of the third step is to generate a sample matrix. There are several sampling techniques that can be used for uncertainty and sensitivity analysis. For this study, 400 samples for each parameter were compiled based on the selected density distribution by using the MCA with Latin hypercube sampling (LHS) method, for it is depending on repeated simulation. This process was performed by using SIMLAB 2.2 which is professional and free software for model developers, scientist to apply global sensitivity and uncertainty analysis techniques in a short time (SIMLAB, 2004). LHS is commonly used with computationally demanding models because its effective stratification features allow the extraction of a large amount of sensitivity with a relatively little sample size. It works by dividing the inputs into strata, and after generating samples, the value created for each parameter comes from a different stratum (Helton et. al. 2006). The minimum number of generated samples for each parameter should not be less than 1.5 times the number of uncertain inputs used in the model. Moreover, after processing 60-80 samples, the increase in the accuracy of the standard deviation is very low in MCA (Lomas and Eppel, 1992, MacDonald, 2002). Thus, the number of simulation was chosen to be 400 to obtain a good accuracy in the sensitivity and uncertainty analysis and thus, 400 samples for every design parameter were generated.

4.3.4. Calculation of Output Variable

Outputs corresponding to generated sample matrix were calculated with the EnergyPlus 5.0.0 simulation software (LBNL, 2008). 400 EnergyPlus input files (idf) including combinations of different values of building design parameters were created by using Excel VBA 2007 for each storey of low-rise apartment block. Thermal model of low-rise apartment block consists of three storeys. Thus, 1200 input files were produced. Then they were simulated to calculate outputs for each climatic data representing present, 2020s, 2050s, and 2080s.

4.3.5. Selection of the Indicator for the Sensitivity

The last step is to determine the sensitivity indicator to be used for evaluation of sensitivity of all building design parameters. Different measures for sensitivity assessment are available in the SIMLAB program when generating samples with the LHC method. They are the Pearson Product Moment Correlation Coefficient (PEAR), Spearman Coefficient (SPEA), Partial Correlation Coefficient (PCC), Partial Rank Correlation Coefficient (PRCC), Standardized Regression Coefficient (SRC), and Standardized Rank Regression Coefficient (SRRC). In this study, Standardized Rank Regression Coefficient (SRRC), which can be used instead of SRC, was selected as an indicator to identify the sensitivity of each building parameter (SIMLAB, 2004) because, like SRC, it is a quantitative measure of the sensitivity based on regression analysis. However, SRRC is calculated using a model covering rank transformation data. In addition, rank transform is essential to evaluate models which have a nonlinear relationship between input(s) and output(s) (Helton et al. 2006).

4. 4. Results of the Uncertainty and Sensitivity Analysis

In the following parts, results of the uncertainty and sensitivity analysis are explained based on the time periods.

4.4.1. Uncertainty in Annual Cooling Energy Loads at Present

Results of 1200 EnergyPlus simulations covering three stories are evaluated with histograms and statistical values to present changes in the annual cooling energy loads per unit of flat area based on the uncertainties caused by building design parameters. Figure 4.9 shows the range of possible annual cooling energy loads together with the frequency of each interval for the ground, intermediate, and top floors.

For annual cooling energy loads, while the range is between 5.30 and 86.09 kWh/m^2 on the ground floor, it is between 16.58 and 97.85 kWh/m^2 on the intermediate floor. It also varies between 12.10 and 98.24 kWh/m^2 on the top floor. It is clear that the ground floor needs the lowest amount of energy for cooling. The maximum energy consumption can take place on the top floor. There is no big difference between intermediate and top floors in terms of mean cooling energy loads. The most frequent annual cooling energy load is 37.78 kWh/m^2 on the ground floor, 39 kWh/m^2 on the intermediate floor, and 48.24 kWh/m^2 on the top floor. It is also clear that the ranges in annual cooling energy loads are different depending on the floor of the low-rise apartment block that is considered. In addition, the difference between possible minimum and maximum annual cooling energy loads in flats is relatively high. Rate of the uncertainty can be defined with standard deviation which is approximately 14 today. It means that design parameters have a considerable impact on variations in annual cooling energy load. Thus they should be arranged to provide less cooling energy load in the early design stage by architects.

Design of low-rise apartment blocks which has a high energy performance may be possible with local mandatory regulations because if minimum and maximum values for especially sensitive design parameters are determined or limited, range for possible annual cooling energy loads can be reduced and limited. Hereby, the decision-makers and architects cannot select the worst values which can lead to high energy consumption for cooling. According to the results, to optimum energy consumption for cooling in low-rise apartment blocks, architects should spend more time on sensitive design parameters in the early stages of design process.

The minimum energy requirements for cooling shown in Fig. 4.9. can be obtained by selecting the upper limit of the design parameters that have a negative

SRRC and by selecting the lowest limit of the design parameters that have a positive SRRC shown in the following section.

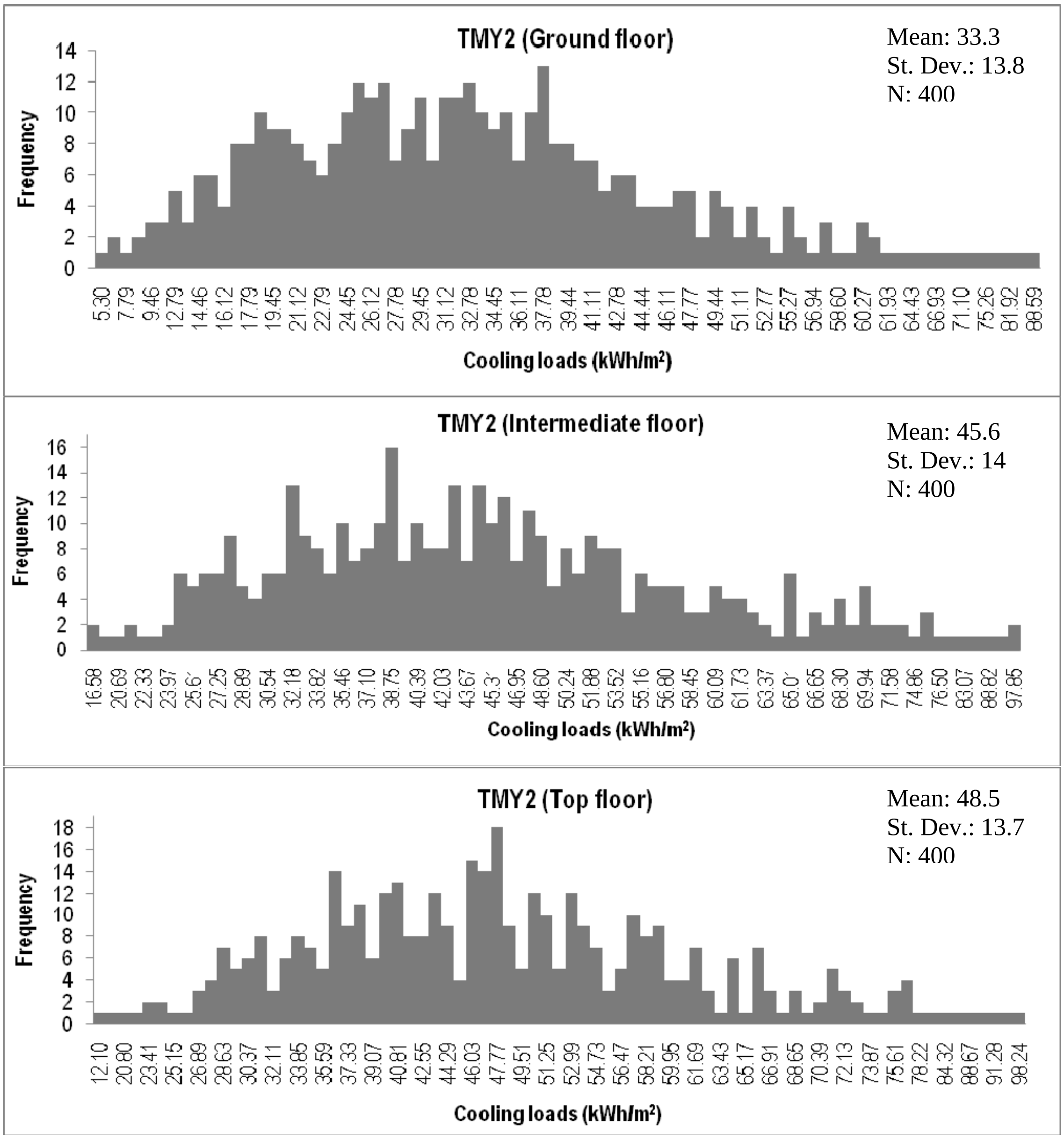


Figure 4.9. Variation of annual cooling energy loads in present

4.4.2. Uncertainty in Annual Cooling Energy Loads in 2020s

Figure 4.10 shows the range of possible annual cooling energy loads together with the frequency of each interval for the ground, intermediate, and top floors in 2020.

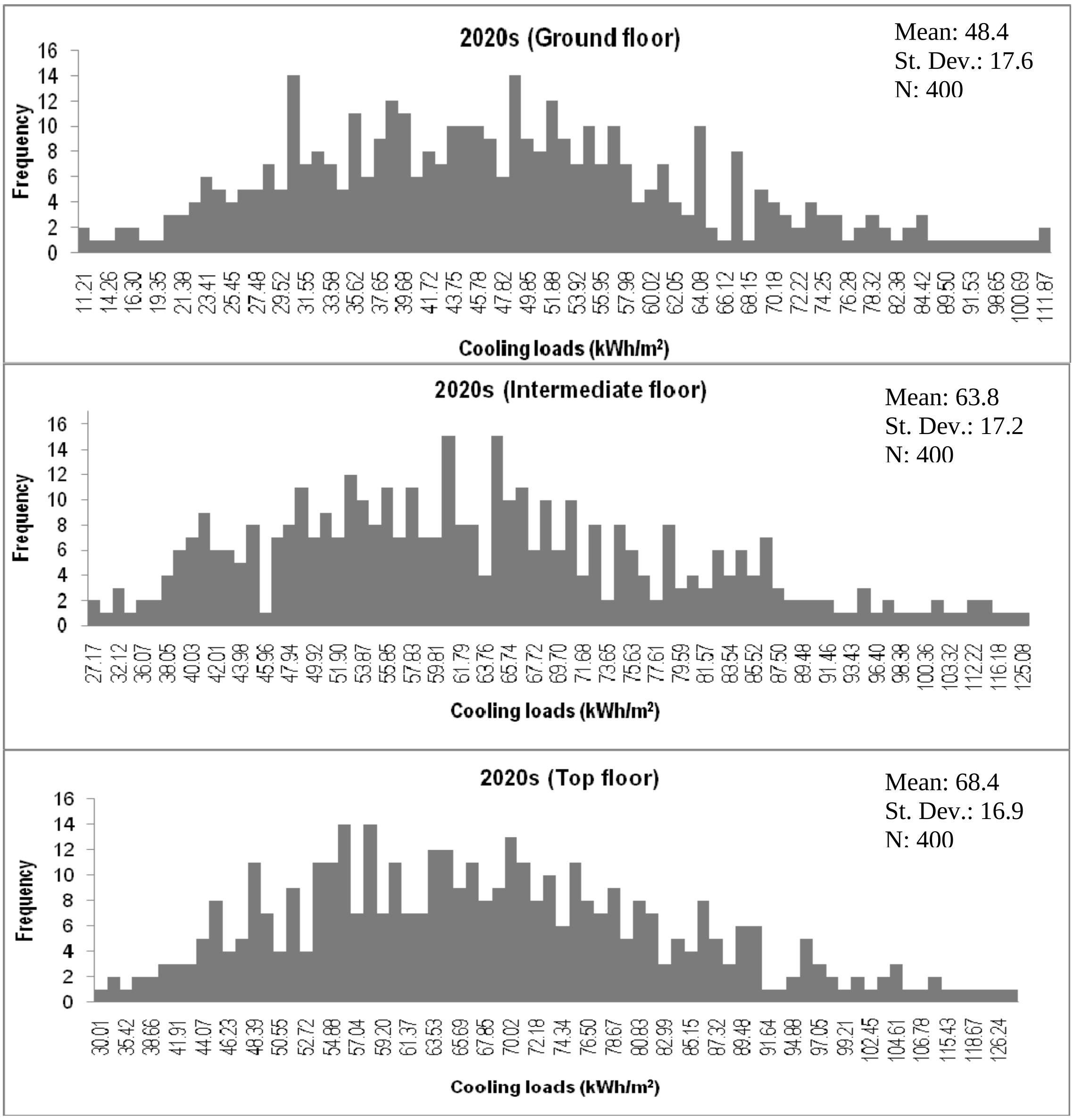


Figure 4.10. Variation of annual cooling energy loads in 2020s

For annual cooling energy loads, while the possible annual cooling energy load is between 11.21 (more than twice compared to today) and 111.87 kWh/m^2 (more than 29% compared to today) on the ground floor, it is between 27.17 (more than 63% compared to today) and 125.08 kWh/m^2 (more than 27% compared to today) on the intermediate floor. It varies between 30.01 (more than 247 % compared to today) and 126.24 kWh/m^2 (more than 124% compared to today) on the top floor. In terms of mean energy demand, the ground floor needs the lowest amount of energy with 17.6 kWh/m^2 for cooling. The maximum mean energy consumption can take place on the top floor with 68.4 kWh/m^2. It may be due to the roof which exposes to high solar radiation. In addition, there is no considerable difference between intermediate and top floors in terms of mean cooling energy loads. The most frequent annual cooling energy load is 30.53 and 48.83 kWh/m^2 on the ground floor, 64.75 kWh/m^2 on the intermediate floor, and 56 and 58 kWh/m^2 on the top floor. Another important point is that uncertainty in 2020 is more than the current situation. In other words, while standard deviation in floors is approximately 14 today, it is 17 in 2020. In other words, climate has an important impact on uncertainty.

4.4.3. Uncertainty Analysis in Annual Cooling Energy Loads in 2050s

The range of possible annual cooling energy loads in 2050 is shown together with the frequency of each interval in Figure 4.11 for the ground, intermediate, and top floors

Annual cooling energy loads change between 20.4 kWh/m^2 (more than four times compared to today) and 142.97 kWh/m^2 (more than 66% compared to today) on the ground floor, it is between 41.18 kWh/m^2 (more than 252% compared to today) and 158 kWh/m^2 (more than 161% compared to today) on the intermediate floor. It can varies between 29.52 kWh/m^2 (more than 243% compared to today) and 160.7 kWh/m^2 (more than 163% compared to today) on the top floor. The ground floor needs the lowest amount of mean energy with 22.1 kWh/m^2 for cooling. The maximum mean energy consumption can take place on the top floor with 92.7 kWh/m^2. It is the same with previous years that there is no significant difference between intermediate and top floors in terms of mean cooling energy loads. The most frequent annual cooling energy load is 65-71-79 kWh/m^2 on the ground floor, 70.3 kWh/m^2 on the intermediate floor, and 95.11 kWh/m^2 on the top floor. Another important point is that uncertainty continuous to rise compared to previous times. In other words, while standard deviation in floors is approximately 14 today, it is 21 in 2050.

