A SIMULATION-BASED OPTIMIZATION METHOD FOR BUILDING THERMAL DESIGN

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ABSTRACT

A SIMULATION-BASED OPTIMIZATION METHOD FOR BUILDING THERMAL DESIGN

Buildings have a remarkable impact on environment, therefore finding efficient design configurations satisfying conflicting criteria such as, economic and environmental performance has become an important task. The aim of this study is to provide a tool to aid designers in satisfying the requirements of government regulations and green building certification programs, while optimizing the costs and maintaining the thermal comfort. In this context, the developed tool combines a dynamic energy simulation module based on heat balance method and a Life Cycle Cost (LCC) module with an optimization toolbox (Matlab - OptimTool). The developed tool offers an effective method to perform large number of simulations to find cost-optimal building configuration. The tool was tested on a case study that represents a typical residential building in Turkey. Based on an extensive market search for building materials, a database required for optimization process is developed. A genetic algorithm (GA) optimization technique is utilized to minimize the objective function and find the cost-optimal building configuration for the selected building. Development of a simulation-based optimization method fulfills the need for a tool that assists designers to find better design alternatives at the preliminary design stage. The tool requires least amount of data input for energy simulation process to improve usability. Besides, instead of coupling two separate software packages, performing the energy simulation and optimization processes on a single platform (Matlab) reduces the time required to find cost optimal design and compatibility issues. The effectiveness of the approach for finding cost optimal building configuration is demonstrated in the presented case studies.

ÖZET

BİNALARIN TERMAL TASARIMI İÇİN SİMULASYON BAZLI BİR OPTİMİZASYON YÖNTEMİ

Binaların çevre üzerinde dikkate değer bir etkisi vardır. Bu nedenle, ekonomik ve çevresel performans gibi çelişkili kriterleri karşılayan etkili tasarım konfigürasyonlarının bulunması önemli bir araştırma alanı haline gelmiştir. Bu çalışmanın amacı, resmi yönetmeliklerin ve yeşil bina sertifikasyon programlarının gereklerini yerine getirmekte ve maliyetleri optimize ederken aynı zamanda bina içerisindeki termal konforu korumakta tasarımcılara yardımcı olacak bir yazılım geliştirmektir. Bu bağlamda, geliştirilen yazılım ısı dengesi methodu tabanlı dinamik bir simulasyon modülünü, yaşam döngüsü maliyeti modülünü ve Matlab optimizasyon araç kutusunu birbirine bağlamaktadır. Ayrıca, geliştirilen araç en uygun maliyetli bina konfigurasyonunun bulunmasında gereken çok sayıda simulasyonu yapacak bir yöntem sağlamaktadır. Bir vaka çalışması yürütülerek geliştirilen araç test edilmiştir. Bu vaka çalışmasında Türkiye'deki tipik konut yapılarını temsil eden, İstanbul'da bulunan beş katlı bir bina kullanılmıştır. Yapı malzemeleri ve enerji piyasasında bir araştırma yapılmıştır ve bu araştırmaya dayanarak bir birim fiyat veritabanı oluşturulmuştur. Seçilen bina için belirlenen amaç fonksiyonunu en küçüklemek ve optimum bina konfigurasyonunu belirlemek amacıyla genetik algoritma optimizasyon yöntemi kullanılmıştır. Enerji simulasyonu sürecinde asgari düzeyde veri girişi gerektirmesi aracın kullanılabilirliğini yükseltmektedir. Ayrıca, iki farklı yazılım platformunu birleştirmek yerine, enerji simülasyonu ve optimizasyon işlemlerini tek bir platformda gerçekleştirmek, optimum tasarım konfigürasyonunun bulunması için gereken süreyi kısaltmakta ve platformlar arası uyum sorunlarını azaltmaktadır. Kullanılan yöntemin, en uygun bina konfigürasyonunun bulunmasındaki etkinliği yürütülen vaka çalışmasında sunulmuştur.

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A	The total window area
A_{cf}	Building air conditioned area
A_i	Surface area
A_{sunlit}	Un-shaded windows area
ACH	Air changes per hour
d	Discount rate
E_r	Incident diffuse reflected irradiation
E_{sc}	The extraterrestrial solar irradiation
$E_{t,b}$	Incident direct beam irradiation
$E_{t,d}$	Incident diffuse irradiation
f	Inflation rate
$FV_{annualcost}$	Future value of annual cost
h_{ci}	Inside convection coefficient
h_{co}	Outside convection coefficient
i	Interest rate
IAC_{diff}	Interior attenuation coefficients
IC	Initial cost
N	Number of years
N_{br}	Number of bedrooms
$P_{annualcosts}$	The present value of annual cost
P_H	Overhang length
PV	Present value
$q^{"}_{CE}$	Convective part of the internal loads
$q^{"}_{conv}$	Convection heat transfer from walls to zone air
$q^{"}_{IV}$	Sensible load due to ventilation and infiltration
$q^{"}_{ko}$	Conduction heat flux on outside face
$q^{"}_{ki}$	Conduction heat flux on inside face
$q^{"}_{LWS}$	Long-wave radiation flux from equipment in the zone

$q^{"}_{LWX}$	Long-wave radiant exchange flux between zone surfaces
q_{SHG}	Total solar heat gain
$q_{SHG,D}$	The direct beam solar heat gain
$q_{SHG,dif}$	Diffuse solar heat gain
$q^{"}_{sol}$	Transmitted solar radiation from windows to inside surface
$q^{"}_{SW}$	Net short-wave radiation flux from lights to surface
$q^{"}_{SYS}$	Heat transfer from heating system
Q_v	Minimum ventilation rate
r	Discount rate
S	Future value of investment
S_H	Shade height
S_t	Savings with the alternative project
$SHGC(\theta)$	Angle dependent SHGC
$SHGC_{dif}$	The diffuse SHGC
SL	Life span of the components
SV	Scrap value
t	Period of analysis
T_a	Zone air temperature
T_i	Inside surface temperature
T_o	Outside surface temperature
T_si	Inside surface temperature
V	Conditioned volume
W_L	Windows length
W_H	Windows height
X_j	Outside conduction transfer function
y	Minimum time period for total investment recovery
Y_j	Cross conduction transfer function
Z_j	Inside conduction transfer function
ΔI_0	Initial investment
ΔI_t	Additional costs related to alternative project

τ_b	Beam optical depth
τ_d	Diffuse optical depth
ρ_g	Ground reflectivity
ϕ	Azimuth angle
Φ_j	Flux conduction transfer function
ψ	Surface azimuth angle

LIST OF ACRONYMS/ABBREVIATIONS

AIRR	Adjusted Internal Rate of Return
ANAO	Australian National Audit Office
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
CFD	Computational Fluid Dynamics
CLF	Cooling Load Factor
CTF	Conduction Transfer Function
DOD	Department of Defense
DOE	Department of Energy
DPB	Discounted Payback
EEM	Energy Efficiency Measure
EPBD	Energy Performance of Buildings Directive
EPS	Expanded Polystyrene
GA	Genetic Algorithm
GB	Gigabyte
HBM	Heat Balance Method
HVAC	Heating Ventilation Air Conditioning
IGDAS	Istanbul Gas Distribution Company
ISO	International Organization for Standardization
LB	Lower Bound
LCC	Life Cycle Cost
LEED	Leadership in Energy and Environmental Design
LON	Longitude
Low-E	Low Emissivity
LSM	Local Standard Meridian in Degrees
LST	Local Standard Time in Minutes
MS	Microsoft
NS	Net Savings
PVC	Polyvinyl Chloride

SHGC	Solar Heat Gain Coefficient
SIR	Savings-to-Investment Ratio
SPB	Simple Payback
TCMB	Central Bank of the Turkish Republic
TEDAS	Turkey Electricity Distribution Company
TETD	Total Equivalent Temperature Difference
TL	Turkish Lira
TS825	Standard Thermal Insulation Requirements for Buildings
TSMS	Turkish State Meteorological Service
TUIK	Turkish Statistical Institute
UB	Upper Bound
US	United States
XPS	Extruded Polystyrene

1. INTRODUCTION

Buildings (residential/commercial/institutional) use approximately 30% - 40% of the total energy consumed in the world [1, 2]. However, finding more efficient design alternatives that fulfill multiple conflicting criteria is a formidable task. Thus, application of simulation-based optimization methods in building sector have been an important research topic due to, efforts to reduce the growing energy costs and rigorous requirements of designing green buildings. Considering the recent advancements in computer science simulation-based methods can be used to improve building performance optimally in a shorter time frame and with less labor.

The main objectives of this study are; defining main energy efficiency measures (EEM's) in buildings and developing an energy simulation software coupled with an optimization algorithm. A life cycle analysis method is utilized to evaluate design alternatives and a genetic algorithm is employed to find optimal (near-optimal) solutions. In addition, to demonstrate capabilities of the approach a case study is presented.

Following sections briefly summarizes the background of the research, problem determination and problem statement, reviews the related studies, presents the objectives of the study, defines the research method and specifies scope and limitations of the thesis.

1.1. Background of the Research

Approximately 50% of the energy used in the buildings is consumed for air conditioning and about 40% of the world's material is used for housing projects [3]. Therefore, over the past two decades, building energy optimization is widely discussed and number of studies in this area sharply increased [4]. Simulation based optimization methods are deployed to satisfy several conflicting criteria and design "greener" buildings.

European Union endeavor to improve energy efficiency in buildings and aim to reach the goal of all buildings to be nearly zero energy building by 2020 [5]. In addition, regulations such as Energy Performance of Buildings Directive (EPBD), American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Handbook and Turkish Standard Thermal Insulation Requirements for Buildings (TS825) force construction sector to build energy efficient buildings. A green building saves energy, minimizes the environmental impacts and provides a healthier environment compared to conventional buildings. However, designing a building is a complex process, in which experts from many disciplines contributes to make decisions to find a design solutions that meet all performance criteria [6]. In addition, green buildings are not considered as an attractive option, because most of the technologies used in green buildings have higher initial costs [2]. On the other hand, a careful design process and right material selection significantly decreases initial costs and in the long term operational costs of the buildings also decrease.

1.2. Problem Determination

For the last 50 years, population of the world is growing more rapidly than ever projected before, and the world has added roughly one billion people to its population in the span of the last 12 years. In parallel with the population building sector is also booming to provide shelters and other services (health, transportation, commercial etc.). It is widely known that, the building sector has a significant part in world's energy dissipation. For this reason, designing energy efficient buildings has become an important research area since late 2000's [4].

The design of the buildings is a complex process. In consequence of its multi-disciplinary structure making decisions about the design, system and material selection are challenging tasks. In the design phase of the projects, while selecting the materials and other systems that will be used in the building, budget and life cycle costs should be taken into consideration. Assessing the energy performance of the buildings and deciding on the materials and systems to be used in the buildings requires complex methods and interrelated calculations. Thus, in most of the construction projects, life cycle cost analysis are not carried out to determine the costs throughout the buildings life cycle. The researchers developed simulation-based optimization methods to overcome the complexity of these calculations. However, one of the main challenges of these calculation methods is to ensure that all the important EEM's (Energy Efficiency Measures) are taken into consideration while keeping the calculation process manageable [5]. In addition, the simulation based optimization is an iterative process and takes too much time and labor to accomplish and also requires expertise.

1.3. Problem Statement

Energy performance of the buildings depends on decisions in the early phases of the design process. The energy consumption and life cycle costs of the buildings are important factors that should be taken into consideration during the design phase of the projects. The majority of the current literature on building energy optimization focuses on coupling an optimization tool and commercial building energy simulation software to optimize the building energy efficiency. Energy Plus and TRNSYS are the most popular building energy simulation programs and Matlab optimization toolbox is the most popular optimization tool used by researchers studying in this area. However, there are still difficulties in coupling efficiency considering time and labor, practicality and flexibility.

This research is based on developing a tailor-made simulation based building energy optimization software to overcome efficiency, flexibility and usability issues of coupling techniques. The literature review indicates that, simulation-based optimization method is certainly a promising technique to overcome architectural and engineering difficulties of constructing energy efficient buildings.

In this respect, a complete, flexible, practical and efficient methodology is required to be developed to take into consideration performance aspects of buildings such as; life cycle costs and energy consumption.

1.4. Related Studies

Recently there is a significantly increasing interest in building energy optimization methods within academic communities. First attempts of simulation based optimization methods started in 70's to optimize thermal performance of the office buildings with computer based models [7]. In 1990 Bouchlagem and Letherman published a study on optimization of passive thermal performance of the buildings by using simplex method and non-random complex method [8]. However, most of the studies related to building thermal design optimization was carried out in 2000's and number of studies sharply increased in 2005 [4].

In 2002, a study was conducted to optimize multiple variables of buildings to reduce the energy consumption implementing the multi criterion genetic algorithm [9]. During that period of time Computer-Based methods are combined with human judgment to optimize thermal design of the buildings. The computer based optimization methods provide different design alternatives and designers hand-pick the suitable design configuration for the buildings [10]. Another study on building energy optimization was focused on the optimization of the windows using a genetic algorithm optimization method [11]. Simulation based optimization methods are also used to optimally design green buildings implementing the combination of energy simulation software and genetic algorithm [1]. In addition, a multi objective genetic algorithm method was developed by the same research group to optimize a single story building thermal design considering both economic and environmental criterion [1]. In a study carried out in 2007; genetic algorithm optimization method was combined with a simple energy simulation technique to optimize a Mediterranean building [12]. GenOpt and EnergyPlus were combined to optimize the investment costs, energy costs and thermal comfort [13]. A research focusing on a detached house was conducted to develop a multi objective optimization method to optimize life cycle costs of the buildings [14]. Genetic algorithm optimization methods were utilized to optimize high performing HVAC systems and outdoor thermal conditions [15–17].

A method combining genetic algorithm and TRNSYS was developed to optimize design parameters of a building renovation [18]. To minimize CO2 emission and life cycle costs a simulation based optimization system created [19] and multi objective optimization methods were implemented to optimize design configuration of dwellings [20]. In 2012, optimization methods developed to optimize air conditioned buildings [21], passive design measures [22] and HVAC systems [17]. A study conducted in 2013 focusing on Finnish buildings developed an optimization method based on genetic algorithm that considers both energy efficiency measures and renewable energy systems [23].

Recently, researchers focus on not only reducing the life cycle costs of buildings but also thermal comfort of the buildings. In 2014, a study carried out to optimize energy costs and thermal comfort of an existing building by combining genetic algorithm, neural network and TRNSYS software [24]. Researchers have shown a great interest in optimization of energy efficiency and thermal comfort of the buildings; a review of thermal comfort [25], a review of energy efficiency potential of tropical buildings [26] and a review of simulation based optimization in building sector is published [4]. Researchers also conducted a study on optimization of energy efficiency and thermal comfort of smart buildings by programming their control systems [27]. A multi variable optimization method was developed for energy optimization of retrofit of a building by combining genetic algorithm and static energy simulation model [28]. Many studies using simulation based optimization methods focused on minimizing the energy costs and maximizing the thermal comfort [5, 29, 30]. In 2016, building energy simulation software and optimization software were combined to minimize energy costs [31, 32].

1.5. Research Objectives

The major motivations of this study are, the rapid advancements in computer science, compulsory requirements of green building credit systems and government regulations. This study aims to provide a plain, flexible, efficient and user friendly software for designers to make decisions related to energy performance of the buildings.

In this respect, it reviews the current methods used to optimize energy efficiency of the buildings and develop a new simulation-based optimization model that integrates material selection, design, budget, and life cycle costs to design the buildings at lowest cost possible and maximum benefit. The proposed building design methodology may support companies in building sector to optimize building designs in the early phases of design process.

The objectives of this research are as follows:

- Determination of energy efficiency measures (EEM's) of buildings.
- Development of energy simulation software based on heat balance method.
- Development of a multi criteria genetic algorithm optimization method and a life cycle cost method for building thermal design optimization.
- Developing a software that combines heat load calculation technique, LCC calculations and optimization method to create a complete system for simulation-based optimization.
- Utilization of developed simulation-based optimization method on a case study.
- Presenting the results and discussions on the performance of the system.

1.6. Research Method

Generally the research method of this study is based on following steps:

- An extensive literature review in the field of building science is carried out. After conducting an extensive literature review; related studies are investigated and similar approaches concerning performance evaluation, modeling, simulation and optimization of buildings are studied.
- Based on the reviews and studies, a simulation-based optimization methodology that is combined with LCC calculations is proposed.
- Using the Matlab software environment a prototype software is developed to test proposed simulation-based optimization methodology.
- The developed software uses numerical information of the building and materials

to assess the energy performance of the buildings. Thus, a database consisting different building components, materials and unit prices is created.

- Finally, the software is utilized to analyze a real-life building project and the results are evaluated and presented.

1.7. Scope and Limitations

This thesis has some limitations based on database creating process and simulation tool. The user of the tool needs to provide financial variables such as; discount rate, inflation, energy prices etc. In addition, the user also needs to provide material and component properties, initial costs, life spans and maintenance costs from the market to carry out the calculations. Considering that the abovementioned variables and data varies among different countries and markets the tool requires substantial amount of preliminary work. The user also needs to provide CTF data representing components of the buildings for the database. However, after creating the required database for materials and weather conditions the software requires the least amount of data input and designers can use the created database in several projects.

To keep the scope of the study and calculations manageable the simulation module of the developed tool only optimizes the envelope design and materials of the buildings. HVAC, lighting and other energy consuming components of the buildings are not projected to be optimized. However, in the future studies new modules to optimize these components may be developed and can easily be adapted to methodology.

1.8. Organization of Thesis

This research involves seven chapters. First step, which is the introduction of this study, summarizes necessity and aims of the study. Second step, introduces the simulation-based optimization method and presents an extensive literature survey. Third step, demonstrates the methodology of this study and extensively explains the proposed methods and their implementation. In the fourth step, the developed prototype is introduced. In addition, the validation runs are presented in this section of the study. The fifth step, presents the case studies carried out in this study. In this step of the study the developed software is tested on a reference building and the results are presented. In the sixth step, the results of the case studies are discussed and evaluated. The findings of the study are presented in the seventh step of the study.

2. SIMULATION-BASED OPTIMIZATION METHOD

Recently, with the rapid advancements in computer science utilizing computer simulations to solve complex engineering problems has become a promising method. Therefore, dynamic simulation methods are commonly used by the designers to simulate thermal behaviors of the buildings. Designers use dynamic simulation methods to reduce energy consumption and environmental impact of the buildings and increase their thermal comfort. Designers can use parametric runs to optimize thermal performance of the buildings. In parametric runs, designers specify the energy efficiency measures of the building and changes each variable while keeping others constant. In this way, effects of each variable on the thermal performance are determined. However, considering the complex nonlinear interrelation between the variables, this method provides only partial improvement. To find an optimal or near optimal design solution for the buildings, usually an iterative method combined with a building simulation is implemented. To reduce the time and labor required for the iterations, usually a computer program is employed. These type of iteration methods are known as simulation- based optimization methods.

The first attempts of the simulation based optimization methods are started in 1970s due to significant advancements in computer science and optimization methods [7]. However, number of articles published in the literature sharply increased in 2000s [4]. Nowadays, simulation-based optimization methods have become an effective tool to design buildings which meet requirements of governmental regulations and green building credit systems. Strict requirements of the governmental regulations and green building credit systems will force the designers and researchers to utilize simulation-based optimization methods in building research and design practice.

2.1. The Major Stages of Simulation-Based Optimization Method

Generally simulation based optimization method can be divided into three stages: preprocessing stage, simulation and optimization stage and post processing stage.

2.1.1. Pre-processing Stage

For the success of the simulation-based optimization method, pre-processing stage is of great importance. Formulation of the optimization problem is the most important part of this stage. The pre-processing stage of the simulation-based optimization method requires extensive knowledge in optimizations processes, mathematics, interrelation between variables, materials etc. At this stage of the optimization process, to keep the problem manageable the building model is required to be simplified [33]. On the other hand, over-simplification reduces the accuracy of the simulation results while, too complicated models greatly increases runtime period of the optimization process.

2.1.2. Optimization Stage

At this stage of the simulation-based optimization methods, the convergence of the problem and error detection is the most important duties of the researchers and designers [4]. Most of the studies in simulation-based optimization methods do not mention about convergence speed and runtime of the optimization process. On the other hand, the methods used to increase the convergence speed and rules to define convergence of the optimization methods are too hard to be applied by building scientists [34]. To reduce the number of errors during the optimization process; the objective functions, boundary conditions of the variables, inputs and outputs of the method are required to be carefully inserted and monitored during the optimization stage.

The optimization process is terminated if one of the termination criteria is met. The followings are the most commonly used termination criteria among the researchers in simulation-based optimization methods: maximum time limit, maximum number of iterations, and convergence of the objective function (change in the objective function in each step is lower than the determined constant) etc.

2.1.3. Post-Processing Stage

At this stage of the simulation based optimization process the results of the analysis are presented and interpreted. The results of the analysis consist; plots, bar charts and tables which demonstrate energy consumption, room temperatures, surface temperatures, convergence etc.

2.2. Building Energy Performance Simulation Programs

Plenty of commercial building energy simulation software have been developed in the last few decades. Whole building energy simulation programs are most commonly preferred tools among the researchers and designers. The major software used in this field of study are: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS [35]. The most popular programs among the researchers are TRNSYS and EnergyPlus.

2.3. Optimization Algorithms and Software

The selection of an optimization program for simulation-based optimization methods is crucial for obtaining better results and reducing the optimization run time. The selection is made based on the nature of decision variables, presence of constraints, objective functions, problem features and optimization performance. The most commonly used algorithms can be listed as: genetic algorithms, particle swarm optimization, hybrid algorithms, linear programming methods, hooke-jeeves algorithms, simulated annealing, ant colony algorithms, branch and bounds methods, tabu search, simplex algorithms, coordinate search algorithms, harmony search algorithms etc. The genetic algorithm is the most popular optimization algorithm in this field because, it can handle both discrete and continuous variables, allows parallel simulations, does not trap at local minima.

Most commonly method used in simulation based optimization studies is to integrate a building simulation program to an optimization program to automatically run building simulations and find optimal building design. After conducting an extensive study, the most commonly used optimization programs can be listed as: Altair, Beopt, BOSS Quattro, DAKOTA, GENE_ARCH, Genopt, GoSUM, iSIGHT, jEPlus+EA, LionSolver, MatLab, MOBO, modeFRONTIER, ModelCenter, MultOpt 2, Opt-E-Plus, ParadisEO, TRNOPT.

2.4. Energy Efficiency Measures

Energy efficiency measures have a significant role in simulation-based optimization methods. For this reason determination of energy efficiency measures are considered to be a part of optimization process.

In buildings several types of energy sources are utilized to provide services such as: ventilation, lighting, heating, elevators, escalators, kitchen equipment, cooking, water heating etc. These energy types can be listed as; electricity, natural gas, diesel fuel, liquefied petroleum gas etc. The primary energy sources used in residential buildings are electricity and natural gas. Main parameters that influence the energy efficiency of buildings are envelope of the buildings, the boiler type and capacity, air conditioning (chiller), lighting, lifts and other equipment. The envelope of the building consist elements such as; wall type, roof type, window type, thickness of internal and external insulations, window size, building orientation, building geometry, material properties etc. Energy efficiency measures are required to be determined to carry out simulation-optimization of the buildings. Thus, an extensive literature review carried out to determine major EEM's.

In a study carried out in 2014 researchers selected thermal resistance of walls, roof and slab internal insulation, window type, window type of south wall and roof, window size, thermal resistance of walls external insulation, thermal resistance of walls and roof additional insulation, heating and cooling system and the ventilation system [5]. In another study conducted in 2015 selected decision variables can be listed as; solar absorbance of external plaster, infrared emittance of external plastering, thickness of thermal insulation, thickness of bricks, brick density and thermal transmittance of windows [29]. Building orientation, aspect ratio of the building, window type, window to wall ratio, wall type, layers of wall, roof type and each layer of roof are chosen as the variables of optimization process in a study conducted to optimize green buildings thermal design [1]. In a research developed to optimize buildings in Colombia used wood components, adhesive sealants, paint, carpet, roofs, glasses and windows as variables of optimization model [2].

According to a research aiming to review articles published in the field of simulation-based optimization method studies, energy efficiency measures affecting the energy performance can be listed as; external wall and roof color, ventilation strategy, external wall type, power of gas stove, discharge coefficient bedrooms, thickness of the ceiling concrete slab, crack window, thickness of roof insulation, maximum number of occupants, thickness of internal mass, window type, density of slab concrete, brick thickness, conductivity of EPS insulation, crack window bedrooms, thickness wooden floor, maximum equipment power, brick density and window size [4]. The list covers almost all the design variables that affect the energy performance of the buildings.

To optimize energy efficiency of the buildings the researchers used different design variables in their optimization models. However most of the variables used for optimization of the buildings are common. Thermal optimization of the buildings mostly depends on the energy efficiency measures taken into consideration. Therefore, for a proper thermal calculation energy efficiency measures are required to be determined cautiously. The number of energy efficiency measures also directly affects the manageability of the calculations and optimization period.

2.5. Simulation Based Optimization Frameworks

The researchers studying in this field of study focused on optimization of green buildings, material selection and system (HVAC) selection of the green buildings and environmental impacts of the buildings. In this study an extensive literature survey is conducted. The previous studies in simulation-based optimization method are investigated. In general, researchers coupled two or more computer programs to find the optimal building design. The coupling loop implemented in the vast majority of the researches is presented in the Figure 2.1. In various studies, researchers used this framework which automatically runs simulations to find optimal building design. In this framework an optimization program and a building simulation program work cooperatively. Although there are disadvantages such as; long optimization runtimes, labor and expertise requirements and coupling problems, researchers prefer this framework in their studies due to its high accuracy.

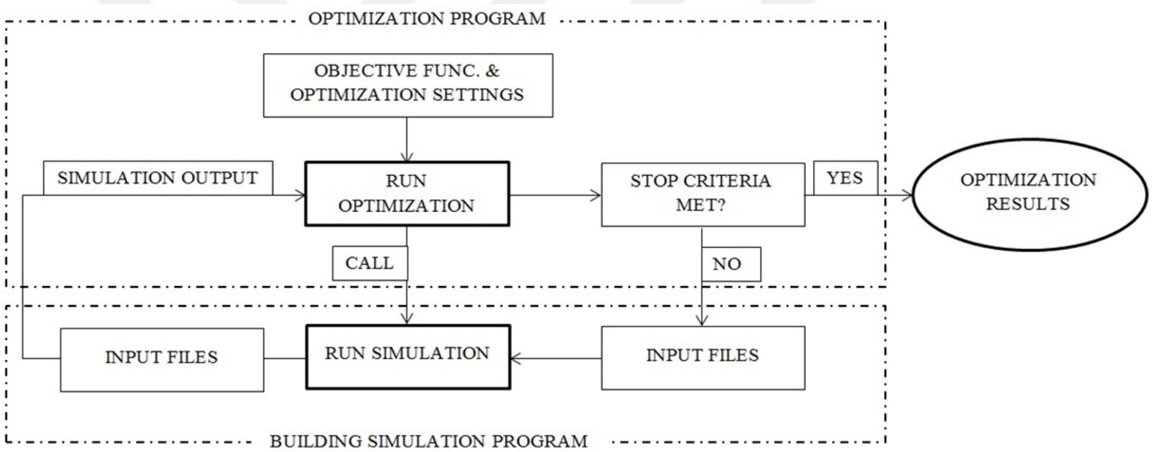

Figure 2.1. Generic Framework for Simulation-Based Optimization Method.

Wilson and Templeman [7] conducted a study to develop an optimization method to optimize thermal performance of an office building. The aim of the study is to couple a geometric programming method with a thermal model for optimization process.

Bouchlaghem and Letherman [8] proposed a computer-based optimization model. The study aims to optimize passive thermal performance of the buildings. A non-random complex method and a simplex method are utilized in the study for the minimization of the objective function.

Caldas and Norford [11] introduced a simulation based optimization system which couples a genetic algorithm optimization method and very detailed thermal analysis software (DOE2.1E). The study aims to optimize the placing and sizing of windows in an office building. However the developed system can be implemented for other problems too.

Coley and Schukat [10] developed a simulation based optimization method by combining a genetic algorithm optimization method and a simple dynamic thermal model. Then, the results of the simulation-based optimization method are presented to users for their judgement. The study aims to evaluate high number of design configurations in a shorter period of time.

Nielsen [36] developed a computer program that supports the optimization of building thermal using a branching optimization method. According to this study the thermal performance of the buildings mostly depends on the decision made during the design process of the buildings. The software aims to help designers to make these decisions faster, handle complex design problems and improve overall performance of the buildings.

Wright *et al.* [9] investigated the application of multi-objective genetic algorithm in finding energy efficient building design configurations. The study aims minimize the building life cycle cost while keeping the building thermal comfort at a certain level. The results demonstrated that GA is an effective method for finding optimum building design.

Wang *et al.* [1] developed a simulation-optimization method to reduce LCC, energy consumption and environmental impacts of the buildings. The developed software aims to find optimal design for building envelope by using a multi-objective genetic algorithm optimization method. To show the effectiveness of the research a case study is conducted.

Thormark [37] carried out a study in Sweden to demonstrate the effects of material substitution on recycling potential and energy efficiency of the buildings. External walls, internal walls, walls between apartments, foundation and roof are selected as decision variables. For the case studies one of the most energy efficient residential building projects in Sweden is selected. The results showed that, material selection during the design phase of the buildings has significant effects on building energy performance.

Znouda *et al.* [12] introduced a simulation based optimization method which combines simple thermal simulation software (CHEOPS) and a genetic algorithm method. The study aims to find cost optimal design solutions for Mediterranean buildings.

Djuric *et al.* [13] conducted a study to optimize parameters that affect energy, investment cost and thermal comfort. In this study a generic optimization program (GenOpt) and a thermal simulation program is coupled.

Hasan *et al.* [14] developed a simulation-based optimization method to find an energy efficient building design for a single family detached Finnish house. The software combines a building thermal simulation software (IDA ICE 3.0) and generic optimization program (GenOpt 2.0). The results are compared to results obtained from brute-force search method.

Castro-Lacoutre *et al.* [2] conducted a study to reduce environmental impacts of the buildings. In this study, Leadership in Energy and Environmental Design (LEED) green building certification system, a mixed integer optimization and a building simulation program is combined. The study proposes a system that reduces life cycle costs of the buildings in developing countries.

Zhou and Haghighat [17] developed a simulation-based optimization method by combining a CFD simulator and a genetic algorithm optimization program. The study aims to increase indoor air quality of the offices in order to boost productivity and well-being of the office workers.

Dubrow and Krarti [38] conducted a study to find cost optimal envelope design for buildings. A genetic algorithm optimization program and DOE II is couple to automatically find optimal solutions. The results showed that trapezoidal and rectangular shaped envelopes have a higher energy efficiency performance.

Bambrook *et al.* [19] developed a simple simulation based optimization model for a detached house in Sydney. The aim of the study is to optimize the thermal performance of the building to the point where the building needs no heating and cooling system. The results of the optimization process are compared to a house designed according to the BASIX. The results showed that LCC of the optimized building is lower than the building designed according to BASIX.

Chantrelle *et al.* [18] conducted a study to develop a simulation-based optimization method by combining a genetic algorithm optimization method and a building thermal simulation program (TRNSYS). The study aims to optimize school buildings in the southern French city Nice.

Hamdy *et al.* [20] conducted a study that aims to reduce environmental and economic impacts of buildings. A genetic algorithm optimization method and a building simulation program (IDA ICE) are combined to minimize carbon emissions and initial costs of the buildings. The results showed that governmental regulations do not guarantee the best economic and environmental performance.

Gong *et al.* [22] carried out a study to optimize passive design measures of residential buildings in different regions of China. In this study, orthogonal and listing methods are implemented to find optimal designs. For the thermal simulation of the buildings a simple dynamic computer program (THERB) is utilized.

Dickson *et al.* [39] separated the construction of the buildings into twelve categories: siting options, electrical systems, wells and septic system, foundation system, plumbing system, walls, windows, doors, roof, ventilation system, heating and cooling system and landscape. In this study a treed regression method is utilized to evaluate each combination and find the cost optimal building design.

Hamdy *et al.* [20] introduces a simulation-based optimization method for finding design alternatives for nearly zero energy buildings. The study also includes renewable energy systems such as; thermal and photovoltaic solar systems and heat recovery systems. The developed simulation-based optimization method is tested on a single-family house in Finland. The results showed that optimal building envelope design heavily depends on heating and cooling system used in the buildings.

Asadi *et al.* [24] developed a simulation based optimization method for existing buildings. The study presents a multi objective optimization model that utilizes artificial neural network and genetic algorithm. The developed model is tested using a school building as a case study. The aim of the study is to improve the comfort and well-being of the occupants in the buildings and reduce energy consumption and carbon emission.

Murray *et al.* [28] conducted a study which aims to develop a simulation-based optimization method for retrofitting of existing buildings. In this study a degree-days simulation technique is coupled with genetic algorithm optimization method to solve optimization problems. The study emphasizes the necessity of simulation-based optimization methods at the design phase of the buildings.

Nguyen *et al.* [4] conducted a study that provides an overview of researches on simulation-based optimization method. The review aims to determine orientation of the future researches. The results of the research indicate that the future works should be focused on reducing time, effort and labor required for simulation-based optimization methods.

Ascione *et al.* [29] introduced a multi-objective approach for building energy performance and thermal comfort optimization. The study aims to develop a simulation-based optimization system by combining Matlab and EnergyPlus. For demonstration the system is applied to a Mediterranean residential building. The results showed that a careful design of building envelope is necessary for high-efficiency-buildings.

Ferrara *et al.* [5] developed a simulation-based optimization method by coupling GenOpt and TRNSYS. The aim of the study is to develop a tool that overcomes the challenges imposed by regulations and green building credit systems. The system utilizes a particle swarm optimization algorithm to find cost-optimal building design.

Delgarm *et al.* [31] developed a simulation-based optimization method by combining an artificial bee colony optimization method (Matlab) and building thermal simulation program (EnergyPlus). The aim of the study is to find energy efficient building design which also satisfies thermal comfort requirements. The developed system is tested on a single office room.

3. RESEARCH METHODOLOGY

In this study a complete, flexible and practical system that integrates material selection, design, budget and life cycle costs to find the optimal design for the buildings is proposed. The system consists a heat balance calculation module, a LCC calculation module and a genetic algorithm optimization module. The process of building thermal optimization is presented in the Figure 3.1. At the pre-processing stage of the optimization parameters such as; ambient dimensions, building orientation, occupancy scenario, boundary conditions of variables, building element types etc. are determined and inserted to the energy model and optimizer. In pre-processing phase the weather conditions and other variables associated to building location are set. Objective function required for genetic algorithm is constituted using LCC calculations. In this phase of the optimization; parameters such as; initial costs, annual costs, discount rates, energy prices etc. are determined and inserted to the model. In this context, the system requires an extensive preliminary preparation due to extended amount of data requirements.