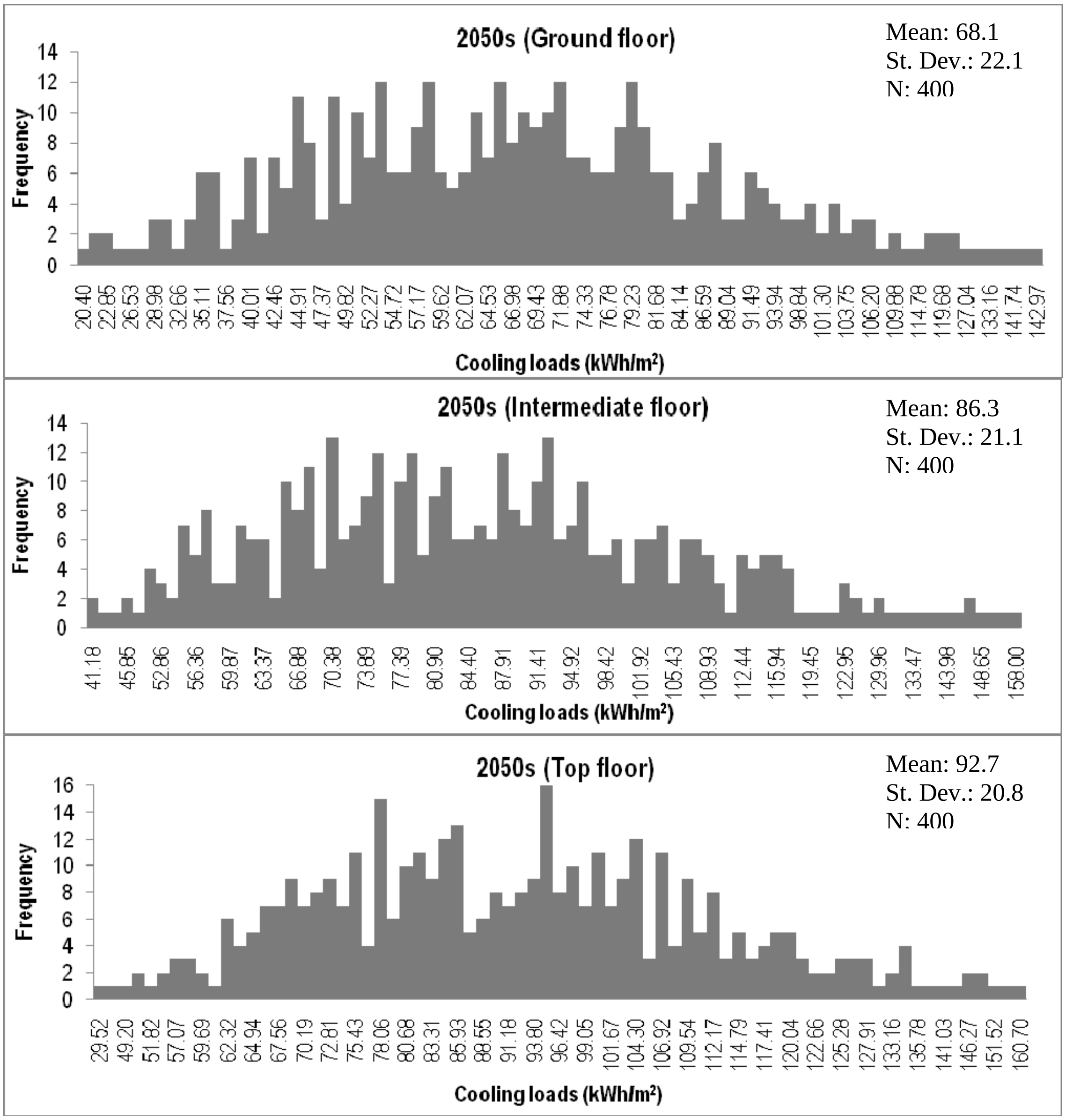
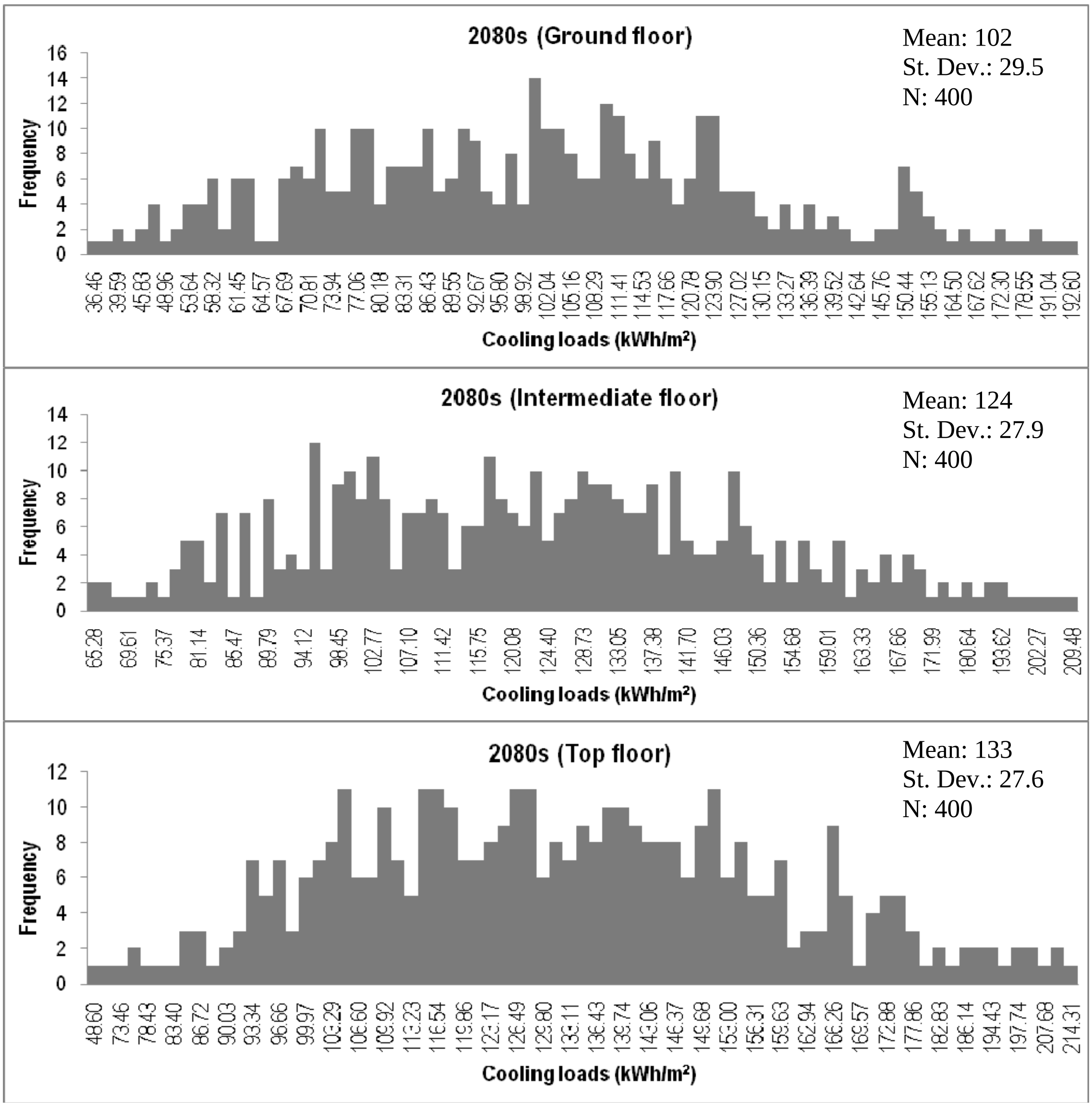


Figure 4.11. Variation of annual cooling energy loads in 2050s

4.4.4. Uncertainty in Annual Cooling Energy Loads in 2080s

Figure 4.12 shows possible annual cooling energy loads in 2080 together with the frequency of each interval for the ground, intermediate, and top floors. Annual cooling energy load can vary between 36.46 kWh/m^2 (more than seven times compared to today) and 192.6 kWh/m^2 (more than 223% compared to today) on the ground floor. It can be between 65.29 kWh/m^2 (more than 393.7% compared to today) and 209.48 kWh/m^2 (more than 214% compared to today) on the intermediate floor. Furthermore, it can take place between 48.6 kWh/m^2 (more than 401% compared to today) and 214.31 kWh/m^2 (more than 218% compared to today) on the top floor. Minimum cooling is necessary in the ground floor and maximum is essential in the top floor because of the roof which exposes to high solar radiation. In addition, there is no big difference between intermediate and top floors in terms of mean cooling energy loads. The most frequent annual cooling energy load is 100.4 kWh/m^2 on the ground floor, 95.5 kWh/m^2 on the intermediate floor, and 128 kWh/m^2 on the top floor. As a result, uncertainty in 2080 is more than the previous years. In other words, while standard deviation in floors is approximately 14 today, it is 29 in 2080.



Mean: 102
St. Dev.: 29.5
N: 400

Mean: 124
St. Dev.: 27.9
N: 400

Mean: 133
St. Dev.: 27.6
N: 400

Figure 4.12. Variation of annual cooling energy loads per floor unit in 2080s

4.4.5. Sensitivity of Design Parameters that Influence Annual Cooling Energy Loads at Present

Importance of each design parameter according to the SRRC value is indicated in Figure 4.13 for Today. A positive SRRC means that as the value of the design parameter increases, the value of the corresponding output simultaneously increases. A negative SRRC implies that changes in the inputs and outputs tend to go in opposite directions.

There are small differences in the order of importance of design parameters according to the level/floor considered. These changes should be admitted as an expected result because sensitivity of the same design parameters may change depending on floors because of the several factors such as difference in cooling energy loads in different floors. Furthermore, ground floor may be more affected by ground temperature and thus thickness of the insulation material is one of the most significant design parameters in the ground floor. Moreover, top floor may be more affected by the roof heat transfer and thus thickness of the insulation material on roof is one of the important design parameters. For that reason, differences in design parameters according to floors should not be considered that though some parameters are important in ground or intermediate floor, they are not important in top floor. It should be considered that all design parameters is significant but degree of the importance of the same parameters can change in different floors.

In this thesis, design parameters which have SRRC value more than 0.1 (absolute value) is admitted as the most effective/important factors and others are classified as the less effective/important parameters in terms of annual cooling load. Based on this classification, there are fourteen the most important design parameters for ground and intermediate floor. It is fifteen for roof floor. Others have the less importance compared to others. The most important design parameters can be sorted as follows:

Ground floor: Thickness: ins-ground, cooling set point t., natural vent., window area: east, window area: west, window: SHGC-east, length of building, window area: north, window: SHGC-south, window: SHGC-west, air infiltration, space height, window area: south, and thermal conduct: ground ins.

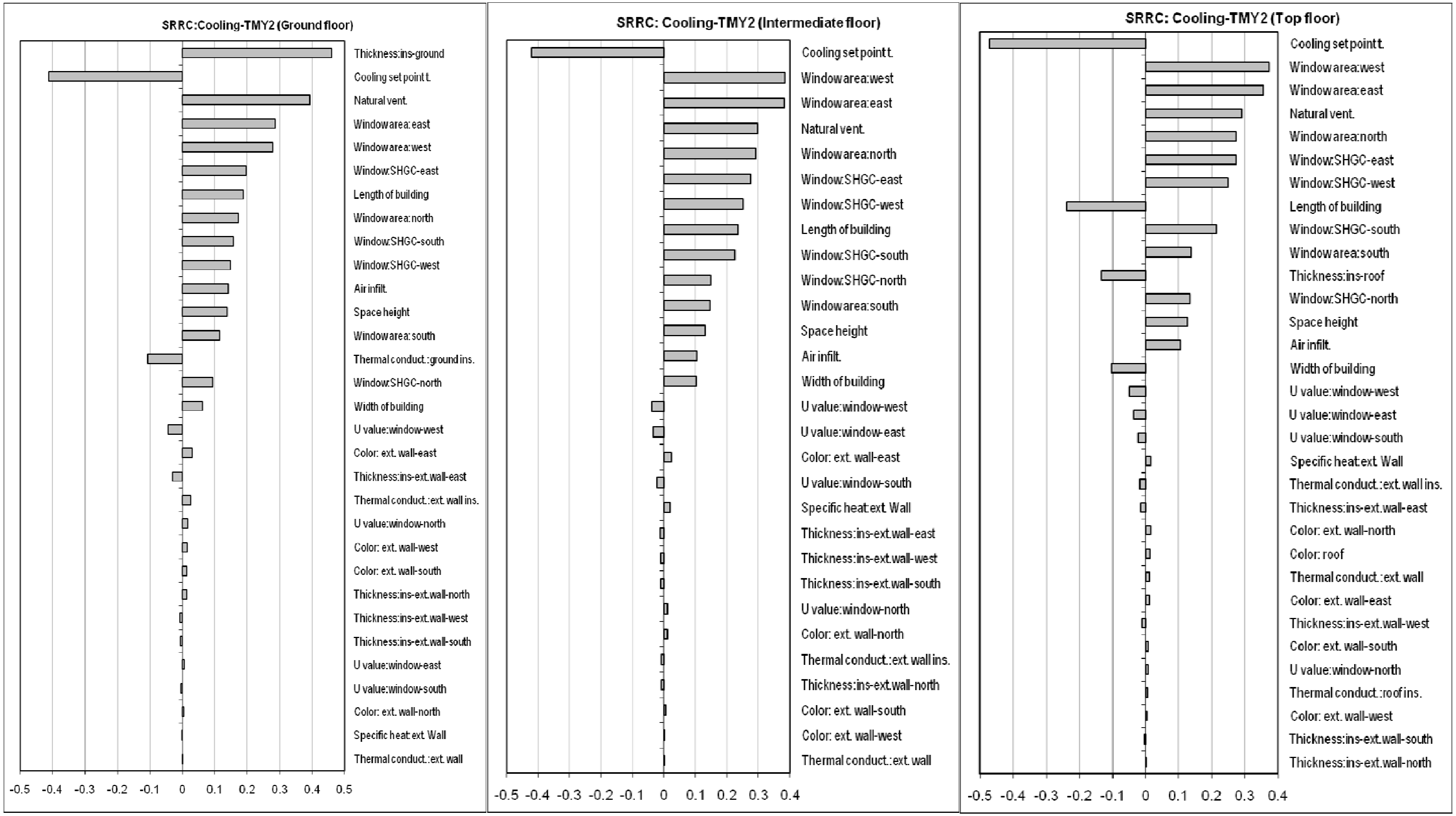


Figure 4.13. Sensitivity of the selected design parameters in present

Intermediate floor: cooling set point t., window area: west, window area: east, natural vent., window area: north, window: SHGC-east, window: SHGC-west, length of building, window: SHGC-south, window: SHGC-north, window area: south, space height, air infiltration and width of building,

Top floor: cooling set point t., window area: west, window area: east, natural vent., window area: north, window: SHGC-east, window: SHGC-west, length of building, window: SHGC-south, window area: south, thickness:ins-roof, window: SHGC-north, space height, air infiltration and width of building,

Width and length of building, space height, window area, SHGC value of glazing, natural ventilation rate, cooling set point temperature, air infiltration rate, and space height are the most effective design parameters on annual cooling energy loads for all floors. However, the color of the external wall and roof, the specific heat of main external wall materials, U value of windows, thicknesses of insulation material on external walls and type of insulation material on external walls are not so much affective for the annual cooling energy loads. In addition, the results of the sensitivity analysis showed that importance of the building design can change depending on orientation.