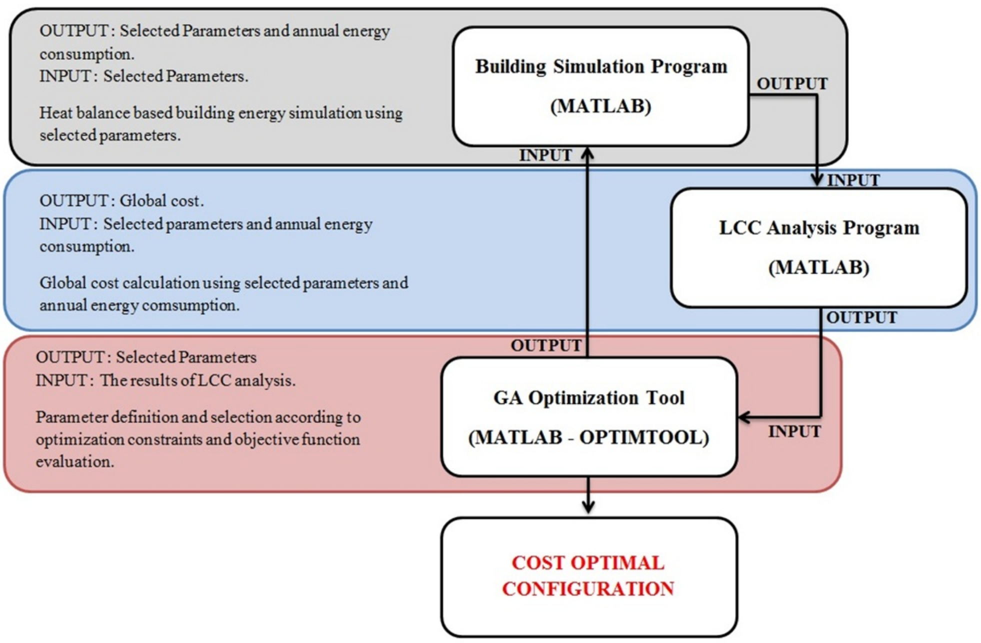

Figure 3.1. Framework of the Methodology.

The steps of the proposed methodology are listed below;

(i) The developed software reads the input data, which consist parameters such as weather condition data, building location, building geometry, optimization constraints, user requirements etc.

(ii) The genetic algorithm optimization module creates a population consisting building configuration combinations according to constraints. Only at the very first cycle of the optimization process the genetic algorithm module creates a random population and in following cycles the module creates populations implementing crossover, elitism, selection and mutation processes.

(iii) The genetic algorithm sends a population of configurations to energy simulation module and energy simulation module runs the energy simulations. The output data of the genetic algorithm optimization module is the input data of the energy simulation module.

(iv) The energy simulation module completes the simulation process and sends the results to LCC module. The output data of the energy simulation data are the input data of the LCC module. The LCC module runs the calculations and sends the results to the genetic algorithm optimization module.

(v) The optimization module evaluates the received LCC calculation results. If the results meets one of the termination criteria the process ends and the software yields an optimal or near optimal solution. If the termination criteria are not met, the cycle goes back to step 2.

The major methodologies used in this study are heat balance method, life cycle cost analysis and a genetic algorithm optimization method. The heat balance method is used to simulate thermal performance of the buildings. Life cycle cost analysis is applied for objective function of the optimization problem. Genetic algorithm optimization method is used to automatize the iteration process and find the cost-optimal/energy efficient building design.

3.1. Heat Balance Method

Heat balance method is an hourly dynamic calculation method in which solar heat gains and internal heat gains are calculated in detail. The building's internal surface temperatures are identified separately and natural ventilation, shading and the heat masses of HVAC equipment are taken into consideration. In this study, heat balance method is implemented because it reduces the number of assumptions and its models are closest to real physical buildings.

The heat balance method takes its name from application of first law of thermodynamics, "energy is conserved" in the inner and outer surfaces and the zone air [40]. The formulation of heat balance method for cooling load calculations was published in 1997 and accepted to be the most scientifically rigorous method [41]. The heat balance method allows designers to calculate net instantaneous heating and cooling loads to be calculated [42]. Actually heat balance procedure is not a new method and has been used by energy analysis programs such as BLAST, TARP and also firstly implemented in a complete method named NBSLD in 1976 [43].

There are many other methods (CLF, TETD, Weighting Factors) suggested and presented by ASHRAE handbooks. However, these methods have many simplifications and assumptions, which make designers to deal with a "black box". Simplifications and assumptions hides the fundamental calculations in each method so, it becomes impossible to say which one is more conservative or risky. In addition to all these obvious problems; it is impossible to reveal the effect of simple changes such as building orientation, window type, wall construction etc. [41]. The main assumption made in heat balance method can be listed as; all the surfaces have uniform temperatures, long and shortwave irradiation is uniform, diffused radiation on surfaces and the heat conduction between layers is one dimensional.

The procedure of HBM calculations consists following processes [44];

- Outside face heat balance

- Wall conduction process
- Inside face heat balance
- Air heat balance

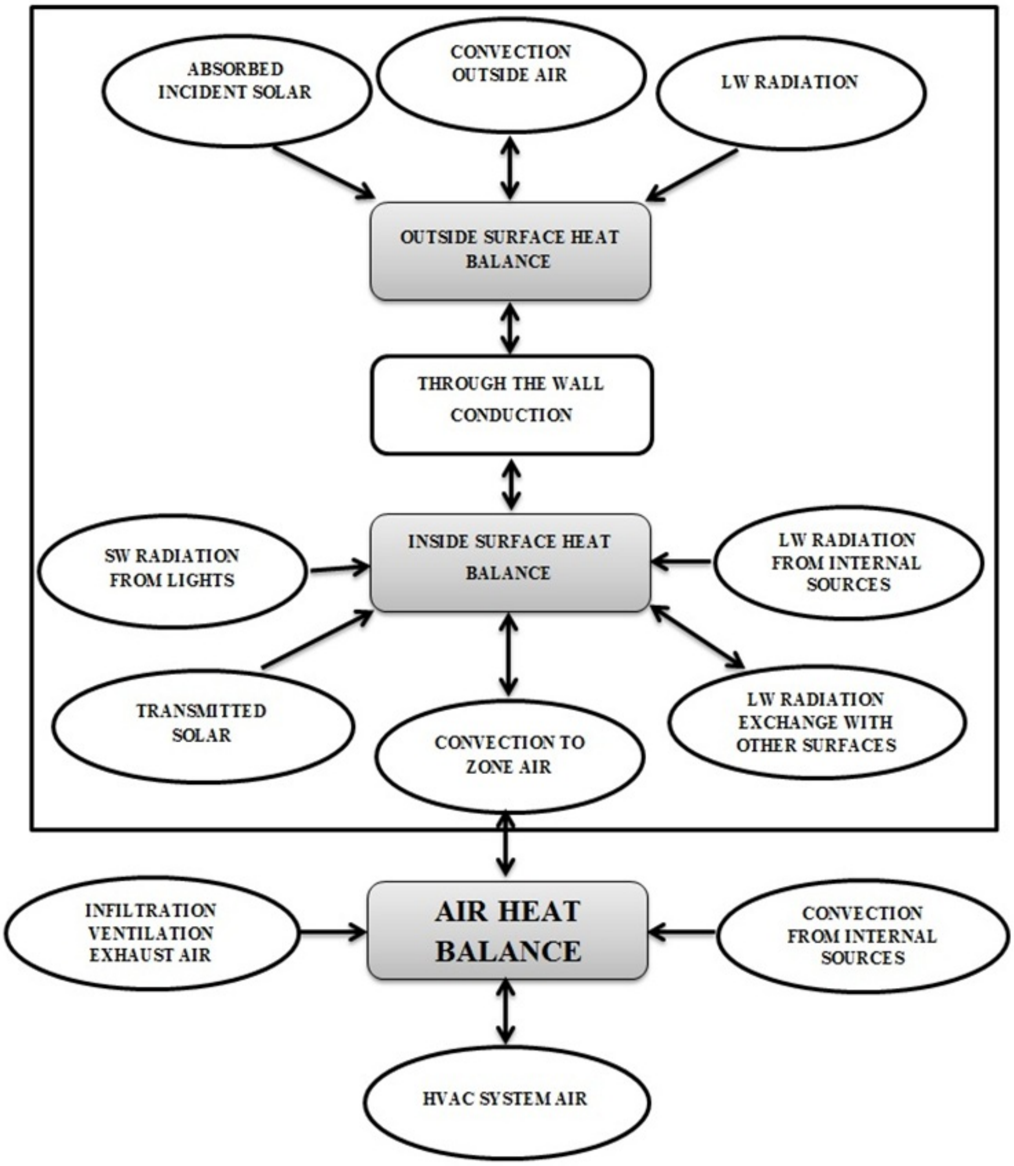

Figure 3.2. Schematic of heat balance process in a zone [41].

Figure 3.2 shows the outline of the process of heat balance method for single opaque surface. The top part of the scheme is repeated for each surface of the zone and their contribution to heating/cooling load is calculated. The bottom part presents the heat balance equation between surfaces and HVAC system and zone air. The arrows with two ends indicate that there is a heat exchange while the one ended arrows shows that the interaction is one way. The major processes of the heat balance method are presented in box shaped frames. HB method is an iterative process which cannot be carried out without assistance of a computer. The concept of HBM is useless without a mathematical form of the process. In the following sections the mathematical formation of the HBM is presented in the context of; outside face, inside face, wall conduction and air-heat balance.

3.1.1. Outside Face Heat Balance Equations

There are four heat exchange processes between outside zone air and outside surface of the walls and the heat balance of the exterior surface can be formulated as:

$$q''_{\propto sol} + q''_{LWR} + q''_{conv} - q''_{ko} = 0 \tag{3.1}$$

3.1.2. Wall Conduction Process Equations

Wall conduction process can be conducted in various ways [44]:

- Numerical finite difference.
- Numerical finite element.
- Transform methods.
- Time series methods.

To make simultaneous calculations for the both surfaces of the walls, conductions transfer function coefficients are utilized. CTF procedures provide a faster calculation than numerical methods with a little loss of generality.

The general form for inside heat flux equation:

$$q''_{ki}(t) = -Z_0 T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\delta} + Y_0 T_{0,t} + \sum_{j=1}^{nz} Y_j T_{0,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ki,i,t-j\delta} \quad (3.2)$$

The general form for outside heat flux equation:

$$q''_{ko}(t) = -Y_0 T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\delta} + X_0 T_{0,t} + \sum_{j=1}^{nz} X_j T_{0,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ko,i,t-j\delta} \quad (3.3)$$

3.1.3. Inside Face Heat Balance Equations

Inside face heat balance is generally modeled by four coupled heat transfer components [42]:

- Conduction through the building walls.
- Convection from walls to zone air.
- Short-wave radiant absorption and reflection.
- Long-wave radiant interchange.

Long-wave radiation includes emittance from people and equipment while shortwave radiation consist radiation enters the zone through windows and emitted from internal sources such as lights.

The general form of inside face heat balance can be formulated as:

$$q''_{LWX} + q''_{SW} + q''_{LWS} + q''_{ki} + q''_{sol} + q''_{conv} = 0 \quad (3.4)$$

3.1.4. Zone Air Heat Balance Equations

The components contributing to the heat balance equation are; convection from inside surface of the walls, infiltration and ventilation, convective part of internal loads and HVAC system.

$$q_{conv} + q_{CE} + q_{IV} + q_{sys} = 0 \tag{3.5}$$

3.1.5. Heat Balance Method Equations Used in Iterations

The general zone for a heat balance procedure presented in the Figure 3.3, has 12 inside surfaces and 12 outside surfaces; four wall surfaces, five window surfaces (for walls and the roof), slab surface and roof surface. The heat balance method consists for each element's inside and outside face and HVAC system as variables for 24 hours. This makes a total of about 600 variables therefore, a routine needed to iterate all these variables for 24 hours a day. In the following part of the study the mathematical procedure of heat balance calculation for generalized zone will be described.

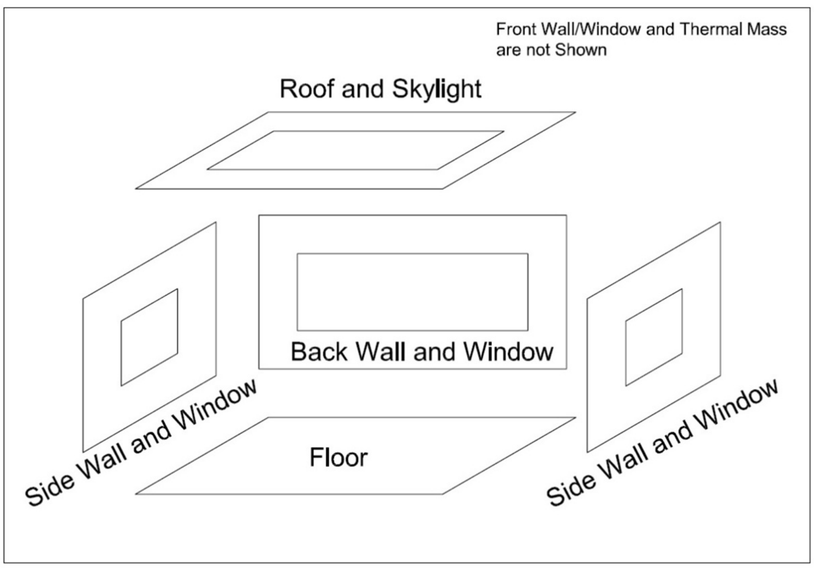

Figure 3.3. General Heat Balance Zone.

The variables of the procedure are 12 inside face and 12 outside face for each 24 hours of the day. Subscript “i” is assigned as the surface index subscript and “j” is assigned as the hour index.

The heat balance equation for outside surfaces:

$$T_{SO_{i,j}} = \frac{\sum_{k=1}^{nz} T_{si_{i,j-k}} Y_{i,k} - \sum_{k=1}^{nz} T_{so_{i,j-k}} Z_{i,k} - \sum_{k=1}^{nq} \Phi_{i,k} q''_{ko_{i,j-k}}}{Z_{i,0} + h_{co_{i,j}}} + \frac{q''_{\alpha sol_{i,j}} + q''_{LWR_{i,j}} + T_{si_{i,j}} Y_{i,0} + T_{o_j} h_{co_{i,j}}}{Z_{i,0} + h_{co_{i,j}}} \tag{3.6}$$

The heat balance equation for inside surfaces:

$$T_{Si_{i,j}} = \frac{T_{so_{i,j}} Y_{i,0} + \sum_{k=1}^{nz} T_{so_{i,j-k}} Y_{i,k} - \sum_{k=1}^{nz} T_{si_{i,j-k}} Z_{i,k} + \sum_{k=1}^{nq} \Phi_{i,k} q''_{ki_{i,j-k}}}{Z_{i,0} + h_{ci_{i,j}}} + \frac{T_{a_j} h_{ci_j} + q''_{LWS} + q''_{LWX_{i,j}} + q''_{SW} + q''_{sol}}{Z_{i,0} + h_{ci_{i,j}}} \tag{3.7}$$

The remaining equation for the heat balance method comes from air heat balance equation:

$$q_{sys_j} = \sum_{i=1}^{12} A_i h_{c,i} \left(T_{si_{i,j}} - T_{a_j} \right) + q_{CE} + q_{IV} \tag{3.8}$$

3.2. Life Cycle Cost Analysis

For a long time the construction sector focused on design and construction costs of the buildings. The owners expected architects to create an aesthetic design that meets their performance requirements and the contractors focused on building techniques and construction costs. However those two main concerns are not the only main issues the clients should concentrate, considering the high service life costs of the buildings. In this respect, instead of solely concentrating on building and design costs, clients should include operational costs such as; operating, maintenance, repair, replacement and disposal costs to their economic investigations. LCC become prominent in early 1960's and by the mid 1970's Life Cycle Cost (LCC) emerged as a new technique to solve the problems of previous techniques in the US Department of Defense [45].

Life cycle cost analysis is defined in various ways in the literature:

"A technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational costs" [46].

"LCC is a method that calculates the total discounted dollar cost of ownership, operation, maintenance and disposal of a building or building system over a period of time" [47].

"LCC analysis is a decision making tool which is based on long run cost calculations to enable choosing the most economical alternative" [48].

"Life cycle cost analysis is an estimating technique to calculate the total cost of ownership of an asset during a given period of time" [45].

LCC method has a new approach to cover all costs from design to disposal of the building. The Life Cycle Costing system includes many analytic methods which are already being used in the construction sector and sounded good in theory, because it covers all the needs for making long term costs forecasts. The LCC method helps engineers to calculate total cost of a project in a given time. Thus, engineers use LCC method as a decision making method to choose between different project alternatives [49].

3.2.1. Purpose of LCC

Approximately 50% of the energy used is consumed for the air conditioning of the buildings and about 40% of the world's material consumption is used for housing projects [3]. Therefore, over the past two decades, building energy optimization widely discussed and number of studies in this area sharply increased [4]. Simulation based optimization methods are deployed to satisfy several conflicting criterion and design "greener" buildings.

Life cycle cost analysis can be used at any phase of an asset's life cycle from preliminary design to disposal [45].

LCC analysis has many uses in construction sector:

- To prepare accounting reports for the resource usage.
- To evaluate future resource requirements and budget preparation.
- Investment valuation and decision making.
- Supplier or source selection.
- System design improvement.
- Logistic support optimization.
- To estimate the disposal time of an asset (when asset reach to end of its economic life).

The LCC is also used to balance the cost of initial investment and operational costs such as; repair, maintenance and renewal. The LCC analysis also can be used to make design improvement decisions, changes in usage etc. The LCC methods range differs with respect to type of decision to be made. Starting a new project requires a wider range of estimation on the other hand, an upgrade on an existing project or an already purchased asset has fixed capital and acquisition costs.

3.2.2. Life Cycle Costing Stages and Elements

The life cycle cost analysis is an economic approach from cradle to grave and each stage, the method estimates the direct monetary costs of the asset. The main stages of a life cycle can be listed as [50]:

(i) Raw Materials Acquisition/Land Acquisition.
(ii) Construction/Manufacturing.
(iii) Use/Reuse/Maintenance.
(iv) Recycling and Waste Management/Disposal.

The scope of the LCC analysis can be summarized as; the total cost of the activities directly causing loss or benefit to owner during the economic life of the asset by determining the cost-effectiveness of the alternative investments. Considering the abovementioned scope, there is not a consensus between researchers on the elements/factors of the LCC method and the number of elements used in LCC analysis varies between the methods. LCC analysis has been used by industry and United States Department of Defense (DOD) since 1970's and 13 factors were used by the DOD: (i) Purchase price, (ii) delivery cost, (iii) testing cost, (iv) installation cost, (v) inventory management, (vi) training, (vii) operating labor, (viii) operating materials, (ix) preventive maintenance, (x) corrective maintenance, (xi) service life, (xii) residual value, (xiii) discount factor [51].

According to a study conducted in 1997, the common elements of LCC models can be listed as [52]:

- Initial capital cost.
  - (i) Purchase costs.
  - (ii) Acquisition costs.
  - (iii) Installation/commissioning/training costs.
- Life of an asset.
  - (i) Functional life.

   (ii) Physical life.
   (iii) Technological life.
   (iv) Economic life.
   (v) Social and legal life
- The discount rate.
   (i) Inflation.
   (ii) Cost of capital.
   (iii) Investment opportunities.
   (iv) Personal consumption preferences.
- Operating and maintenance costs.
   (i) Energy costs.
   (ii) Direct labor.
   (iii) Direct materials.
   (iv) Direct expenses.
   (v) Indirect labor.
   (vi) Indirect materials.
   (vii) Establishment costs.
- Disposal cost.
- Uncertainty and sensitivity analysis.

3.3. Life Cycle Cost Calculations

While making a choice between alternative potential projects, the LCC calculations are sensitive to timing and the amount of cash flow generated by those investments. Concept of the time value of money represents that the amount of money today is worth more than the same amount of money in the future. Therefore we can say that the benefits and costs worth more if they occur earlier in the projects. Time value of the money can be computed using a discount rate and present value calculations. The net present value of the money is calculated through using the compounding method and discount rate to show how the value of money increases.

Discount process shows the present worth of a future payment by using a discount rate. However the problem in this technique is how someone can specify a discount rate. The discount rate (r) can be both nominal, which is adjusted according to the value of inflation rate and also real discount rate, which eliminates the effect of inflation. In LCC analysis a real or nominal discount rate can be used to make calculations. To approximate a real discount value inflation rate is subtracted from the nominal interest rate. Market interest rates are nominal interest rates in that sense.

The following formula can be implemented to calculate the real discount rate:

$$r = \frac{i - f}{1 + f} \tag{3.9}$$

To calculate the present value of a future cash flow the compounding process is used. The formula of the compounding process for the scrap value is presented:

$$\mathrm{PV} = \mathrm{S}(1 + r)^{-t} \tag{3.10}$$

3.3.1. LCC Analysis Decision Making Measures

When evaluating a project the LCC method shows if the project alternative is cost effective or not. However, while evaluating mutually exclusive project alternatives supplementary decision making measures such as Net Savings (NS), Savings-to-Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), Discounted Payback (DPB) and Simple Payback (SBP) should be preferred [53].

3.3.1.1. Net Savings. The net saving method is mostly applied when the investment benefits occur mainly by reducing operational costs. The NS method simply calculates the net present value dollars that a project alternative is expected to save in a specific period of time. While evaluating mutually exclusive alternatives both NS and LCC calculations gives the same results. However, the LCC method does not require the base case calculations while NS requires base case present value to be calculated.

The simple NS equation is presented below:

$$NS_{A:BC} = \sum_{t=0}^{N} \frac{S_t}{(1+r)^t} - \sum_{t=0}^{N} \frac{\Delta I_t}{(1+r)^t} \tag{3.11}$$

3.3.1.2. Savings to Investment Ratio. In SIR method generally the project alternative is considered to be economically justified if the SIR is greater than 1.0. It is a relative measure thus, there needs to be a base case to complete SIR calculations. For different project alternative when using the SIR method same period of time and same discount rate must be used. SIR is useful for evaluation of mutually exclusive project alternatives.

The general formula for SIR calculations is presented below:

$$SIR_{A:BC} = \frac{\sum_{t=0}^{N} S_t/(1+d)^t}{\Delta I_t/(1+d)^t} \tag{3.12}$$

3.3.1.3. Adjusted Internal Rate of Return. For adjusted internal rate of return method for each project alternative same study period, discount rate and base time must be used to carry out correct calculations. The AIRR method provides annual percentage savings from the investments. After completion of the calculations the AIRR is compared to minimum acceptable rate of return (mostly the discount rate) to find out if the project alternative is economic or not. The AIRR is a developed version of IRR (internal rate of return) which assumes that the savings of the alternative project can be reinvested in the remaining duration of the calculation period. The AIRR can be used to rank a single project with respect to its base case and also can be used to rank independent projects if a limited amount of capital is going to be allocated.

The simple AIRR equation is presented below:

$$AIRR = (1 + r)\,(SIR)^{\frac{1}{N}} - 1 \tag{3.13}$$

3.3.1.4. Simple Payback and Discounted Payback Method. Both simple payback and discounted payback method calculates the total time required to recover total capital invested for the alternative project. DPB is a more preferred method compared to SPB because DPB takes the time value of the money into consideration. If the DPB time is shorter than the total service time of the alternative asset the alternative is considered to be economic. SPB is more frequently used however; it does not use the discount rate and also ignores the price changes. In addition, SPB time period is generally shorter than DPB because it does not use the discounted values of savings thus, the SPB times periods are shorter and misleading. Generally payback methods are rough guide for decision making processes.

The general payback formula is presented below:

$$\sum_{t=1}^{y} \frac{(S_t - \Delta I_t)}{(1+d)^t} \geq \Delta I_0 \tag{3.14}$$

The formula changes with respect to discount rate. If the discount rate (d) is zero then the formula gives simple payback period; if the discount rate (d) is non-zero the formula results the discounted payback time period.

3.3.2. Application of LCC measures in Decision Making

There are five types of typical investment decisions made in water and energy conservation projects:

(i) Accepting/rejecting a single project.

(ii) Selecting an efficient building system.

(iii) Selecting an optimal system among competing alternatives.

(iv) Selecting an optimal combination of interdependent alternative systems.

(v) Ranking independent projects to allocate a limited capital.

3.4. Genetic Algorithm

Genetic Algorithm (GA) is a search method which is based on simplified natural evolution theory. GA can be categorized as a meta-heuristic with global perspectives [54]. Unlike other search method GA focuses on a pool of solutions while other methods focus on a single solution. The principles of GA were firstly revealed by John Holland in 1960's and he was accepted as the pioneer of GA. The GA seemed to be a strong search algorithm for optimization however; coding complexity and requirement of powerful computers were the barriers in front of GA method. In 1989 with the advancements in computer science and faster computers Goldberg opened up a new horizon in GA literature [55]. GA has become a proved method as a robust heuristic search technique which is capable of quickly finding optimal solution for the problems while avoiding convergence on local optima [56].

The GA starts with a randomly generated starting population and repeats the following steps until the termination criterion met:

- Evaluation of each element in the population using the fitness function
- Selecting pairs of elements as parents to mate
- Application of crossover to selected parents to create a new population
- Application of mutation on selected elements
- Replacement of old population with new population

Steps of GA show that different operators and functions can be used in GA method. The operators of GA increase the flexibility of GA to solve different problems. Genetic algorithms are not dependent to problem they are applied and it is not effected by the variable magnitudes. The method codes each variable and operates in the space defined by representation of the solution instead of space defined by the problem [57]. The elements in the GA provide variable variation and flexibility to GA method thus, it is more popular among researchers than neighborhood search methods.

3.4.1. Genetic Algorithm Terminology

The GA terminology is borrowed from biology and the basic components can be listed as; (i) fitness function, (ii) chromosomes/members, (iii) selection, (iv) crossover, (v) mutation [58]. In the following sections main elements of GA method are introduced;

3.4.1.1. Crossover. During the reproduction phase of the GA two parent members which are selected based on their fitness, exchange their attributes. In this way, new members (offspring) that inherit their parent's attributes are created to replace the older population. There are many different ways of crossover used in GA method.

Single point crossover is the simplest crossover method. The crossover position is selected randomly and the gene strings are exchanged between the chromosomes. In scattered crossover offspring chromosome receives a gene from first parent whenever there is a "1" in the string and takes the gene from second parent whenever there is a "0". In two points crossover two points are selected randomly (a, b). Genes from 1 to a taken from parent 1, a+1 to "b" taken from parent 2 and the rest of the genes are taken from parent 1 again. Two point crossover is very similar to single point crossover method. In two point crossover method the software randomly selects two numbers (k, n) between 1 and number of genes in each parent member. The genes from 1 to k and n+1 to end are taken from first parent. The genes from k to n are selected from second parent and a child member is returned by the GA tool. Two point and single point crossover methods are not recommended to be used for the problems with linear constraints.

In heuristic crossover method the child created using parent 1 and parent 2 is created using the equation presented below [59].

$$\begin{gathered} z_i(t) = x_i(t) + a\,(y_i(t) - x_i(t)) \\ z_i(t) = y_i(t) \\ y_{Fitness} \geq x_{Fitness} \end{gathered} \tag{3.15}$$

Parameter "a" can be a constant value determined or a value selected randomly from a uniform distribution between 0 and 1.

Scattered crossover method is the default method used by Matlab optimization tool for problems without any linear constraints. In scattered crossover method the software creates a binary matrix and selects the genes from frist parent if the matrix value is 1 and selects genes from the second parent if the matrix is a 0. By using this method the tool returns a child member.

3.4.1.2. Fitness Function. Fitness function is described as; "some measure of profit, utility, or goodness that we want to maximize" [55]. Fitness can also be defined as ability of a member of a population to compete in an environment. To sum up briefly; fitness is the function, GA try to optimize.

3.4.1.3. Chromosomes/Members. Each chromosomes/members represents a solution for the problem that GA is trying to solve and chromosomes compose a population. At the beginning of the problems the searching parameters are defined and these parameters are the genes of the chromosomes. These parameters can be real coded or binary coded.

3.4.1.4. Selection. The chromosomes in the population are evaluated by objective function and each fitter chromosome is more likely to be selected as parent member. Each pair of chromosomes produce new chromosomes that consist attributes of its parent chromosomes. Scaling is a sub-element of selection in which each chromosome is ranked with respect to fitness function. The most commonly known selection type is known as roulette-wheel selection. In roulette-wheel selection each chromosomes have a slice on the wheel. The areas of the slices are proportional to the probabilities provided by scaling. Using the wheel randomly each chromosome is selected as parent chromosome to create a new population. The chromosomes with bigger slices have a higher chance to be selected. In an alternative method n number of chromosomes is selected and the fittest chromosome is selected among the n.

3.4.1.5. Mutation. Mutation is a very important operator of the GA because it brings diversity to the populations reproduced [60]. To increase the variation in the population mutation flips an attribute of chromosome in the population. It is a random alteration of gene or genes in a chromosome. The alteration could be made using a random value from a uniform distribution or a Gaussian distribution can be utilized. The variance of the Gaussian distribution decreases with the each iteration reaching to the optimum. Implementation of mutation is a choice of implementation. The probability of mutation is can also be determined at the beginning of the GA utilization. Using a high probability of mutation or no mutation will decrease the chance of finding the optimal solution to the problem.

3.4.1.6. Initial Population. GA method randomly creates a group of chromosomes as the initial population before starting GA operations. The size of the population is decided by the user before using the GA method. Using small sized populations decrease the chance of finding the optimal solution for the problem while large populations significantly increase the operation time to acquire an optimal solution for the problem. To acquire the optimal population size researchers attempted to find a method to determine optimal population size. Unfortunately, the studies showed that there is an exponential relation between the population size and chromosome string length. Other empirical studies showed that a linear approach between chromosome string length and population size is adequate [61].

3.4.1.7. Termination Criteria. Genetic Algorithm is a stochastic search method and unlike other search methods if a termination criterion is not defined the GA runs forever. Thus, one or more termination criterion are defined to stop the operations of GA. Termination criteria can be determined as number of iterations, time limit, maximum number of iterations without any improvement.

3.4.1.8. Elitism. In each generation because of the reproduction of population the next generation might not include the best individual from the previous generation. Losing the best chromosome in the population lowers the chance or increase the time required to find an optimal solution to the problem. Therefore, a number of members/member is allowed to directly pass to the next generation.

3.5. Research Procedures

As mentioned previously, this study proposes a framework that contains 3 main methodologies. The following sections introduces the procedures of the proposed framework in detail.

3.5.1. Determination of EEM's

To characterize the building's envelope system a component description system for all component types forming the building envelope except doors is suggested. The description format consist component's layer thicknesses, thermal properties, material types, heat capacities, material densities, service life of the components and initial costs. Conduction transfer functions (CTF) of the components characterize the thermal properties of the materials used in envelope components. The CTF's are calculated utilizing the material thickness, heat capacity and density using an external computer program called PRF/RTF generator [62]. The CTF values can also be obtained from ASHRAE handbooks.

As a result of the reviews made on the comprehensive literature and regulations, factors that affect energy efficiency of the buildings have been determined. The factors chosen for this study concern building exterior systems such as; exterior walls, windows, roofs and floors in contact with the floor. In addition using different systems, different configurations are created by changing the properties of the elements in the system such as thickness, size, material type etc. Also, different systems being used in Turkish construction sector are proposed for windows, roofs, slabs in contact with soil and walls. The maximum and minimum values of insulation material thickness used in walls, floors and roof systems and the restrictions on window sizes and other variables have been determined considering the Turkish regulations (TS825).

Table 3.1. Energy Efficiency Measures.

Parameter Description	**Parameter Name**	**Unit**	**Variation**
WTN	Window Type	[-]	Choice Between Options
WSS1	Window Size (Surface 1)	[m2]	Continuous
WSS2	Window Size (Surface 2)	[m2]	Continuous
WSS3	Window Size (Surface 3)	[m2]	Continuous
WSS4	Window Size (Surface 4)	[m2]	Continuous
ST	Slab Type	[-]	Choice Between Options
SIT I	Slab Insulation I Thickness	[m]	Discrete
SIT II	Slab Insulation II Thickness (If exist)	[m]	Discrete
RT	Roof Type	[-]	Choice Between Options
RIT I	Roof Insulation I Thickness	[m]	Discrete
RIT II	Roof Insulation II Thickness (If exist)	[m]	Discrete
WT	Wall Type (S1, S2, S3, S4)	[-]	Choice Between Options
WI I	Wall Insulation I Thickness	[m]	Discrete
WI II	Wall Insulation II Thickness (If exist)	[m]	Discrete
BWC	Building Wall Absorption Coefficient	[-]	Discrete
BRC	Building Roof Absorption Coefficient	[-]	Discrete

The design variables used in optimization model can be continuous (real values in a determined range), discrete (only integer values or discrete values) or both can be used. The determined energy efficiency measures are presented in the Table 3.1. The range of the variables and their variable type (discrete/continuous) are defined for optimization model. The specifications and parameter definitions are filled into the table based on the project type, location, construction market, etc.

3.5.2. Heat Balance Calculation Procedure

As mentioned in previous sections of the study; heat balance method is an hourly dynamic calculation method in which solar heat gains and internal heat gains are calculated in detail. In the following sections steps of the simulation and optimization processes are explained in detail to provide a better understanding of what constitutes the steps of the system.

3.5.2.1. Solar Radiation Calculations. Location of the building and the earth's rotational position relative to the sun alters the daily solar heat gain of the buildings. Calculation of solar heat gain requires the angles presented in Figure 3.4. To calculate the building's heat gain through solar radiation following calculations are needed to be operated.

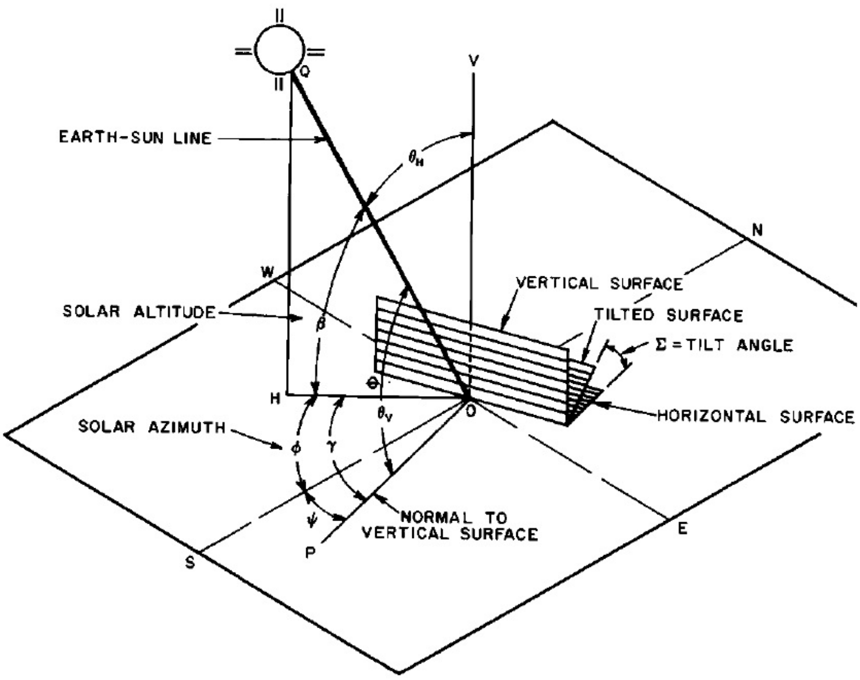

Figure 3.4. Solar Angles [40].

The orbital rotation speed of the earth differs all through the year so the difference can be calculated in minutes by equation of time (ET). ET can be read from ASHRAE handbooks or can be calculated using the following equation:

$$\mathrm{ET} = 9.87\sin(2\mathrm{B}) - 7.53\cos(\mathrm{B}) - 1.5\sin(\mathrm{B}) \tag{3.16}$$

Where parameter B can be calculated using following equation:

$$\mathrm{B} = 360\left(\frac{\mathrm{n}-1}{364}\right) \tag{3.17}$$

Apparent solar time (AST) can be calculated using:

$$\mathrm{AST} = \mathrm{LST} + \mathrm{ET} + 4(\mathrm{LSM} - \mathrm{LON}) \tag{3.18}$$

Local standard meridian (LSM) is obtained from:

$$\mathrm{LSM} = -15\mathrm{TimeZone} \tag{3.19}$$

Another angle required to calculate the solar radiation is declination angle. Declination angle is the angle between earth's pole and the vector from earth to the sun. The pole of the earth is tilted at an angle of 23.45° therefore the declination angle varies as the earth rotates around the sun. The declination angle can be calculated using the following formula:

$$\begin{aligned}\delta = \quad & 0.39 - 22.91cos(\Gamma) + 4.02sin(\Gamma) - 0.38cos(2\Gamma) + 0.05cos(2\Gamma) \\ & -0.15cos(3\Gamma) + 0.08sin(3\Gamma)\end{aligned} \tag{3.20}$$

The solar altitude angle (β) is calculated using Latitude (L) of the location Declination (δ) angle and the hour angle H:

$$\mathrm{H} = 15\left(\mathrm{AST} - 12\right) \tag{3.21}$$

Then the solar altitude angle (β) can be calculated using:

$$\mathrm{sin}\beta = \mathrm{cosLcos}\delta\mathrm{cosH} + \mathrm{sinLsin}\delta \tag{3.22}$$

The azimuth angle can be uniquely determined using the following sine and cosine equations:

$$\begin{gathered} \mathrm{sin}\phi = \mathrm{sinHcos}\delta/\mathrm{cos}\beta \\ \mathrm{cos}\phi = \left(\mathrm{cosHcos}\delta\mathrm{sinL} - \mathrm{sin}\delta\mathrm{cosL}\right)/\mathrm{cos}\beta \end{gathered} \tag{3.23}$$

Surface azimuth angle (ψ) is as presented in Figure 3.2 the angle between OP and OS. Some examples of surface azimuth angle are demonstrated in the Table 3.2.