4.4.6. Sensitivity of Design Parameters that Influence Annual Cooling Energy Loads in 2020s

Figure 4.14 shows the sensitivity coefficient and importance of each design parameter in 2020. The most important design parameters are as follows:

Ground floor: Natural vent., thickness: ins-ground, cooling set point t., window area: east, window area: west, length of building, window: SHGC-east, air infiltration, window area: north, space height, window: SHGC-south, window: SHGC-west, thermal conduct:ground ins., and window area: south.

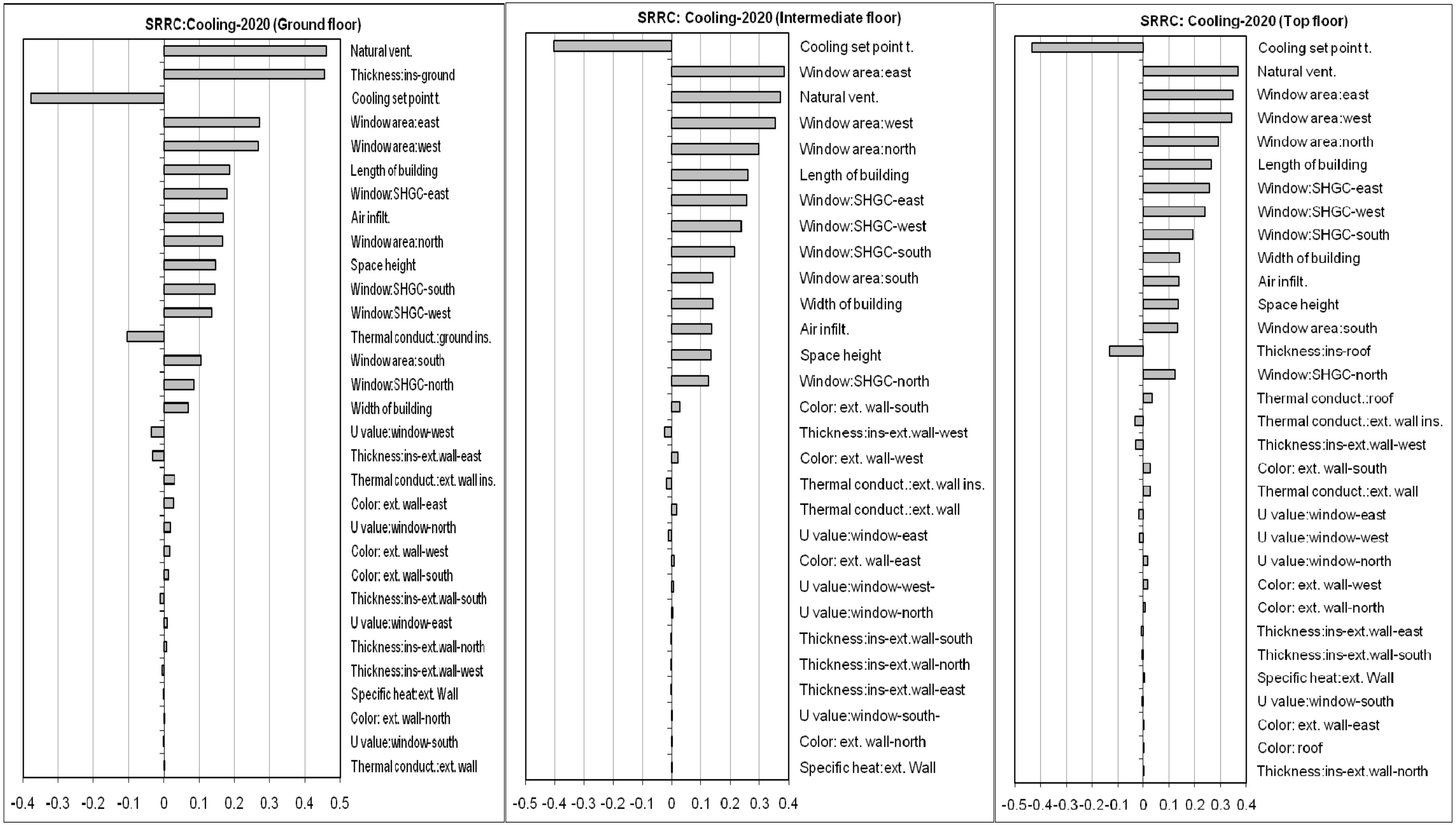


Figure 4.14. Sensitivity of the selected design parameters in 2020s

Intermediate floor: Cooling set point t., window area: east, natural vent., window area: west, window area: north, length of building, window: SHGC-east, window: SHGC-west, window: SHGC-south, window area: south, width of building, air infiltration, space height and window: SHGC-north.

Top floor: Cooling set point t., natural vent., window area: east, window area: west, window area: north, length of building, window: SHGC-east, window: SHGC-west, window: SHGC-south, width of building, air infiltration, space height, window area: south, thickness:ins-roof and window: SHGC-north.

Significant design parameters on annual cooling energy loads for all floors are width and length of building, space height, window area, SHGC value of glazing, natural ventilation rate, cooling set point temperature, air infiltration rate, and space height.

The color of envelope, the specific heat of main external wall material, thicknesses of insulation material on external walls, U value of windows, and type of insulation material on external walls are not affective as others for the annual cooling energy loads. These can be defined as robust design parameters.

4.4.7. Sensitivity of Design Parameters that Influence Annual Cooling Energy Loads in 2050s

Sensitivity coefficient and importance of each design parameters are presented in Figure 4.15 for 2050. The most important design parameters depending on different floors are as follows:

Ground floor: Natural vent., thickness: ins-ground, cooling set point t., window area: east, window area: west, air infiltration length of building, window area: north, window: SHGC-east, space height, window: SHGC-south, window: SHGC-west, thermal conduct:ground ins., and window area: south.

Intermediate floor: Natural vent., cooling set point t., window area: east, window area: west, window area: north, length of building, window: SHGC-east, window: SHGC-west, window: SHGC-south, air infiltration, width of building, space height, window area: south, and window: SHGC-north.

Top floor: Natural vent., cooling set point t., window area: west, window area: east, window area: north, length of building, window: SHGC-east, window: SHGC-west, air infiltration, window: SHGC-south, width of building, thickness:ins-roof, space height, window area: south and window: SHGC-north.

It is clear that, the same design parameters are significant in 2050 compared to important parameters in current situation and 2020. There is only small difference in order of design parameters. One of the remarkable points is that importance of natural ventilation and air infiltration has been increasing. Again, SHGC value of windows and window area are one of the effective design parameters. In addition to this, length and width of building and space height are significant. Insulation material on external walls, thickness of insulation on external walls, envelope color, U value of windows are not so effective as other design parameters.

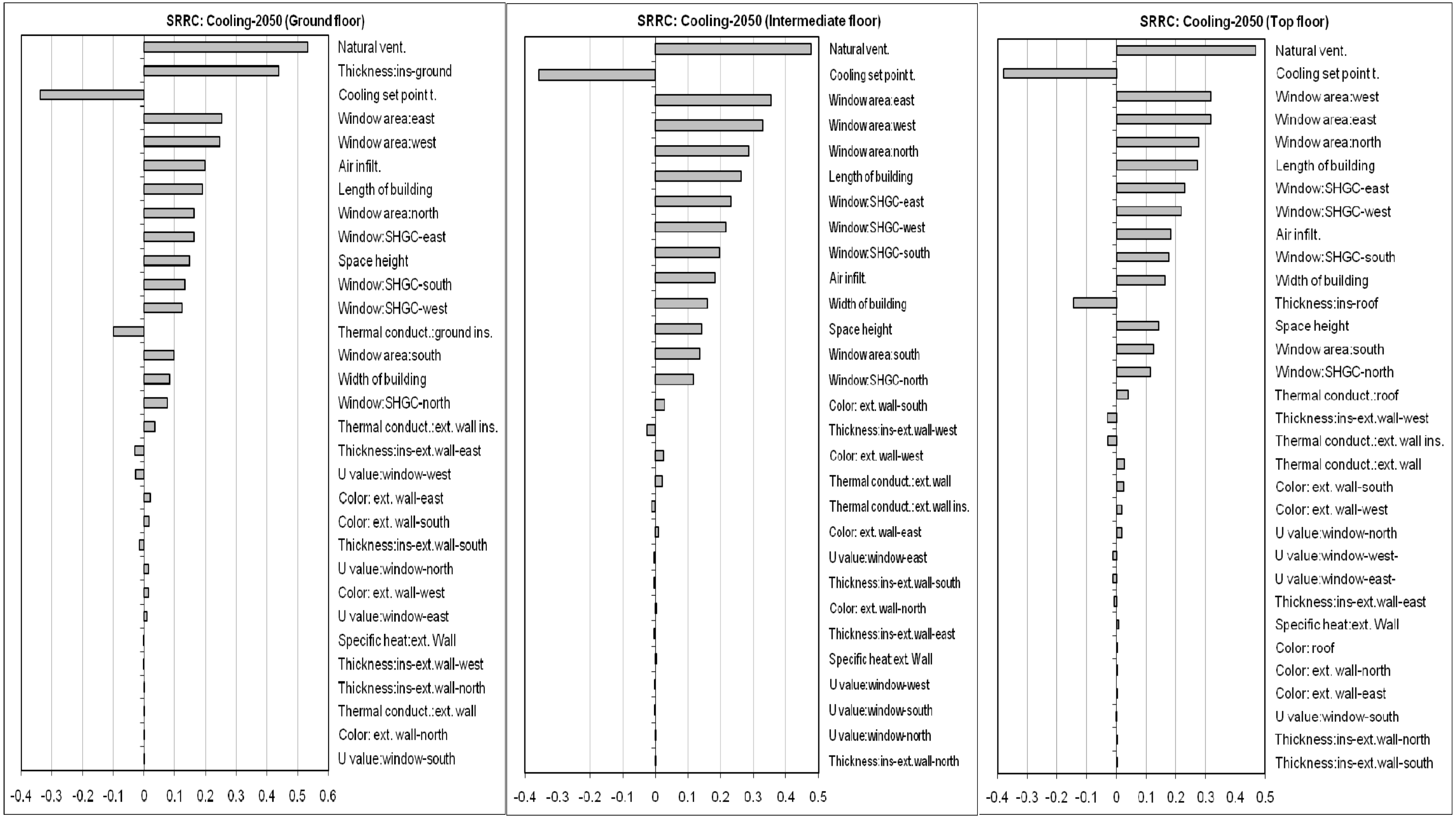


Figure 4.15. Sensitivity of the selected design parameters in 2050s

4.4.8. Sensitivity of Design Parameters that Influence Annual Cooling Energy Loads in 2080s

Figure 4.16 represents importance of each design parameters in 2080 depending on the SRRC value. Dominant design parameters can be sorted as follows:

Ground floor: Natural vent., thickness:ins-ground, cooling set point t., air infiltration, window area: east, window area: west, length of building, window area: north, space height, window: SHGC-east, window: SHGC-south, window: SHGC-west, width of building.

Intermediate floor: Natural vent., window area: west, window area: east, cooling set point t., window area: north, length of building, air infiltration, window: SHGC-east, window: SHGC-west, window: SHGC-south, width of building, space height, window area: south, and window: SHGC-north.

Top floor: Natural vent., cooling set point t., window area: west, length of building, window area: east, window area: north, air infiltration, window: SHGC-east, window: SHGC-west, thickness:ins-roof, width of building, window: SHGC-south, space height, window area: south and window: SHGC-north.

Almost the same design parameters are significant in 2080 compared to dominant parameters in current situation, 2020 and 2050 except for type of insulation material and window area on south in ground floor. There is only small difference in order of design parameters. Natural ventilation and air infiltration rate are more effective parameters compared to the previous years. Again, SHGC value of glazing and window area are effective design parameters. In addition to this, length and width of building and space height are significant but these are related to size of the external wall area exposed to outdoor conditions and volume of the spaces. Insulation material on external walls, thickness of insulation on external walls, color, U value of windows are not so effective as other design parameters.

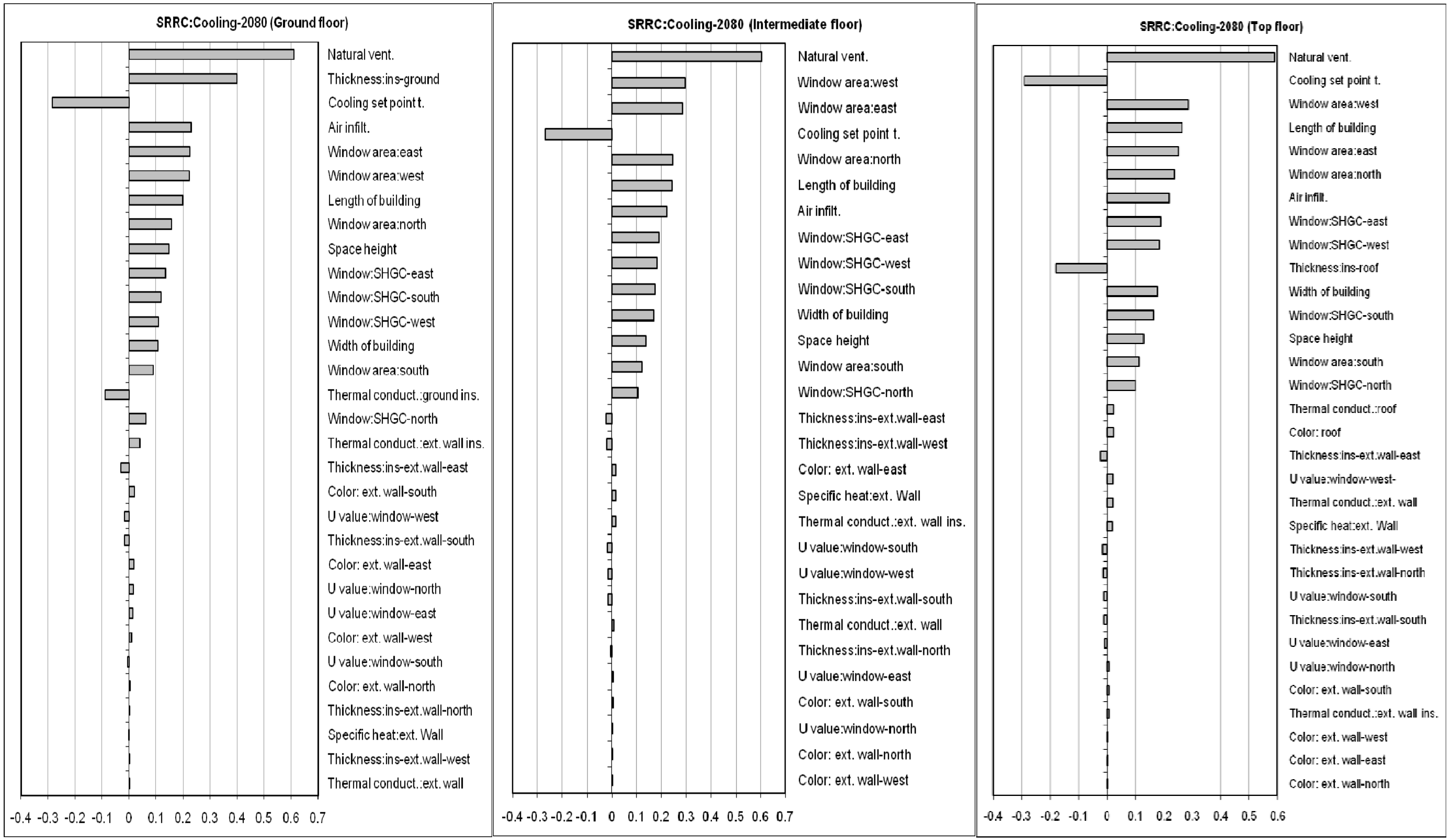


Figure 4.16. Sensitivity of the selected design parameters in 2080

CHAPTER 5

PREPARATION OF THE PRACTICAL GUIDE

5.1. Approaches to Support Building Design Process in terms of Energy Performance

Increasing of energy demand and decreasing of energy sources in the world are leading to compulsory usage of energy efficiently in every sector. One of the main sectors consumed high energy is buildings. Thus, design of buildings and their energy performance are a critical issue for designers today (Petersen and Svendsen, 2010). The design process can be defined as ongoing activities and decisions need to be taken by designers and should be governed to manage new artefacts depending on their experience, knowledge, talent, and creativity (Mardjono, 2002). The design process covers different objectives and scopes under the designer's consideration. According to RIBA (Royal Institute of British Architects) (1995), design process consists of three main stages:

1. Outline design stage: it consists of the feasibility studies and includes gathering of information about the site, function, circulation, mass of building, spaces and their relations,
2. Scheme design stage: it starts after approving the outline design stage by customer and contains site layout, planning and spatial arrangements, elevation treatment, construction and environmental systems.
3. Detailed design stage: it starts after approving the scheme design stage by customer. Technical drawings are prepared with collaboration of other team members such as civil and mechanical engineers. Drawings generally cover fittings, equipment and finishes.

Design of buildings which have high energy performance is a complex and iterative process. Performance evaluation of buildings is important and requires a multiplicity of views but each team member during the design process usually takes decisions depending on his or her own professional view (Mora, Bédard and Rivard, 2008). Moreover, analysis of energy performance to support design process is mostly made for buildings which are to be considered for certification such as LEED but it is generally performed after the design process. Maybe reasons of this are that architects are not aware of significance of early design process, performance evaluation and usage of energy simulation tools for this purpose. In addition, the architects mostly focus on limited characteristic features of buildings like shape during the design consideration. If energy performance is considered, decision-making process should be supported during the early design stage (Schlueter and Thesseling 2009). This process can be supported with collaboration of different approaches such as building energy analysis tools, different professionals, and paper-based documents because decisions taken in design stages are usually depending on incorrect, incomplete or highly complex knowledge (de Groot, 1999) and it can lead to buildings which does not meet the expected energy performance targets.

5.1.2. Building Energy Analysis Tools

Energy analysis is very important topic since 1970s and lots of computer based tools has been developed to support design of products or buildings until now. Clarke and Maver (1991) has evaluated this duration under the four sections. In the first generation, tools were handbook oriented and they could not show the real energy and mass flow paths in buildings. Their objective was to present general energy performance of buildings. Second generation simulation tools started to appear in the mid-seventies. There was an attempt to model the real physical conditions in buildings such as multilayered contractions in this period. Third generation tools started to be used in the mid-eighties. Thermal, visual, and acoustic performances of buildings were evaluated together. In the fourth generation which began in the mid-nineties, knowledge based on user interfaces, application of quality control and user training systems were developed for simulation tools. In the first times, usage of the simulation tools was easy but modeling of the real world was difficult. In the following generations, modeling closed to the real world conditions but tools had more complex structure.

Evaluation of energy performance for buildings is not an easy task during the design process. Thus building energy simulation tools has an important role because of their powerful abilities such as modeling lots of possibilities in a short time for passive or active systems. However, most of the available tools are still not common among designers, architects or engineers, for they do not have enough ability and background to assist them during the decision-making process (Sebastian and Ledoux 2009). In addition, most of the energy analysis tools are not well suitable to support early building design process because there are various difficulties. Some of them can be summarized as follows (Xia, Zhu and Lin, 2008, Hobbs et. al. 2003):

- Most of the current tools are needed all of the detailed information to predict energy performance of buildings.
- Simulation tools are usually designed for engineers. Therefore, the inputs or outputs are not consistent for an architect’s background.
- Creation of a thermal model for complex buildings is not easy and mostly possible.
- The architects have poor understanding about simulation and energy modeling.
- Extra workload and time are essential for designers and it leads to extra cost.

Another important point is that one simulation tool is not enough to evaluate energy performance together for heating or cooling, lighting and ventilation. For that reason, designers should select one or more appropriate tools for defined problems. The following criterias can be used for selection of tools (Hong, Chou and Bong, 2000):

- Computing capability: it is defined as core algorithm, application scope, computing speed and accuracy.
- Usability: it should be understandable to learn and user friendly and should also include a well-written user manual.
- Data exchange capability: preparation of input data for tools is a time consuming task and lots of error can happen in this process. Thus they should have a feature to import and export data from different simulation tools.
- Database support: these kinds of tools require many data such as building materials, HVAC components, weather data and etc. Thus they should allow database transfer.

After selection of energy analysis tool, integration of the tool into the design process is difficult and very significant. There are a few work related to integration of simulation tools into the building design stages. Nytsch-Geusen et al. (2003) integrated two energy simulation tools (SMILE and CFD) into a CAAD-program to optimize energy requirements in design stage and the generated software packages was tested successfully for several 3D building constructions. Furthermore, Morbitzer (2003) was developed a concept to support different design stages defined in the Royal Institute of British Architects Design Plan of Work. In this study, interfaces were developed for usage of an advanced energy analysis tool throughout the design process. In addition, several studies about overview of energy simulation tools are available in literature. For example, Hong et al. (2000), Haapio and Viitaniemi (2008), Al-Homoud (2001) and Crawley et al. (2008) investigated available simulation tools and building energy analysis techniques.

Some of the building energy analysis tools commonly used is defined as follows (Crawley et al. 2008):

DOE-2.1: It can be used to calculate the hourly energy usage and energy costs for buildings.

ECOTECT: The most important advantages of this tool is that it has a powerful visual interface for architects and includes a lot of calculation features such as thermal, energy, shading, solar, acoustic, lighting, and costs at the same time. In addition, results of the volumetric and spatial analysis can be shown as 3D.

*Energy 10***:** It is developed to analyze the energy performance of buildings in the early design stage of buildings. By using this tool, many strategies can be assessed related to building envelope such as insulation, glazing, shading, and etc. and system efficiency options like daylighting, photovoltaic and etc.

*EnergyPlus***:** It is a powerful tool for mostly engineers, architects, and researchers to analyze energy (heating, cooling, lighting, ventilation, thermal comfort and etc.) and water usage in buildings. One of the disadvantages for especially architects that EnergyPlus does not have a user-friendly interface.

eQUEST: It is designed to perform detailed comparative analysis for building design and technologies. It can be used to calculate energy cost, daylighting system control and automatic application of energy efficient measures. It is also capable to make multiple simulations for evaluating alternative recommendations.

ESP-r: It is a simulation tool to address thermal, visual and acoustic performance of buildings, energy consumption and gaseous emissions. It also supports early design stage of buildings and enables integrated performance evaluation.

IES: It is helpful to investigate impact of energy efficient strategies, passive/hybrid/renewable strategies, the impact of daylight and solar and etc. It consists of different modules for different purposes.

Tas: It is usable to evaluate thermal performance of new and existing buildings. It consists of three main modules as 3D modeler, building simulator and results viewer.

DesignBuilder: it is the comprehensive user interface to the EnergyPlus software.

5.1.3. Professionals

During the building design process, collaboration of different specialists such as architect, project manager, mechanical, electrical and civil engineer for different purposes (landscaping, acoustics, daylighting, and etc.) is necessary according to complexity of the project. However, today the design process is still architect dominated and most of the specialists join into the design process after completion of architectural design process. Ideally, during the design stages architects should take decisions together with necessary specialist because every specialist can produce a lot of information about own responsibility to increase building performance and every decision can affect the other decisions taken by different discipline (Intelligent Energy, 2009). For instance, architect takes a decision to maximize usage of natural daylighting but it can impact decisions of all specialists like that (Energy Design Resource, 2009):

- The architect updates building envelope for maximum daylight,
- Cost consultant assess effect of the new situation,
- The civil engineer evaluates constructability possibilities for proposed changes,
- The electrical engineer determines suitable lighting alternatives and their control,
- The mechanical engineer calculates the quantity of solar radiation, heat losses and gains and glazing type according to the local climate,
- Energy modeler and sustainability consultant consider energy performance of building and indoor quality according to determined glazing area.

Under the integrated design process, a few studies have been made about importance of cooperation of all disciplines in design process of buildings. One of them is INTEND which is a European Union supported project. Its objective is to improve integrated energy design as European practice and determine a new standard in view of the European Commission Directive on energy performance of buildings. One of the significant parts of the project is inter-disciplinary study between architects, civil, electric, management engineers, and etc. from starting of the design duration (Synnefa, Karlessi and Santamouris, 2008).

5.1.4. Paper-based Documents

Paper based documents can be grouped as special papers, national codes and standards. They are essential tools for countries since construction industry cannot guarantee minimum standards for energy performance in buildings every time. In addition, construction industry usually does not take into consideration operation costs for heating, cooling, ventilating and lighting energy in buildings because they assume that homebuyers are responsible from the operating costs. Therefore they usually do not focus on energy efficient design and solutions.

5.1.4.1. Special Papers

For designer, there are various sources in literature which do not provide predictions about energy performance of buildings. They usually include best practice examples, recommendations and compulsory requirements to provide possible energy efficient design solutions.

These kinds of documents to support design process can be summarized as published textbooks, best practice publications, databases, web-based, media publications, professional journals, statutory instruments, design research, refereed papers and journals, manufacturer’s literature, and precedent (Tunstall, 2006). If this kinds of documents lead to awareness about importance of energy consumption in buildings for designer, it may be accepted that it has succeed its major purpose. After that design team can focus or investigate on appropriate energy efficient strategies for own buildings.

One of the important documents is guidelines for supporting design process. They are usually developed by consultancy companies, institutions, and special organizations such as ASHRAE, CIBSE and etc. Bay (2001) stated that design guidelines for sustainable and climate conscious building design can be used in analogical, pre-parametric and qualitative design thinking process.

5.1.4.2. National Codes and Standards

Codes and standards related to energy performance of buildings usually covers different recommendations to minimum energy requirements for building design. They can be mandatory or preferable in national level. Codes are written in mandatory by states or local governments. Standards are prepared by various organizations and are a kind of national recommendations depending on local climate (Bartlett, Halverson and Shankle, 2003).

The most important reasons to use building energy codes or standards defined by U.S. Department of Energy are as follows (U.S. Department of Energy, 2010):

1. Excessive energy consumption can be reduced for heating, cooling, lighting, ventilating, and providing hot water.
2. Rate of the emissions can be limited.
3. New job and opportunities can be increased.
4. Energy efficiency requirements can be learned.
5. Cost-effective solutions can be shared.
6. New building technologies and design strategies can be developed,
7. Common actions and solutions can be supported.

Therefore, many countries have different building codes and standards for new or existing buildings. For example, today almost all OECD countries have building codes and standards supporting minimum energy efficiency requirements in buildings. In addition developing countries such as China and India investigates extra ways to improve thermal comfort conditions and to decrease rapid increase in energy consumption (Laustsen, 2008).

5.1.5. Decision Support Techniques

Making a decision can be defined as selecting one among multiple alternatives. Thus we can need to techniques to make right selection which means taking optimum benefits as a result of the final choice. According to a study made in 1980 by Alter decision support systems is grouped into seven types:

1. File drawer systems,
2. Data analysis systems,
3. Analysis information systems,
4. Accounting and financial models,
5. Optimization models,
6. Representation models,
7. Suggestion models.

In this part, optimization models commonly used techniques to support energy efficient building design are investigated. Different techniques can be used to generate the best possible solutions in terms of maximum energy efficiency together with user, occupant, owner demands, social and financial factors in buildings (Diakaki, Grigoroudis and Kolokotsa, 2008). These techniques are usually related to multi-criterion optimization problems. One of them is multi-criteria based decision making.

The general aim of the multi-criteria decision making is to support people while taking decision about selection of the best alternative among lots of possible alternatives depending on several criteria and priorities (Jankowski and Richard, 1994). The multi-criteria decision making can also be used to optimize final solution by considering preferred all criterias such as energy performance, initial cost, thermal comfort and etc. during the design process.