Table 3.2. Surface Azimuth Angles for Istanbul.

Orientation of the building	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
ψ	180	-135	-90	-45	0	45	90	135

Difference between solar azimuth and surface azimuth:

$$\gamma = \phi - \psi \tag{3.24}$$

The angle of incidence is:

$$\cos\theta = \cos\beta\cos\gamma\sin\Sigma + \sin\beta\cos\Sigma \tag{3.25}$$

The extraterrestrial solar irradiation is given by:

$$\mathrm{E_0} = \mathrm{E_{SC}}\left\{1 + 0.033\cos\left[\frac{(\mathrm{n}-3)}{365}\right]\right\} \tag{3.26}$$

The relative air mass:

$$\mathrm{m} = 1/(\sin\beta + 0.50572(6.07995+\beta)^{-1.6364}) \tag{3.27}$$

The air mass components can be computed:

$$\begin{aligned} \mathrm{ab} &= 1.454 - 0.406\tau_\mathrm{b} - 0.268\tau_\mathrm{d} + 0.021\tau_\mathrm{b}\tau_\mathrm{d} \\ \mathrm{ad} &= 0.507 + 0.205\tau_\mathrm{b} - 0.080\tau_\mathrm{d} - 0.190\tau_\mathrm{b}\tau_\mathrm{d} \end{aligned} \tag{3.28}$$

ρ_g is the ground reflectivity and values for this parameter can be obtained from ASHRAE handbook.

Total solar radiation on an un-shaded surface can be calculated:

$$\mathrm{E_t} = \mathrm{E_{t,b}} + \mathrm{E_{t,d}} + \mathrm{E_{t,r}} \tag{3.29}$$

After completing the calculations of diffuse, direct and reflective solar radiations, the solar radiation transmitted through the windows is needed to be calculated. To calculate the profile angle following equation is needed to be operated:

$$\tan(\Omega) = \frac{\tan(\beta)}{\cos(\gamma)} \tag{3.30}$$

To calculate the sun lit area of the windows the shade height is calculated utilizing following equation:

$$\mathrm{S_H} = \mathrm{P_H}\tan(\Omega) \tag{3.31}$$

The sunlit area can be calculated using:

$$\mathrm{A_{sunlit}} = \mathrm{W_L}\left(\mathrm{W_H} - \mathrm{S_H}\right) \tag{3.32}$$

Diffuse solar heat gain and direct solar heat gain through windows calculations are carried out using the following equations:

$$\begin{aligned} \mathrm{q_{SHG,D}} &= \mathrm{E_{t,b}A_{sunlit}SHGC}(\theta) \\ \mathrm{q_{SHG,dif}} &= \left(\mathrm{E_{t,d}} + \mathrm{E_{t,r}}\right)\mathrm{ASHGC} \\ \mathrm{q_{SHG}} &= \mathrm{q_{SHG,D}} + \mathrm{q_{SHG,dif}} \end{aligned} \tag{3.33}$$

3.5.2.2. Internal Load Calculations. After calculating heat loads from solar irradiation, internal heat gain calculations consisting lighting and people inside the buildings, equipment and infiltration loads are need to be calculated. In heat balance calculations the internal heat loads can be calculated according to a heat gain schedule considering occupation of the building or equipment and lighting usage. Sample rates of lighting usage in various spaces are presented in the Table 3.3.

Table 3.3. Lighting Power Densities for Various Spaces [44].

Common Space Types	**LPD, W/m^2**
Classroom/Lecture/Training	13.3
Conference/Meeting/Multipurpose	13.2
Corridor/Transition	7.1
Dining Area	7.0
Dressing/Fitting Room	4.3
Food Preparation	10.7
Laboratory	13.8
Classrooms	13.8
Medical/Industrial/Research	19.5
Lobby	9.675
Elevator	6.88
Locker Room	8.1
Enclosed Office	11.9
Open Plan Office	10.5
Restrooms	10.5

The occupants in the buildings also give off heat and moisture into the building. The loads can be presented as latent and sensible heat load. The latent load is directly added to interior zone air temperature while sensible load is divided into radiative and convective load fractions. The rates of heat given off by occupants in the building are presented in the Table 3.4.

The diffused and direct solar beam radiation is calculated using the equations above. Part of the diffused and direct solar beam radiation is absorbed or transmitted through the windows. Direct solar beam radiation is assumed to be intercepted by the floor and the diffused solar radiation is uniformly distributed to internal surfaces of the buildings. The internal loads are taken from the ASHRAE Handbook, to calculate internal heat loads caused by people, lighting, equipment etc. The radiative fraction of the heat is distributed uniformly amongst internal surfaces. Using obtained results for each surface a heat balance equation is developed and the equations are solved by utilizing an iteration process. The iteration process and the equations implemented will be presented in the following sections.

Table 3.4. The Rates at Which Heat is Given Off by Human Beings [40].

Degree of Activity	**Location**	**Adult Male (W)**	**Adjusted M/F (W)**	**Sensible Heat (W)**	**Latent Heat (W)**
Seated at theater	Theater, matinee	115	95	65	30
Seated at theater, night	Theater, night	115	105	70	35
Seated, very light work	Office, hotels, apartments	130	115	70	45
Moderately active, office work	Offices, hotels, apartments	140	130	75	55
Standing, light work, walking	Department store, retail store	160	130	75	55
Walking, standing	Drug store, bank	160	145	75	70
Sedentary work	Restaurant	145	160	80	80
Light bench work	Factory	235	220	80	140
Moderate dancing	Dance hall	265	250	90	160
Walking 4.8 km/h; light machine work	Factory	295	295	110	185
Bowling	Bowling alley	440	425	170	255
Heavy work	Factory	440	425	170	255
Heavy machine work, lifting	Factory	470	470	185	285
Athletics	Gymnasium	585	525	210	315

Air exchange between outdoor air and indoor air can be divided into two categories; infiltration and ventilation. Ventilation is intentional while infiltration is uncontrolled flow of air into the buildings. To complete the heat load calculations the heat load due to infiltration and ventilation is determined using the following procedures;

Infiltration rate can be calculated using:

$$Q_{\mathrm{inf}} = \mathrm{ACHV}\,(1000/3600) \tag{3.34}$$

Minimum ventilation rate;

$$Q_v = 0.05A_{cf} + 3.5\left(N_{br} + 1\right) \tag{3.35}$$

3.5.2.3. Heat Balance Method Iteration Equations. Heat balance equations of building external and internal surfaces are constituted using above mentioned heat loads. The following three main equations are evaluated using an iteration process;

The heat balance equation for outside surfaces:

$$T_{SO_{i,j}} = \frac{\sum_{k=1}^{nz} T_{si_{i,j-k}} Y_{i,k} - \sum_{k=1}^{nz} T_{so_{i,j-k}} Z_{i,k} - \sum_{k=1}^{nq} \Phi_{i,k} q''_{ko_{i,j-k}}}{Z_{i,0} + h_{co_{i,j}}} + \frac{q''_{\alpha sol_{i,j}} + q''_{LWR_{i,j}} + T_{si_{i,j}} Y_{i,0} + T_{o_j} h_{co_{i,j}}}{Z_{i,0} + h_{co_{i,j}}} \tag{3.36}$$

The heat balance equation for inside surfaces:

$$T_{Si_{i,j}} = \frac{T_{so_{i,j}} Y_{i,0} + \sum_{k=1}^{nz} T_{so_{i,j-k}} Y_{i,k} - \sum_{k=1}^{nz} T_{si_{i,j-k}} Z_{i,k}}{Z_{i,0} + h_{ci_{i,j}}} + \frac{\sum_{k=1}^{nq} \Phi_{i,k} q''_{ki_{i,j-k}} + T_{a_j} h_{ci_j} + q''_{LWS} + q''_{LWX_{i,j}} + q''_{SW} + q''_{sol}}{Z_{i,0} + h_{ci_{i,j}}} \tag{3.37}$$

The remaining equation for the heat balance method comes from air heat balance equation:

$$q_{sys_j} = \sum_{i=1}^{12} A_i h_{c,i}\left(T_{si_{i,j}} - T_{a_j}\right) + q_{CE} + q_{IV} \tag{3.38}$$

3.5.2.4. HB Iterative Solution Procedure. The steps of heat balance calculations are listed below:

(i) Identify the area properties, face temperatures for surfaces and other properties, for all 24 hours.

(ii) Incident and transmitted solar fluxes for the building surfaces calculated.

(iii) The calculated transmitted solar energy is distributed to all surfaces inside (Incident transmitted solar radiation is intercepted by floor).

(iv) Internal load quantities, for all 24 hours (people, lighting, machines etc.).

(v) Long-wave, short-wave and convective energy from internal loads to all surfaces for all 24 hours is calculated.

(vi) Infiltration and ventilation loads are calculated for all 24 hours.

(vii) Iteration is utilized for heat balance equations according to following pseudo-code scheme [41].

- For Day = 1 to Maxdays
- For j = 1 to 24 (Hours in a day)
- For SurfaceIteration = 1 to MaxIter
- For i=1 to 12 (Number of Zone Surfaces)
- Evaluate Equation of Tsi and Tso
- Next Surface "i"
- Next SurfaceIteration
- Evaluation Equation of qsys
- Next "j"
- If not converged, Next Day
- Display Results

(viii) Present results

3.5.3. LCC Calculation Procedures

The LCC calculation procedure mainly consist two steps including data collection and global cost calculations. Considering that the objective function of the optimization model is based on total life cycle costs of the building envelope system, financial data for each component in the system is needed to be acquired. The financial data required consists; duration of the calculation, initial costs, operational and maintenance costs, scrap values of the components, energy prices and discount rates. After obtaining required data for LCC calculations present value calculation method is utilized to choose the most cost effective design for the building. The LCC calculation procedure steps are presented in the following sections.

3.5.3.1. Step 1: Financial Data Collection.

- The duration of the calculations is decided according to building life span or the building owner's will. The default value for duration of the calculation could be the expected value of the building's lifespan. Shorter calculation durations also can be used to evaluate short term costs of the alternatives.
- The inflation rate is estimated using the data acquired from economic institutes. The expected value of the data over the calculation period can be implemented. Market interest rate can be obtained by calculating the average value of interest rate values over the calculation period.
- Energy price raises can be considered as inflation rates or the energy price information from energy utilities can be obtained. In this study electricity and natural gas unit prices and energy price raises from energy utilities are used.

3.5.3.2. Step 2: Energy Systems and Components.

- Data concerning the energy systems and components are collected and the information related to lifespan and maintenance is acquired at this step of calculation.
- The investment and maintenance costs for components of the building envelope are needed to be collected. At this step the costs can be collected from manufacturers or from the database of Turkish Ministry of Environment and Urbanization.
- Replacement costs are needed for energy systems and components and can be acquired from manufacturers.
- Operational costs, (excluding energy) maintenance and repair costs.

<u>3.5.3.3. Step 3: Energy Costs.</u> The energy consumption should be coupled with energy costs at this step of the calculation. Building energy consumption values are calculated using heat balance method and coupled with energy costs to yearly energy costs of the alternatives.

<u>3.5.3.4. Step 4: Global Cost calculation.</u>

- The final value at the end of the calculation period is summation of final values for all systems and components.
- For each costs present value factors are calculated and the global costs are calculated by summing all the costs such as; investment, energy, replacement, maintenance and the final value of the systems. The scrap value of the components can be calculated by using the following equation:

$$SV = IC\frac{SL - t}{SL} \tag{3.39}$$

After calculating final values of all building components, the life cycle cost including the scrap value is calculated by:

$$LCC = IC + P_{annual\cos ts} - \left(\frac{SV}{(1+r)}\right) \tag{3.40}$$

Present value of annual costs calculated using following equation:

$$P_{annual\cos t} = FV_{annul\cos ts}\left(\frac{1}{(1+r)^t}\right) \tag{3.41}$$

3.5.4. Optimization Procedure

To provide fast and easy energy simulations the heat balance method software and LCC analysis software are coupled with Matlab's GA toolbox. The process of building energy optimization is presented in the Figure 3.5.

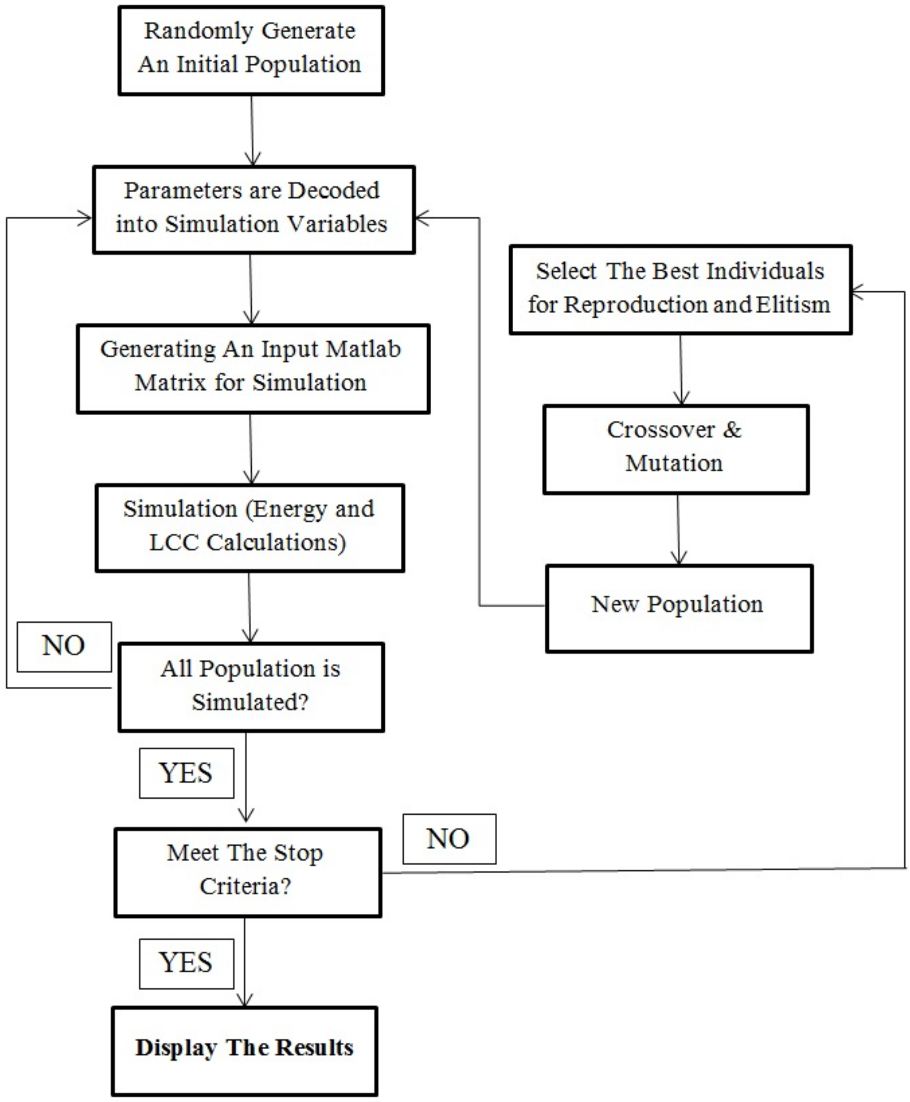

Figure 3.5. Genetic algorithm optimization process.

The variables of buildings envelope are needed to be converted into GA strings to insert into the simulation software developed. The constraints of the problems are determined according to the governmental regulations, technical limitations and owners will. At the beginning of the process the GA creates an initial population and the variables of each member in the population are decoded and sent to building energy simulation module. The building energy simulation module receives the variables and simulates the building by using heat balance method and calculates life cycles cost of the building's envelope system. After all the members of population are simulated and LCC calculations are completed, the results fitness are evaluated by the optimization module. If the stop criteria are met the GA displays the results else, the LCC values are sorted and the elite individuals and best individuals are selected for reproduction. During the reproduction phase crossover and mutation processes are applied to population members. The generated new population is sent back to second step until the termination conditions are met. Finally, if the termination conditions are met the process ends and the results are displayed.

4. PROTOTYPE

A prototype software is developed based on the design methodology presented in chapter 3. The developed software aims to support the designers at the preliminary stages of the design process. The constraints are inserted to the software according to governmental regulations, technical limitations and owner's wishes. Based on these factors, the designers input the geometric parameters, alternative components and performance expectations to find the cost-optimal building configuration. The genetic algorithm is applied to automatically run the developed simulation software and find the cost optimal solution. Life cycle costs or energy consumption can be defined as objective function of the optimization tool. If the total energy expenditure is determined as the objective function, the budget should be defined as a constraint.

The prototype software is developed in Matlab (Matlab 2012b). Matlab is a software environment which is primarily used for numerical computing, consisting many toolboxes for technical computing, and supports object oriented programming. The developed simulation software, can only execute on Matlab environment. Optimtool is the optimization toolbox of the Matlab which provides functions for finding parameters that minimize or maximize objectives while satisfying constraints. In this study Optimtool's genetic algorithm solver is implemented to find cost optimal building configurations. Other popular software such as; Python, C/C++ or C# could have been selected as the software environment for this study. However, Matlab is a user-friendly software with a powerful optimization toolbox. Besides, the author of the research is familiar with Matlab due to his previous experience. For this reason, Matlab is preferred as the software environment for this study.

4.1. Prototype Structure and Database

A MS Excel sheet is implemented to create a database and input data from the user. Matlab graphical output tools are utilized to present the results of the analysis. The data required to run the building simulation such as; economic constants, unit prices, weather data, building components data, building usage schedules, internal loads, indoor temperatures and orientation of the building are inserted to Microsoft Excel sheet. Using the inserted information the Microsoft Excel automatically fills other forms to numerically represent the building geometry and configuration. The Energy simulation software requires least amount of data input, it is easy to use and simulations processes require less run time compared to other software. The simulation software reads the MS Excel sheet once and takes the required data for energy simulation and optimization processes. After the data from MS Excel sheet is read, the building information is passed into the optimization loop. The optimization module completes the solving process and gives the optimal values of the building configuration. There are three main processes in the software; energy simulation, LCC analysis and optimization.

The heat balance based simulation software implements conduction transfer functions to simulate building. Therefore, the CTF coefficients are needed to be inserted to the software database. Ideally the prototype tool database is required to include all CTF coefficients for each building components in software database. However, if a new component is needed to be defined, the user can input the necessary coefficients himself. In this study, a PRF/RTF generator is utilized to calculate the CTF coefficients of the building components and the obtained coefficients are stored in the software database [62]. Building energy simulation is also requires weather data of the building location. Therefore, the user needs to input the required hourly weather data into the software database.

The objective functions are directly dependent to LCC analysis in cost minimization problems and indirectly dependent to LCC analysis in energy minimization problems. For the LCC analysis the unit price of the materials used in the building and the unit price of the energy consumed in the building is stored in the database. The stored information can easily be altered by the user if it is needed. The LCC analysis software obtains the data from the database and executes the analysis.

The optimization process is started by genetic algorithm toolbox and the optimization loop automatically runs the LCC and energy simulation software. The constraints and variable boundaries are inserted by the user. To perform the genetic algorithm optimization process the GA parameters are needed to be defined. The GA parameters can be listed as; number of objectives, number of constraints, mutation probability, crossover probability, population size, maximum number of generations, function tolerance, elitism rate etc. The objective of the optimization process is also defined and in this study the objective of the optimization process is to minimize the life cycle cost of the buildings envelope or energy consumption of the building.

4.2. The Software Implementation

The software requires the following input to run design problems; the building component database, economic data, weather and location data, building geometry, genetic algorithm optimization parameters, building schedules and performance expectations. To input the information required for the building energy simulation, the table presented in Figure 4.1 is required to be filled. The building components properties can be edited using "energy simulation data input" form. The form includes inside temperature demands, location information, building components geometry, internal heat loads and weather condition cells. To execute the building energy simulation, these cells must be filled by the user.

The software do the solar radiation calculation by using the location parameters, optical depth for diffuse irradiance (τ_d) and optical depth for beam irradiance (τ_b). These parameters are required to be inserted by the user. These parameters are easy to obtain and requires very little amount of time to be inserted into the software. The (τ_d) and (τ_b) values are inserted to the MS Excel form presented in Figure 4.2. Heat balance based building simulation method requires hourly air temperature and soil temperature values for 1 year. In addition, for infiltration and ventilation calculations the software requires monthly humidity values.

ENERGY SIMULATION DATA INPUT	
AIR CONDITIONING	
Cooling (°C)	-
Heating (°C)	-
LOCATION	
Latitude	-
Longitude	-
Time Zone (Hour)	-
BUILDING COMPONENTS	
Wall 1	
Length (m)	-
Height/Width (m)	-
Tilt Angle (deg)	-
Direction (deg)	-
Wall 2	
Length (m)	-
Height/Width (m)	-
Tilt Angle (deg)	-
Direction (deg)	-
Wall 3	
Length (m)	-
Height/Width (m)	-
Tilt Angle (deg)	-
Direction (deg)	-
Wall 4	
Length (m)	-
Height/Width (m)	-
Tilt Angle (deg)	-
Direction (deg)	-
Roof	
Length (m)	-
Height/Width (m)	-
Tilt Angle (deg)	-
Direction (deg)	-
Foundation	
Length (m)	-
Height/Width (m)	-
Tilt Angle (deg)	-
Direction (deg)	-

INTERNAL HEAT GAIN	
Number of People (Nr)	-
Ligthing (W/m2)	-
Equipments (W/m2)	-
Lighting Schedule	Building Type
People Schedule	Building Type

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Weather file
Hourly Soil Temp. (°C)	Weather file
Monthly Humidity (%)	Weather file

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure 4.1. User Interface for Entering Energy Simulation Input Data.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	-	-	-	-	-	-	-	-	-	-	-	-
taud	-	-	-	-	-	-	-	-	-	-	-	-

Figure 4.2. User Interface for Entering Monthly τ_d and τ_b

For LCC calculations the form presented in Figure 4.3 is required to be filled. The calculation period is determined according to life span of the building and other values required are location dependent parameters. The unit price for materials and components are obtained from the software database and users can easily modify the software database if it is required. Other constants, coefficients and data required for the thermal simulations are stored in the database.

Economic Parameters	
Calculation Period (Year)	-
Interest Rate (%)	-
Infilation (%)	-
Yearly Electricity Price Rise Rate (%)	-
Yearly Natural Gas Price Rise Rate (%)	-
Natural Gas Price (TL/KWh)	-
Electricity Price (TL/KWh)	-

Figure 4.3. User Interface for Entering Economic Parameters.

The GA parameters needed to perform optimization process can be listed as; number of objectives, number of constraints, mutation probability, crossover probability, population size, maximum number of generations, function tolerance, elitism rate, number of variables and boundary conditions. To define the boundary conditions of the variables, the form presented in Figure 4.4 is required to be filled. The number of wall type, roof type, foundation type and window type are dependent on the market research or the user's will. The window area at each surface of the building are defined considering governmental regulations, the owner's will and architectural design.

The other parameters required to be set by the user are presented in the Figure 4.5. The population size, maximum generation, elitism and crossover probability constants are decided based on the user's experience. The optimization toolbox ends due to determined number of iterations, time limit, maximum number of iterations without any improvement.

Variables	Lower Bound	Upper Bound
Wall Type	1	Number of Wall Types
Roof Type	1	Number of Roof Types
Foundation Type	1	Number of Foundation Types
Window Type	1	Number of Window Types
South Window Area	20% of the Wall Area	70% of the Wall Area
North Window Area	20% of the Wall Area	70% of the Wall Area
East Window Area	20% of the Wall Area	70% of the Wall Area
West Window Area	20% of the Wall Area	70% of the Wall Area

Figure 4.4. User Interface for Entering Lower and Upper Boundary Conditions.

For the selection process of the GA optimization stochastic uniform function is selected which is the default function of Matlab optimization toolbox. The stochastic uniform function lays a line and the line is divided into sections. The each section represents an individual of the population and the length of the section is proportional to its fitness. At each generation randomly an individual is selected as a parent individual for the next generation. For each individual, the probability of being selected as a parent individual is directly dependent on their fitness.

Genetic Algorithm Options	Description	Value
Population Size	Size of Population	-
Selection	Selection of individuals for the next generation	-
Maximum Generations	Maximum number of iteration	-
Elitism	How many individual in the current generation are guaranteed to survive	-
Tolerance Function	If the average relative change in the best fitness function value is less or equal to Funtol	-
Crossover Function	Constraint Dependent	-
Crossover Probability	The fraction of the population created by crossover function	-
Mutation Function	Constraint Dependent	-

Figure 4.5. User Interface for Entering Genetic Algorithm Options.

The crossover function is determined based on if the problem constraints are linear or nonlinear. If there are linear constraints in the problem, the Matlab toolbox uses the intermediate crossover function for creating the next generation individuals. The Intermediate function creates the child individuals by a random weighted average of parent individuals. When all the constraints in the problem are nonlinear the Matlab toolbox uses a Scatter function to create child individuals. The Scatter function creates a random binary vector and using the binary vector the genes from each parent individual is selected to create a child individual.

The mutation function of the genetic algorithm optimization is chosen based on if the problem has constraints or not. If the problem consists constraints the adaptive feasible function is selected. The adaptive feasible function generates direction with respect to previous successful generation. The mutations are much more purposeful than traditional methods. If there is no constraint in the optimization problem the Gaussian mutation function is implemented by Matlab optimization toolbox. The Gaussian function puts a random number to each individual vector and the random number is taken from a Gaussian distribution.

4.3. Validation of Building Energy Simulation Software

The developed energy simulation software aims to carry out yearly energy analysis in a shorter period of time with a limited amount of input data. Besides, in this study the energy simulation tool is expected to give reasonable results. To validate the results of building energy simulation software, the results from the developed software and a detailed energy analysis tool (EnergyPlus) are compared. Energy Plus is an open source software used to calculate and analyze indoor environment and energy demand of the buildings [63]. The EnergyPlus software implements a heat balance based model to carry out thermal simulations of the buildings. The program calculates all the energy inputs and outputs including; lighting, heating, cooling and appliances. The program also divides the buildings into zones and calculates the heat loss by ventilation, infiltration, transmission and the thermal gains from internal loads, solar radiation and HVAC system for each zone. However the program requires a detailed input data for building description, materials, windows and HVAC systems.

A commercial prototype building model developed by the U.S. Department of Energy (DOE) is used for comparison. The prototype buildings are a set of structure that covers almost 80% of the commercial buildings in United States. The commercial prototype buildings energy calculations are carried out using EnergyPlus for recent editions of ASHRAE Standard 90.1. The energy analyses of the buildings are published by DOE to support development of commercial building energy codes and standards. Energy simulation results of mid-rise apartment in 10 different climate locations are compared to the developed software results.

In this study, a completely new software for building energy analysis is proposed. Therefore, the validation of the energy simulation software is one of the most important aspects of the study. For this reason, the software is tested by running yearly analysis in 10 different climate regions. Cosidering that, both EnergyPlus and developed software implement a heat balance based model to carry out thermal calculations, EnergyPlus is a reasonable choice for validation analysis. In addition, the prototypes of DOE are analyzed by impartial experts which eliminates errors to be made while using EnergyPlus.

4.4. Test Case for Validation Analysis

A four story mid-rise apartment published by DOE is selected as the test case for validation analysis. The total floor area of the building is 3131 m^2, floor to ceiling height is 3 m and the average total window area consist the %20 of the total wall area. The floor length is 46.3 m and the width is 17 m long. The total wall area is 1519 m^2 and the total window area is 303.8 m^2. Each floor of the building has 8 apartments except the ground floor which has 7 apartments and a lobby. The mid-rise apartment used for validation analysis is presented in the Figure 4.6.

For EnergyPlus analysis, an extensive amount of input data is required to carry out the building energy simulations. The simulation software requires inputs such

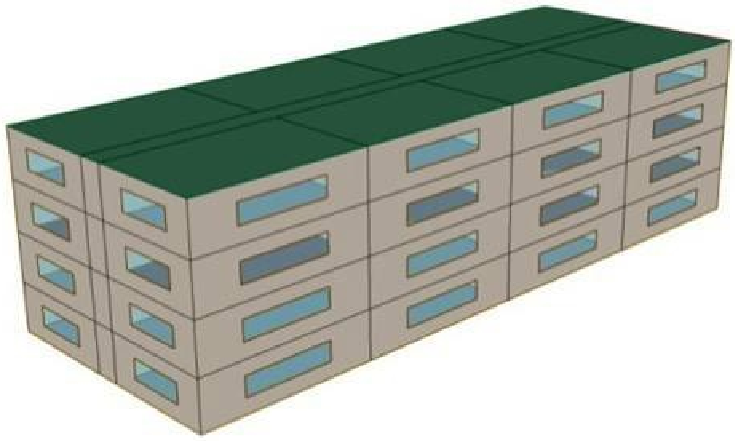

Figure 4.6. User Interface for Entering Genetic Algorithm Options.

as; building shape, aspect ratio, number of floors, window fraction, window location, thermal zones, exterior wall properties, roof properties, window properties, foundation properties, HVAC systems, usage schedules, weather conditions etc. The building external elements and layer properties are presented in the Table 4.1. The window SHGC factors are also required for the thermal simulation calculations and required values can be obtained from codes and standards. Natural gas is used for heating and the heating system efficiency is 0.8. Air conditioning units use electricity and the average efficiency is about 3.45.

In the reference case the building is heated to 21 °C and cooled to 24 °C. It is assumed that an ideal controller controls the heating and cooling when it is necessary and the power needed for cooling and heating system is available. The building is ventilated by a mechanical ventilation system and the ventilation is assumed to be homogenous in the building. The weather data and building occupation schedule is obtained from DOE website. The Energy Plus software's main focus is to calculate required HVAC system capacity for the building. Thus, the weather data is formed of worst weather conditions in last 30 years. The schedule is utilized to find internal heat loads such as, appliances and lighting loads.

The building information, weather data and schedules are inserted to developed dynamic simulation software and the building is simulated in 10 different climate locations in USA. The building usage schedule is presented in the Table 4.2. The results of the developed software are compared to EnergyPlus results and presented in following section.

Table 4.1. External layers and basic properties.

Construction	Layers	Dimensions	Tilt Angle
External Walls	Steel-frame walls (2X4 16IN o.c.) 0.4 in. Stucco 5/8 in. gypsum board Wall Insulation 5/8 in. gypsum board	2 x (46.3 m x 12m) 2 x (17m x 12m) Total Area = 1519 m^2	Vertical
Roof	Roof membrane Roof insulation Metal decking	46.3 m x 17 m Total Area = 781.1 m^2	Horizontal
Foundation	20 cm thick concrete slab poured directly on to the earth	46.3 m x 17 m Total Area = 787.1 m^2	Horizontal
Windows	Double Glazing 8mm thick	Total Area = 303.8 m^2	Vertical

Table 4.2. Building Occupational and Lighting Schedule.

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
People	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.85	0.39	0.25	0.25	0.25
Lighting	0.067	0.067	0.067	0.067	0.187	0.394	0.440	0.393	0.172	0.119	0.119	0.119

Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
People	0.25	0.25	0.25	0.25	0.30	0.52	0.87	0.87	0.87	1.00	1.00	1.00
Lighting	0.119	0.119	0.119	0.206	0.439	0.616	0.829	0.986	1.000	0.692	0.384	0.160

4.5. Results

Compared to detailed EnergyPlus building simulation the developed software gives reasonable results for cooling and heating loads. Although, Energy Plus splits the buildings into zones to increase the accuracy of the calculations the results of developed software and Energy Plus calculations are similar. Simulation results for

ASHRAE 2004, 2007, 2010 and 2013 are presented to give a better understanding of precision of the software calculations. For each climatic location annual and monthly results are presented in Appendix A.

4.5.1. Chicago – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Chicago are presented in the Section 1 of the Appendix A. The forms presented in Figure A.1 and Figure A.2 are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the Chicago is 41.98, the longitude is -87.92 and the time zone is -6 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.1 [64]. The data shows that the weather in Chicago is hot in summer and cold in winters. According to weather data, the use of energy for heating is expected to be much higher than the energy used for cooling. Monthly natural gas and electricity usage are presented in the Figure A.3 and Figure A.4. The results show that the developed software gives results which are very similar to EnergyPlus simulation results. The Developed software (E-Mat) results are within the range of between the results of the simulations carried out according to 2013 ASHRAE 90.1 standard results and 2004 ASHRAE 90.1 standard. The yearly results are also presented in Figure A.5 and Table A.4.

4.5.2. Memphis – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Memphis are presented in the Section 2 of the Appendix A. The forms presented in Figure A.6 and Figure A.7 are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the Memphis is 35.04, the longitude is -89.99 and the time zone is -6 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.5 [64].

The data shows that the weather in Memphis has a subtropical climate. In summers and winters, drastic temperature swings occur. Considering the weather conditions, a balanced use of energy for heating and cooling purposes is expected. Monthly natural gas and electricity usage are presented in the Figure A.8 and Figure A.9. The results showed that the developed software result accuracy is above the expectations. The developed software (E-Mat) results are very close to the EnergyPlus simulation carried out using the 2013 ASHRAE 90.1 standard. The yearly results are also presented in Figure A.10 and Table A.8.

4.5.3. Baltimore – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Baltimore are presented in the Section 3 of the Appendix A. The forms presented in Figure A.11 and Figure A.12 are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the Baltimore is 39.17, the longitude is -76.68 and the time zone is -5 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.9 [64]. The data shows that the weather in Baltimore has a subtropical humid climate. Winters are chilly and summers are humid and hot. With respect to weather conditions data, use of energy for heating purposes is expected to be higher than energy consumed for cooling. Monthly natural gas and electricity usage are presented in the Figure A.13 and Figure A.14. The results show that the developed software accuracy is above the expectations compared to EnergyPlus simulation results. The developed software (E-Mat) results are very close to the EnergyPlus simulation carried out according to the 2013 ASHRAE 90.1 standard. The yearly results are also presented in Figure A.15 and Table A.12.

4.5.4. Vancouver – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Vancouver are presented in the Section 4 of the Appendix A. The forms presented in Figure A.16

and Figure A.17 are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24°C and heated up to 21°C. The latitude of the Vancouver is 49.18, the longitude is -123.17 and the time zone is -8 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.13 [64]. The data shows that Vancouver has a moderate oceanic climate. Winters are mild and summers are warm. With respect to weather conditions use of energy for heating purposes is expected to be higher than energy consumed for cooling. Monthly natural gas and electricity usage are presented in the Figure A.18 and Figure A.19. When the results are compared to EnergyPlus results it can be seen that, the developed software gives reasonable results. The Developed software (E-mat) results are within the range of between the results of the simulations carried out according to 2013 ASHRAE 90.1 standard and 2004 ASHRAE 90.1 standard. The yearly results are also presented in Figure A.20 and Table A.16.