Today several studies are available about multi-criteria techniques used to improve energy performance in literature. Diakaki et al. (2008) examined feasibility of multi-objective optimization methods for development of energy performance of buildings in 2008. Diakaki and her friends (2010) evaluated lots of possible alternative measures based on annual primary energy consumption, the annual carbon dioxide emissions and the initial investment costs to develop energy performance of a building by using a multi-objective decision model. Hamdy et al. (2011) was used a modified multi-objective optimization approach to minimize the carbon dioxide equivalent emissions and the initial cost investment for a two-storey house and its HVAC system. Modified multi-objective optimization approach consists of genetic algorithm and a building performance simulation (IDA ICE). Flourentzou and Roulet (2002) and Rey (2004) used multicriteria analysis approach to help experts in generating retrofitting alternatives. Blondeau et al. (2002) determined the most appropriate ventilation strategy on a university building for summertime by using multicriteria analysis methods.

Another decision support method is genetic algorithm. It is used for mostly multi-criterion optimization problems. Genetic algorithm is a kind of heuristic search that simulates the process of natural evolution (Ivashkov, 2004). Genetic algorithms can be used for various energy optimization processes such as energy efficient building design, solar hot water systems, and etc (Znouda et. al. 2007). There are limited resources about multi-criteria decision based on genetic algorithm related to buildings in the published work. Tuhus-Dubrow and Krarti (2010) developed a simulation-optimization tool to find optimum building shape and envelope features. Magnier and Haghighat (2010) showed a fast and efficient multi-objective optimization approach including genetic algorithm, artificial neural network and TRNYS simulation. This approach was used to optimize the energy consumption and thermal comfort of a residential building. Znouda et al. (2007) generated an optimization algorithm based on genetic algorithm to determine the best configurations in terms of energetic and economic points of view. Wright et al. (2002) investigated feasibility of a multi-criterion genetic algorithm to optimize energy costs caused by HVAC system operation and size and thermal comfort in buildings.

5.2. Proposed Approach to Develop the Practical Guide

A general issue in terms of energy performance of buildings during the design phases is that there are many different design alternatives and materials and also major decisions should be taken in early stages to design buildings consumed low energy. In the late design process, reduction of energy consumption is possible but interventions can remain in the limited level because many design decisions already have taken. Therefore, interventions can lead to waste of time and resource.

There are different ways to overcome this problem. One of them is to use appropriate approaches to support design process to provide information about general effects of design and material alternatives on energy performance during the design process. For example, guidelines can be used for that purpose because they can include knowledge about probable impacts of design parameters on energy performance and can lead to easily creation of alternatives by design teams. Moreover, extra data from simulations could also be considered and used. In addition, guidelines can be helpful to spread scientific knowledge to the professionals. In other words, it can also be a source to integrate scientific information into the practical design process. The practical capacity of scientific knowledge depends on two preconditions: results of the scientific knowledge should be problem oriented and it should be admitted in the practical field (Pregernig, 2000). For that reason, findings of scientific studies should be understandable by professionals. However, statements preferred in the scientific and practical studies are generally different. For instance, while the term ‘energy efficient buildings’ are usually used in scientific researches, ‘green buildings’ are used for the same expression among professionals in Turkey. Thus, terms used in practical life should be preferred. Generally, while scientific studies are examined and read by academicians and researchers, professionals mostly prefers to examine documents and journals related to practical conditions.

In this dissertation, a practical guide is developed to convert findings of thesis to practical life. Original language of the practical guide was determined as Turkish because it is intended to use by architects in Turkey. The practical guide was developed by following four steps explained below (Figure 5.1):

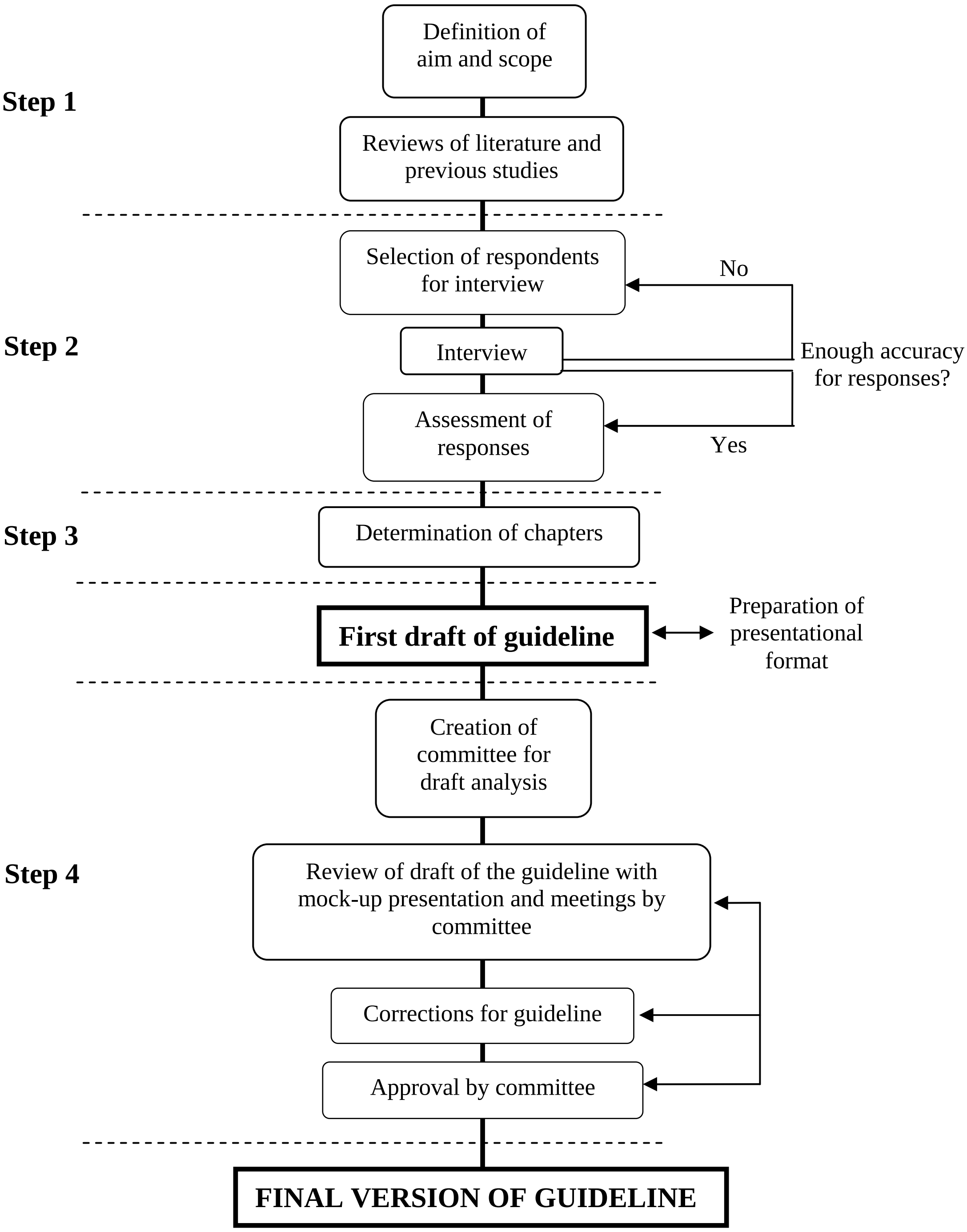


Figure 5.1. The four steps for practical guide

Step 1: The first step is to determine aim and scope of the practical guide depending on necessitates and problems in a local region. The practical guideline is written to help architects responsible from building design parameters which can be controlled and used to improve energy performance and reduce negative environmental effects of energy consumption. Thus, architects are the main audience of the practical guide.

The aim of the guide should be specific and narrow and should not be too general because there already several sources like books for different subjects and climatic conditions. Thus, basic objective of the guide is to support architects while improving design alternatives and taking decisions in order to reduce cooling demand of low-rise apartment buildings in Izmir located in hot-humid climatic region of Turkey. In other words, it shows potential impacts of selected building design parameters on annual cooling energy load for the time period of today, 2020s, 2050s, and 2080s. Cooling loads in low-rise apartment blocks in hot-humid climate is bigger problem than heating because annual cooling loads is usually more than heating loads in that region and while heating loads would decrease, cooling loads would increase depending on magnitude of the global warming over time.

The practical guide provides recommendations and rules-of-thumb to reduce cooling requirements of low rise apartment buildings located in hot-humid climatic region of Turkey in design stage. Design of a low-rise apartment block based on the practical guide is lead to low energy consumption for cooling when compared to the same apartment buildings designed based on the minimum requirements defined in TS 825-Thermal Insulation Regulation in Buildings. It should be noted that the guide does not cover other aspects required for energy efficient building design such as heating, lighting, and water usage or hot water requirements. In addition, knowledge in the guide cannot be applied to all climatic conditions and all kind of building by architects.

Existing studies depending on determined aim and scope of the practical guide are reviewed. Literature review is necessary to collect and summerize existing sources about building design parameters and methods which can be used in development phase of the practical guide. Another reasons to make literature review can be summurized as follows (Hart, 1998):

- Investigation of significant points related to the subject,
- Gain of a unifying and new perspective,
- Definition of relations between ideas and practices,
- Constitute of the coherence of the subject,
- Rationalizing of the importance of the problem,
- Investigation of relating ideas and theory to apply,

- Discovering of the metholodigies used before.

There are several guidelines about improvement of energy performance in buildings, which were constituted by various institutions and organizations. Here a few of the outstanding guidelines were only summarized.

ASHRAE GreenGuide: The Design, Construction, and Operation of Sustainable Buildings were developed by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2006). It is mainly focuses on technical aspect of high performance design and teamwork and also close coordination between professionals. There is only one part about effects of architectural design on energy performance.

The ASHRAE Advanced Energy Design Guides are a series of guidelines including recommendations to save energy more than minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1. The guidelines are for small hospitals and healthcare facilities, highway lodging, small warehouses and self-storage buildings, K-12 school buildings, small retail buildings, and small office buildings. They were produced with energy professionals from ASHRAE, the American Institute of Architects, the Illuminating Engineering Society of North America, and the U.S. Green Building Council and also it is supported by the Department of Energy. The most important feature of these guidelines is that they have different recommendations depending on the eight U.S. climates zones. All recommendations are tested by using building hourly energy analysis software by using a prototype building in different climatic regions of U.S. Then the results are compared to buildings designed based on Standard 90.1-1999 (ASHRAE, 2011). Lastly, The ASHRAE was published a new guideline in 2011 for small to medium office buildings to succeed 50% energy savings more than the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004. Its method is the same with previous guidelines.

Environmental design is a guideline developed by The Chartered Institution of Building Services Engineers (CIBSE). CIBSE is an institution which publishes different guidance and codes related to improvement of building energy performance. The guideline was developed by a group of professionals. Its main aim is to provide information about design, installation, commissioning, operation and maintenance of building services (CIBSE, 1999).

Multifamily Green Building Guidelines was produced by Green Building in Alameda County and Build It Green. It consists of cost-effective recommendations to minimize construction –related waste and to reduce operating costs for owners. In addition, it shows methods to reduce impact of buildings on environment in California communities (Build It Green, 2008). There are lots of similar guidelines for different cities and building types in literature.

Step 2: The second step is to constitute an interview. Interview is preferred because of the limited reliable existing data about how to prepare a guideline in literature. This part is important because it is helpful to obtain information on a specific topic or a specific area to be researched. Type of interview can be structured or unstructured depending on the subject. One of important points in this process is to determine participants and their number for interview. Participants should be selected among professionals who have experience about determined subject and is located determined region because the guide is used by architects who working in Izmir and do not have enough background in that subject. They are also main audience of practical guide. Therefore, architects who have enough information should formalize first draft of the guide. Interview is organized to constitute feedback for practical guide and find out audience's necessitates and considerations depending on scope of the guide.

The interview was conducted in spring 2010 to find out considerations of architects about four topics as follows:

- Energy for heating or cooling which is mostly needed in apartment buildings during the one year in Izmir,
- Architectural measures to reduce energy consumption for cooling in apartment buildings in Izmir,
- Information which is necessary to develop and integrate architectural measures into the design process to reduce energy consumption for cooling in apartment buildings,
- Source which is necessary to get that information (book, journal, internet and etc.).

Another objective of the interviews is to constitute a general feedback for practical guide.

Therefore, at the end of each interview, interviewees were asked to comment on what you consider about necessity of a practical guide related to reduction of energy consumption for cooling in apartment buildings in Izmir.

The respondents are consists of five architects who worked at national level, on commercial architectural projects in Izmir and are considered as experts on energy efficiency in buildings. Thus the sample size is admitted as enough and satisfactory because there are no lots of special architects and if the number of the respondents increases, data gathered from respondents can start to become similar. The probable reason of this is that importance of energy performance in buildings in terms of cooling requirements is still a new issue among architects in Izmir and they have lack of information about that. The interviews can be categorized as qualitative semi-structured and were performed face to face.

The responses shown here are limited with issues related to the questions. Five interviewees are coded as A, B, C, D and E in order.

Responds for question 1: There is no common perception among the interviewees about the amount of the annual heating and cooling loads but a part of the interviewees agrees that mainly cooling requirements is more than heating or they are equal. Heating loads are greater than cooling is only opinion of the one interviewer.

- It is stated that cooling loads is more than heating loads in apartment buildings in Izmir (A).
- Both the heating and cooling requirements are almost the same in apartment buildings but heating degree days (HDD) are less than cooling degree days (CDD). In addition, the need for cooling in apartment buildings is an emerging occupancy demand in terms of comfort was also emphasized (B).
- Although cooling requirement is more than heating there is no too much difference between them was called (C).
- Cooling loads are greater than the heating loads and cooling is a major problem in apartment buildings because individual measures can be taken to be protected from the negative impacts of low temperature in winter. However individual measures to be protected from the negative impacts of high temperature are limited in summer (D).

- Heating need is more than cooling demand in apartment buildings. Furthermore, cooling requirement in terms of comfort conditions is a new expectation by owners (E).

Responds for question 2: Most of the interviewees have the similar opinion that orientation, usage of thermal insulation and material choice are common measures. In addition, there is almost no chance to select appropriate orientation for apartment buildings because of the high density especially in city center was strongly emphasized by all interviewees.