4.5.5. San Francisco – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in San Francisco are presented in the Section 5 of the Appendix A. The forms presented in Figure A.21 and Figure A.22 are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the San Francisco is 37.62, the longitude is -122.40 and the time zone is -8 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.17 [64]. The data shows that San Francisco has a warm summer Mediterranean climate. Winters are moist and mild, summers are dry. With respect to weather conditions a balanced and low use of energy for heating and cooling purposes is expected. Monthly natural gas and electricity usage are presented in the Figure A.23 and Figure A.24. The results of the developed software are compared to EnergyPlus simulation results. It can be said that, the developed software gives reasonable results. However, the results are less accurate compared to other validation simulations due to fluctuating weather temperatures. The yearly results are also presented in Figure A.25 and Table A.20.

4.5.6. Miami – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Miami are presented in the Section 6 of the Appendix A. The forms presented in Figure A.26 and Figure A.27. are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the Miami is 25.82, the longitude is -80.30 and the time zone is -5 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.21 [64]. The data shows that Miami has a tropical climate. Winters are short and warm, summers are humid and hot. With respect to weather conditions the energy for heating is expected to be very low and the energy needs to be consumed for cooling is expected to be very high. Monthly natural gas and electricity usage are presented in the Figure A.28 and Figure A.29. The result of the developed software is compared to EnergyPlus results and the results show that the developed software accuracy is above the expectations. The developed software (E-Mat) results are very similar to the EnergyPlus simulation carried out according to the 2013 ASHRAE 90.1 standard. The yearly results are also presented in Figure A.30 and Table A.24.

4.5.7. Phoenix – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Phoenix are presented in the Section 7 of the Appendix A. The forms presented in Figure A.31 and Figure A.32 are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the Phoenix is 33.45, the longitude is -111.98 and the time zone is -7 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.25 [64]. The data shows that Phoenix has a subtropical desert climate. Summers are long and hot and winters are warm and mild. With respect to weather conditions the energy for heating is expected to be very low and the energy needs to be consumed for cooling is expected to be very high. Monthly natural gas and electricity usage are presented in the Figure A.33 and Figure A.34. When the results are compared to EnergyPlus results it can be said that, developed software accuracy is above the expectations. The developed software (E-Mat) results are very similar to the EnergyPlus simulation carried out according to the 2013 ASHRAE 90.1 standard. The yearly results are also presented in Figure A.35 and Table A.28.

4.5.8. Houston – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Houston are presented in the Section 8 of the Appendix A. The forms presented in Figure A.36 and Figure A.37 are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the Houston is 30.00, the longitude is -95.37 and the time zone is -6 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.29 [64]. The data shows that Houston has a humid subtropical climate. Summers are very hot and humid, winters are warm and mild. With respect to weather conditions the energy for heating is expected to be very low and the energy needs to be consumed for cooling is expected to be very high. Monthly natural gas and electricity usage are presented in the Figure A.38 and Figure A.39. The Developed software (E-mat) results are within the range of between the results of the simulations carried out according to 2013 ASHRAE 90.1 standard and 2004 ASHRAE 90.1 standard. The yearly results are also presented in Figure A.40 and Table A.32.

4.5.9. Boise Idaho – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Boise Idaho are presented in the Section 9 of the Appendix A. The forms presented in Figure A.41 and Figure A.42 are filled according to the information given in the Department of

Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the Boise Idaho is 43.62, the longitude is -116.62 and the time zone is -7 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.33 [64]. The data shows that Boise Idaho has a semi-arid continental climate. Summers are hot and dry, winters are moderately cold. According to weather data, the use of energy for heating is expected to be higher than the energy used for cooling. Monthly natural gas and electricity usage are presented in the Figure A.44 and Figure A.45. The developed software simulation results are compared to EnergyPlus simulation results. The developed software (E-Mat) results are very similar to the EnergyPlus simulation carried out according to the 2013 ASHRAE 90.1 standard. The yearly results are also presented in Figure A.45 and Table A.36.

4.5.10. Fairbanks – Midrise Building Validation Analysis Results

The results of the validation analysis of midrise residential building in Fairbanks are presented in the Section 10 of the Appendix A. The forms presented in Figure A.46 and Figure A.47 are filled according to the information given in the Department of Energy website [64]. The building is cooled to 24 °C and heated up to 21 °C. The latitude of the Fairbanks is 64.82, the longitude is -147.85 and the time zone is -9 hour. For the analysis a 1 year hourly weather temperature data is used. The required weather condition data is acquired from the DOE website and the data summary is presented in Table A.37 [64]. The data shows that Fairbanks has a subarctic climate. Summers are short and warm, winters are very cold and long. With respect to weather conditions the energy for heating is expected to be very high and the energy needs to be consumed for cooling is expected to be very low. Monthly natural gas and electricity usage are presented in the Figure A.48 and Figure A.49. When the simulation results of the each software are compared it can be said that the developed software gives reasonable results. However, the results are less accurate compared to other validation simulations due to extraordinary weather temperatures and humidity values. The yearly results are also presented in Figure A.50 and Table A.40.

4.5.11. Evaluation of the Results

The prototype building is simulated in 10 different locations to validate the developed software. The results of the analysis are compared to EnergyPlus simulation results. It can be said that, the vast majority of the analysis have given reasonable results. The results for the buildings simulated in, Memphis, Baltimore, Miami, Phoenix and Boise Idaho are above expectations. The developed software results are very similar to EnergyPlus simulation results which are carried out with respect to 2013 ASHRAE 90.1 Standard. The simulation results for Chicago, Vancouver and Houston are also compared to results of EnergyPlus energy simulations and it can be said that the results are reasonable. The obtained results are in the area between the line of 2004 ASHRAE 90.1 and 2013 ASHRAE 90.1 simulation results. However, the results for San Francisco and Fairbanks are less accurate due to extraordinary weather conditions and fluctuating weather temperature. However, there are significant difference between the simulation results for ASHRAE 2004, 2007, 2010 and 2013. For this reason, it is understood that energy simulation methods are a developing field of study.

The results show that the developed software gives reasonable results for heating and cooling requirements compared to EnergyPlus results. The presented monthly energy consumption profiles also show similar behavior. The calculated monthly cooling loads and heating loads are compared to EnergyPlus results by using a root mean square error method. The results of the root mean square error analysis are presented in the Table 4.3 and Table 4.4. Compared to ASHRAE 2004, ASHRAE 2013 includes very detailed and sophisticated simulation methods. The new methods increases the accuracy of the calculations. On the other hand, the new methods require significant amount of data input and expertise. Considering the advantages of the proposed software, it is understood that the margin of error in the calculations is acceptable. The results prove that the developed software gives reliable results and it is a valid tool to be used in this study.

Table 4.3. Root Mean Square Error Analysis - Cooling Loads

	RMSE			
Location	**ASHRAE 2004**	**ASHRAE 2007**	**ASHRAE 2010**	**ASHRAE 2013**
Chicago	1189.14	995.83	887.72	1375.57
Memphis	3269.74	1329.56	1034.42	1032.11
Baltimore	1980.33	900.46	760.20	465.54
Vancouver	251.12	294.85	140.96	385.35
San Francisco	422.05	1300.74	1066.35	1600.81
Miami	4910.24	2668.26	2176.20	1211.61
Phoenix	5361.80	1938.96	1502.45	774.43
Houston	4338.03	2041.13	1682.88	1145.20
Boise-Idaho	1259.00	486.33	475.74	235.78
Fairbanks	218.33	441.64	289.23	444.39

Table 4.4. Root Mean Square Error Analysis - Heating Loads

	RMSE			
Location	**ASHRAE 2004**	**ASHRAE 2007**	**ASHRAE 2010**	**ASHRAE 2013**
Chicago	4579.85	2706.96	2009.02	3146.83
Memphis	2579.53	2164.67	1079.21	807.67
Baltimore	2600.76	1438.04	2063.35	2339.76
Vancouver	3330.85	1843.47	1436.63	2234.67
San Francisco	816.48	392.86	529.57	420.05
Miami	42.98	32.92	7.35	16.56
Phoenix	220.39	636.23	711.34	618.71
Houston	725.94	1601.82	2121.92	1886.50
Boise-Idaho	1379.41	2516.94	4244.98	4444.25
Fairbanks	8265.07	11057.52	13367.07	14763.82

5. CASE STUDIES

The first objective of the case studies is to show how design problems are defined in the developed software. The second objective is to evaluate the results obtained from the developed methodology. Finally, the case studies are used to identify weaknesses and strengths of the developed methodology to offer changes and improvements in the prototype software. In order to test the developed method, the prototype software was tested on a residential building in Istanbul. Two different cases were prepared for the case study and applied on the reference building.

- Minimization of 30-year life cycle costs required to provide thermal comfort conditions in the reference building.
- Minimization of the amount of energy required to be consumed to provide thermal comfort in the reference building with a low, average and high budget constraint.

In the first case the aim is to find the minimum LCC cost possible to maintain the building thermal comfort. In this aspect, the configuration found in the first case is the most economic but not the greenest. Therefore, the second case is carried out to determine the green configurations with low, average and high budget constraints.

5.1. Typical Residential Building

In Turkey, the urban regeneration law enforced in May 2012 is being applied. For this reason, the construction of new buildings in Turkey has gained a great speed since 2012. Since 2002, 98602 buildings have been constructed in Istanbul and 88277 of the buildings built are residential buildings. In addition, 27.9% of the residential buildings built in Istanbul have 5 floors and 19.9% have 6 floors [65]. The number of residential buldings constructed in Istanbul since 2002 is presented in Table 5.1. In this context, the building used in case studies represents a large scale of buildings in Istanbul. Therefore, in this study the building selected for the case study is a real 5-storey building located in Istanbul at 41.01^o latitude and 28.77^o longitude.

Table 5.1. Number of Residential Buildings Constructed in Istanbul.

Year	**Total**	**1 Story**	**2 Story**	**3 Story**	**4 Story**	**5 Story**	**6 Story**	**7 Story**	**8 Story**	**9 Story**	**10+ Story**
2015	15397	199	546	736	1401	5552	4312	1501	230	204	716
2014	14584	297	561	967	1387	5071	3841	1373	206	161	720
2013	13848	126	518	994	1295	4850	3669	1221	247	196	732
2012	10175	163	552	1030	883	3382	2400	765	177	114	709
2011	11133	146	855	1508	925	3445	2419	681	231	143	780
2010	6294	123	347	1232	587	1858	1028	372	154	103	490
2009	6662	156	968	1730	484	1468	654	402	125	82	593
2008	3156	153	583	608	334	526	327	143	82	71	329
2007	3020	119	648	717	230	478	271	152	32	96	277
2006	2958	114	1024	655	215	337	186	71	41	28	287
2005	5118	181	855	2262	1202	180	187	70	36	26	119
2004	1718	76	395	585	148	120	111	94	23	46	120
2003	2509	40	320	1516	143	114	120	68	31	22	135
2002	2030	67	309	1022	102	118	69	65	27	23	228
Total	98602	1960	8481	15562	9336	27499	19594	6978	1642	1315	6235

The reference building sits on an area of 300 m^2 and has 5 normal floors and 1 attic floor. The total area of ground floor is 300 m^2 and other floors are 320 m^2. The height of each storey (floor to floor height) is 3.20 m. 25% of the building surface in the south-west direction and 30% of the other surfaces are constituted of windows. All the windows are polyvinyl chloride, have double glasses 4/16/4. 4 cm thick insulation material is used on external walls and 6 cm on the roof. External concrete walls are made of 20 cm thick bricks and other walls are made of 10 cm thick bricks. Furthermore, a conventional roof system covered with tiles and insulated using stone wool is used for the roof.

The building is assumed to be cooled to 24 °C and heated to 21 °C. Since the building is a typical residential building, it is considered that there is no mechanical ventilation. Internal heat loads other than lighting have been neglected. The reference building occupation schedule has been determined in accordance with the ASHRAE standards [64]. Due to the limits of the prototype software, the reference building has been regarded as a single zone. However, this simplification makes the software more user-friendly and more practical and also shortens the calculation time.

5.2. Building Geometry

The reference building faces 45 degrees Southwest direction. Southwest and northeast faces are 460.80 m^2 and, southeast and northwest faces are 321.60 m^2. The floor and roof areas are 400 m^2 and the height of the reference building is 19.20 m. The plans and northwest side view drawings of the reference building is presented in the Figure 5.1.

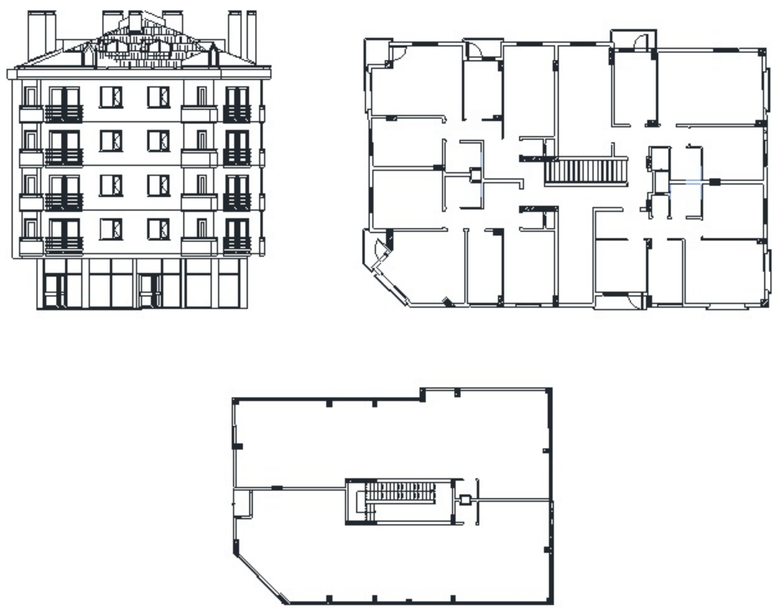

Figure 5.1. Plans and Cross-Section of the Reference Building.

5.3. Energy Efficiency Measures Used in the Case Studies

In the following sections the features of the EEM's used in the study are described. EEM types are stored in a database to be used by prototype software to create design alternatives. The prices of all materials were evaluated according to the 2017 unit price list of the Ministry of Environment and Urbanization.

A name and a number are assigned for each design variable in the EEM database. The design module utilizes the numbers of the design variables to create different design configurations for the buildings. For example, in the prototype software, x (1) represents the outer walls of the buildings. If x (1) = 10, then it indicates that the prototype software have selected the 10th outer wall for the building. The CTF coefficients of each component were previously calculated and recorded in the database.

5.3.1. Outer Wall Construction

Four types of outer walls are defined in the prototype software's database; WT1, WT2, WT3 and WT4. In the Turkish construction sector, the most used exterior wall types in residential constructions were selected. The main material of the four outer walls is brick. EPS, rock wool, cement bonded particle board and aluminum composite panels are preferred for heat isolation. The service life of the exterior walls is estimated to be 30 years and is assumed to require no maintenance.

5.3.1.1. Outer Wall Type 1 (WT1). WT1 is formed of 20 mm gypsum plaster, 100 mm brick wall, 20 mm cement plaster, 20 – 100 mm rock wool and 6-30 mm cement bonded particle board. The properties of the materials are given in the Table 5.2.

Table 5.2. Wall Type 1 Layers.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Rock Wool	20-100	0.05	25.00	0.80
Cement Bonded Particle Board	6-30	0.25	1150.00	0.84

5.3.1.2. Outer Wall Type 2 (WT2). WT2 is formed of 20 mm gypsum plaster, 100 mm brick wall, 20 mm cement plaster, 20-100 mm EPS and 20 mm cement plaster.

The properties of the layers are given in the Table 5.3.

Table 5.3. Wall Type 2 Layers.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Thermal Insulation (EPS)	20-100	0.03	22.00	1.50
Cement Plaster	20	0.72	1860.00	0.84

5.3.1.3. Outer Wall Type 3 (WT3). WT3 is formed of 20 mm gypsum plaster, 100 mm brick wall, 20 mm cement plaster, 20-100 mm rock wool, 20-100 mm EPS and 20 mm cement plaster. The properties of the layers are given in the Table 5.4.

Table 5.4. Wall Type 3 Layers.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Thermal Insulation (EPS)	20-100	0.03	22.00	1.50
Cement Plaster	20	0.72	1860.00	0.84

5.3.1.4. Outer Wall Type 4 (WT4). WT4 is formed of 20 mm gypsum plaster, 100 mm brick wall, 20 mm cement plaster, 20-100 mm EPS and 4 mm aluminum composite panel. The properties of the layers are given in the Table 5.5.

Table 5.5. Wall Type 4 Layers.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Thermal Insulation (EPS)	20-100	0.03	22.00	1.50
Aluminum Composite Panel	4	0.44	1900.00	1.20

5.3.2. Roof Construction.

Four types of roofs are defined in the prototype software's database; RT1, RT2, RT3 and RT4. In the construction sector, the most used roof types in residential constructions were selected. XPS foam board, rock wool and gravel are preferred for heat isolation. The service life of the roof is estimated to be 30 years and is assumed to require no maintenance.

5.3.2.1. Roof Type 1 (RT1). RT1 is formed of 20 mm gypsum plaster, 200 mm concrete slab, 20 – 100 mm XPS foam board, 50 mm protective concrete, 30 mm gravel. The properties of the layers are given in the Table 5.6.

Table 5.6. Roof Type 1 Layers.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
XPS Foam Board	20-100	0.03	30.00	1.50
Protective Concrete	50	0.68	897.00	0.84
Gravel	30	0.36	1840.00	0.84

<u>5.3.2.2. Roof Type 2 (RT2).</u> RT2 is formed of 20 mm gypsum plaster, 200 mm concrete slab, 20 – 100 mm XPS foam board, 50 mm screed. The properties of the layers are given in the Table 5.7.

Table 5.7. Roof Type 2 Layers.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
XPS Foamboard	20-100	0.03	30.00	1.50
Screed	50	1.40	1200.00	0.84

<u>5.3.2.3. Roof Type 3 (RT3).</u> RT3 is formed of 20 mm gypsum plaster, 200 mm concrete slab, 20 – 100 mm rock wool, 20 – 100 XPS foam board, 50 mm protective concrete. The properties of the layers are given in the Table 5.8.

Table 5.8. Roof Type 3 Layers.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
Rock Wool	20-100	0.05	25.00	0.80
XPS Foamboard	20-100	0.03	30.00	1.50
Protective Concrete	50	0.68	897.00	0.84

<u>5.3.2.4. Roof Type 4 (RT4).</u> RT4 is formed of 20 mm gypsum plaster, 200 mm concrete slab, 20 – 100 mm XPS foam board, 50 mm protective concrete and roof tiles. The properties of the layers are given in the Table 5.9.

Table 5.9. Roof Type 4 Layers.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
XPS Foamboard	20-100	0.03	30.00	1.50
Protective Concrete	50	0.68	897.00	0.84
Roof Tiles	40	0.52	837.00	0.84

5.3.3. Slab Construction

Two types of slabs are defined in the prototype software's database; ST1 and ST2. In the construction sector, the most used slab types in residential constructions were selected. Rock wool is preferred for heat isolation. The service life of the slab is estimated to be 30 years and is assumed to require no maintenance.

5.3.3.1. Slab Type 1 (ST1). ST1 is formed of 50 mm screed, 500 mm foundation slab, 50 mm protective concrete and 150 mm blockage. The properties of the layers are given in the Table 5.10.

Table 5.10. Slab Type 1 Layers.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Screed	50	1.40	1200.00	0.84
Foundation Slab	500	1.50	2400.00	0.80
Protective Concrete	50	0.68	897.00	0.84
Blockage	150	0.36	1840.00	0.84

5.3.3.2. Slab Type 2 (ST2). ST2 is formed of 50 mm screed, 40 – 100 mm rock wool, 500 mm foundation slab, 100 mm lean concrete and 150 mm blockage. The properties of the layers are given in the Table 5.11.

Table 5.11. Slab Type 2 Layers.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Screed	50	1.40	1200.00	0.84
Rock Wool	40 - 100	0.05	25.00	0.80
Foundation Slab	500	1.50	2400.00	0.80
Lean Concrete	100	0.68	897.00	0.84
Blockage	150	0.36	1840.00	0.84

5.3.4. Windows

For windows, a database of glass and frame combinations was created. Frames made of aluminum, polyvinyl chloride, wood and glass types with different thicknesses and coatings are defined in the database. In addition, the SHGC coefficients required to calculate the amount of solar radiation entering the building through the windows are defined in the database. Window prices are taken from the 2017 unit price list of the Ministry of Environment and Urbanization. The service life of the windows is estimated to be 30 years and is assumed to require no maintenance. The properties of the windows inserted to prototype database are given in the Table 5.12, 5.13 and 5.14.

Table 5.12. Window Types and Properties (Without Joints and Woodwork Frames).

	Glass	**Space Between Glasses (mm)**	**Thermal Transmittance W/m^2K**	**0**	**40**	**50**	**60**	**70**	**80**	**Diffuse**	**Normal**	**Glass Thickness (mm)**
Without Joints	Single Glazing	0.00	5.7	1	0.977	0.953	0.907	0.779	0.488	0.907	0.86	4
	Double Glazing	0.01	3.3	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	2.9	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.02	2.7	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
	Double Glazing Low-E	0.01	2.6	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.1	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	1.8	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.02	1.6	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
Woodwork	Single Glazing	0.00	5.1	1	0.977	0.953	0.907	0.779	0.488	0.907	0.86	4
	Double Glazing	0.01	3.3	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3.1	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.02	2.8	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
	Double Glazing Low-E	0.01	2.8	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.3	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.2	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.02	2	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8

Table 5.13. Window Types and Properties (Aluminium Frames).

	Glass	**Space Between Glasses (mm)**	**Thermal Transmittance W/m^2K**	**0**	**40**	**50**	**60**	**70**	**80**	**Diffuse**	**Normal**	**Glass Thickness (mm)**
Aluminium Joint	Single Glazing	0.00	5.9	1	0.977	0.953	0.907	0.779	0.488	0.907	0.86	4
	Double Glazing	0.01	4	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3.9	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3.7	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.02	3.6	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
	Double Glazing Low-E	0.01	3.6	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	3.1	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	3	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.02	2.8	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
Aluminium Joint With Insulation Bridge	Single Glazing	0.00	5.2	1	0.977	0.953	0.907	0.779	0.488	0.907	0.86	4
	Double Glazing	0.01	3.4	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3.2	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.02	2.9	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
	Double Glazing Low-E	0.01	2.9	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.4	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.3	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.02	2.1	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8

Table 5.14. Window Types and Properties (PVC Frames).

	Glass	Space Between Glasses (mm)	Thermal Transmittance W/m^{2}K	0	40	50	60	70	80	Diffuse	Normal	Glass Thickness (mm)
PVC 2o Joint	Single Glazing	0.00	5.2	1	0.977	0.953	0.907	0.779	0.488	0.907	0.86	4
	Double Glazing	0.01	3.4	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3.2	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.02	2.9	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
	Double Glazing Low-E	0.01	2.9	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.4	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.3	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.02	2.1	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
PVC 3o Joint	Single Glazing	0.00	5	1	0.977	0.953	0.907	0.779	0.488	0.907	0.86	4
	Double Glazing	0.01	3.2	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	3	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.01	2.8	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
		0.02	2.7	1	0.974	0.934	0.842	0.658	0.342	0.868	0.76	8
	Double Glazing Low-E	0.01	2.7	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.2	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.01	2.1	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8
		0.02	1.9	1	0.985	0.938	0.862	0.662	0.354	0.877	0.65	8

5.4. Economic Assumptions

In the reference building natural gas is used for space heating and electricity is used for cooling. Natural gas unit prices required for LCC calculations are acquired from IGDAS (Istanbul Gas Distribution Industry and Trade Incorporated Company) website. Natural gas unit prices and annual price change rates are presented in the Table 5.15. For LCC calculations average annual raise (12.32) and 2017 natural gas unit price (0.0877) are utilized.

Table 5.15. Natural Gas Unit Prices [66].

Date (d/m/year)	**Price (TL/KWh)**	**Annual Raise (%)**
01.01.2004	0.0251	-
01.01.2005	0.0280	11.28
01.01.2006	0.0392	40.23
01.01.2007	0.0433	10.50
01.01.2008	0.0535	23.38
01.01.2009	0.0862	61.27
01.01.2010	0.0581	-32.57
01.01.2011	0.0588	1.18
01.01.2012	0.0672	14.24
01.01.2013	0.0860	28.04
01.01.2014	0.0866	0.71
01.01.2015	0.0942	8.69
01.01.2016	0.0948	0.68
01.01.2017	0.0877	-7.54

Electricity unit prices required for LCC calculations are acquired from TEDAS (Turkish Electricity Distribution Corporation). Electricity unit prices and annual price change rates are presented in the Table 5.16. For LCC calculations average annual raise 11.98% and 2017 electricity unit price are utilized.

Table 5.16. Electricity Unit Prices [67].

Date (year)	**Unit Price (TL/KWh)**	**Annual Raise (%)**
2008	0.123	19.55
2009	0.152	33.53
2010	0.229	9.37
2011	0.253	9.58
2012	0.280	19.60
2013	0.348	0.00
2014	0.348	0.35
2015	0.349	9.00
2016	0.384	6.80
2017	0.412	0.00

The inflation rates and interest rates for the last 10 years required for LCC calculations are acquired from TCMB (Central Bank of Turkey) and presented in the Table 5.17.

Table 5.17. Interest and Inflation Rates in Turkey [68].

Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Infilation Rate (%)	9.5	8.19	4.9	10.61	7.31	7.48	7.51	9.58	9.22	9.22
Interest Rate (%)	17.84	14.37	9.27	9.21	10.04	8.07	9.85	9.85	11.01	11.6

As a result, LCC calculations are based on the constants presented in the Table 5.18.

Table 5.18. Parameters for LCC calculations.

Calculation Period	30 Years
Interest Rate	11.11%
Infilation	8.35%
Yearly Electricity Price Rise Rate	11.98%
Yearly Natural Gas Price Rise Rate	12.32%
Natural Gas Price	0.088 TL/KWh
Electricity Price	0.412 TL/KWh

5.5. Meteorological Data

The air temperature data required to be used in the building energy simulation are taken from Turkish State Meteorological Service. The monthly average temperatures and standard deviations of the data are given in the Table 5.19.

Table 5.19. Weather Temperature Data Used in Building Simulation.

Month	Average Temperature (°C)	Standard Deviation
1	6.74	3.95
2	6.93	3.70
3	8.92	3.59
4	12.14	3.63
5	17.87	4.17
6	22.33	3.34
7	25.24	3.06
8	25.44	3.12
9	21.23	3.48
10	16.34	3.65
11	12.31	3.92
12	9.18	4.55

The relative humidity ratio is required to calculate the heat load due to infiltration. Thus, the required relative humidity ratio is also acquired from Turkish State Meteorological Service. The monthly average humidity ratios and standard deviations of the data are given in the Table 5.20.

Table 5.20. Weather Temperature Data Used in Building Simulation.

Month	**Average Humidity (%)**	**Standard Deviation**
1	81.66	11.89
2	81.91	12.01
3	81.98	11.47
4	81.43	11.54
5	79.41	10.82
6	75.67	11.59
7	75.62	10.85
8	78.47	10.51
9	80.93	11.54
10	83.12	11.51
11	82.07	12.40
12	80.69	12.13

5.6. Ventilation and Internal Loads

People and lighting schedules are required to calculate the internal loads of the reference building. The people and lighting schedules obtained from Building America Benchmark are presented in the table. Considering that the reference building is a residential building, it is assumed that there is no equipment that will generate considerable amount of heat load. The internal load schedule is presented in the Table 5.21.

Table 5.21. Building Occupational and Lighting Schedule.

Hours	1	2	3	4	5	6	7	8	9	10	11	12
People	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.85	0.39	0.25	0.25	0.25
Lighting	0.067	0.067	0.067	0.067	0.187	0.394	0.440	0.393	0.172	0.119	0.119	0.119

Hours	13	14	15	16	17	18	19	20	21	22	23	24
People	0.25	0.25	0.25	0.25	0.30	0.52	0.87	0.87	0.87	1.00	1.00	1.00
Lighting	0.119	0.119	0.119	0.206	0.439	0.616	0.829	0.986	1.000	0.692	0.384	0.160

5.7. Case Planning

In previous sections the properties of the reference building are demonstrated extensively. As mentioned previously, two different cases were prepared for the case study and applied on the reference building. The cases are prepared to test the efficiency of the developed software and methodology. In the first case, the objective is to minimize total LCC of the reference building. No constraints apart from lower and upper boundaries are defined in case 1.

In Case 2; the aim is to minimize the amount of energy required to be consumed to provide thermal comfort in the reference building. The calculated lowest and highest initial cost for the reference building is calculated to be 850,441 TL and 1,306,200 TL respectively. The lowest and highest priced envelope configurations are presented in Table 7.20. The initial cost (budget) of the reference building envelope is defined as a constraint in the optimization software. Four different initial budget assumptions are made and four optimization processes are carried out in second case. 1.05, 1.10, 1.25, 1.40 times the lowest cost possible are defined as budget constraint for each analysis. The main objective of the Case 2 is to determine, the greener building configurations for the reference building.

Table 5.22. Building Configurations with the Lowest and Highest Initial Budgets.

Wall Type	Roof Type	Slab Type	Window Type	Surface 1 Window Area (m^2)	Surface 2 Window Area (m^2)	Surface 3 Window Area (m^2)	Surface 4 Window Area (m^2)	Wall Abs.	Roof Abs.	Initial Cost (TL)
137	1	1	10	92.6	92.6	64.32	64.32	0.2	0.2	850,441
455	323	14	54	322.56	322.56	225.12	225.12	0.2	0.2	1,306,200

5.8. Case 1: LCC optimization (No Constraint)

In case 1, the 30 year life cycle costs of the reference building is minimized using the prototype tool. Considering the land constraints and dense housing in İstanbul, orientation and geometry of the building are fixed. The window area at each façade may range from %20 to %70 of the area of the façade they are placed. The building components that can be varied in the optimization can be listed as; exterior walls, windows, foundation, roof, wall absorption coefficient and roof absorption coefficient. The exterior wall types, roof types, foundation types and roof types are described as discrete variables. The window area, roof absorption coefficient and wall absorption coefficient are continuous variables in the optimization. The building is required to be heated below 21 °C and cooled above 24 oC. The design variables and their upper and lower bounds are filled in the form presented in Figure 5.2. Considering that the reference building is a residential building, the windows without joints are removed from the window lists by setting window type lower bound to 10.

Variables	Lower Bound	Upper Bound
Wall Type	1	459
Roof Type	1	340
Foundation Type	1	14
Window Type	10	54
South Window Area (m2)	92.16	322.56
North Window Area (m2)	92.16	322.56
East Window Area (m2)	64.32	225.12
West Window Area (m2)	64.32	225.12
Wall Absorbance Coefficient	0.2	1
Roof Absorbance Coefficient	0.2	1

Figure 5.2. Case 1: Determined LB and UB Parameters for GA Optimization.

For GA optimization the GA toolbox options also need to be determined. The determination of the options can only be set according to user's experience and problem size. The determined GA options filled in the software form are presented in Figure 5.3.

Genetic Algorithm Options	Description	Value
Population Size	Size of Population	100
Selection	Selection of individuals for the next generation	Default Stochastic Uniform
Maximum Generations	Maximum number of iteration	100
Elitism	How many individual in the current generation are guaranteed to survive	0.05*Population Size
Tolerance Function	If the average relative change in the best fitness function value is less or equal to Funtol	1.00E-08
Crossover Function	When there are linear constraints : Intermediate When there is no linear constraints : Scatter	Constraint Dependent
Crossover Probability	The fraction of the population created by crossover function	Default value : 0.8
Mutation Function	The default mutation function when there are constraints: Adaptive Feasible The default mutation function when there is no constraints: Gaussian	Constraint Dependent

Figure 5.3. Case 1: Determined LB and UB Parameters for GA Optimization.

The weather data acquired from Turkish State Meteorological Service, building geometry and other information related to building location and geometry are inserted into the simulation software form as presented in Figure 5.4.

ENERGY SIMULATION DATA INPUT

AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21

LOCATION	
Latitude	41.01
Longitude	28.77
Time Zone (Hour)	2

BUILDING COMPONENTS	
Wall 1	
Length (m)	24
Height/Width (m)	19.2
Tilt Angle	90
Direction	225
Wall 2	
Length (m)	16.75
Height/Width (m)	19.2
Tilt Angle	90
Direction	315
Wall 3	
Length (m)	24
Height/Width (m)	19.2
Tilt Angle	90
Direction	405
Wall 4	
Length (m)	16.75
Height/Width (m)	19.2
Tilt Angle	90
Direction	495
Roof	
Length (m)	24
Height/Width (m)	16.75
Tilt Angle	0
Direction	225
Foundation	
Length (m)	24
Height/Width (m)	16.75
Tilt Angle	0
Direction	225

INTERNAL HEAT GAIN	
Number of People (Nr)	40
Ligthing (W/m2)	9.167
Equipments (W/m2)	0
Lighting Schedule	Residential Building
People Schedule	Residential Building

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Istanbul (TSMS)
Hourly Soil Temp. (°C)	Istanbul (TSMS)
Monthly Humidity (%)	Istanbul (TSMS)

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological Service).

Figure 5.4. Case 1: Building Energy Simulation Input Form.

After making a couple of trial runs, the size of the population and maximum number of generations are determined to be 100. The selection function, elitism coefficient, crossover function, crossover probability coefficient and mutation function are set as default values. The tolerance function is set as 1.00E-08. The objective function of the optimization problem is the minimization of LCC of the building. To calculate the LCC of the building, the economic parameters are filled in the software form presented in Figure 5.5. The methods used to determine the economic parameters are stated in the previous sections.

Economic Parameters	
Calculation Period (Year)	30
Interest Rate (%)	11.11%
Inflation (%)	8.35%
Yearly Electricity Price Raise Rate (%)	11.98%
Yearly Natural Gas Price Raise Rate (%)	12.32%
Natural Gas (TL/KWh)	0.088
Electricity Price (TL/KWh)	0.412

Figure 5.5. Case 1: Building Energy Simulation Input Form.

For the solar radiation calculation İstanbul's optical depth for beam irradiance coefficients and optical depth for diffuse irradiance coefficients are inserted in the software form presented in Figure 5.6.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.32	0.34	0.37	0.39	0.41	0.46	0.46	0.44	0.41	0.35	0.33	0.31
taud	2.51	2.45	2.38	2.29	2.20	2.07	2.13	2.19	2.32	2.47	2.55	2.63

Figure 5.6. Case 1: Optical Depth Coefficients.

5.8.1. Optimization Results

The computer used for optimization has an i7-2600 central processing unit and 16 GB ram. Developed software run 10000 thermal simulations and took about 3.5 hours to complete optimization process. Using a newer computer with a better configuration may reduce the processing time. It can be seen that from generation 60 to 100 the best member of the population has shown no improvements. The genetic algorithm optimization is terminated after 100 generations and the optimization results are presented in Figure 5.7. Different genetic algorithm parameters (population, mutation, elitism, selection etc.) are tested in the toolbox and parameters are determined according to researchers experience and Matlab recommendations.