- Shading, orientation and insulation are important measures but architects usually do not prefer shading devices which do not add aesthetical advantages to building. Moreover, the usage of plants, natural ventilation and wind catchers can be used to reduce cooling loads in apartment buildings (A).
- It is difficult to take benefit from the orientation in city center, and shading device and insulation are helpful. Furthermore, it was expressed that though natural ventilation is an effective measure for cooling, configuration of windows is not easy in apartment buildings. The choice of the material is another important measure which is easily applicable (B).
- Insulation is necessary to reduce both heating and cooling demands in residential buildings. Therefore, the regulation, Thermal Insulation in Buildings (TS 825) should be known very well by architects but it is not easily understandable. It is also stated that the use of appropriate material is important measure for cooling in apartment buildings (C).
- Wind direction should be considered during the design process and, shading device and usage of thermal insulation are significant factors to reduce cooling demand (D).
- Orientation is the most important measure for cooling. Material selection and especially usage of the ecological materials are other effective measures. In addition, space organization is also helpful to decrease cooling loads (E).

Responds for question 3: all respondents consider that local climatic data and information about the ecological materials are needed.

Responds for question 4: The interviewees believe that necessary information can be provided from mostly internet, journals, magazines, and seminars organized by different institutions.

- Information is accessible from internet, journals, and seminars. In addition, experience is so important and it was stated that undergraduate courses are still useful in professional life (A).
- Most knowledge can get from internet, material catalogs and journals (B).
- It was expressed that seminars about thermal insulation organized by Chamber of Architects and journals are helpful to obtain adequate information. Today, search engines are also easy way to reach all knowledge (C).
- Cooperation with mechanical engineer is an effective way. Seminars organized by Chamber of Architects are helpful. Sectoral trade fairs and journals are another ways to access knowledge (D).
- Magazine and internet are easy way to access desired information (E).

Another subject in discussion was the practical guide. All interviewees answered that practical guide should cover local climatic data and they should be explained with graphics to easy understand. In addition, shapes and complementary texts to express any kind of information in practical guide can improve intelligibility is general belief among interviewees. A number of interesting conclusions resulted from the interviews are as follows:

- Cooling in residential buildings is a new requirement for comfort conditions.
- Directed to appropriate orientation is usually not possible to increase energy performance in dense cities.
- Thermal insulation is very well known measure but another measures related to color usage, glazing selection, thermostat temperature, air infiltration and etc. have not been emphasized and called by interviews.
- Major source to get information is search engines in internet and other common source is journals. Any book name could not given by interviews.

Step 3: Chapters for practical guide were determined according to aim of the practical guide and results of interviews. Then essential information was used to constitute chapters of first draft of practical guide.

Chapters were mostly developed by using current chapters of thesis. Therefore, Chapter 2 and 4 of the thesis were reorganized by using common words used in building sector in Turkey. Additional data was created to show rate of heating and cooling loads in low-rise apartment blocks in the future. It was calculated by using energy analysis tool, EnergyPlus. In addition, possible variations in annual cooling energy loads obtained by changing values of some design parameters were investigated. Outcomes of these analyses are shown in APENDIX A. A brief outline of each chapter for first draft of practical guide is as follows:

Chapter 1 is an introductory part covering basic information about audience, aim, content and limitations in the practical guide.

Chapter 2 shows general information related to climatic features of Izmir, effects of global warming on annual cooling and heating energy loads. Thus energy loads for cooling and heating of selected existing low-rise apartment block was calculated for the time periods of today, 2020s, 2050s, and 2080s.

Chapter 3 consists of short explanations of major building design parameters which have impact on annual energy loads for cooling in low-rise apartment buildings. Design parameters summarized in practical guide were taken from second chapter of the thesis.

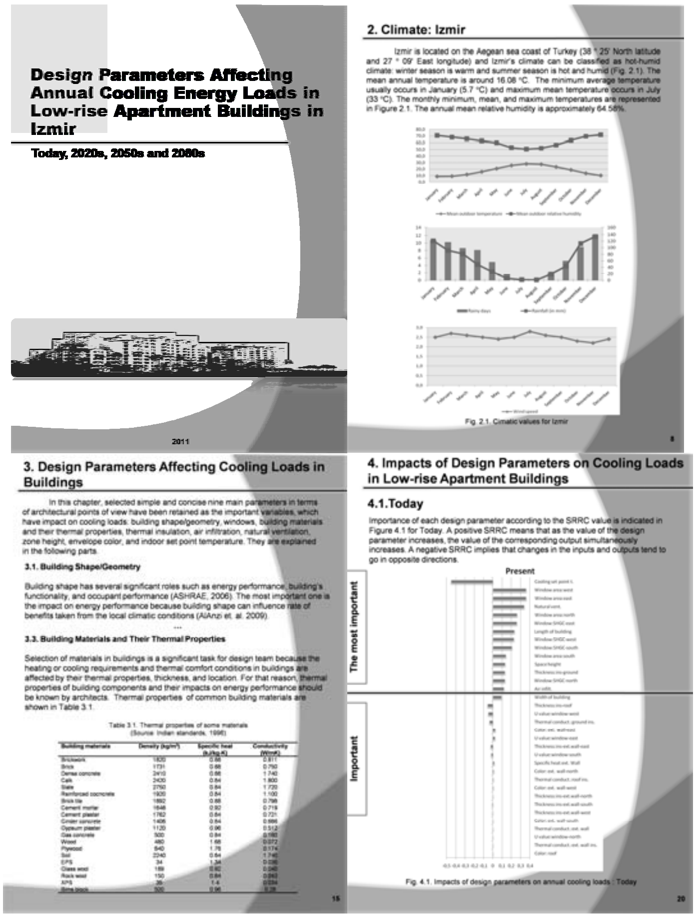
Chapter 4 is the main part of the practical guide. In this part, effects of the selected building design parameters such as main external wall material, insulation material, thickness of the insulation on external wall, roof, and ground floor, window to wall area ratio, heat transfer coefficient of glazing, solar heat gain coefficient of glazing on annual cooling energy loads are showed and discussed. In addition, possible variations in annual cooling loads as percentage based on change in each selected design parameter was indicated and examined.

Step 4: After development of first draft of the practical guide preparation process continues with a series of mock-up presentations and meetings together with four academicians (three architects and one mechanical engineer) who are expert on energy efficiency in buildings to evaluate and constitute final draft of the practical guide. In addition, individual meetings were also made with four academicians. During this process, a PowerPoint slides showing was made to all academicians before completing final draft. The results of the conservations and presentation can be summarized as follows:

- More graphs should be used in practical guide and they should be very clear and easy understandable for audience. Explanation of the graphs is important and necessary.

- Words used in practical guide should be selected from practical life.
- The length of the practical guide should not be long. It should give all information directly.
- Visual design of practical guide is significant issue but extra help can be taken from professional about journal designer.
- In brief, it is expected that the practical guide can help architects in the design process

According to results of these meetings and presentation first draft of practical guide was improved and final draft was completed (See Figure 5.2).



Design Parameters Affecting Annual Cooling Energy Loads in Low-rise Apartment Buildings in Izmir

Today, 2020s, 2050s and 2080s

2011

2. Climate: Izmir

Izmir is located on the Aegean sea coast of Turkey (38 ° 25' North latitude and 27 ° 09' East longitude) and Izmir's climate can be classified as hot-humid climate: winter season is warm and summer season is hot and humid (Fig. 2.1). The mean annual temperature is around 16.08 °C. The minimum average temperature usually occurs in January (5.7 °C) and maximum mean temperature occurs in July (33 °C). The monthly minimum, mean, and maximum temperatures are represented in Figure 2.1. The annual mean relative humidity is approximately 64.58%.

Fig. 2.1. Cimatic values for Izmir

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3. Design Parameters Affecting Cooling Loads in Buildings

In this chapter, selected simple and concise nine main parameters in terms of architectural points of view have been retained as the important variables, which have impact on cooling loads: building shape/geometry, windows, building materials and their thermal properties, thermal insulation, air infiltration, natural ventilation, zone height, envelope color, and indoor set point temperature. They are explained in the following parts.

3.1. Building Shape/Geometry

Building shape has several significant roles such as energy performance, building's functionality, and occupant performance (ASHRAE, 2006). The most important one is the impact on energy performance because building shape can influence rate of benefits taken from the local climatic conditions (AlAnzi et. al. 2009).

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3.3. Building Materials and Their Thermal Properties

Selection of materials in buildings is a significant task for design team because the heating or cooling requirements and thermal comfort conditions in buildings are affected by their thermal properties, thickness, and location. For that reason, thermal properties of building components and their impacts on energy performance should be known by architects. Thermal properties of common building materials are shown in Table 3.1.

Table 3.1. Thermal properties of some materials
(Source: Indian standards, 1996)

Building materials	Density (kg/m³)	Specific heat (kJ/kg.K)	Conductivity (W/mK)
Brickwork	1820	0.88	0.811
Brick	1731	0.88	0.750
Dense concrete	2410	0.88	1.740
Calk	2420	0.84	1.800
Slate	2750	0.84	1.720
Reinforced cocncrete	1920	0.84	1.100
Brick tile	1892	0.88	0.798
Cement mortar	1648	0.92	0.719
Cement plaster	1762	0.84	0.721
Cinder concrete	1406	0.84	0.686
Gypsum plaster	1120	0.96	0.512
Gas concrete	500	0.84	0.190
Wood	480	1.68	0.072
Plywood	640	1.76	0.174
Soil	2240	0.84	1.740
EPS	34	1.34	0.035
Glass wool	189	0.92	0.040
Rock wool	150	0.84	0.043
XPS	35	1.4	0.034
Bims block	500	0.96	0.28

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4. Impacts of Design Parameters on Cooling Loads in Low-rise Apartment Buildings

4.1.Today

Importance of each design parameter according to the SRRC value is indicated in Figure 4.1 for Today. A positive SRRC means that as the value of the design parameter increases, the value of the corresponding output simultaneously increases. A negative SRRC implies that changes in the inputs and outputs tend to go in opposite directions.

Fig. 4.1. Impacts of design parameters on annual cooling loads : Today

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Figure 5.2. Examples from the final version of the developed practical guide

CHAPTER 6

CONCLUSIONS

6.1. Concluding Remarks

Global warming may require new considerations for the built environment because it is projected that cooling demand in buildings can increase especially in warmer parts of the world over time. In addition to this, expectation of high living standards in apartment buildings has raised usage of air conditioning devices and energy consumption for cooling. For that reason, necessity for climatically responsive buildings which consume low energy for cooling has increased but design of them is not possible every time since architectural design is generally a complex issue and process. Moreover, effective and efficient design to keep up the energy performance in satisfactory level is not an easy work during the design process. Collaboration with other professionals such as mechanical engineer is limited and application of passive design strategies cannot always be possible in dense cities. Thus, design process is usually architect dominated and building design parameters may have an important effect to provide desired energy performance in apartment buildings.

For that reason, the dissertation firstly explores the most significant building design parameters which affect annual cooling energy loads in low-rise apartment blocks in the hot-humid climatic region of Turkey by using global sensitivity analysis technique. In addition, change in annual cooling energy loads due to the uncertainty caused by building design parameters and global warming is investigated. Moreover, hourly climatic data for the time horizons of 2020s, 2050s, and 2080s is generated to examine impact of global warming on the sensitivity of building design parameters and to investigate variations in annual cooling energy loads. Conclusions of sensitivity and uncertainty analysis can be stated as follows, but it should not be forgotten that the results can change for different climatic conditions:

1. Major architectural design solutions should be determined based on the dominant energy requirements in low-rise apartment blocks, because the

sensitivity of building design parameters can mainly vary depending on the annual heating and cooling energy loads.

2. The amount of the energy for cooling can change according to which floor is considered. Thus, thermal models of apartment blocks should be prepared by subdividing them into ground, intermediate and top floors to evaluate energy performance in detail. Such a procedure also provides feedback for clients to select flats which need low energy.
3. The annual cooling energy loads are mostly affected by the features of the windows (such as the area, and SHGC value depending on orientation), building length and width, natural ventilation, air infiltration, thickness of ground and roof insulation, zone height, and cooling set point temperature in hot-humid climatic region of Turkey. Other design parameters have little impact on annual cooling energy loads compared to the most sensitive design parameters. Thus, design team should mostly focus on the most sensitive design parameters to improve the energy performance of low-rise apartment buildings in the early design stage. According to the global warming order of the design parameters can change but almost the same parameters are the most important design parameters for all the time periods.
4. It is clear that natural ventilation is one of the most important design parameter after the window area on east and west direction at present and its importance is increasing in 2020s, 2050s, and 2080s. In other words, it is a critical factor in low-rise apartment blocks in terms of annual cooling energy load. If the natural ventilation rate is increased, especially when outside temperature is higher than inside temperature during the day, it can lead to increase in energy consumption for cooling. In those times, natural ventilation should be reduced. However, night ventilation can be helpful to reduce annual cooling energy loads because of the low temperature at night, for it can decrease heat stored in the building mass during the day. Therefore, size and location of windows on the plan and section for natural ventilation should be one of the significant design decisions for architects. Windows should be designed to allow controllable ventilation in buildings during the day and night.
5. Windows have very important impact on annual cooling energy load in hot-humid climates. In general, a decrease in window area results in reduction of

annual cooling energy loads because of the low solar radiation. It can also be seen that east and west facing windows are more significant than south and north facing windows. It may be related to that east and west facing windows receive excessive solar radiation in the morning and afternoon in summer. In addition, solar radiation comes with very low angle towards the east and west facing windows. Therefore, the control of the sun is difficult on those orientations. Windows facing east and west can be smaller than south and north facing-windows to reduce solar radiation.

6. Thermophysical properties of glazing have influence on the energy performance of buildings. However, the results showed that only low SHGC value can provide significant energy reduction in annual cooling energy load in the hot-humid climate and its importance varies depending on orientation. Low SHGC means that low solar radiation enters into the building from windows. In winter it can increase heating demand. Hence, solar radiation can also be blocked using shading device but shading devices are mostly beneficial on windows facing south. The glazing with low SHGC should be preferred for east and west facing windows or window size can be decreased if possible. U value of windows has too small impact on annual cooling energy load. In other words, it does not have a deterministic role in design process in that climate. Selection of glazing should mostly be made according to the SHGC value in hot-humid climate. This value provides advantages to easily reduce annual cooling energy load especially if window area is high.
7. Building shape can influence the rate of benefits taken from the local climatic conditions. Thus it is described with building length and width in this study. In real situation, building shape usually is defined based on lots of factors considered by architects. It is found that building length has more impact than building width on annual cooling energy load and its importance is increasing in the future. Reason of this may be related to orientation that building length including facades is directed to east and west. These directions exposure to high solar radiation in summer. Thus the amount of these facades should be little than facades facing north and south but it cannot be possible or not preferable every time for architects.