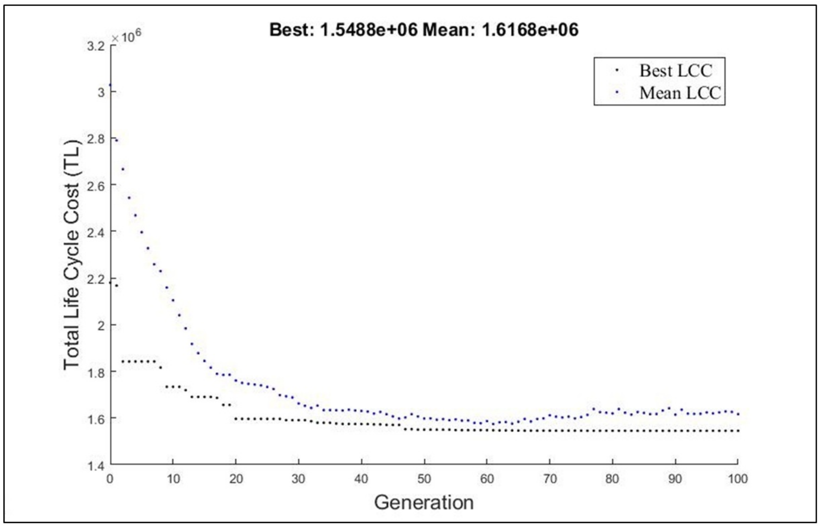

Figure 5.7. Case 1 Genetic Algorithm Results.

The selected envelope configuration for the reference building is presented in Table 5.23. The windows area facing to 225° and 405° are 92.38 m^2 and 92.40 m^2 respectively. 92.16 m^2 is the lower boundary condition for these two surfaces. The windows facing to 315° and 495° are 64.84 m^2 and 64.41 m^2, which is again very close to the lower boundary condition for the surfaces.

Table 5.23. Case 1 Optimization Results for Reference Building.

Building Components	**Selected Components/Values**
External Wall Type	153
Roof Types	17
Slab Type	1
Window Type	36
Surface 1 - Window Area	92.38
Surface 2 - Window Area	92.40
Surface 3 - Window Area	64.84
Surface 4 - Window Area	64.41
Wall Absorbance Coefficient	0.2
Roof Absorbance Coefficient	0.2

The software selected nearly the smallest windows for the reference building. In addition, for the roof and walls the software selected the minimum absorbance values (0.2). Therefore, lightest colors possible must be used in the building for optimal configuration. For the external walls, 153rd wall is selected and its layer properties are presented in the Table 5.24. The selected wall is a traditional brick wall with 100 mm thermal insulation (EPS). The unit cost of the wall is 166.78 TL/m^2.

Table 5.24. Wall 153 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Thermal Insulation (EPS)	100	0.03	22.00	1.50
Cement Plaster	20	0.72	1860.00	0.84

The software selected roof type 17th for the reference building. The selected roof has 100mm XPS insulation and 30 mm gravel layer. The layer properties are presented in Table 5.25. The unit price for the selected roof is 688.93 m^2.

Table 5.25. Roof 17 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
XPS Foam Board	100	0.03	30.00	1.50
Protective Concrete	50	0.68	897.00	0.84
Gravel	30	0.36	1840.00	0.84

The 1st slab is selected to be the foundation of the reference building. The selected slab has 150 mm blockage, 50 mm protective concrete, 500 mm foundation slab and 50 mm screed. The layer properties are presented in the Table 5.26 and the unit price for the selected slab is 826.76 m^2.

Table 5.26. Slab 1 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Screed	50	1.40	1200.00	0.84
Foundation Slab	500	1.50	2400.00	0.80
Protective Concrete	50	0.68	897.00	0.84
Blockage	150	0.36	1840.00	0.84

The reference building optimal window type is selected to be the 36th window. The 36th window is a double glazing low-E window with PVC 3o joints. The window properties are presented in the Table 5.27. The unit price for the 36th window is 254.14 m^2.

Table 5.27. Window 36 Properties.

Glass	**Space (mm)**	**Thermal Trans. (W/m^{2}K)**	**0**	**40**	**50**	**60**	**70**	**80**	**Diff.**	**Normal**	**Glass Thickness (mm)**
Double Glazing Low-E	0.016	1.9	1	0.98	0.93	0.86	0.66	0.35	0.87	0.65	8

The objective of the Case 1 is to minimize the LCC of the reference building while keeping the thermal comfort in the building at a certain level. Using the optimal building configuration the electricity consumption for cooling is 26,635 KWh and natural gas consumption for heating is 47,320 KWh. The present value of the total LCC of the reference building for 30 years is 1,548,800 TL and the buildings envelop initial cost is 897.717 TL. The results of the first case demonstrated that, the operation costs of the building are the significant part of the buildings life cycle costs. Therefore, the developed optimization software used components with high insulation values to reduce high heating and cooling costs.

5.9. Case 2: Energy optimization (Initial Cost Constraint)

The objective of the Case 2 is to minimize energy consumption of the reference building using the prototype software. The total initial cost of the building envelope is taken as a constraint and the budget is assumed to be 1.05, 1.10, 1.25 and 1.40 times the lowest initial cost possible for each analysis. The aim is to determine a configuration with lowest energy consumption possible with a low budget constraint. The same software settings in Case 1, except for budget constraints are implemented in the Case 2. The constraints of the Case 2 are presented in table 5.28.

Table 5.28. Initial Budget Constraints for Case 2.

Case	**Constraint**
Case 2.a	Initial Cost $\leq$ 892,963 TL
Case 2.b	Initial Cost $\leq$ 935,485 TL
Case 2.c	Initial Cost $\leq$ 1,063,051 TL
Case 2.d	Initial Cost $\leq$ 1,190,617 TL

5.9.1. Case 2a Energy Consumption Minimization (Initial Cost Constraint)

The initial budget constraint for Case 2a is assumed to be 892,963 TL and the aim is to minimize total energy consumed to maintain the thermal comfort in the reference building. The results of the genetic algorithm optimization process are presented in Figure 5.8. At first 10 generations the genetic algorithm tool couldn't find results meeting the initial cost constraint. After 10th generation the toolbox started to show results for the optimization problem. It can be seen that from generation 60 to 100 the best member of the population has shown no improvements.

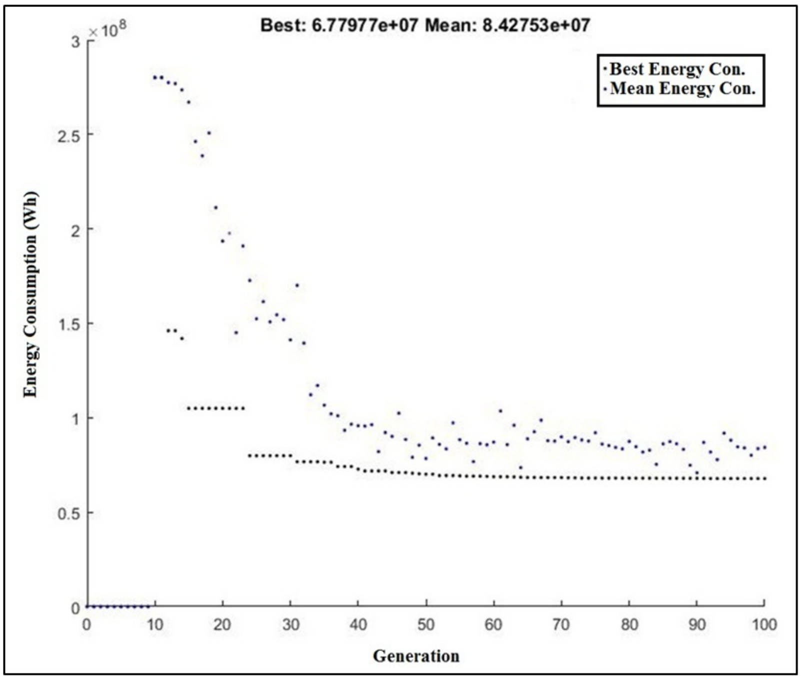

Figure 5.8. Case 2a Genetic Algorithm Results.

Optimal building envelope configuration for Case 2a is presented in Table 5.29. The windows facing to 315° and 495° are 64.57 m^2 and 103.53 m^2 respectively.

Table 5.29. Case 2a Optimization Results for Reference Building.

Building Components	**Selected Components/Values**
External Wall Type	152
Roof Types	16
Slab Type	1
Window Type	18
Surface 1 - Window Area	92.21
Surface 2 - Window Area	92.31
Surface 3 - Window Area	64.57
Surface 4 - Window Area	103.53
Wall Absorbance Coefficient	0.99
Roof Absorbance Coefficient	0.93

The software selected nearly the smallest windows for the reference building except for the surface directed to 495°. In addition, for the roof and walls the software selected the highest absorbance values 0.93 and 0.99 respectively. Therefore, darkest colors possible must be used in the building for optimal configuration. For the external walls, 152nd wall is selected and its layer properties are presented in the Table 5.30. The selected wall is a traditional brick wall with 100 mm thermal insulation (EPS). The unit cost of the wall is 166.01 TL/m^2.

Table 5.30. Wall 152 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Thermal Insulation (EPS)	95	0.03	22.00	1.50
Cement Plaster	20	0.72	1860.00	0.84

The software selected roof type 16th for the reference building. The selected roof has 95mm XPS insulation. The layer properties are presented in Table 5.31. The unit price for the selected roof is 687.55 TL/m^2.

Table 5.31. Roof 16 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
XPS Foam Board	95	0.03	30.00	1.50
Protective Concrete	50	0.68	897.00	0.84
Gravel	30	0.36	1840.00	0.84

The 1st slab is selected to be the foundation of the reference building. The selected slab has 150 mm blockage, 50 mm protective concrete, 500 mm foundation slab and 50 mm screed. The layer properties are presented in the Table 5.32 and the unit price for the selected slab is 826.76 TL/m^2.

Table 5.32. Slab 1 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Screed	50	1.40	1200.00	0.84
Foundation Slab	500	1.50	2400.00	0.80
Protective Concrete	50	0.68	897.00	0.84
Blockage	150	0.36	1840.00	0.84

The reference building optimal window type is selected to be the 18th window. The 18th window is a double glazing low-E window with wooden joints. The window properties are presented in the Table 5.33. The unit price for the 18th window is 235.21 TL/m^2.

Table 5.33. Window 18 Properties.

Glass	**Space (mm)**	**Thermal Trans. (W/m^{2}K)**	**0**	**40**	**50**	**60**	**70**	**80**	**Diff.**	**Normal**	**Glass Thickness (mm)**
Double Glazing Low-E	0.016	2.0	1	0.98	0.94	0.86	0.66	0.35	0.88	0.65	8

Using the optimal building configuration, the electricity consumption for cooling is 40,957 KWh and natural gas consumption for heating is 26,840 KWh. The present value of the total LCC of the reference building for 30 years is 1,757,402 TL and the buildings envelop initial cost is 892,650 TL.

5.9.2. Case 2b Energy Consumption Minimization (Initial Cost Constraint)

The initial budget constraint for Case 2b is assumed to be 935,485 TL and the aim is to minimize total energy consumed to maintain the thermal comfort in the reference building. The results of the genetic algorithm optimization process are presented in Figure 5.9. It can be seen that from generation 60 to 100 the best member of the population has shown no improvements. Between generation 60 and 100 average relative change of the best value is very low. However, the optimization process did not terminate because a very low (10^{-8}) tolerance function is selected. The genetic algorithm tool exceeded 100 generation limit and terminated.

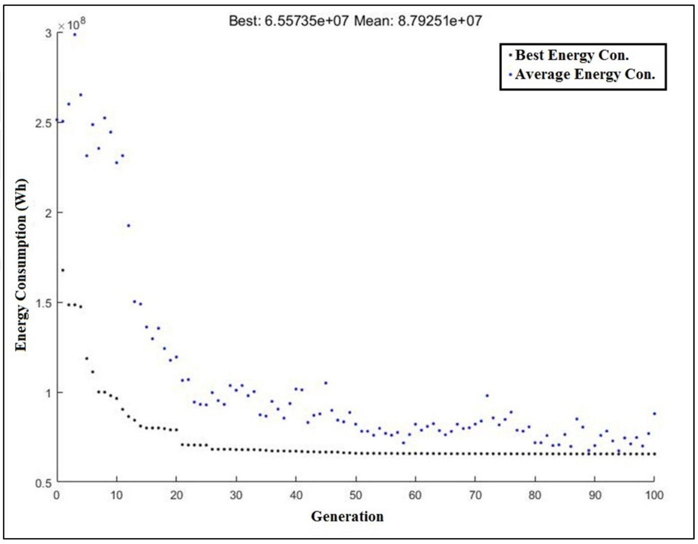

Figure 5.9. Case 2b Genetic Algorithm Results.

Optimal building envelope configuration for Case 2b is presented in Table 5.34. The windows area facing to 225° and 405^o are about 92.2 m^2. 92.16 m^2 is the lower boundary condition for these two surfaces. The windows facing to 315° and 495° are 64.37 m^2 and 64.33 m^2 respectively. The software selected nearly the smallest windows for the reference building for all surfaces. In addition, for the walls the software selected the highest absorbance value (0.99) and for the roof the software selected lowest absorbance coefficient possible (0.2).

Table 5.34. Case 2b Optimization Result for Reference Building.

Building Components	**Selected Components/Values**
External Wall Type	153
Roof Types	289
Slab Type	2
Window Type	18
Surface 1 - Window Area	92.18
Surface 2 - Window Area	92.19
Surface 3 - Window Area	64.37
Surface 4 - Window Area	64.33
Wall Absorbance Coefficient	0.99
Roof Absorbance Coefficient	0.21

For the external walls, 153rd wall is selected and its layer properties are presented in the Table 5.35. The selected wall is a traditional brick wall with 100 mm thermal insulation (EPS). The unit cost of the wall is 166.78 TL/m^2.

Table 5.35. Wall 153 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Thermal Insulation (EPS)	100	0.03	22.00	1.50
Cement Plaster	20	0.72	1860.00	0.84

The software selected roof type 289th for the reference building. The selected roof has 90 mm XPS insulation and 100 mm rock wool. The layer properties are presented in Table 5.36. The unit price for the selected roof is 754.21 TL/m^2.

Table 5.36. Roof 289 Layer Properties.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
Rock Wool	100	0.05	25.00	0.80
XPS Foamboard	90	0.03	30.00	1.50
Protective Concrete	50	0.68	897.00	0.84

The 2nd slab is selected to be the foundation of the reference building. The selected slab has 150 mm blockage, 100 mm lean concrete, 500 mm foundation slab, 40 mm rock wool and 50 mm screed. The layer properties are presented in the Table 5.37 and the unit price for the selected slab is 869.90 TL/m^2.

Table 5.37. Slab 2 Layer Properties.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Screed	50	1.40	1200.00	0.84
Rock Wool	40	0.05	25.00	0.80
Foundation Slab	500	1.50	2400.00	0.80
Lean Concrete	100	0.68	897.00	0.84
Blockage	150	0.36	1840.00	0.84

The reference building optimal window type is selected to be the 18th window. The 18th window is a double glazing low-e window with wooden joints. The window properties are presented in the Table 5.38. The unit price for the 18th window is 235.21 TL/m^2. Using the optimal building configuration, the electricity consumption for cooling is 46,716 KWh and natural gas consumption for heating is 18,864 KWh. The present value of the total LCC of the reference building for 30 years is 1,886,021 TL and the buildings envelop initial cost is 935,485 TL.

Table 5.38. Window 18 Properties.

Glass	Space (mm)	Thermal Trans. (W/m²K)	0	40	50	60	70	80	Diff.	Normal	Glass Thickness (mm)
Double Glazing Low-E	0.016	2.0	1	0.98	0.93	0.86	0.66	0.35	0.87	0.65	8

5.9.3. Case 2c Energy Consumption Minimization (Initial Cost Constraint)

The initial budget constraint for Case 2c is assumed to be 1,027,300 TL and the aim is to minimize total energy consumed to maintain the thermal comfort in the reference building. The results of the genetic algorithm optimization process are presented in Figure 5.10. It can be seen that from generation 60 to 94 the best member of the population has shown no improvements. The optimization process is terminated at generation 94 because average relative change of the best value was lower than the tolerance function (10^{-8}).

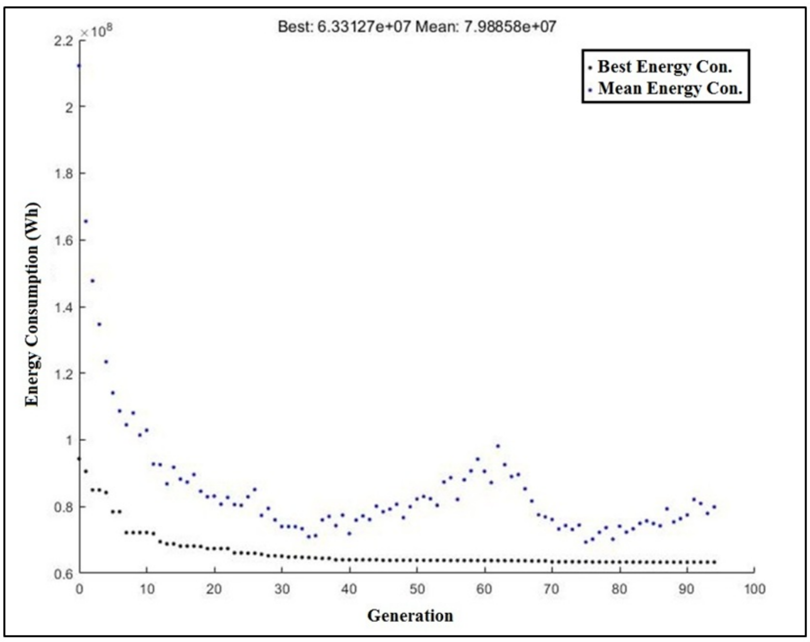

Figure 5.10. Case 2c Genetic Algorithm Results.

Optimal building envelope configuration for Case 2c is presented in Table 5.39. The windows area facing to 225° and 405° are 92.16 m^2. 92.16 m^2 is the lower boundary condition for these two surfaces. The windows facing to 315° and 495° are 64.32 m^2. The software selected nearly the smallest windows for the reference building for all surfaces. In addition, for the walls the software selected a medium absorbance coefficient (0.47) and for the roof the software selected lowest absorbance coefficient possible (0.2). Therefore, a medium color must be used for the building walls and lightest colors for the roof of the building for optimal configuration. Compared to cooling system the heating system efficiency is very low. Therefore the GA optimization tool focused on minimizing the heating loads. The optimization tool selected walls, roof and slab with thickest insulation possible.

Table 5.39. Case 2c Optimization Result for Reference Building.

Building Components	**Selected Components/Values**
External Wall Type	442
Roof Types	289
Slab Type	2
Window Type	36
Surface 1 - Window Area	92.16
Surface 2 - Window Area	92.16
Surface 3 - Window Area	64.32
Surface 4 - Window Area	64.32
Wall Absorbance Coefficient	0.47
Roof Absorbance Coefficient	0.20

For the external walls, 442nd wall is selected and its layer properties are presented in the Table 5.40. The selected wall is a traditional brick wall with 100 mm thermal insulation (EPS) and 100 mm rock wool. The unit cost of the wall is 235.58 TL/m^2.

Table 5.40. Wall 442 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Rock Wool	100	0.05	25.00	0.80
Thermal Insulation (EPS)	100	0.03	22.00	1.50
Cement Plaster	20	0.72	1860.00	0.84

The software selected roof type 289st for the reference building. The selected roof has 90 mm XPS insulation and 100 mm rock wool. The layer properties are presented in Table 5.41. The unit price for the selected roof is 754.21 TL/m^2.

Table 5.41. Roof 289 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
Rock Wool	100	0.05	25.00	0.80
XPS Foamboard	90	0.03	30.00	1.50
Protective Concrete	50	0.68	897.00	0.84

The 2nd slab is selected to be the foundation of the reference building. The selected slab has 150 mm blockage, 100 mm lean concrete, 500 mm foundation slab, 40 mm rock wool and 50 mm screed. The layer properties are presented in the Table 5.42 and the unit price for the selected slab is 869.90 TL/m^2.

Table 5.42. Slab 2 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Screed	50	1.40	1200.00	0.84
Rock Wool	40	0.05	25.00	0.80
Foundation Slab	500	1.50	2400.00	0.80
Lean Concrete	100	0.68	897.00	0.84
Blockage	150	0.36	1840.00	0.84

The reference building optimal window type is selected to be the 36th window. The 36th window is a double glazing low-E window with PVC 3o joints. The window properties are presented in the Table 5.43. The unit price for the 36th window is 254.14 TL/m^2.

Table 5.43. Window 36 Properties.

Glass	**Space (mm)**	**Thermal Trans. (W/m^{2}K)**	**0**	**40**	**50**	**60**	**70**	**80**	**Diff.**	**Normal**	**Glass Thickness (mm)**
Double Glazing Low-E	0.016	1.9	1	0.98	0.94	0.86	0.66	0.35	0.88	0.65	8

Using the optimal building configuration, the electricity consumption for cooling is 42,413 KWh and natural gas consumption for heating is 20,900 KWh. The present value of the total LCC of the reference building for 30 years is 1,901,907 TL and the buildings envelop initial cost is 1,027,300 TL. Although the initial budget is increased considerably, there is not a considerable reduction in the energy consumed for heating and cooling purposes.

5.9.4. Case 2d Energy Consumption Minimization (Initial Cost Constraint)

The initial budget constraint for Case 2d is assumed to be 1,190,617 TL and the aim is to minimize total energy consumed to maintain the thermal comfort in the reference building. The results of the genetic algorithm optimization process are presented in Figure 5.11. It can be seen that from generation 60 to 100 the best member of the population has shown no improvements. Between generation 60 and 100 average relative change of the best value is very low. However, the optimization process did not terminate because a very low (10^{-8}) tolerance function is selected. The genetic algorithm tool exceeded 100 generation limit and terminated.

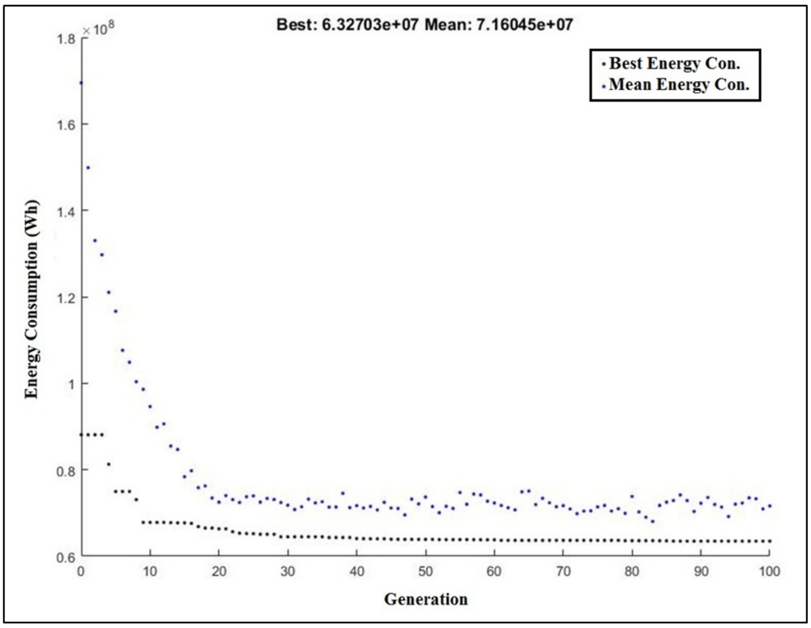

Figure 5.11. Case 2d Genetic Algorithm Results.

Optimal building envelope configuration for Case 2d is presented in Table 5.44. The windows area facing to 225° and 405° are 92.18 m^2 and 92.17 m^2 respectively. 92.16 m^2 is the lower boundary condition for these two surfaces. The windows facing to 315° and 495° are about 64.32 m^2. The software selected nearly the smallest windows for the reference building for all surfaces. In addition, for the walls the software selected an above average absorbance coefficient (0.72) and for the roof the software selected nearly the lowest absorbance coefficient possible (0.2). Therefore, an above medium color must be used for the building walls and lightest colors for the roof of the building for optimal configuration.

Table 5.44. Case 2d Optimization Result for Reference Building.

Building Components	**Selected Components/Values**
External Wall Type	442
Roof Types	306
Slab Type	2
Window Type	36
Surface 1 - Window Area	92.18
Surface 2 - Window Area	92.17
Surface 3 - Window Area	64.33
Surface 4 - Window Area	64.32
Wall Absorbance Coefficient	0.72
Roof Absorbance Coefficient	0.23

For the external walls, 442nd wall is selected and its layer properties are presented in the Table 5.45. The selected wall is a traditional brick wall with 100 mm thermal insulation (EPS) and 100 mm rock wool. The unit cost of the wall is 235.58 TL/m^2.

Table 5.45. Wall 442 Layer Properties.

Layers	**Thickness (mm)**	**Conductivity W/(m.K)**	**Density (kg/m^3)**	**Specific Heat kJ/(kg.K)**
Gypsum Plaster	20	0.73	1600.00	0.84
Brick Wall	100	0.73	1922.00	0.84
Cement Plaster	20	0.72	1860.00	0.84
Rock Wool	100	0.05	25.00	0.80
Thermal Insulation (EPS)	100	0.03	22.00	1.50
Cement Plaster	20	0.72	1860.00	0.84

The software selected roof type 306th for the reference building. The selected roof has 95 mm XPS insulation and 100 mm rock wool. The layer properties are presented in Table 5.46. The unit price for the selected roof is 755.58 TL/m^2.

Table 5.46. Roof 306 Layer Properties.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Gypsum Plaster	20	0.73	1600.00	0.84
Concrete Slab	200	1.50	2400.00	0.80
Rock Wool	100	0.05	25.00	0.80
XPS Foamboard	95	0.03	30.00	1.50
Protective Concrete	50	0.68	897.00	0.84

The 2nd slab is selected to be the foundation of the reference building. The selected slab has 150 mm blockage, 100 mm lean concrete, 500 mm foundation slab, 40 mm rock wool and 50 mm screed. The layer properties are presented in the Table 5.47 and the unit price for the selected slab is 869.90 TL/m^2.

Table 5.47. Slab 2 Layer Properties.

Layers	Thickness (mm)	Conductivity W/(m.K)	Density (kg/m^3)	Specific Heat kJ/(kg.K)
Screed	50	1.40	1200.00	0.84
Rock Wool	40	0.05	25.00	0.80
Foundation Slab	500	1.50	2400.00	0.80
Lean Concrete	100	0.68	897.00	0.84
Blockage	150	0.36	1840.00	0.84

The reference building optimal window type is selected to be the 36th window. The 36th window is a double glazing low-e window with PVC 3c joints. The window properties are presented in the Table 5.48.

Table 5.48. Window 36 Properties.

Glass	Space (mm)	Thermal Trans. (W/m^{2}K)	0	40	50	60	70	80	Diff.	Normal	Glass Thickness (mm)
Double Glazing Low-E	0.016	1.9	1	0.98	0.94	0.86	0.66	0.35	0.88	0.65	8

Using the optimal building configuration, the electricity consumption for cooling is 43,924 KWh and natural gas consumption for heating is 19,346 KWh. The present value of the total LCC of the reference building for 30 years is 1,926,777 TL and the buildings envelop initial cost is 1,027,900 TL. The results of the Case 2d are very similar to Case 2c. Although the initial budget is increased considerably, there is not a considerable reduction in the energy consumed for heating and cooling purposes.

5.9.5. Evaluation of Case 2

In Case 2, major amount of the cooling load is caused by the infiltration/ventilation and radiation through windows. The developed software minimizes the area of the windows however; it is not possible to reduce heating and cooling loads caused by infiltration and ventilation. Therefore, the optimization tool selected a configuration that reduces the heating loads to minimize the total energy consumed. On the other hand selecting a configuration which reduces the heating loads significantly increases the cooling loads and energy costs. For this reason, the LCC calculated in the Case 2 is higher than Case 1. The developed software proposes a greener building with lower energy consumption but, significantly increases the LCC in Case 2. The results of the Case 2 are presented in Figure 5.12. Increasing the budget by 40% reduced the energy consumption of the building by only 8%. It can be seen that, in Case 2 initial costs higher than 1,050,000 TL does not provide any significant reduction on energy consumption. The results showed that if designers use simulation-based optimization methods, they can find energy efficient building designs with lower initial costs. The results of the case studies emphasizes necessity of using simulation-based optimization methods.

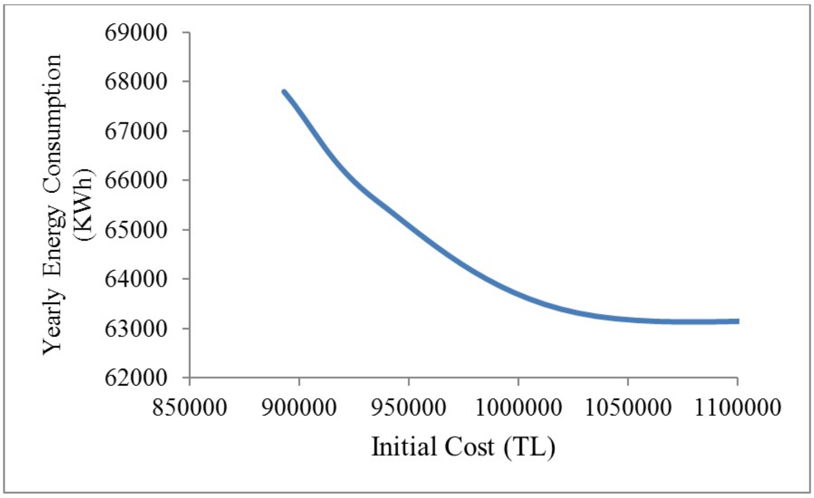

Figure 5.12. Case 2d Genetic Algorithm Results.

5.10. Parametric Study

Based on the Case 1 solution parametric runs are carried out to demonstrate the effects of each parameter and constraints. The optimal configuration acquired from Case 1 is used and in each simulation a single parameter is changed while all other variables are kept constant. The results of the parametric runs for each variable are presented in Appendix C. The purpose of the parametric runs is to show the influence of the design changes on building energy performance and LCC. The most effective design variables for Case 1 are selected and a brief summary of parametric results are presented in this section. The most influential parameters are selected as; exterior wall type, window type, surface 2 and window area (directed to north).

In building component database there are mainly 4 types of external walls and by varying the insulation thicknesses, the number of external walls are increased to 459. 47 parametric runs are carried out by changing the external wall type while keeping all other variables constant and the results are presented in Table C.1. In addition, by selecting 2 representatives from each wall types, a summary of external wall parametric runs are formed and presented in Figure 5.13 and Figure 5.14.

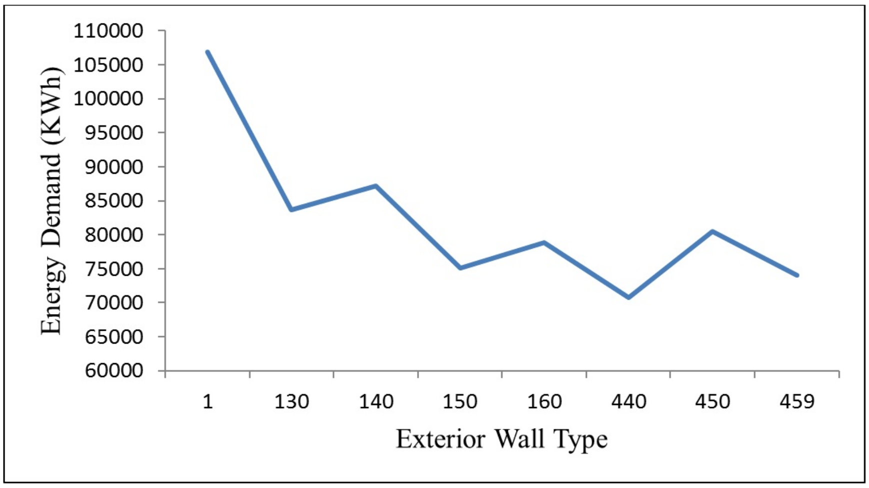

Figure 5.13. Effects of External Wall Variation on Energy Demand.

The Figure 5.13 demonstrates that the external wall variation greatly affects the energy demand of the reference building. The external wall selection has a significant effect on heating loads. The wall variation has no effect on infiltration/ventilation and solar radiation. Therefore, external wall type does not have a remarkable influence on cooling loads. It can be seen that, to reduce the energy demand of the building the buildings with higher insulations should be selected.

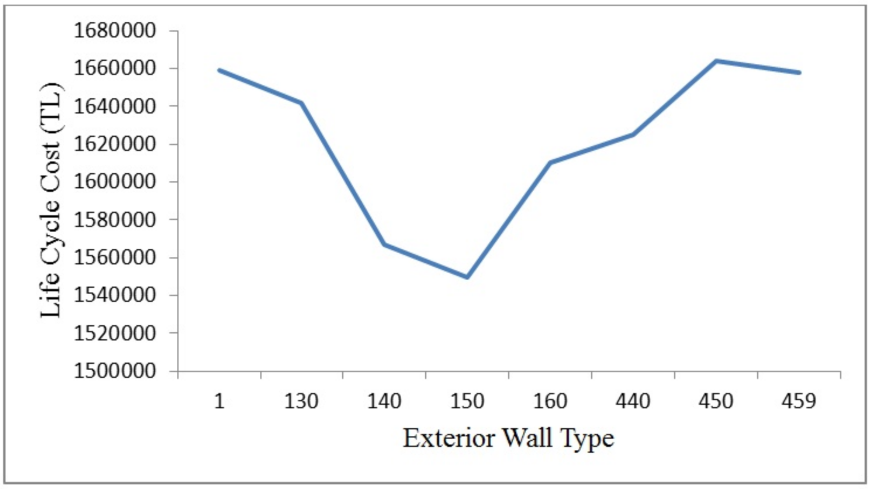

Figure 5.14. Effects of External Wall Variation on LCC.

This causes an increase on the LCC of the reference building. The effects of the external wall selection on building LCC is presented in Figure 5.14. The influence of external walls on heating load, directly affects the LCC of the reference building. For Case 1, among the selected external wall types, Wall 150 gives the minimum life cycle cost.

Building component database consist mainly 6 types of windows and by varying the glass type, number of windows are increased to 54. However for the Case 1, 45 of the windows are used because windows without joints cannot be used for residential buildings. 45 parametric runs are carried out by changing the window type while keeping all other variables constant and the results are presented in Table C.4. PVC 2o Joint window types (WinT19 – WinT27) are selected and a representative part of window parametric runs are presented in Figure 5.15 and Figure 5.16.

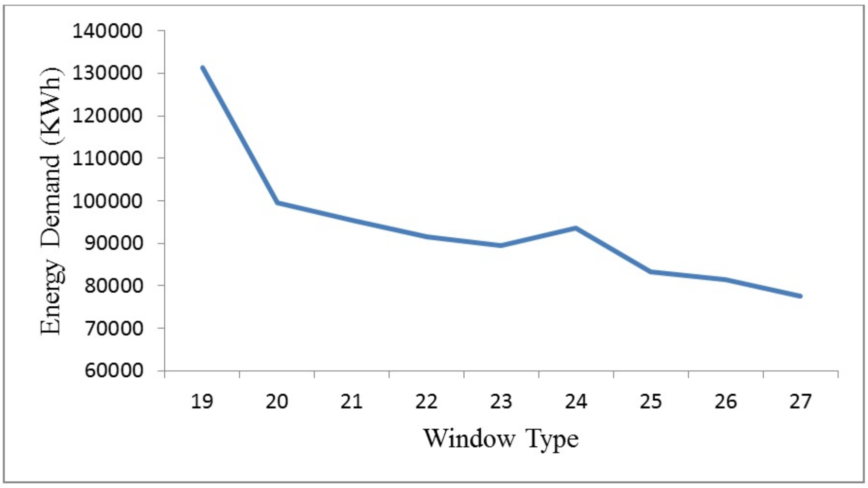

Figure 5.15. Effects of Window Type Variation on Energy Demand.

It is seen that, type of window is one of the most influential components affecting the energy demand of the residential building. Window selection has a significant effect on the amount of solar radiation entering to reference building. In addition, using single glazing greatly increases energy demand of the building. Low emissivity glazing shows the highest insulation performance. Therefore, in case studies the developed software selected windows with Low-E glazing to reduce the heating loads of the reference building. Low-E glasses are relatively expensive but greatly reduce life cycle cost of the building. The influence of windows on heating load and cooling loads, considerably affects the LCC of the reference building. For Case 1, among the selected window types, WinT27 gives the minimum LCC and WinT19 gives the maximum LCC.

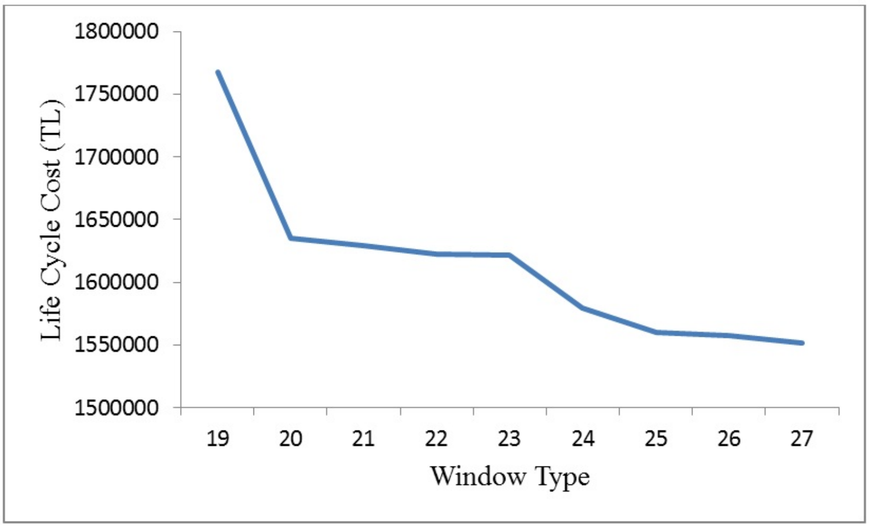

Figure 5.16. Effects of Window Type Variation on LCC.

Architectural design of the building is an effective factor, has an essential impact on building energy consumption. Window area has a significant effect on the amount of solar radiation entering to reference building. Increasing the window area raises the amount of solar radiation entering to building. Solar radiation reduces the heating loads and increases the cooling loads of the building. On the other hand using windows with low U-value greatly affects the heating loads of the buildings.

In case studies; the window areas are assumed to be between 20% and 70% of the total surface area. 24 parametric runs for Surface 1 and Surface 3, 18 parametric runs for Surface 2 and Surface 4 are carried out by changing the window area while keeping all other variables constant and the results are presented in Table C.5, C.6, C.7 and C.8 The results of the parametric runs carried out for the Surface 2 are presented in Figure 5.17 and Figure 5.18.

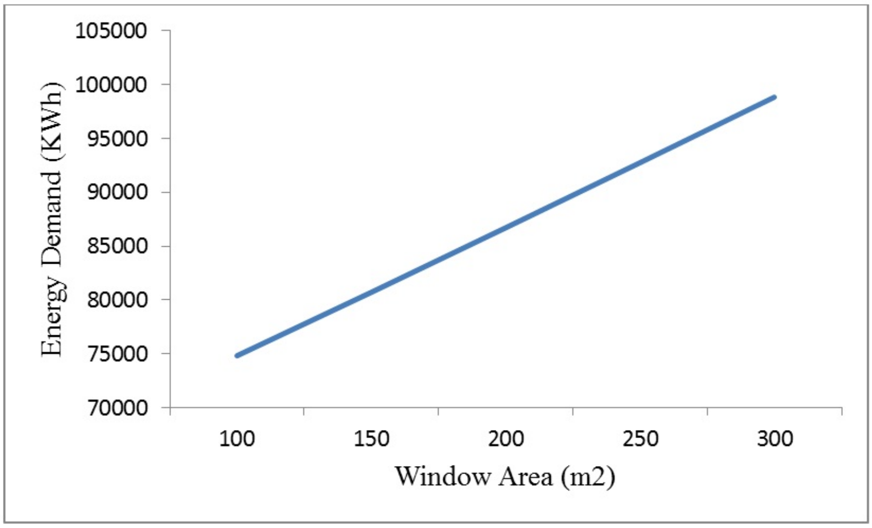

Figure 5.17. Effects of Window Area Variation on Energy Demand.

It can be seen that, there is a linear relationship between energy demand and surface 2 window area. Surface 2 is directed to NorthEast and receives notable amount of solar radiation. According to parametric runs increasing the window area of surface 2 significantly increases both cooling loads and heating loads of the reference building. Therefore, in case studies the developed software selected smallest windows possible for the reference building.

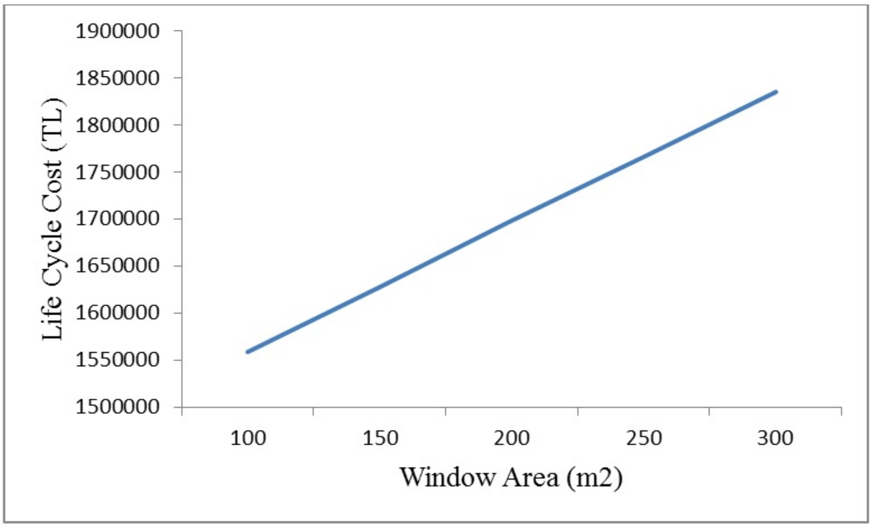

Figure 5.18. Effects of Window Area Variation on LCC.

6. DISCUSSIONS AND EVALUATION

The aim of the study is to develop an optimization software that helps designers to make decisions in the early phase of the building design process. The hypothesis of the study alleges that, the tool is helpful in the early design phase of the design process, uses a material database to select building components, implements an automatic genetic algorithm optimization tool, easily handles complex design processes, requires least amount of input data and has a user-friendly interface. The software is developed on Matlab platform and tested with several analyzes in previous sections.

In literature, the major part of the studies on simulation based optimization methods couple a commercial building energy simulation software and an optimization software to carry out optimization analysis [1, 5, 24, 29, 32]. On the other hand, in this study a completely new heat balance based building energy simulation software is developed. Therefore, before using the developed energy simulation software validation runs are required to be carried out. Unlike other studies in literature, a very extensive validation analysis is carried out and the developed simulation software is tested by running yearly validation analysis in 10 different climate regions [21, 36]. A four story residential apartment is selected from United States Department of Energy prototype buildings. Using a prototype building analyzed by an impartial expert increases the credibility of the validation analysis. Besides, both EnergyPlus and the developed building energy simulation software are based on heat balance method and EnergyPlus is the most popular software among the researchers studying in simulation based optimization methods [4]. Therefore, EnergyPlus is a suitable choice for validation analysis.

The validation analysis results showed that, the developed software gives reasonable results compared to detailed analysis of EnergyPlus. The results for the buildings simulated in, Memphis, Baltimore, Miami, Phoenix and Boise Idaho are above expectations and the results are very similar to EnergyPlus simulation results which are carried out with respect to 2013 ASHRAE 90.1 standard. The simulation results for Chicago, Vancouver and Houston are also compared to results of EnergyPlus energy simulations and it can be said that the results are reasonable. The obtained results are in the area between the line of 2004 ASHRAE 90.1 and 2013 ASHRAE 90.1 simulation results. However, the results for San Francisco and Fairbanks are less accurate due to extraordinary weather conditions and fluctuating weather temperature. The results of prototype building thermal analysis based on ASHRAE 2004, 2007, 2010 and 2013 show similar profiles but different consumption levels [64]. Therefore, it can be said that the energy simulation of the buildings is a developing research area and there is still room for improvement. The results of the validation analysis demonstrated that, the developed software gives reasonable results and can be used for optimization analysis.

Implementing a general genetic algorithm optimization method greatly reduces the required expertise and preparation work for the analysis. On the other hand, the optimization tool has no knowledge about the relationships between the design variables, which increases the optimization process time period. The parameters of the genetic algorithm such as population, crossover fraction and mutation probability can only be decided by experience and trial runs [30]. Increasing the number of design variables to be optimized directly affects the generation and population numbers. Therefore, the number of design variables must be decided carefully to keep the optimization period at a reasonable level.

In this study, 2 case studies including 5 analyzes carried out to test the developed software using a relatively old computer. It took 4-12 hours to complete optimization process depending on the constraints and objective functions. To accelerate the optimization, Matlab's parallel programming codes are implemented in this study to run 4 Matlab software in parallel. In addition, using a computer with better configurations (CPU with more than 4 cores) or clustering multiple computers may reduce the process time in a limited amount. Due to lack of technical possibilities and expertise in parallel computing the software could not be tested on cluster systems and better configurations. In the case 1 the LCC of the reference building is minimized and in Case 2 the energy consumption of the building is minimized with a budget constraint. Similar to other studies, the case study results showed that the optimal or near optimum configurations cost a small amount more than the minimum cost of the configuration [5, 69]. Consistent with the results of other studies, the optimization analysis carried out in case 1 showed that the window areas converges to lower bound and the software selected high efficiency windows [1, 5]. In addition, for external walls and roof the software selected thickest insulation possible. The reason is that, selecting thicker insulations does not have a significant impact on LCC, which means thick insulations have a high benefit-cost ratio. Lastly the software selected light colored external walls and roofs to reduce cooling loads. The result of the Case 2 demonstrated that, initial budgets more than 1.25 times the minimum initial cost possible (850,441 TL) has no effect on the energy performance of the buildings. Consequently, case studies showed that it is possible to develop a simulation based optimization software that supports the designers at the preliminary design phase.

Using the results of the case 1, parametric runs for each design variable is carried out to determine the influence of the design variables to energy consumption. In parallel with the literature the results showed that the thickness of the insulation has an important influence on the thermal performance of the residential building (Ascione et.al., 2015; Wang et.al., 2005). On the other hand, insulation materials with average thickness and performance provide satisfactory thermal performance. The slab of the building consists a very thick concrete layer, which provides a satisfactory thermal resistance. Therefore, the insulation thickness in the slab also has a very little effect on thermal performance of the building. In accordance with other studies in literature, parametric analysis showed that there is a linear relationship between the window size and solar radiation entering to buildings, which directly affects cooling and heating loads [1,5]. Similar to other studies the current study showed that the glazing selection is one of the most effective factors in building design, because the windows have very low thermal masses [5, 24, 29]. For this reason, selecting windows with high thermal performance (Low-E) is very important. In addition, similar to other studies the results of the parametric runs demonstrated that, the roof type and absorbance coefficients moderately affect the thermal performance of the buildings [5]

The results of the case studies, parametric runs and validation analysis showed that the developed software is a reliable tool for solving complex design problems. Unlike other studies in literature, in this study a standalone simulation-based optimization software is developed and gathering all modules on the same platform (Matlab) eliminated coupling problems. In coupling methods a text file is used, which can be accessed by both optimization and energy simulation software simultaneously. However, accessing to the text file for reading/writing significantly increases the optimization time process. In addition, commercial energy simulation software packages carry out very detailed thermal analysis taking a long time because the commercial softwares are not designed for optimization purposes, which requires numerous analysis in a short time period. Therefore, developing a tailor-made energy simulation software for building energy optimization, significantly reduces optimization time period.

In previous studies, the most popular energy simulation softwares used by researchers for optimization processes are open source programs, which are not user friendly and require high expertise. The developed prototype software requires minimum amount of experience in building energy simulation and genetic algorithm. The software requires least amount of input data, which greatly saves time for designers. Although, the developed software requires least amount of input data and energy simulation processes are simpler compared to commercial softwares the results obtained from case studies and parametric runs are in line with previous studies in the literature, which indicates that the developed methodology is successful.

7. CONCLUSION AND FUTURE WORK

The purpose of this study is to provide a plain, flexible, efficient and user friendly software that supports the designers at the preliminary design phase of the building projects to make decisions related to energy performance of the buildings. By optimizing a building, designers aim to reduce life cycle costs and energy consumptions to design cost effective and greener buildings. However, while designing cost effective and green buildings, designers also must satisfy the requirements of governmental regulations and users of the building. In this study, a simulation based optimization prototype software is developed to optimize energy performance of the buildings. The developed prototype implements a genetic algorithm optimization tool to optimize buildings considering performance aspects such as; energy consumption and life cycle cost.

Energy performance of the buildings depends on decisions in the early phases of the design process. In consequence of building design's multi-disciplinary structure, making decisions about the design, system and material selection are challenging tasks. In the design phase of the projects, while selecting the materials and other components that will be used in the building, budget and life cycle costs should be taken into consideration. However, in traditional projects the designs are made by consultants and there is no communication between the consultant and contractors, suppliers and manufacturers. Thus, in most of the construction projects, life cycle cost analyses are not carried out to calculate the costs throughout the buildings life cycle. Therefore, monitoring life cycle costs and energy dissipation of the building to assess the energy performance of the buildings is an important task. Considering the complexity of the task a computer simulation is required for the assessment of the different building configurations. For the reasons stated above, designing energy efficient buildings has become an important research area.

Numerous articles published in the literature on building energy optimization focuses on coupling an optimization tool and commercial building energy simulation software to optimize the building energy efficiency. Energy Plus and TRNSYS are the most popular building energy simulation programs and Matlab optimization toolbox is the most commonly preferred optimization tool used by researchers studying in this area. TRNSY and EnergyPlus are very detailed whole building energy simulations software which require expertise and extensive preparatory work. Only a very small group of researchers developed their own energy simulation software for building energy optimization. The developed building energy simulation software, use either too simplified dynamic simulation methods or static simulation method. In addition, the researchers developed their own building energy simulation have conducted a very limited number of validation analyzes. The results of the previous studies showed that simulation based optimization methods is a promising field of study.

In this study, a simulation based optimization methodology is proposed and a prototype software is developed. To prepare a database for the developed prototype software, the functional needs of the users are converted into measureable variables and an input data set is created. The input data such as building geometry, location, weather data, room temperature etc. are inserted into an MS Excel sheet. At the beginning of the analysis the developed prototype software reads the input data to automatically run optimization processes. A heat balance based dynamic thermal simulation software is developed to carry out hourly thermal simulations. For validation analyses a midrise apartment acquired from U.S. Department of Energy is implemented. The building is simulated using prototype software for 10 different climatic regions and the results are compared to Energy Plus simulation results published on DOE's website. The results showed that the developed simulation software gives reasonable results for heating and cooling loads compared to Energy Plus results. A genetic algorithm optimization method is implemented to automatically run the thermal simulations and evaluate the performance of building configurations using a LCC method. The optimization tool evaluates the performance of the buildings according to their life cycle costs and energy consumptions. The developed software is tested in 2 cases. For the case studies a 5 storey typical residential building in Istanbul is selected as the reference building. In the first case; the objective function is to minimize the LCC of the reference building. In second case, the objective function is minimizing the energy consumption.

2 case studies consisting 5 analyses carried out to test the developed software and the results showed that the software handles complex optimization problems without any problem.

Although there are similar studies on the subject, there are still difficulties in coupling efficiency considering time and labor, practicality and flexibility. The developed software is user-friendly and requires least amount of input data. Gathering both simulation and optimization tools on the same platform (Matlab) eliminates the coupling problems and greatly speeds up the optimization process. The software designed to require least amount of input data so; simulation preparations are significantly shortened. Therefore, the developed software is appropriate for evaluating and optimizing large number of buildings in a short period of time. Using widely known software (MS Excel) for database creation is a major advantage. In addition, the designers create a single database that can be used in several projects. Unlike other energy simulation and optimization software packages, the developed software does not require any expertise to implement. Using a genetic algorithm optimization method which requires very little preparation and expertise, helps designers to save time at preliminary design phase. Compared to other studies, an advanced building energy simulation software using dynamic thermal calculations is developed. In addition, unlike other studies, a very comprehensive validation analysis was conducted in this study.

The developed prototype software showed that; developing a user-friendly tool that optimizes envelope of the building with a little amount of preparation and input data is a great asset for designers at the preliminary design phase of the buildings. Energy consumption minimization helps designers to build greener buildings that satisfy the governmental regulations and green certification programs. Minimizing the LCC helps to maintain thermal comfort in the building at minimum cost possible. The results of the case studies and parametric runs showed which design variables affect the thermal performance of the buildings more. In this way, the developed prototype software directs which design variables the designers should focus on. The methods used for building thermal simulation are globally accepted and implemented.

Thus, the developed standalone software can be both used for global and local purposes. In addition, the Turkish insulation regulation (TS825) only introduces heating load calculations and uses a static calculation method for heat loads. In this context, the developed methodology and prototype software can be a good alternative to TS825 based software.

As previously discussed, an important limitation of this research is that, the genetic algorithm optimization methods do not guarantee to find global minima but requires very little amount of parameter input. Genetic algorithm tool does not have any knowledge about problems and relationships between the design variables, which means genetic algorithm is independent of the problem formulation. Thus, the process time to find optimal configuration increases. In the study 10 design variables are used for the optimization problems to keep the problem manageable. The developed software can be edited and design variables such as; overhang length, building rotation, building aspect ratio etc. can be added. However, adding more design variables will increase the optimization process time period. The other arguable point of developed software is preparation of material database. Although, the material database can be used for several different projects and the designer needs to create only once, considering the number of materials in the market it takes too much time and labor to be created.

The developed software can be empowered and extended by adding new modules such as, renewable energy systems, HVAC systems and lighting systems etc. Thus, the energy performance of the buildings can be analyzed and optimized in all aspects. In addition, adding a well-designed graphical user interface and a computer aided drawing interface, will increase its user-friendliness of the prototype software. Although an extensive validation analysis is carried out for the developed building energy software, the optimization software is not tested with different building types. In addition, the results of the software can be compared to building configurations proposed by local and global regulations and green building certification programs.

To sum up, most of the design decisions affecting the energy performance of the buildings are made in the preliminary design phase of the buildings. Therefore, the design variables affecting the building energy performance must be carefully decided. Implementing a simulation based software at the preliminary design stage of the building is a great help to designers.

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APPENDIX A: VALIDATION ANALYZES INPUT DATA AND RESULTS

ENERGY SIMULATION DATA INPUT

AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21

LOCATION	
Latitude	41.98
Longitude	-87.92
Time Zone (Hour)	-6

BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Chicago
Hourly Soil Temp. (°C)	Chicago
Monthly Humidity (%)	Chicago

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.1. Chicago Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.29	0.31	0.33	0.36	0.37	0.38	0.42	0.42	0.39	0.34	0.31	0.29
taud	2.52	2.47	2.47	2.34	2.31	2.29	2.21	2.24	2.34	2.49	2.63	2.58

Figure A.2. Optical Depth Values Form for Chicago.

Table A.1. Weather Conditions in Chicago for Thermal Simulation

Month	Average Temperature	Standard Dev.
1	-4.64	7.16
2	-2.52	7.15
3	3.82	5.02
4	9.95	8.08
5	15.31	6.13
6	21.11	5.51
7	24.13	4.62
8	21.77	4.21
9	18.13	4.95
10	10.98	4.94
11	4.73	8.39
12	-3.68	5.55

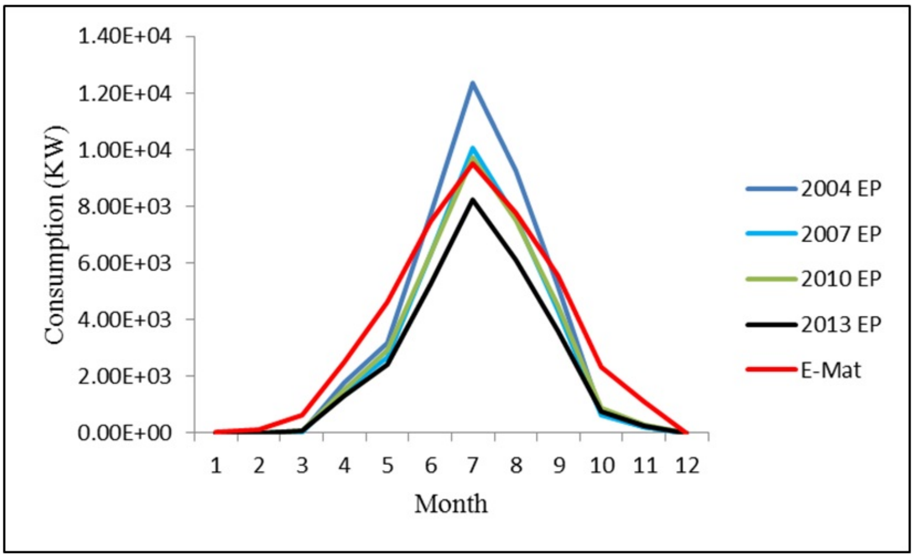

Figure A.3. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Chicago.

Table A.2. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Chicago.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	1.47E+00	3.68E+00	2.83E+00	3.76E+00	2.27E+01
2	2.41E+00	4.13E+00	4.67E+00	5.54E+00	1.14E+02
3	4.48E+01	4.91E+01	7.22E+01	6.55E+01	6.45E+02
4	1.76E+03	1.46E+03	1.52E+03	1.29E+03	2.50E+03
5	3.19E+03	2.68E+03	2.91E+03	2.40E+03	4.61E+03
6	7.74E+03	6.34E+03	6.33E+03	5.25E+03	7.45E+03
7	1.23E+04	1.00E+04	9.70E+03	8.23E+03	9.49E+03
8	9.26E+03	7.59E+03	7.52E+03	6.12E+03	7.77E+03
9	5.17E+03	4.33E+03	4.47E+03	3.61E+03	5.56E+03
10	6.88E+02	6.28E+02	8.70E+02	7.69E+02	2.31E+03
11	1.89E+02	1.82E+02	2.90E+02	2.50E+02	1.09E+03
12	1.11E+00	2.73E+00	1.91E+00	2.62E+00	5.59E+00

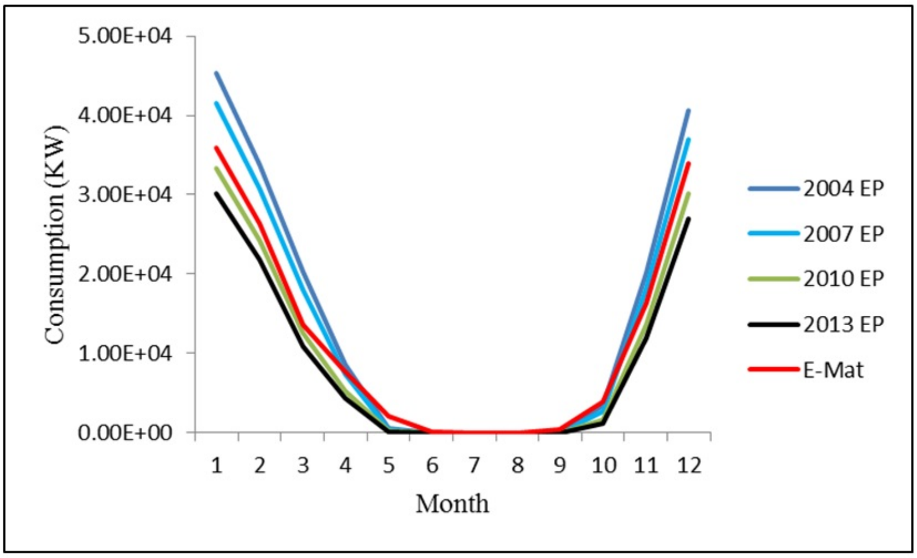

Figure A.4. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Chicago.

Table A.3. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Chicago.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	4.53E+04	4.15E+04	3.34E+04	3.01E+04	3.59E+04
2	3.39E+04	3.08E+04	2.43E+04	2.17E+04	2.63E+04
3	2.02E+04	1.80E+04	1.25E+04	1.08E+04	1.36E+04
4	8.64E+03	7.46E+03	5.26E+03	4.39E+03	7.75E+03
5	5.62E+02	3.99E+02	2.36E+02	1.69E+02	2.09E+03
6	1.66E+00	1.20E-01	0.00E+00	0.00E+00	1.50E+02
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E+00
8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.14E+01
9	1.86E+01	2.81E+00	1.13E-01	0.00E+00	4.22E+02
10	3.47E+03	2.71E+03	1.61E+03	1.14E+03	3.92E+03
11	2.02E+04	1.82E+04	1.37E+04	1.20E+04	1.63E+04
12	4.05E+04	3.69E+04	3.02E+04	2.70E+04	3.40E+04

Table A.4. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Chicago.

Software/Standart	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	41,562	140,445	182,007
EP ASHRAE 2013	28,001	99,047	127,048
EP ASHRAE 2010	33,696	121,149	154,845
EP ASHRAE 2007	33,307	156,004	189,311
EP ASHRAE 2004	40390	172856	213246

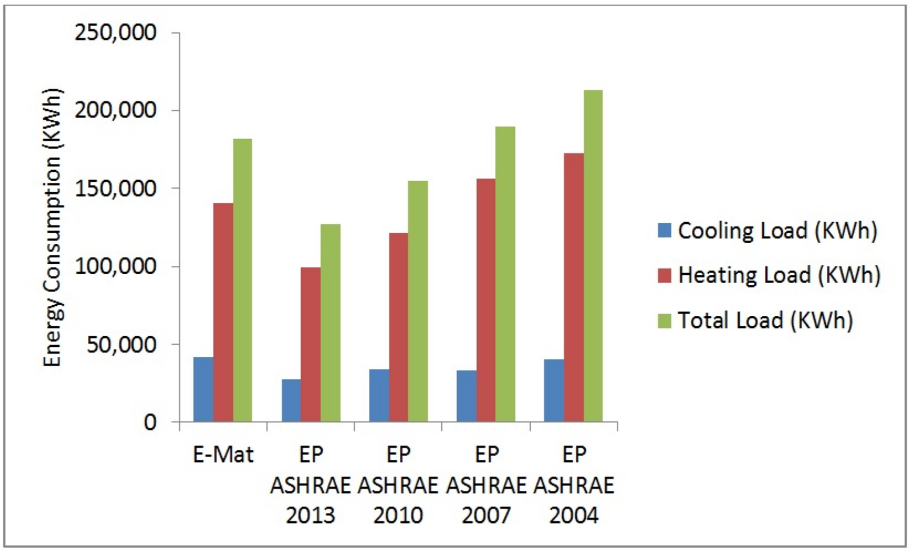

Figure A.5. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Chicago.

ENERGY SIMULATION DATA INPUT	
AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21
LOCATION	
Latitude	35.04
Longitude	-89.99
Time Zone (Hour)	-6
BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Memphis
Hourly Soil Temp. (°C)	Memphis
Monthly Humidity (%)	Memphis

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.6. Memphis Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.33	0.33	0.36	0.37	0.38	0.41	0.43	0.42	0.38	0.36	0.34	0.34
taud	2.60	2.57	2.43	2.36	2.33	2.22	2.20	2.27	2.42	2.49	2.58	2.58

Figure A.7. Optical Depth Values Form for Memphis.

Table A.5. Weather Conditions in Memphis for Thermal Simulation.

Month	Average Temperature	Standard Dev.
1	4.19	7.40
2	6.45	6.92
3	12.51	5.90
4	17.05	5.22
5	22.36	4.45
6	26.06	4.41
7	28.17	3.92
8	27.51	4.36
9	24.41	4.30
10	16.42	5.33
11	11.80	5.86
12	6.76	6.46

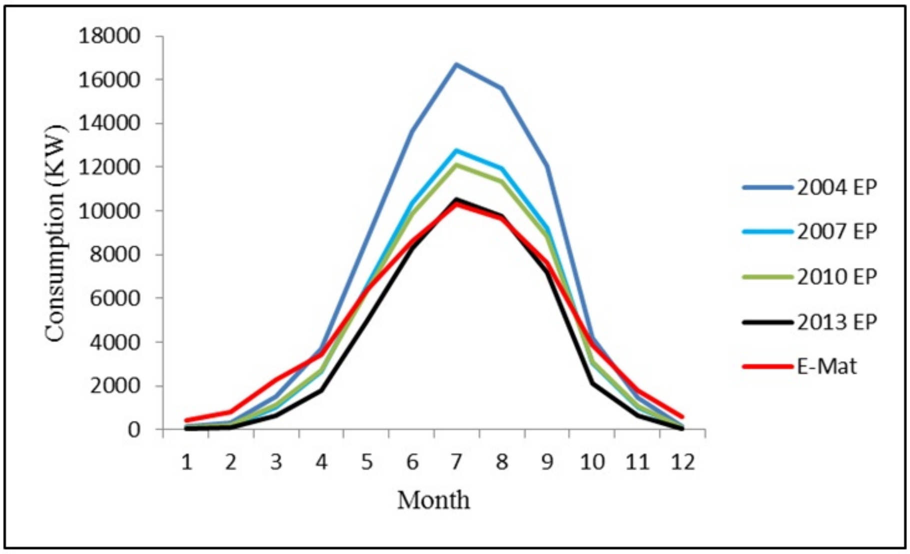

Figure A.8. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Memphis.

Table A.6. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Memphis.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	1.36E+02	7.22E+01	1.01E+02	4.02E+01	4.27E+02
2	2.92E+02	1.52E+02	1.95E+02	6.88E+01	7.80E+02
3	1.52E+03	1.01E+03	1.13E+03	6.34E+02	2.27E+03
4	3.69E+03	2.64E+03	2.71E+03	1.76E+03	3.40E+03
5	8.69E+03	6.53E+03	6.32E+03	4.95E+03	6.36E+03
6	1.36E+04	1.04E+04	9.88E+03	8.29E+03	8.60E+03
7	1.67E+04	1.28E+04	1.21E+04	1.05E+04	1.03E+04
8	1.56E+04	1.19E+04	1.14E+04	9.75E+03	9.66E+03
9	1.21E+04	9.20E+03	8.84E+03	7.19E+03	7.61E+03
10	4.20E+03	3.07E+03	3.09E+03	2.13E+03	3.84E+03
11	1.47E+03	1.02E+03	1.08E+03	6.25E+02	1.80E+03
12	1.48E+02	7.89E+01	1.06E+02	4.14E+01	5.70E+02

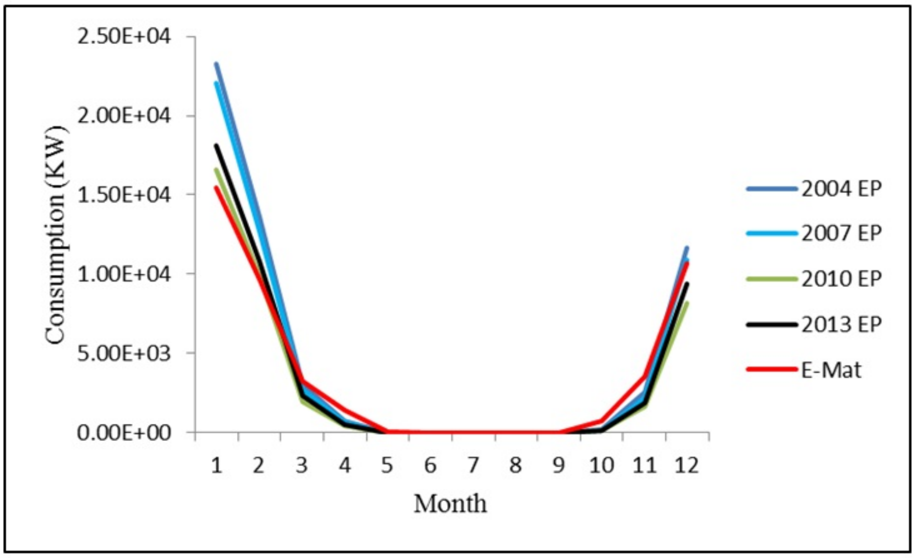

Figure A.9. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Memphis.

Table A.7. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Memphis.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	2.33E+04	2.21E+04	1.66E+04	1.81E+04	1.55E+04
2	1.36E+04	1.27E+04	9.93E+03	1.08E+04	9.67E+03
3	3.00E+03	2.74E+03	1.93E+03	2.32E+03	3.21E+03
4	7.10E+02	6.35E+02	4.12E+02	4.87E+02	1.43E+03
5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.75E+01
6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.99E+00
10	1.81E+02	1.23E+02	1.02E+02	1.19E+02	7.64E+02
11	2.56E+03	2.20E+03	1.66E+03	1.84E+03	3.52E+03
12	1.17E+04	1.09E+04	8.18E+03	9.41E+03	1.06E+04

Table A.8. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Memphis.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	55,614	44,718	100,332
EP ASHRAE 2013	46,004	43,151	89,155
EP ASHRAE 2010	56,917	38,785	95,702
EP ASHRAE 2007	58,870	51,398	110,268
EP ASHRAE 2004	78,053	55,031	133,084

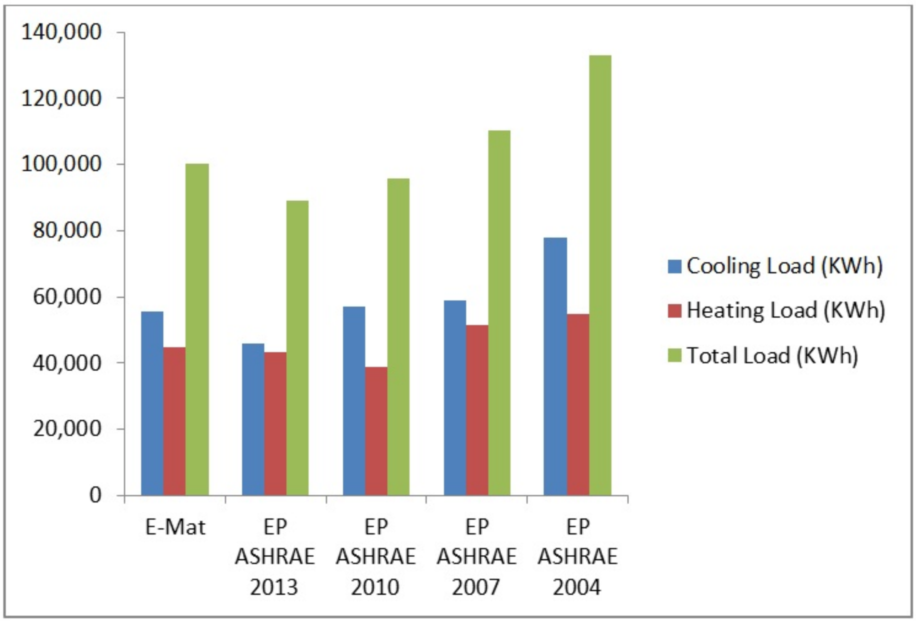

Figure A.10. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Memphis.

ENERGY SIMULATION DATA INPUT	
AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21
LOCATION	
Latitude	39.17
Longitude	-76.68
Time Zone (Hour)	-5
BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Baltimore
Hourly Soil Temp. (°C)	Baltimore
Monthly Humidity (%)	Baltimore

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.11. Baltimore Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.32	0.33	0.36	0.41	0.42	0.48	0.46	0.44	0.41	0.35	0.33	0.33
taud	2.49	2.46	2.40	2.23	2.17	2.01	2.13	2.19	2.32	2.47	2.55	2.53

Figure A.12. Optical Depth Values Form for Baltimore.

Table A.9. Weather Conditions in Baltimore for Thermal Simulation.