8. Thermal insulation is an easy and cost effective solution, thus, should be first measure for energy conservation in buildings, but features of the climate and dominant energy demand should be taken into account while determining thickness of thermal insulation. Increasing of insulation thickness on external walls has a relatively small effect on annual cooling energy loads for all the time periods in hot-humid climate. Therefore, insulation thickness for external walls should be determined depending on annual heating demand and mandatory regulations. Increasing insulation thickness should not be preferred as the first energy efficient measure in order to reduce annual cooling energy loads. Firstly, the most sensitive design parameters should be used to reduce annual cooling energy load. Ground insulation has relatively high influence on annual cooling energy loads compared to insulation on external walls but an increase in insulation thickness on ground is lead to more energy consumption for cooling. One reason for this may be that the ground surface is cooler than the above-ground space in summer because of the low soil temperature, and high insulation thickness can reduce heat losses from inside to the ground. Minimum insulation thickness shown by mandatory regulations is enough on the ground in terms of cooling demand in hot-humid climates. It can also be concluded that insulation on floors is an essential measure in multistory buildings because insulation on ground floor has a significant impact on annual cooling load of a nine storey building. Insulation is also one of the effective ways on the roof than external wall because the roof surface is exposed to high solar radiation during the all day in summer. Insulation thickness on the roof can be increased to reduce annual cooling energy loads in hot-humid climate.
9. The infiltration in buildings is usually related to quality of construction process and materials. It is clear that rate of the infiltration affects annual cooling demand in buildings. Increasing infiltration rate can lead to high cooling demand in buildings. It is mostly due to the high outdoor temperature in summer. Its sensitivity is also rising in the following years because mean outdoor temperature can be higher than today because of the global warming. For that reasons, airtight buildings should be designed to reduce uncontrolled air flow. It can be derived that airtightness is a significant design parameter to provide low cooling requirement in buildings in hot-humid climate.

10. Zone height directly affects volume of the space and it changes cooling demand. Therefore, floor height should be minimized for low cooling requirement depending on architectural and technical necessities. In addition, its sensitivity is almost the same for all the time periods.
11. There are different external wall and insulation materials in construction industry. Thus the architects can select one of them in design process. In terms of cooling demand, the external wall and insulation materials are not one of the sensitive parameters in low-rise apartment blocks. It means that changing of insulation or external wall materials does not affect so much cooling requirement in hot-humid climates. Their sensitivity is almost the same for other time periods.
12. The color of building envelope has minimum influence on annual cooling energy load but it can be observed that light color and light colored materials are suitable for external walls and roof in hot-humid climates.
13. Design decisions related to color, insulation thickness, thermophysical feature of glazing, window size and etc. should be specific to the orientation to take high benefits from these parameters in low-rise apartment blocks.
14. Global warming has a significant impact on the uncertainty in the annual cooling energy loads.
15. The uncertainty in the annual cooling energy loads is relatively high and it rises because of the global warming. Therefore, min. and max. values of especially sensitive building design parameters may be determined by compulsory regulations. As a result of this, architects cannot select values which can lead to excessive annual cooling energy load in low-rise apartment blocks. These limitations can provide high energy performance in buildings in a short time.
16. Sensitivity analysis can also be used for retrofitting of existing buildings because the most effective measures can be determined easily depending on results of sensitivity analysis.
17. The sensitivity of building design parameters and possible ranges in annual heating and cooling energy demands for different climatic conditions can be determined easily by applying the process discussed in the present thesis.

As a result, the findings of thesis can provide more consciousness and flexibility for architects in the early design process of low-rise apartment blocks in the hot-humid climate. Firstly, by considering considerable reductions in energy consumption for cooling, to know the most important building design parameters before the building is constructed can affect material, dimensional, functional or visual choices of architects in more energy-efficient way. Secondly, since the rate of the seasonal energy consumption for cooling varies based on ground, intermediate and top floors, it gives an opportunity to develop specific energy performance improvement and optimization strategies for particular lateral zones of low-rise apartment blocks, which provide more flexibility in design of both building itself and its cooling systems. Lastly, early information provided by global sensitivity and uncertainty analysis can be used easily in the architectural practice. In other words, sensitivity and uncertainty analyses can be helpful to improve the energy performance of buildings in early stage of the building design.

A practical guide was developed to integrate produced information in thesis into the architectural practice for Izmir. This part of the study shows an approach to develop a practical guide about reduction of energy consumption in buildings located in a city or climatic region. Suggested approach consists of the following steps: literature review about case-specific subject, interviews with main audience of the guide, determination of chapters for practical guide, and mock-up presentations and meetings with professionals to constitute final draft of guideline. It can be concluded that (1) this type of approach needs a long process to obtain extensive and reliable data, but it is feasible and easily applicable for a region or city; (2) the global sensitivity analysis with the defined approach is helpful to develop a practical guide showing sensitive and robust design parameters; (3) this kind of practical guide provides helpful information to assess relevance and importance of design parameters for architects in the early design process; (4) low energy consumption in buildings compared to buildings designed based on the mandatory regulations defined by countries can be possible by designing them in view of a specific guide. Furthermore, the global sensitivity and uncertainty analysis can be used to generate case-specific information for guidelines.

6.2. Recommendations for Future Work

As a further step, the methods to find the most important building design parameters, which is used in this study, can be developed as a tool to increase usability for architects. Simulation tools are not widely used by designers in Turkey because they are not familiar with simulation tools due to their complexity and the lack of information about building physics. This research may be a beginning point towards better understanding of importance of building design parameters, simulation tools and sensitivity and uncertainty analysis in the building sector of Turkey. Several practical guides to reduce heating, lighting, ventilation energy can be developed for different building types by using the approach showed in this thesis.

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APPENDIX A

ADDITIONAL INFORMATION FOR PRACTICAL GUIDE

Here, additional information used in practical guide is summarized. This information is added to emphasize importance of sensitive design parameters and to ease understanding of reader.

Annual heating and cooling energy loads and also the range of influence of only sensitive design parameters on annual cooling energy consumption are indicated for today, 2020s, 2050s, and 2080s. The existing low-rise apartment block is defined in Chapter 4 in detail. It is admitted that the building has a central cooling system because generation of a general schedule for cooling is not easy for each flat because of the different behavior and daily activities of occupancies. Set point temperature is 26°C for cooling and 21°C for heating. In addition, heating system is turned on between 7 and 24 in winter season. Air-conditioner is turned on between 11 and 24 during the summer season. Furthermore, constant air infiltration rate is accepted as 1ach in all calculations.

A.1. Annul Cooling and Heating Loads in Existing Low-Rise Apartment Block

Figure A.1 and A.2 shows annual heating and cooling energy loads based on ground, intermediate and top floors. It is clear that average annual heating loads can be less than today. Percentage decrease for heating would be 20% in 2020s, 36% in 2050s, and 56% in 2080s compared to today. It can be seen that annual cooling load would be more than 32% in 2020s, 68% in 2050s, and 230% in 2080s compared to today.

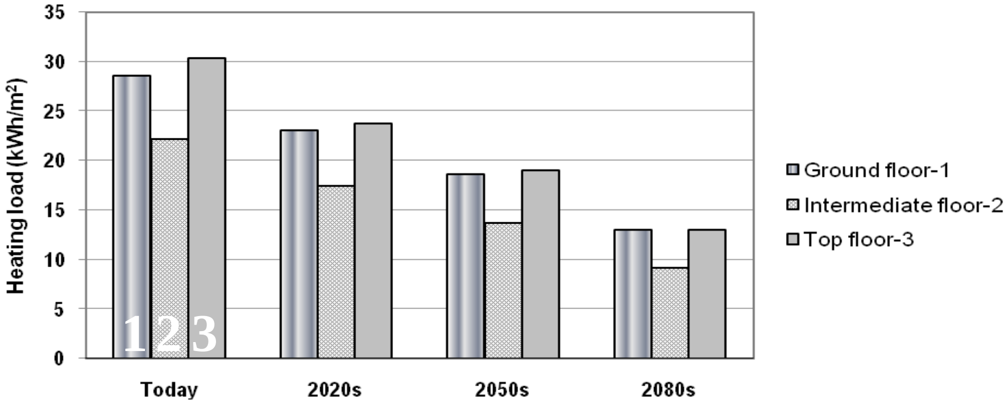

Figure A.1. Annual heating loads according to years

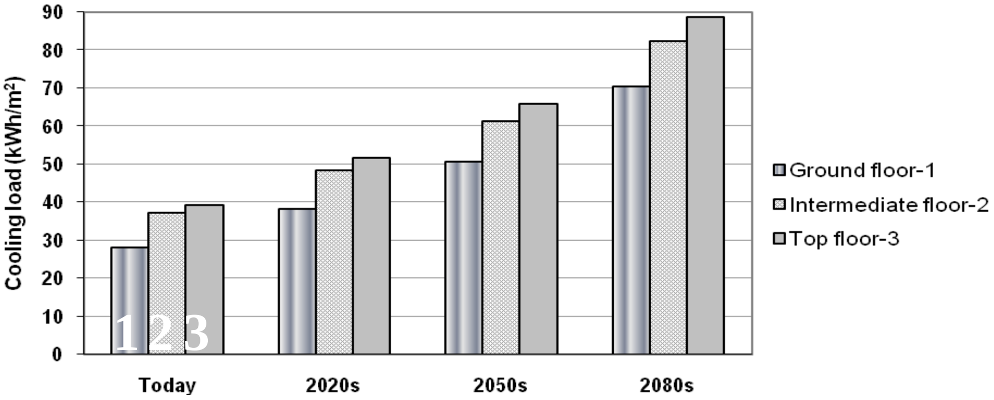

Figure A.2. Annual cooling loads according to years

A.2. Relative Effect of Sensitive Design Parameters on Annul Cooling Loads

All values are calculated by using existing low-rise apartment block and annual cooling loads are shown for all floors.

A.2.1. Set Point Temperature

When set point temperature decreases from 26°C to 23°C, annual cooling load would be more than 69% today. Percentage increase in annual cooling load would be 28% in 2020s, 73% 2050s, and 235% in 2080s.

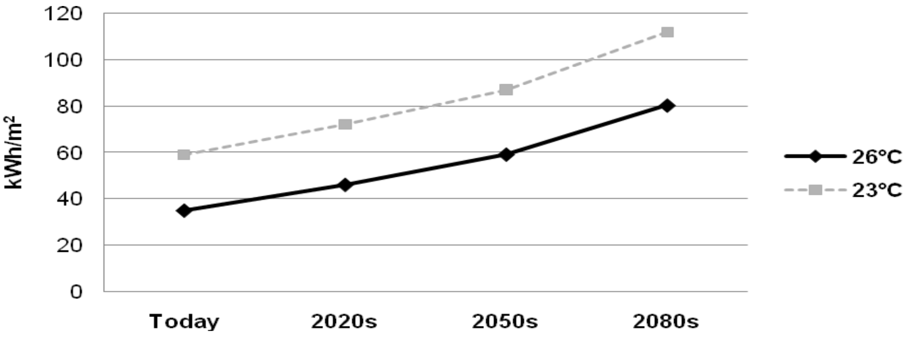

Figure A.3. Influence of set point temperature on annual cooling load

A.2.2. Window

Windows are one of the important parameters affecting cooling load. Thus, decreased window area in all orientations improves energy performance in terms of cooling.

If window area is reduced, cooling load can be decreased and reduction rate can change based on the directions. For example, if window area on south direction is designed as 30% instead of 50%, annual cooling load in existing low-rise apartment block can be 13% less today, 10.8% less in 2020s, 8.8% less in 2050s, and 7.2% less in 2080s (Figure A.4).

If window area on east direction is design as 20% instead of 40%, 11% today, 9.6% in 2020s, 8.2% in 2050s, and 6.5% annual cooling energy load in 2080s can be saved (Figure A.5).

If window area on west direction is design as 30% instead of 50%, annual cooling load in existing low-rise apartment block can be 11% less today, 9.6% in 2020s, 8.2% in 2050s, and 6.5% in 2080s (Figure A.6).

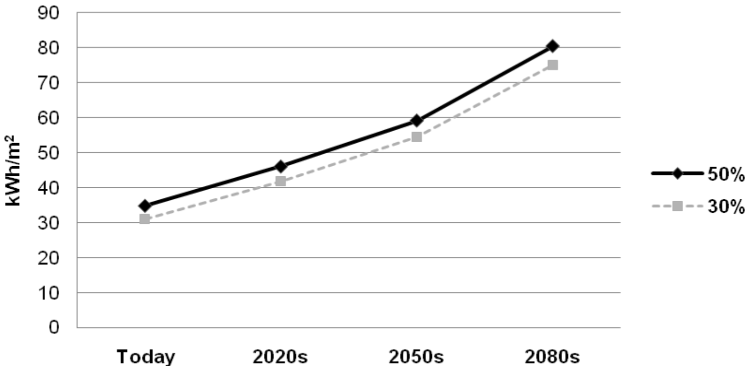

Figure A.4. Influence of window area (on south) on cooling load

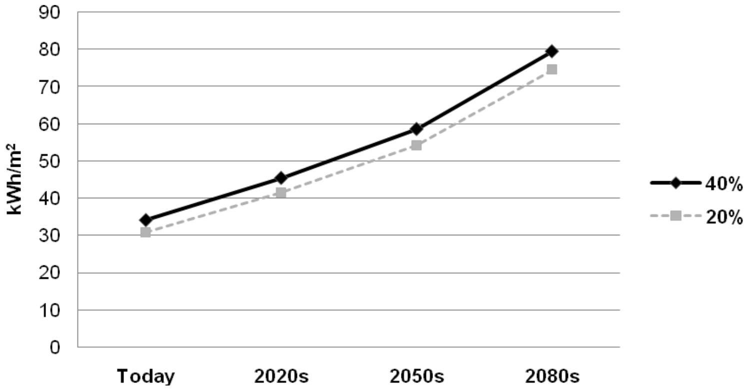

Figure A.5. Influence of window area (on east) on cooling load

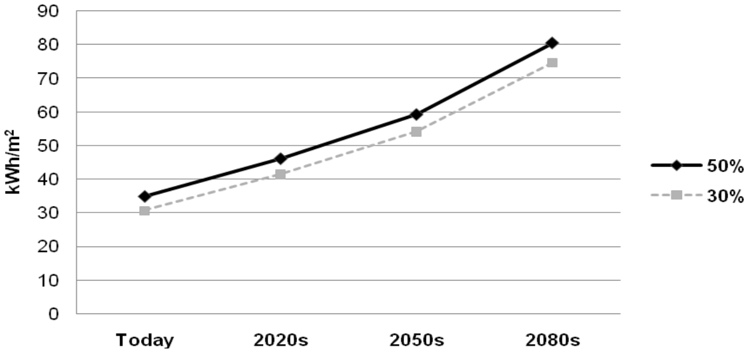

Figure A.6. Influence of window area (on west) on cooling load

Another important feature is glazing on windows since its thermal properties such as SHGC value can influence the amount of energy consumption. When a glazing which has 0.4 SHGC value instead of 0.6 is preferred in windows at only south direction in existing low-rise apartment block, 8.7% reduction of cooling consumption today, 7.4%

reduction of cooling consumption in 2020s, 6.2% reduction of cooling consumption in 2050s, and 5.3% reduction of cooling consumption in 2080s can be possible (Figure A.7). On east direction, when glazing which has 0.4 SHGC value is used, percentage decrease in cooling load would be 8.9% today, 7.8% in 2020s, 6.6% in 2050s, and 5.7% in 2080s (Figure A.8). On west direction, percentage reduction in cooling load would be 9.3% today, 7.9% in 2020s, 6.4% in 2050s, and 5.9% in 2080s (Figure A.9).