Month	Average Temperature	Standard Dev.
1	-0.07	5.06
2	1.86	6.13
3	8.08	6.02
4	13.40	4.58
5	18.52	6.10
6	23.04	4.83
7	25.49	3.96
8	24.16	4.37
9	20.30	4.53
10	12.24	5.40
11	9.02	4.87
12	1.78	7.16

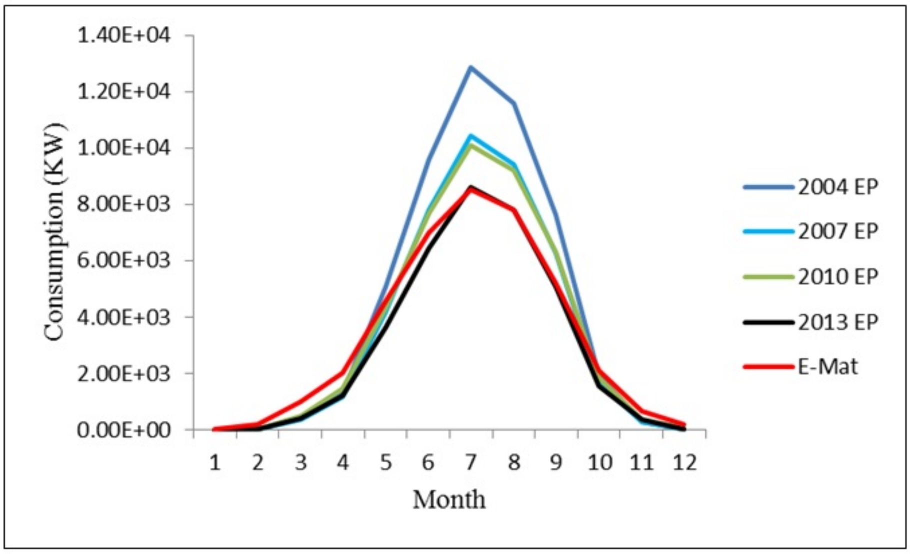

Figure A.13. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Baltimore.

Table A.10. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Baltimore.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	1.52E+00	4.51E+00	3.55E+00	4.61E+00	1.68E+01
2	1.60E+01	1.99E+01	2.12E+01	2.13E+01	1.94E+02
3	4.25E+02	3.78E+02	5.00E+02	4.24E+02	9.98E+02
4	1.32E+03	1.16E+03	1.48E+03	1.23E+03	2.03E+03
5	5.07E+03	4.19E+03	4.32E+03	3.63E+03	4.57E+03
6	9.60E+03	7.82E+03	7.70E+03	6.43E+03	6.99E+03
7	1.29E+04	1.04E+04	1.01E+04	8.60E+03	8.53E+03
8	1.16E+04	9.42E+03	9.20E+03	7.82E+03	7.81E+03
9	7.62E+03	6.29E+03	6.30E+03	5.09E+03	5.20E+03
10	1.93E+03	1.67E+03	1.87E+03	1.58E+03	2.12E+03
11	2.73E+02	2.66E+02	3.91E+02	3.55E+02	6.47E+02
12	3.11E+01	3.79E+01	6.09E+01	4.59E+01	1.84E+02

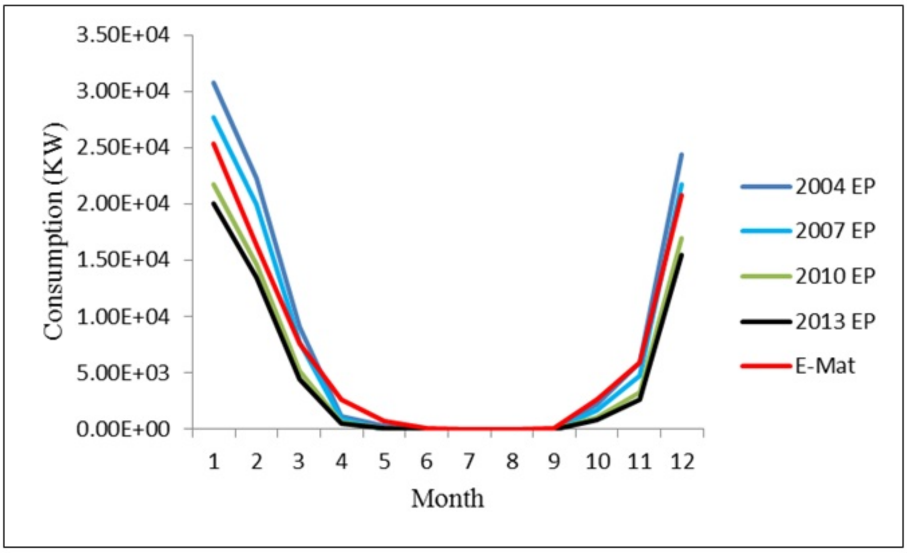

Figure A.14. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Baltimore.

Table A.11. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Baltimore.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	3.07E+04	2.77E+04	2.17E+04	2.00E+04	2.53E+04
2	2.22E+04	1.99E+04	1.47E+04	1.35E+04	1.63E+04
3	9.15E+03	7.74E+03	5.12E+03	4.43E+03	7.64E+03
4	1.18E+03	8.99E+02	5.64E+02	4.55E+02	2.63E+03
5	2.44E+02	3.85E-03	9.65E+01	7.00E+01	7.49E+02
6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E+01
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.37E+01
10	2.15E+03	1.70E+03	9.93E+02	7.78E+02	2.66E+03
11	5.96E+03	4.78E+03	3.25E+03	2.65E+03	5.88E+03
12	2.43E+04	2.17E+04	1.70E+04	1.55E+04	2.08E+04

Table A.12. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Baltimore.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	39,275	82,133	121,408
EP ASHRAE 2013	35,226	57,342	92,568
EP ASHRAE 2010	41,962	63,387	105,349
EP ASHRAE 2007	41,676	84,586	126,262
EP ASHRAE 2004	50,743	95,969	146,712

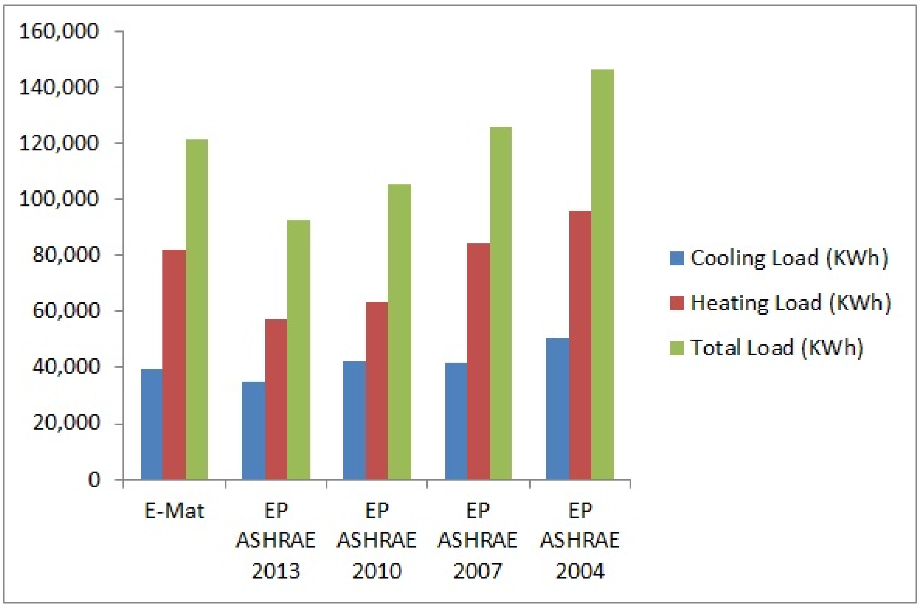

Figure A.15. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Baltimore.

ENERGY SIMULATION DATA INPUT

AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21

LOCATION	
Latitude	49.18
Longitude	-123.17
Time Zone (Hour)	-8

BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Vancouver
Hourly Soil Temp. (°C)	Vancouver
Monthly Humidity (%)	Vancouver

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.16. Vancouver Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.32	0.32	0.33	0.34	0.33	0.35	0.34	0.35	0.36	0.34	0.33	0.33
taud	2.51	2.51	2.44	2.38	2.42	2.39	2.45	2.49	2.47	2.55	2.52	2.48

Figure A.17. Optical Depth Values Form for Vancouver.

Table A.13. Weather Conditions in Vancouver for Thermal Simulation.

Month	Average Temperature	Standard Dev.
1	3.33	3.08
2	4.91	2.60
3	6.24	3.61
4	8.92	3.65
5	11.95	2.96
6	15.13	2.80
7	17.00	3.39
8	16.97	2.74
9	13.71	3.46
10	9.60	2.60
11	5.34	4.20
12	3.50	3.22

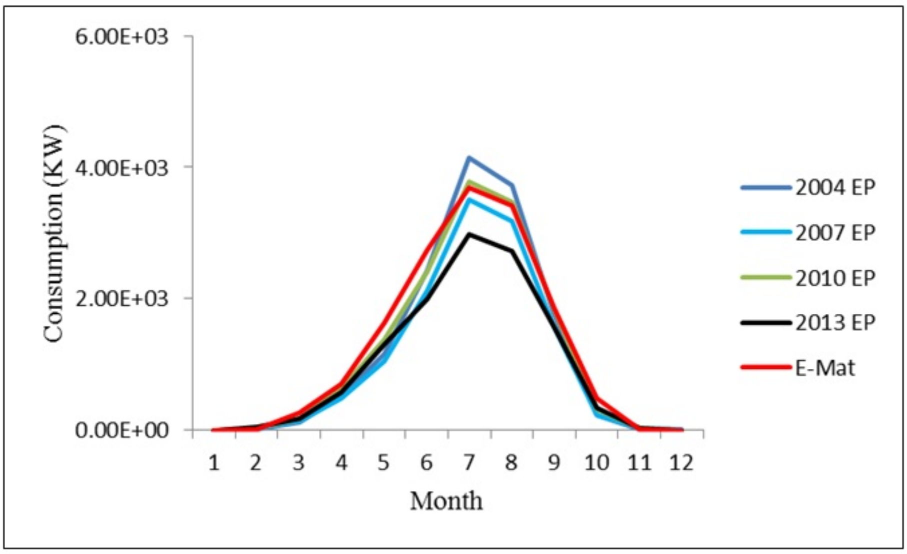

Figure A.18. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Vancouver.

Table A.14. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Vancouver.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	2.75E-01	3.11E+00	1.26E+00	2.22E+00	2.28E-01
2	2.01E+01	2.91E+01	3.38E+01	4.22E+01	5.31E+00
3	1.31E+02	1.33E+02	1.72E+02	1.83E+02	2.76E+02
4	5.23E+02	4.84E+02	6.37E+02	5.79E+02	6.96E+02
5	1.16E+03	1.05E+03	1.37E+03	1.31E+03	1.63E+03
6	2.44E+03	2.12E+03	2.41E+03	2.00E+03	2.75E+03
7	4.15E+03	3.51E+03	3.78E+03	2.97E+03	3.68E+03
8	3.73E+03	3.18E+03	3.47E+03	2.72E+03	3.42E+03
9	1.78E+03	1.57E+03	1.85E+03	1.58E+03	1.87E+03
10	2.31E+02	2.31E+02	3.17E+02	3.42E+02	4.86E+02
11	1.81E+01	2.58E+01	2.99E+01	3.64E+01	1.62E+01
12	5.12E-01	4.15E+00	2.28E+00	3.47E+00	0.00E+00

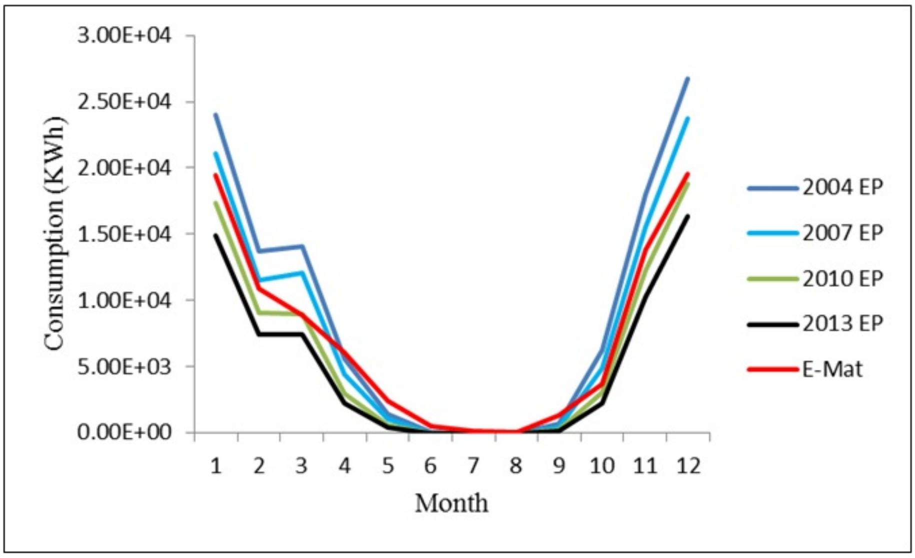

Figure A.19. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Vancouver.

Table A.15. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Vancouver.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	2.40E+04	2.11E+04	1.74E+04	1.49E+04	1.95E+04
2	1.37E+04	1.16E+04	9.11E+03	7.39E+03	1.09E+04
3	1.41E+04	1.21E+04	9.00E+03	7.44E+03	8.91E+03
4	5.60E+03	4.40E+03	2.98E+03	2.23E+03	6.04E+03
5	1.45E+03	1.05E+03	6.22E+02	4.30E+02	2.39E+03
6	4.23E+01	1.65E+01	1.70E+00	9.90E-02	5.08E+02
7	2.18E-02	0.00E+00	0.00E+00	0.00E+00	1.38E+02
8	2.49E-02	0.00E+00	0.00E+00	0.00E+00	5.32E+01
9	7.00E+02	4.63E+02	2.36E+02	1.18E+02	1.36E+03
10	6.29E+03	4.87E+03	3.11E+03	2.22E+03	3.68E+03
11	1.80E+04	1.56E+04	1.22E+04	1.02E+04	1.38E+04
12	2.67E+04	2.38E+04	1.88E+04	1.63E+04	1.96E+04

Table A.16. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Vancouver.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	14,834	86,780	101,614
EP ASHRAE 2013	11,774	61,253	73,027
EP ASHRAE 2010	14,077	73,520	87,597
EP ASHRAE 2007	12,341	94,836	107,177
EP ASHRAE 2004	14,177	110,621	124,798

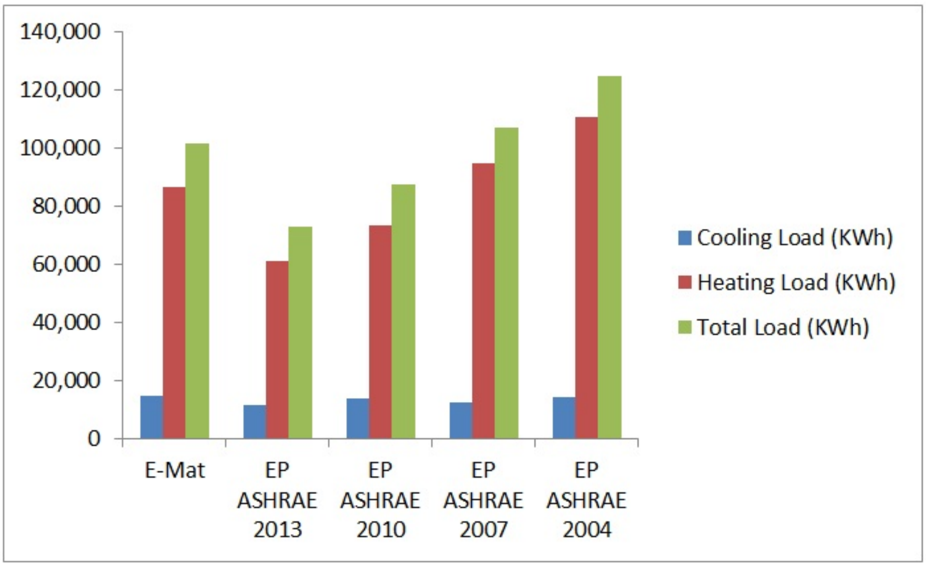

Figure A.20. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Vancouver.

ENERGY SIMULATION DATA INPUT

AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21

LOCATION	
Latitude	37.62
Longitude	-122.4
Time Zone (Hour)	-8

BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	San Francisco
Hourly Soil Temp. (°C)	San Francisco
Monthly Humidity (%)	San Francisco

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.21. San Francisco Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.33	0.34	0.32	0.31	0.32	0.32	0.31	0.32	0.33	0.33	0.32	0.33
taud	2.68	2.60	2.63	2.58	2.51	2.48	2.54	2.55	2.60	2.62	2.69	2.65

Figure A.22. Optical Depth Values Form for San Francisco.

Table A.17. Weather Conditions in San Francisco for Thermal Simulation.

Month	Average Temperature	Standard Dev.
1	9.64	2.69
2	11.37	2.95
3	12.90	3.22
4	13.68	3.09
5	14.89	3.73
6	15.29	4.13
7	16.01	2.75
8	16.59	3.36
9	16.66	3.18
10	15.12	3.15
11	12.66	2.46
12	10.65	2.56

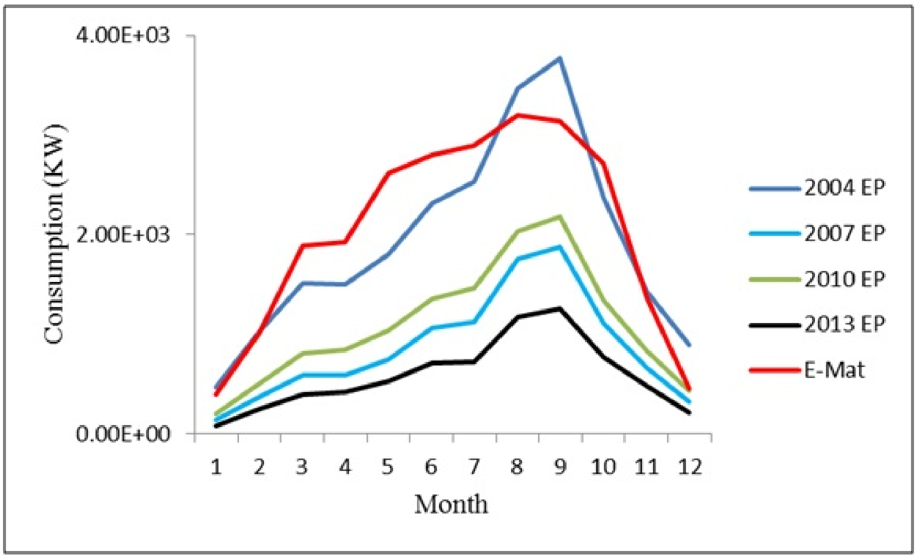

Figure A.23. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in San Francisco.

Table A.18. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in San Francisco.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	4.68E+02	1.40E+02	1.98E+02	8.06E+01	3.99E+02
2	1.03E+03	3.73E+02	5.12E+02	2.47E+02	1.01E+03
3	1.51E+03	5.93E+02	8.11E+02	4.00E+02	1.89E+03
4	1.50E+03	5.90E+02	8.52E+02	4.21E+02	1.93E+03
5	1.80E+03	7.50E+02	1.05E+03	5.27E+02	2.62E+03
6	2.31E+03	1.07E+03	1.35E+03	7.12E+02	2.80E+03
7	2.54E+03	1.13E+03	1.47E+03	7.29E+02	2.89E+03
8	3.46E+03	1.76E+03	2.04E+03	1.18E+03	3.20E+03
9	3.77E+03	1.88E+03	2.18E+03	1.26E+03	3.14E+03
10	2.38E+03	1.11E+03	1.35E+03	7.67E+02	2.72E+03
11	1.43E+03	6.69E+02	8.34E+02	4.82E+02	1.37E+03
12	9.01E+02	3.19E+02	4.35E+02	2.18E+02	4.60E+02

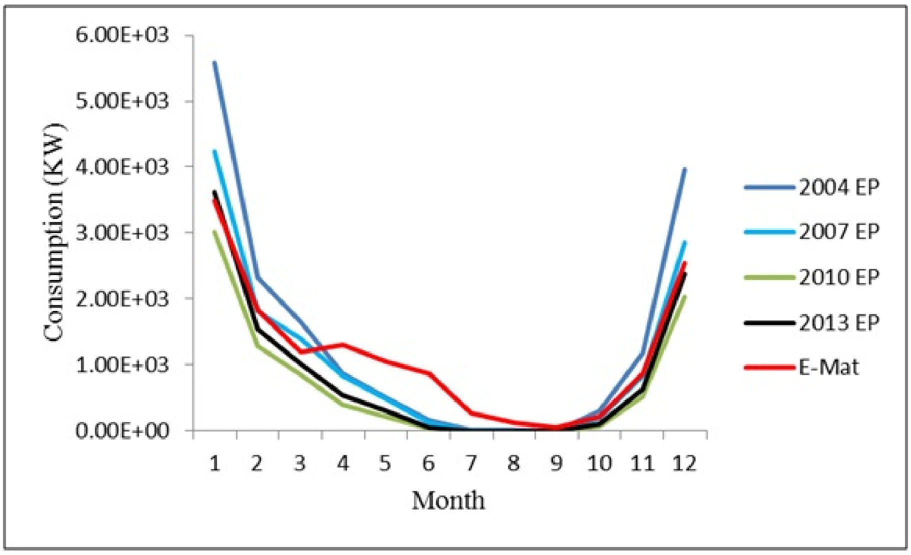

Figure A.24. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in San Francisco.

Table A.19. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in San Francisco.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	5.59E+03	4.23E+03	3.02E+03	3.62E+03	3.50E+03
2	2.32E+03	1.81E+03	1.29E+03	1.54E+03	1.84E+03
3	1.65E+03	1.40E+03	8.46E+02	1.02E+03	1.20E+03
4	8.72E+02	8.41E+02	3.96E+02	5.33E+02	1.30E+03
5	5.01E+02	4.84E+02	2.07E+02	3.05E+02	1.05E+03
6	1.56E+02	1.20E+02	2.65E+01	4.76E+01	8.62E+02
7	5.76E+00	2.44E+00	0.00E+00	3.92E-02	2.74E+02
8	7.34E+00	3.34E+00	0.00E+00	1.37E-01	1.17E+02
9	3.14E+00	1.25E-01	0.00E+00	0.00E+00	5.05E+01
10	3.13E+02	1.94E+02	6.87E+01	1.03E+02	2.08E+02
11	1.18E+03	8.31E+02	5.17E+02	6.25E+02	8.76E+02
12	3.96E+03	2.85E+03	2.04E+03	2.37E+03	2.54E+03

Table A.20. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in San Francisco.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	24,429	13,809	38,238
EP ASHRAE 2013	7,024	10,169	17,193
EP ASHRAE 2010	13,074	8,410	21,484
EP ASHRAE 2007	10,380	12,771	23,151
EP ASHRAE 2004	23,102	16,555	39,657

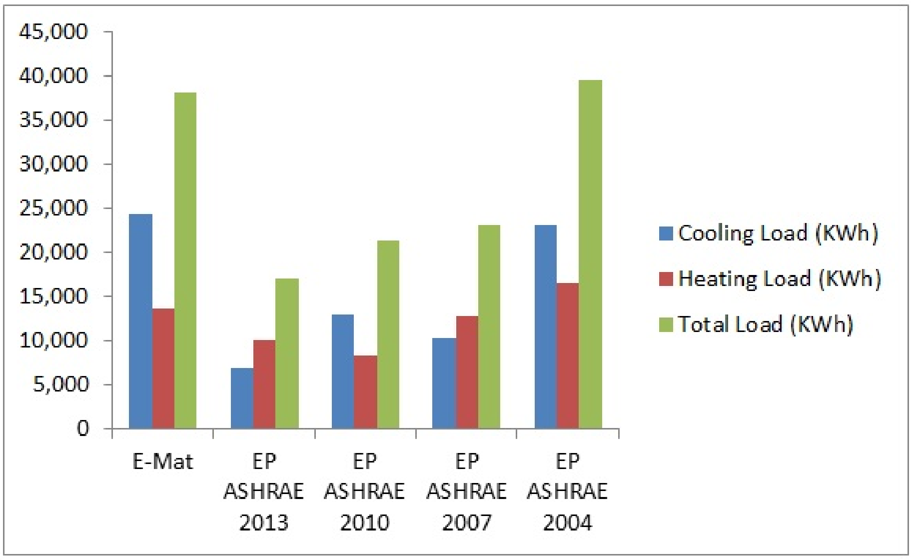

Figure A.25. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in San Francisco.

ENERGY SIMULATION DATA INPUT	
AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21
LOCATION	
Latitude	25.82
Longitude	-80.3
Time Zone (Hour)	-5
BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Miami
Hourly Soil Temp. (°C)	Miami
Monthly Humidity (%)	Miami

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.26. Miami Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.38	0.37	0.38	0.38	0.37	0.38	0.42	0.41	0.40	0.41	0.39	0.38
taud	2.66	2.61	2.51	2.46	2.46	2.49	2.35	2.41	2.50	2.53	2.62	2.64

Figure A.27. Optical Depth Values Form for Miami.

Table A.21. Weather Conditions in Miami for Thermal Simulation.

Month	Average Temperature	Standard Deviation
1	19.40	4.15
2	20.75	4.36
3	21.73	4.14
4	24.17	2.81
5	26.49	2.45
6	27.68	2.08
7	28.16	2.70
8	27.97	2.34
9	27.39	2.53
10	26.26	2.29
11	23.61	3.72
12	20.18	4.39

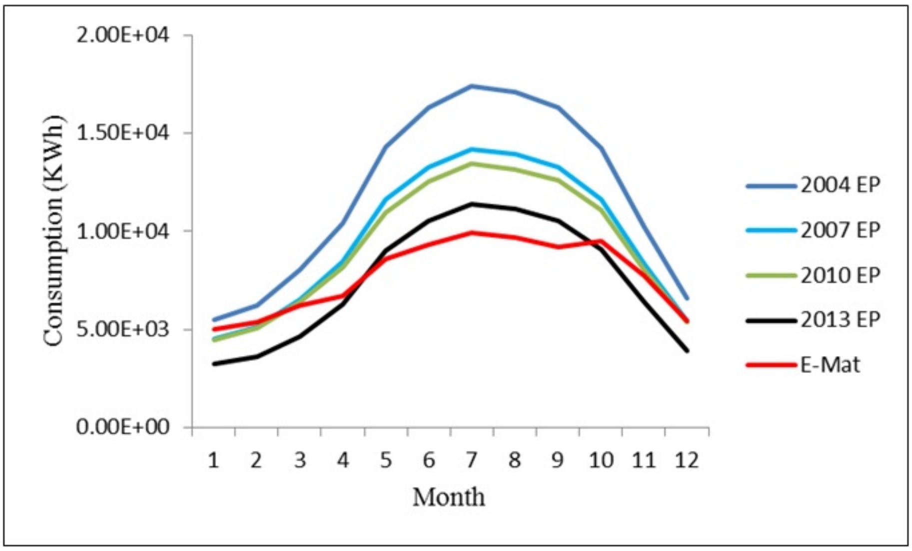

Figure A.28. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Miami.

Table A.22. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Miami.

Month	2004 (KWh)	2007 (KWh)	2010 (KWh)	2013(KWh)	E-Mat (KWh)
1	5.49E+03	4.52E+03	4.48E+03	3.24E+03	5.03E+03
2	6.24E+03	5.11E+03	5.05E+03	3.63E+03	5.40E+03
3	8.03E+03	6.55E+03	6.41E+03	4.68E+03	6.24E+03
4	1.04E+04	8.50E+03	8.17E+03	6.32E+03	6.70E+03
5	1.43E+04	1.16E+04	1.10E+04	9.01E+03	8.62E+03
6	1.63E+04	1.33E+04	1.25E+04	1.05E+04	9.34E+03
7	1.74E+04	1.42E+04	1.34E+04	1.14E+04	9.92E+03
8	1.71E+04	1.39E+04	1.32E+04	1.12E+04	9.71E+03
9	1.63E+04	1.33E+04	1.26E+04	1.06E+04	9.21E+03
10	1.42E+04	1.16E+04	1.11E+04	9.10E+03	9.52E+03
11	1.02E+04	8.36E+03	8.06E+03	6.39E+03	7.75E+03
12	6.62E+03	5.43E+03	5.36E+03	3.93E+03	5.44E+03

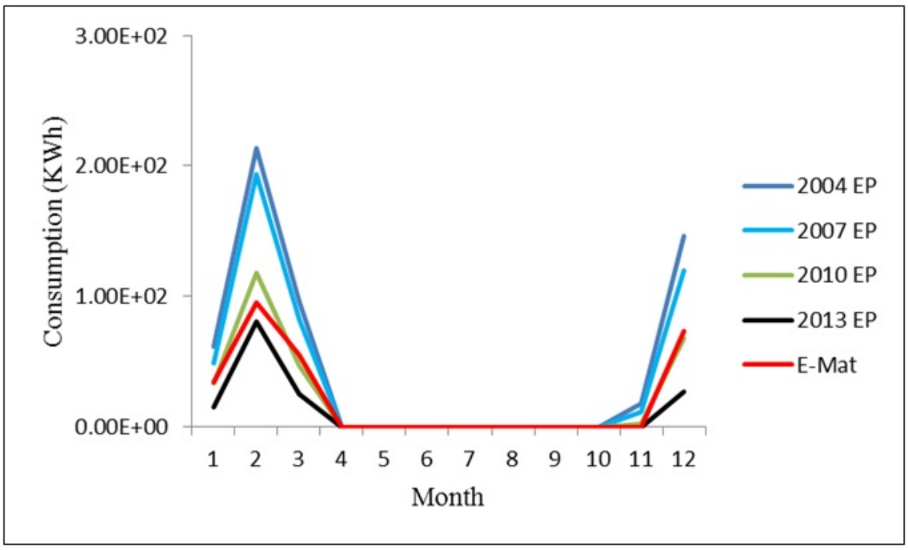

Figure A.29. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Miami.

Table A.23. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Miami.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	6.15E+01	4.86E+01	3.30E+01	1.51E+01	3.46E+01
2	2.14E+02	1.93E+02	1.18E+02	8.04E+01	9.49E+01
3	9.61E+01	8.30E+01	4.72E+01	2.52E+01	5.50E+01
4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	1.80E+01	1.15E+01	2.68E+00	1.57E-02	8.72E-02
12	1.46E+02	1.20E+02	6.83E+01	2.70E+01	7.36E+01

Table A.24. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Miami.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	92,855	288	93,143
EP ASHRAE 2013	89,922	147	90,069
EP ASHRAE 2010	111,330	269	111,599
EP ASHRAE 2007	116,371	455	116,826
EP ASHRAE 2004	142,662	536	143,198

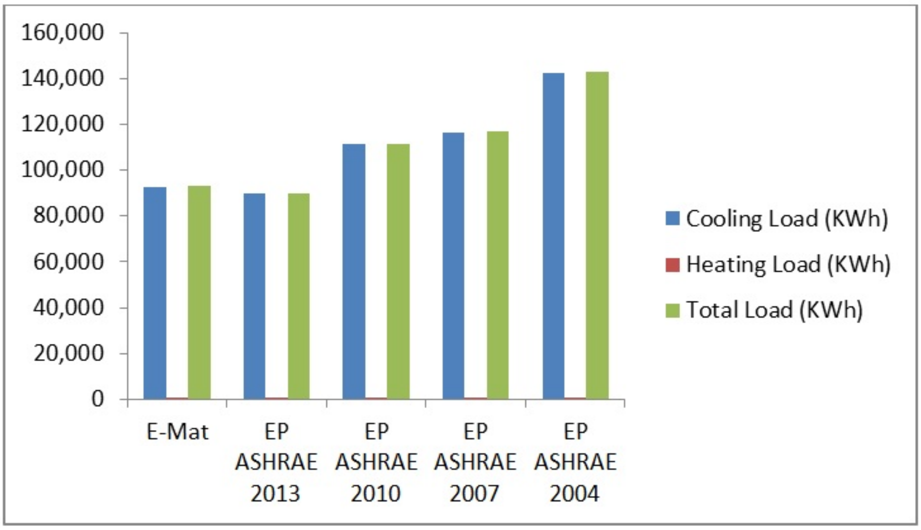

Figure A.30. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Miami.

ENERGY SIMULATION DATA INPUT

AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21

LOCATION	
Latitude	33.45
Longitude	-111.98
Time Zone (Hour)	-7

BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Phoenix
Hourly Soil Temp. (°C)	Phoenix
Monthly Humidity (%)	Phoenix

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.31. Phoenix Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.31	0.32	0.34	0.32	0.32	0.32	0.36	0.38	0.35	0.34	0.32	0.31
taud	2.64	2.56	2.44	2.45	2.41	2.39	2.36	2.37	2.47	2.48	2.55	2.62

Figure A.32. Optical Depth Values Form for Phoenix.

Table A.25. Weather Conditions in Phoenix for Thermal Simulation.

Month	Average Temperature	Standard Dev.
1	13.12	4.66
2	15.66	6.28
3	17.33	5.53
4	24.05	6.82
5	27.42	6.00
6	34.12	4.96
7	35.60	4.55
8	33.79	4.59
9	30.18	4.81
10	24.52	5.87
11	17.73	4.58
12	11.63	4.47

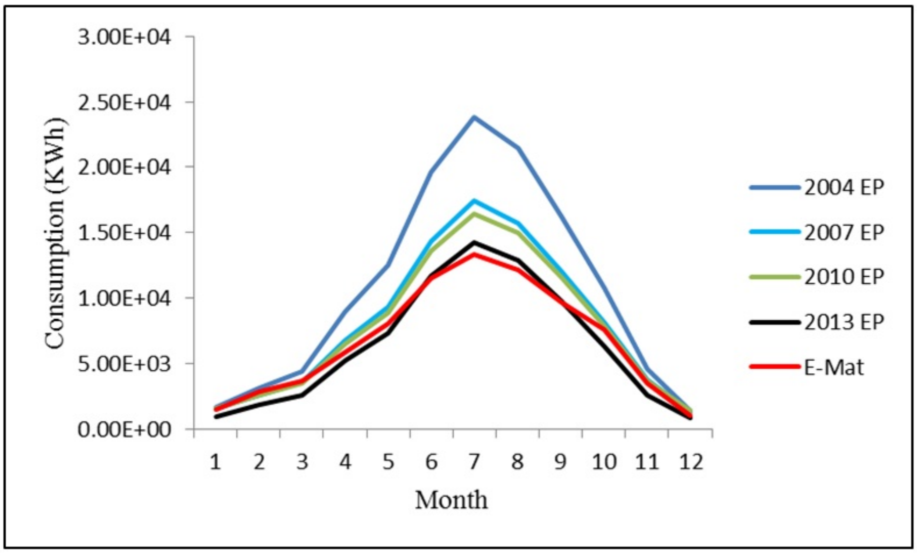

Figure A.33. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Phoenix.

Table A.26. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Phoenix.