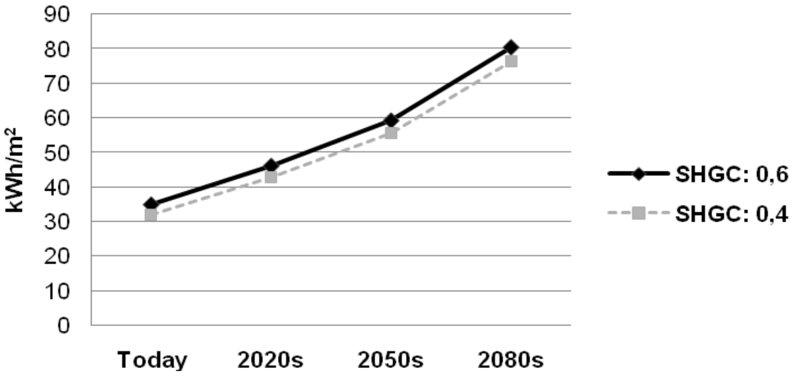

Figure A.7. Influence of SHGC value of glazing (on south) on cooling load

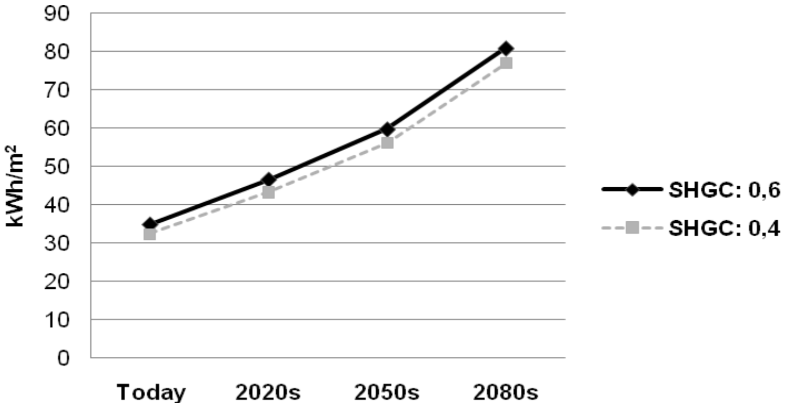

Figure A.8. Influence of SHGC value of glazing (on east) on cooling load

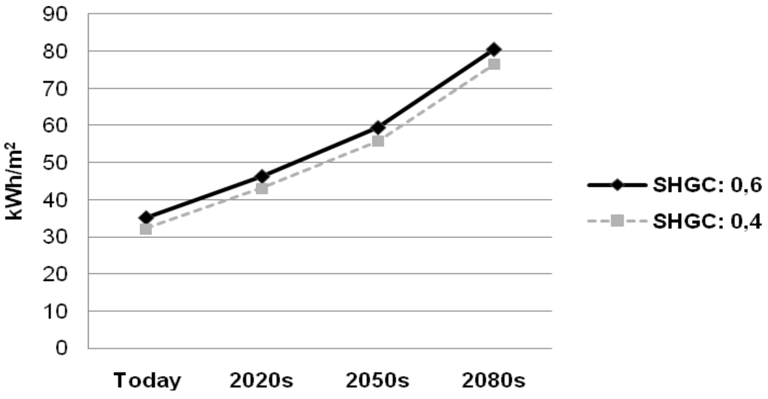

Figure A.9. Influence of SHGC value of glazing (on west) on cooling load

A.2.3. Natural Ventilation

Natural ventilation is one of the effective parameters on cooling load in low-rise apartment blocks. If natural ventilation rate is increased four times during the day when especially outside temperature is so high from inside temperature, the energy necessity for cooling would rise 16% today, 26% in 2020s, 35% in 2050s, and 44% in 2080s (Figure A.10).

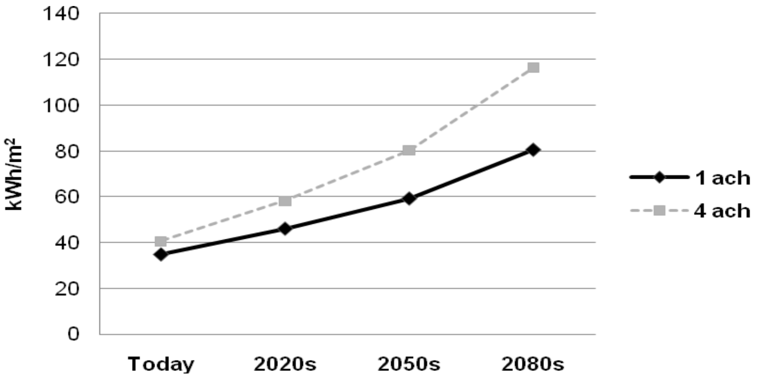

Figure A.10. Influence of natural ventilation rate on cooling load (during the day)

However, energy saving with natural ventilation is possible at night, for outside temperature is usually lower than inside temperature. If natural ventilation rate is increased three times during the night, the energy requirement for cooling would decrease 4.8% today, 10% in 2020s, 13% in 2050s, and 17% in 2080s (Figure A.11).

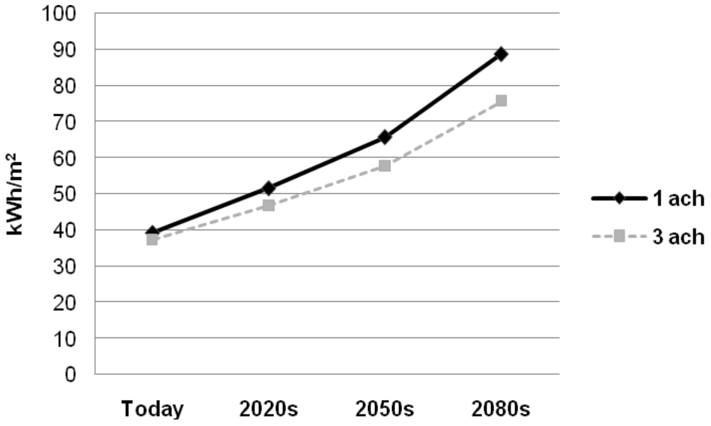

Figure A.11. Influence of night ventilation rate on cooling load

A.2.4. Building Geometry

Building geometry is evaluated with building width and length. Therefore, firstly impact of building length on cooling is investigated. When length of a low-rise apartment block reduces from 24.6m to 22.6m, cooling load can be less 9% today, 8.6% in 2020s, 6.5% in 2050s, and 5.3% in 2080s (Figure A.12).

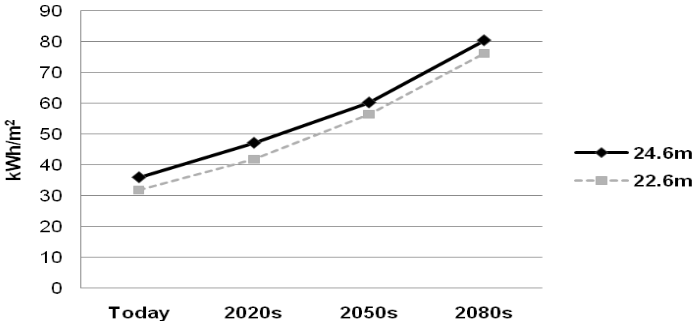

Figure A.12. Influence of building length on cooling load

Secondly, influence of building width on cooling is assessed. When width of a low-rise apartment block reduces from 23.3m to 21.3m, cooling load can be less 7.7% today, 5.7% in 2020s, 5.1% in 2050s, and 5.6% in 2080s (Figure A.13).

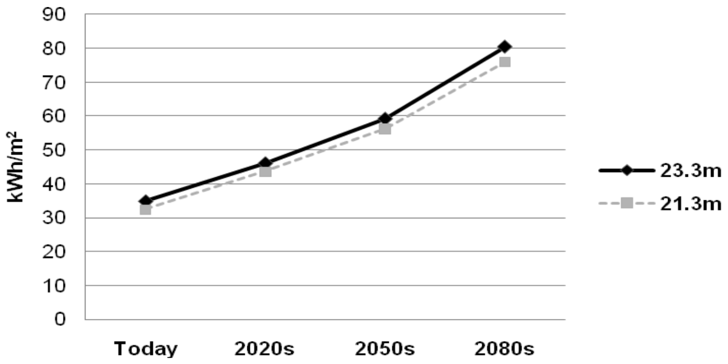

Figure A.13. Influence of building width on cooling load

A.2.5.Thermal Insulation

Insulation thickness on ground and roof are among the sensitive design parameters but they have mostly considerable impact on cooling load in ground and top floor. Therefore, cooling load in only ground and top floor is examined in this part. If insulation thickness on ground floor is increased from 4cm to 7cm, cooling load can increase 16% today, 12% in 2020s, 10% in 2050s, and 7.8% in 2080s. It may be due to low temperature on ground. Thus heat loss should be more from the ground in summer season (Figure A.14).

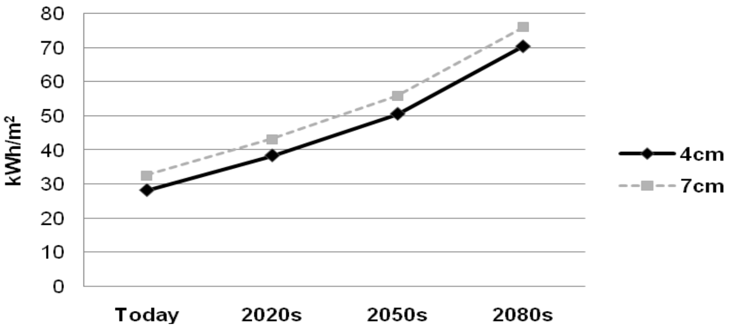

Figure A.14. Influence of insulation thickness (on ground) on cooling load

If insulation thickness on roof is increased from 7cm to 10cm, cooling load can decrease 1.8% today, 2% in 2020s, 2.2% in 2050s, and 2.7% in 2080s (Figure A.15).

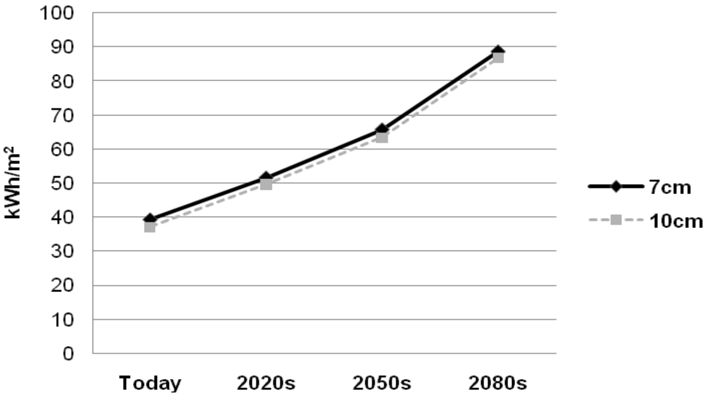

Figure A.15. Influence of insulation thickness (on roof) on cooling load

A.2.6. Zone Height

Zone height affects directly volume of cooling space. For that reason, it has important impact on cooling load in low-rise apartment block. When only zone height is increased from 2.8m to 3m, cooling load can increase 2.5% today, 2.4% in 2020s, 2.7% in 2050s, and 4.3% in 2080s (Figure A.16).

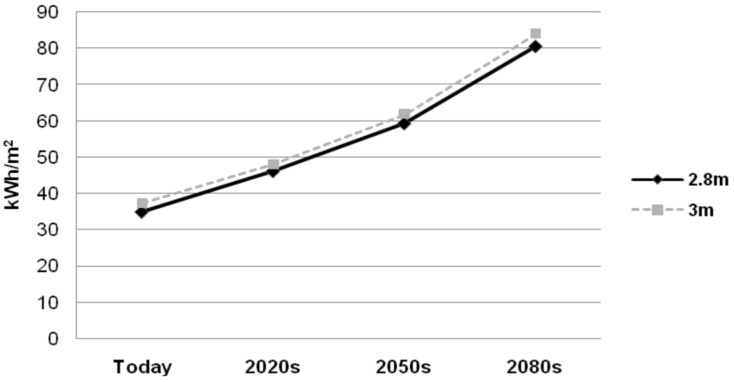

Figure A.16. Influence of zone heaight on cooling load

A.2.7. Air Infiltration

The general reason of air infiltration is quality of construction in buildings but its influence is significant on energy consumption for cooling.

Thus, it should be minimized in low-rise apartment blocks. When air infiltration rate increased from 0.7ach to 1, cooling load can increase 2.5% today, 2.9% in 2020s, 3.2% in 2050s, and 3.7% in 2080s (Figure A.17).

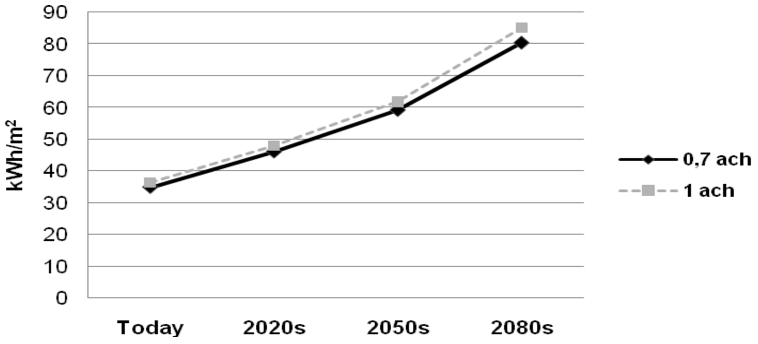

Figure A.17. Influence of air infiltration rate on cooling load

VITA

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