Month	2004 (KWh)	2007 (KWh)	2010 (KWh)	2013 (KWh)	E-Mat (KWh)
1	1.70E+03	1.58E+03	1.64E+03	1.01E+03	1.56E+03
2	3.17E+03	2.62E+03	2.63E+03	1.84E+03	2.91E+03
3	4.48E+03	3.61E+03	3.56E+03	2.58E+03	3.74E+03
4	8.95E+03	6.78E+03	6.54E+03	5.29E+03	5.86E+03
5	1.26E+04	9.34E+03	8.91E+03	7.39E+03	8.04E+03
6	1.96E+04	1.43E+04	1.36E+04	1.17E+04	1.15E+04
7	2.39E+04	1.74E+04	1.65E+04	1.43E+04	1.34E+04
8	2.14E+04	1.57E+04	1.50E+04	1.29E+04	1.22E+04
9	1.63E+04	1.21E+04	1.16E+04	9.79E+03	9.75E+03
10	1.08E+04	8.16E+03	7.91E+03	6.36E+03	7.62E+03
11	4.60E+03	3.78E+03	3.74E+03	2.62E+03	3.55E+03
12	1.43E+03	1.33E+03	1.40E+03	8.52E+02	1.11E+03

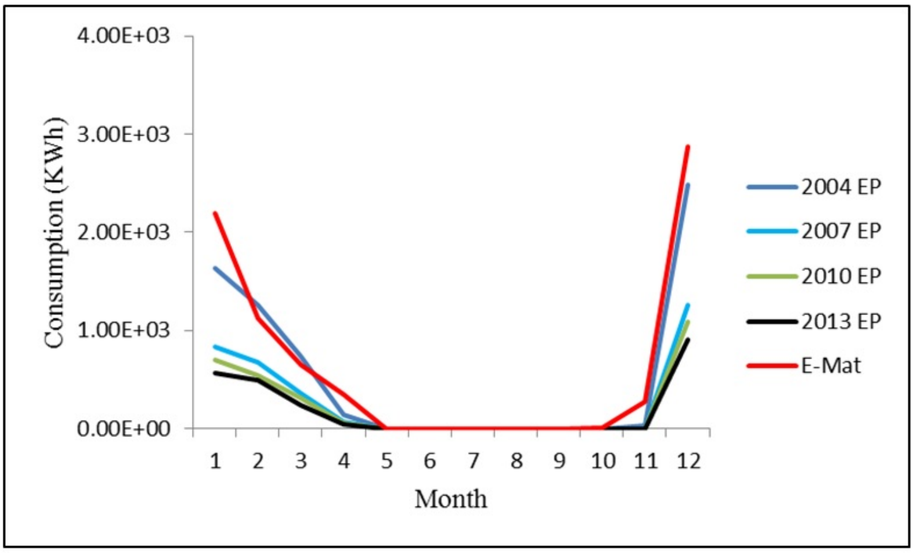

Figure A.34. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Phoenix.

Table A.27. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Phoenix.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	1.64E+03	8.39E+02	6.96E+02	5.73E+02	2.19E+03
2	1.26E+03	6.77E+02	5.43E+02	4.97E+02	1.13E+03
3	7.38E+02	3.66E+02	3.10E+02	2.44E+02	6.51E+02
4	1.40E+02	7.52E+01	5.29E+01	4.00E+01	3.49E+02
5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.82E+00
11	3.69E+01	1.86E+00	5.54E-01	1.41E-01	2.71E+02
12	2.49E+03	1.26E+03	1.08E+03	9.09E+02	2.87E+03

Table A.28. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Phoenix.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	81,253	7,475	88,728
EP ASHRAE 2013	76,684	2,263	78,947
EP ASHRAE 2010	93,083	2,686	95,769
EP ASHRAE 2007	96,755	3,224	99,979
EP ASHRAE 2004	128,843	6,299	135,142

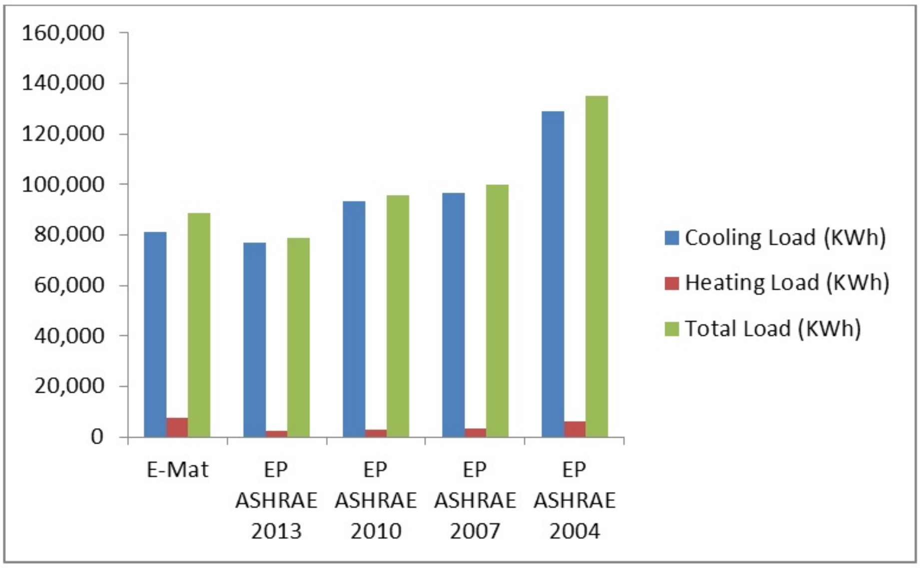

Figure A.35. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Phoenix.

ENERGY SIMULATION DATA INPUT	
AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21
LOCATION	
Latitude	30
Longitude	-95.37
Time Zone (Hour)	-6
BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Houston
Hourly Soil Temp. (°C)	Houston
Monthly Humidity (%)	Houston

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.36. Houston Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.36	0.37	0.37	0.39	0.38	0.38	0.40	0.40	0.40	0.37	0.38	0.37
taud	2.56	2.49	2.45	2.34	2.38	2.40	2.36	2.41	2.44	2.53	2.48	2.56

Figure A.37. Optical Depth Values Form for Houston.

Table A.29. Weather Conditions in Houston for Thermal Simulation.

Month	Average Temperature	Standard Dev.
1	10.65	5.91
2	13.02	7.44
3	16.25	6.10
4	20.48	4.91
5	24.23	4.05
6	27.07	3.40
7	28.36	3.54
8	28.09	4.21
9	26.48	4.60
10	20.00	6.19
11	17.13	6.24
12	12.30	6.70

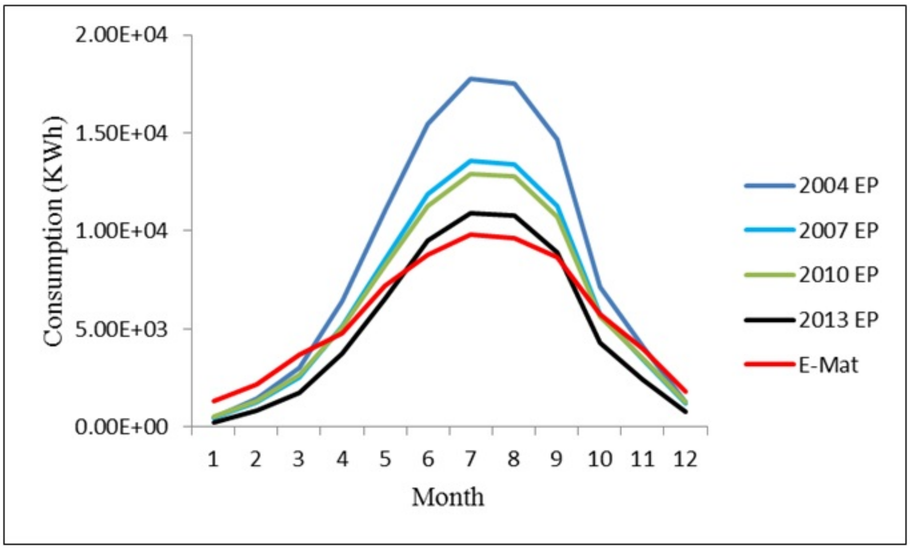

Figure A.38. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Houston.

Table A.30. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Houston.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	4.65E+02	4.44E+02	5.07E+02	2.38E+02	1.34E+03
2	1.43E+03	1.27E+03	1.32E+03	8.08E+02	2.17E+03
3	3.04E+03	2.55E+03	2.65E+03	1.76E+03	3.67E+03
4	6.43E+03	5.17E+03	5.09E+03	3.75E+03	4.80E+03
5	1.10E+04	8.57E+03	8.21E+03	6.51E+03	7.18E+03
6	1.54E+04	1.19E+04	1.13E+04	9.48E+03	8.81E+03
7	1.78E+04	1.36E+04	1.29E+04	1.09E+04	9.83E+03
8	1.75E+04	1.34E+04	1.28E+04	1.08E+04	9.66E+03
9	1.47E+04	1.13E+04	1.07E+04	8.87E+03	8.69E+03
10	7.17E+03	5.77E+03	5.61E+03	4.27E+03	5.75E+03
11	4.14E+03	3.46E+03	3.48E+03	2.41E+03	3.97E+03
12	1.28E+03	1.18E+03	1.27E+03	7.46E+02	1.81E+03

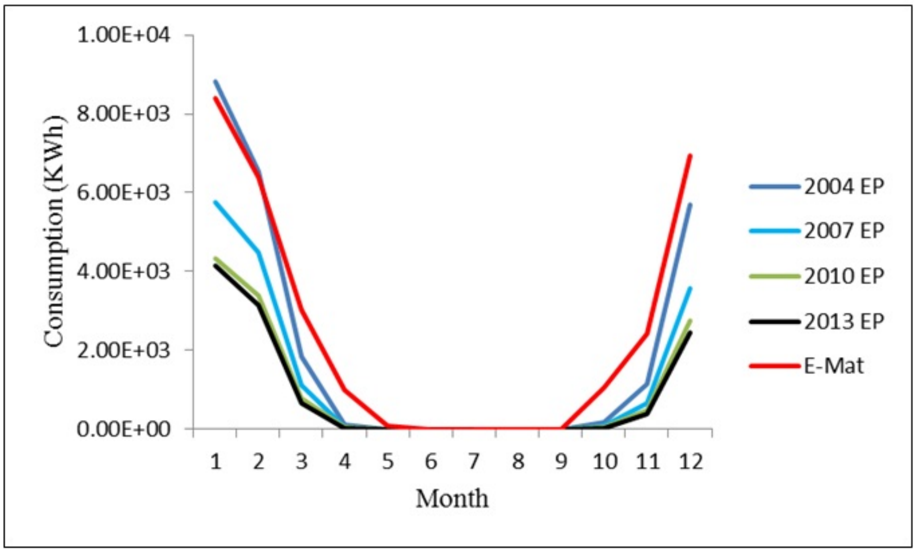

Figure A.39. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Houston.

Table A.31. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Houston.

Month	2004 (KWh)	2007 (KWh)	2010 (KWh)	2013 (KWh)	E-Mat (KWh)
1	8.82E+03	5.76E+03	4.34E+03	4.14E+03	8.41E+03
2	6.56E+03	4.49E+03	3.38E+03	3.13E+03	6.39E+03
3	1.83E+03	1.10E+03	7.73E+02	6.72E+02	3.03E+03
4	1.23E+02	6.23E+01	4.04E+01	2.82E+01	9.97E+02
5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.25E+01
6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	1.88E+02	6.95E+01	6.64E+01	2.81E+01	1.07E+03
11	1.15E+03	6.53E+02	4.88E+02	3.76E+02	2.41E+03
12	5.70E+03	3.56E+03	2.74E+03	2.44E+03	6.95E+03

Table A.32. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Houston.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	67,680	15,688	83,368
EP ASHRAE 2013	60,559	10,813	71,372
EP ASHRAE 2010	75,900	11,824	87,724
EP ASHRAE 2007	78,584	15,699	94,283
EP ASHRAE 2004	100,361	24,371	124,732

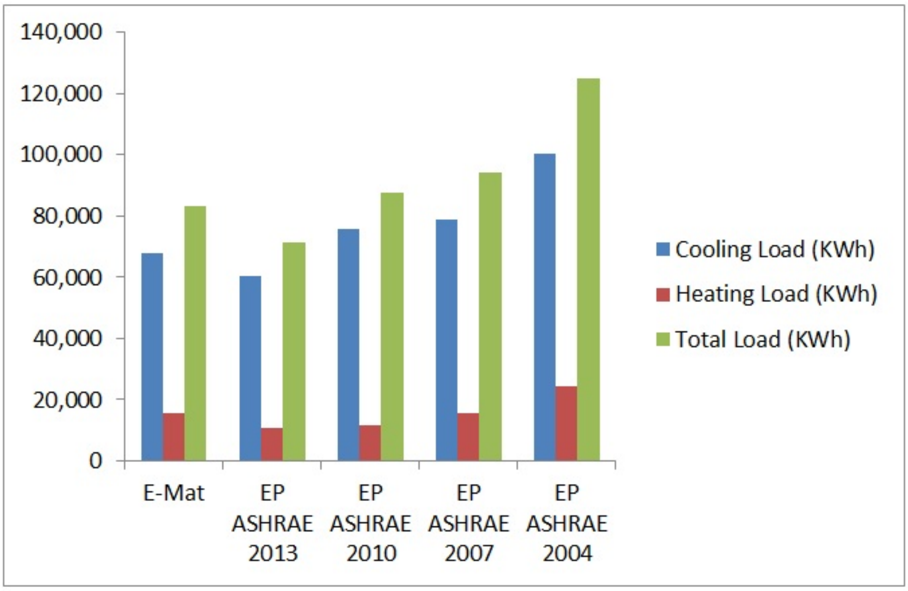

Figure A.40. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Houston.

ENERGY SIMULATION DATA INPUT

AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21

LOCATION	
Latitude	43.62
Longitude	-116.62
Time Zone (Hour)	-7

BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Boise - Idaho
Hourly Soil Temp. (°C)	Boise - Idaho
Monthly Humidity (%)	Boise - Idaho

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.41. Boise Idaho Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.27	0.28	0.29	0.30	0.30	0.31	0.31	0.33	0.31	0.30	0.29	0.28
taud	2.52	2.55	2.53	2.48	2.46	2.45	2.47	2.42	2.53	2.59	2.64	2.57

Figure A.42. Optical Depth Values Form for Boise Idaho.

Table A.33. Weather Conditions in Boise Idaho for Thermal Simulation

Month	Average Temperature	Standard Dev.
1	-1.35	5.09
2	2.78	4.14
3	6.09	4.95
4	11.86	6.09
5	14.87	5.54
6	19.72	7.03
7	24.53	6.72
8	21.27	7.19
9	17.21	5.77
10	11.35	5.51
11	3.61	5.67
12	2.04	3.92

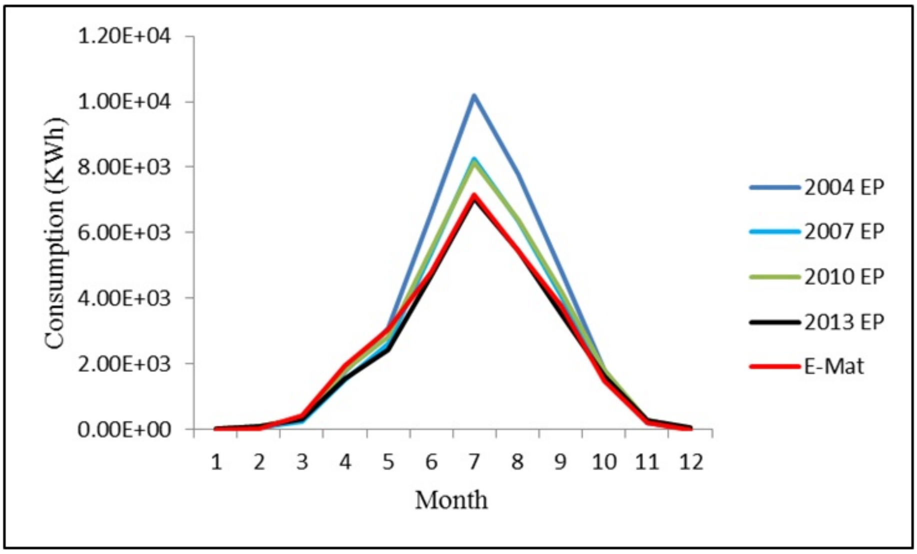

Figure A.43. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Boise Idaho.

Table A.34. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Boise Idaho.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	5.36E+00	1.10E+01	8.50E+00	1.13E+01	2.77E+00
2	7.33E+01	7.92E+01	9.78E+01	1.07E+02	2.06E+01
3	2.74E+02	2.59E+02	3.51E+02	3.28E+02	4.16E+02
4	1.77E+03	1.52E+03	1.80E+03	1.56E+03	1.97E+03
5	3.08E+03	2.60E+03	2.82E+03	2.45E+03	3.06E+03
6	6.57E+03	5.38E+03	5.48E+03	4.69E+03	4.78E+03
7	1.02E+04	8.24E+03	8.14E+03	7.06E+03	7.17E+03
8	7.78E+03	6.35E+03	6.40E+03	5.47E+03	5.46E+03
9	4.84E+03	4.05E+03	4.22E+03	3.52E+03	3.76E+03
10	1.82E+03	1.60E+03	1.80E+03	1.62E+03	1.49E+03
11	2.16E+02	2.12E+02	2.67E+02	2.70E+02	1.99E+02
12	2.92E+01	3.81E+01	4.24E+01	5.08E+01	0.00E+00

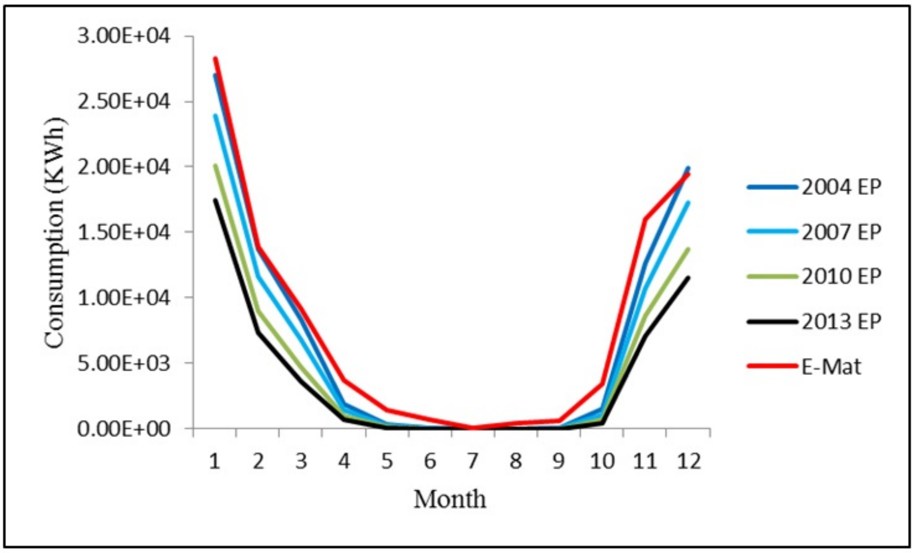

Figure A.44. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Boise Idaho.

Table A.35. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Boise Idaho.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	2.70E+04	2.39E+04	2.01E+04	1.74E+04	2.83E+04
2	1.37E+04	1.17E+04	8.99E+03	7.37E+03	1.39E+04
3	8.32E+03	6.76E+03	4.73E+03	3.64E+03	9.20E+03
4	1.91E+03	1.46E+03	9.31E+02	6.69E+02	3.69E+03
5	3.73E+02	2.49E+02	1.30E+02	8.85E+01	1.42E+03
6	4.04E+01	2.54E+01	4.91E+00	6.04E-01	6.70E+02
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E+01
8	1.65E+00	9.15E-02	0.00E+00	0.00E+00	4.47E+02
9	5.53E+01	2.37E+01	6.54E+00	8.82E-02	5.86E+02
10	1.53E+03	1.05E+03	6.71E+02	4.01E+02	3.46E+03
11	1.27E+04	1.07E+04	8.62E+03	7.07E+03	1.60E+04
12	1.99E+04	1.73E+04	1.37E+04	1.16E+04	1.94E+04

Table A.36. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Boise Idaho.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	28,332	86,354	114,686
EP ASHRAE 2013	27,132	48,198	75,330
EP ASHRAE 2010	31,421	57,909	89,330
EP ASHRAE 2007	30,346	73,053	103,399
EP ASHRAE 2004	36,649	85,475	122,124

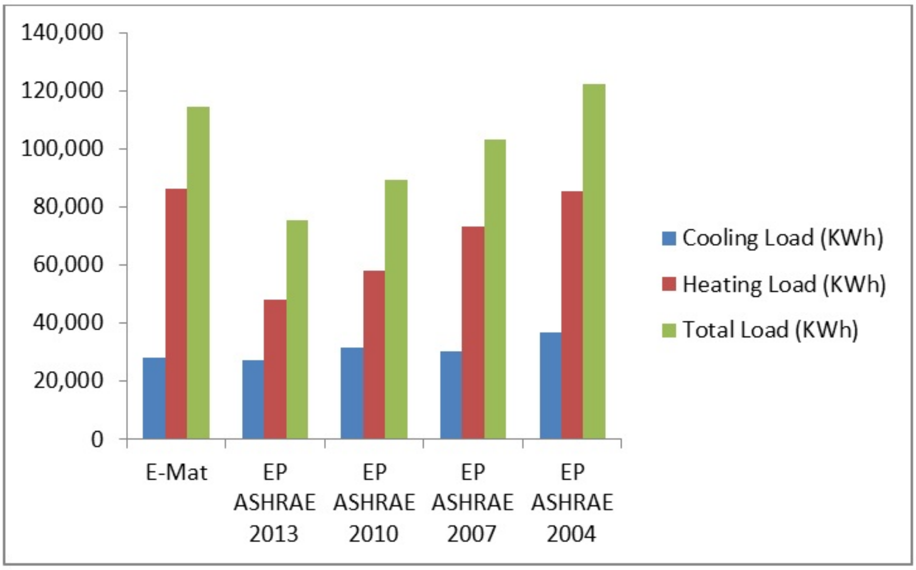

Figure A.45. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Boise Idaho.

ENERGY SIMULATION DATA INPUT

AIR CONDITIONING	
Cooling (°C)	24
Heating (°C)	21

LOCATION	
Latitude	64.82
Longitude	-147.85
Time Zone (Hour)	-9

BUILDING COMPONENTS	
Wall 1	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	180
Wall 2	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	270
Wall 3	
Length (m)	46.5
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	0
Wall 4	
Length (m)	17
Height/Width (m)	12
Tilt Angle (deg)	90
Direction (deg)	90
Roof	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180
Foundation	
Length (m)	46.5
Height/Width (m)	17
Tilt Angle (deg)	0
Direction (deg)	180

INTERNAL HEAT GAIN	
Number of People (Nr)	75
Ligthing (W/m2)	4.85
Equipments (W/m2)	2
Lighting Schedule	Residential
People Schedule	Residential

Standard occupational and lighting schedules will be automatically inserted by the software. (Residential, Office, Commercial, etc)

WEATHER CONDITIONS	
Hourly Temperature (°C)	Fairbanks
Hourly Soil Temp. (°C)	Fairbanks
Monthly Humidity (%)	Fairbanks

The Weather Condition data is required to be inserted to relevant partitions. The data is acquired from TSMS (Turkish State Meteorological

Figure A.46. Fairbanks Midrise Residential Building Input Form.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Novem	Dec.
taub	0.22	0.26	0.26	0.28	0.29	0.30	0.31	0.31	0.28	0.27	0.26	0.23
taud	2.40	2.56	2.50	2.41	2.45	2.43	2.43	2.48	2.58	2.57	2.58	2.61

Figure A.47. Optical Depth Values Form for Fairbanks.

Table A.37. Weather Conditions in Fairbanks for Thermal Simulation.

Month	Average Temperature	Standard Deviation
1	-17.65	7.68
2	-15.64	8.78
3	-9.81	7.57
4	1.30	7.09
5	10.69	4.94
6	15.98	4.42
7	16.95	4.78
8	14.07	5.04
9	6.63	4.88
10	-3.64	7.50
11	-18.08	5.91
12	-19.15	6.93

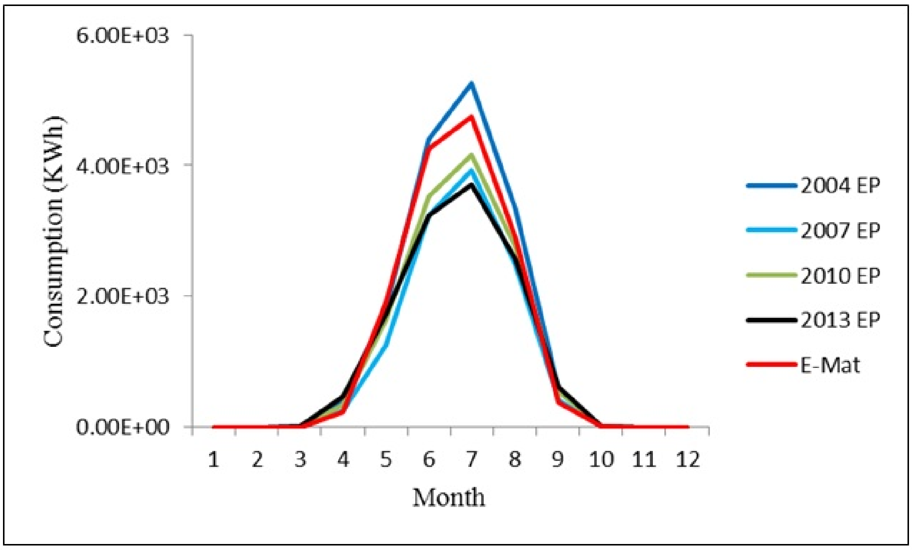

Figure A.48. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Fairbanks.

Table A.38. Monthly Electricity Consumption for Midrise Residential Building Space Cooling in Fairbanks.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	4.53E+00	3.11E+00	2.03E+00	4.20E+00	0.00E+00
4	4.01E+02	2.42E+02	3.44E+02	4.64E+02	2.33E+02
5	1.79E+03	1.25E+03	1.64E+03	1.72E+03	1.92E+03
6	4.39E+03	3.23E+03	3.53E+03	3.23E+03	4.25E+03
7	5.26E+03	3.93E+03	4.16E+03	3.71E+03	4.74E+03
8	3.33E+03	2.47E+03	2.74E+03	2.57E+03	2.89E+03
9	5.79E+02	4.18E+02	5.35E+02	6.23E+02	3.76E+02
10	1.34E+01	1.21E+01	1.25E+01	2.19E+01	6.66E+00
11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

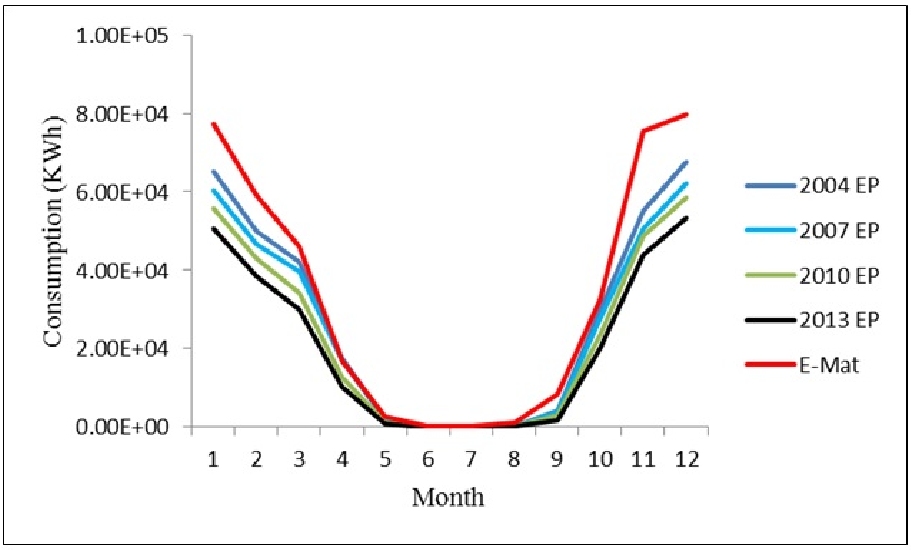

Figure A.49. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Fairbanks.

Table A.39. Monthly Natural Gas Consumption for Midrise Residential Building Space Heating in Fairbanks.

Month	2004 (KWh)	2007(KWh)	2010(KWh)	2013(KWh)	E-Mat (KWh)
1	6.53E+04	6.01E+04	5.58E+04	5.07E+04	7.72E+04
2	5.01E+04	4.65E+04	4.29E+04	3.83E+04	5.89E+04
3	4.19E+04	3.95E+04	3.43E+04	2.98E+04	4.60E+04
4	1.76E+04	1.69E+04	1.27E+04	1.04E+04	1.68E+04
5	2.01E+03	2.00E+03	1.22E+03	8.43E+02	2.78E+03
6	1.57E+01	1.56E+01	1.79E-01	5.34E-03	9.50E+01
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.73E+01
8	2.94E+02	2.74E+02	1.56E+02	7.12E+01	1.11E+03
9	4.23E+03	3.84E+03	2.82E+03	1.75E+03	8.52E+03
10	2.99E+04	2.79E+04	2.35E+04	2.03E+04	3.28E+04
11	5.52E+04	5.06E+04	4.89E+04	4.40E+04	7.54E+04
12	6.76E+04	6.20E+04	5.86E+04	5.34E+04	7.97E+04

Table A.40. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Fairbanks.

	Cooling Load (KWh)	Heating Load (KWh)	Total Load (KWh)
E-Mat	14,415	399,470	413,885
EP ASHRAE 2013	12,341	249,606	261,947
EP ASHRAE 2010	12,952	280,856	293,808
EP ASHRAE 2007	11,546	309,699	321,245
EP ASHRAE 2004	15,777	334,273	350,050

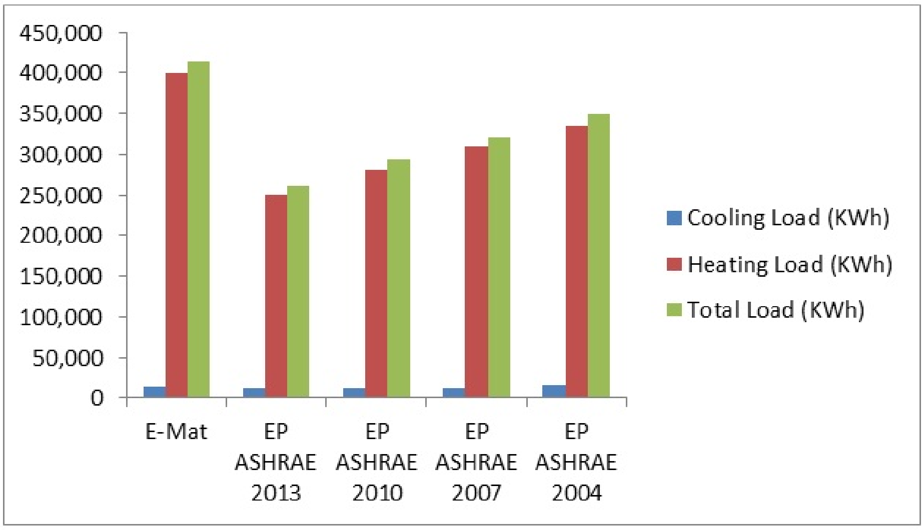

Figure A.50. Yearly Energy Consumption for Midrise Residential Building Space Heating and Cooling in Fairbanks.

APPENDIX B: UNIT PRICE DATABASE

Table B.1. Wall Type 1 Unit Prices

Gysum Plaster (mm)	Brick Wall (mm)	Cement Plaster (mm)	Rock Wool (mm)	CB Particle Board (mm)	Total Price (TL)
20	200	20	20	6	191.10
20	200	20	25	6	192.54
20	200	20	30	6	193.98
20	200	20	35	6	195.42
20	200	20	40	6	196.86
20	200	20	45	6	198.30
20	200	20	50	6	199.75
20	200	20	55	6	201.20
20	200	20	60	6	202.64
20	200	20	65	6	204.55
20	200	20	70	6	206.44
20	200	20	75	6	207.42
20	200	20	80	6	208.41
20	200	20	85	6	209.40
20	200	20	90	6	210.38
20	200	20	95	6	211.36
20	200	20	100	6	212.35
20	200	20	20	8	192.80
20	200	20	25	8	194.24
20	200	20	30	8	195.68
20	200	20	35	8	197.12
20	200	20	40	8	198.56
20	200	20	45	8	200.00

Table B.1. Wall Type 1 Unit Prices (cont.).

Gysum Plaster (mm)	**Brick Wall (mm)**	**Cement Plaster (mm)**	**Rock Wool (mm)**	**CB Particle Board (mm)**	**Total Price (TL)**
20	200	20	50	8	201.45
20	200	20	55	8	202.90
20	200	20	60	8	204.34
20	200	20	65	8	206.25
20	200	20	70	8	208.14
20	200	20	75	8	209.12
20	200	20	80	8	210.11
20	200	20	85	8	211.10
20	200	20	90	8	212.08
20	200	20	95	8	213.06
20	200	20	100	8	214.05
20	200	20	20	10	194.50
20	200	20	25	10	195.94
20	200	20	30	10	197.38
20	200	20	35	10	198.82
20	200	20	40	10	200.26
20	200	20	45	10	201.70
20	200	20	50	10	203.15
20	200	20	55	10	204.60
20	200	20	60	10	206.04
20	200	20	65	10	207.95
20	200	20	70	10	209.84
20	200	20	75	10	210.82
20	200	20	80	10	211.81
20	200	20	85	10	212.80

Table B.1. Wall Type 1 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	Cement Plaster (mm)	Rock Wool (mm)	CB Particle Board (mm)	Total Price (TL)
20	200	20	90	10	213.78
20	200	20	95	10	214.76
20	200	20	100	10	215.75
20	200	20	20	12	196.80
20	200	20	25	12	198.24
20	200	20	30	12	199.68
20	200	20	35	12	201.12
20	200	20	40	12	202.56
20	200	20	45	12	204.00
20	200	20	50	12	205.45
20	200	20	55	12	206.90
20	200	20	60	12	208.34
20	200	20	65	12	210.25
20	200	20	70	12	212.14
20	200	20	75	12	213.12
20	200	20	80	12	214.11
20	200	20	85	12	215.10
20	200	20	90	12	216.08
20	200	20	95	12	217.06
20	200	20	100	12	218.05
20	200	20	20	14	199.00
20	200	20	25	14	200.44
20	200	20	30	14	201.88
20	200	20	35	14	203.32
20	200	20	40	14	204.76

Table B.1. Wall Type 1 Unit Prices (cont.).

Gysum Plaster (mm)	**Brick Wall (mm)**	**Cement Plaster (mm)**	**Rock Wool (mm)**	**CB Particle Board (mm)**	**Total Price (TL)**
20	200	20	45	14	206.20
20	200	20	50	14	207.65
20	200	20	55	14	209.10
20	200	20	60	14	210.54
20	200	20	65	14	212.45
20	200	20	70	14	214.34
20	200	20	75	14	215.32
20	200	20	80	14	216.31
20	200	20	85	14	217.30
20	200	20	90	14	218.28
20	200	20	95	14	219.26
20	200	20	100	14	220.25
20	200	20	20	16	203.75
20	200	20	25	16	205.19
20	200	20	30	16	206.63
20	200	20	35	16	208.07
20	200	20	40	16	209.51
20	200	20	45	16	210.95
20	200	20	50	16	212.40
20	200	20	55	16	213.85
20	200	20	60	16	215.29
20	200	20	65	16	217.20
20	200	20	70	16	219.09
20	200	20	75	16	220.07
20	200	20	80	16	221.06

Table B.1. Wall Type 1 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	Cement Plaster (mm)	Rock Wool (mm)	CB Particle Board (mm)	Total Price (TL)
20	200	20	85	16	222.05
20	200	20	90	16	223.03
20	200	20	95	16	224.01
20	200	20	100	16	225.00
20	200	20	20	18	205.55
20	200	20	25	18	206.99
20	200	20	30	18	208.43
20	200	20	35	18	209.87
20	200	20	40	18	211.31
20	200	20	45	18	212.75
20	200	20	50	18	214.20
20	200	20	55	18	215.65
20	200	20	60	18	217.09
20	200	20	65	18	219.00
20	200	20	70	18	220.89
20	200	20	75	18	221.87
20	200	20	80	18	222.86
20	200	20	85	18	223.85
20	200	20	90	18	224.83
20	200	20	95	18	225.81
20	200	20	100	18	226.80
20	200	20	20	20	207.82
20	200	20	25	20	209.26
20	200	20	30	20	210.70
20	200	20	35	20	212.14

Table B.1. Wall Type 1 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	Cement Plaster (mm)	Rock Wool (mm)	CB Particle Board (mm)	Total Price (TL)
20	200	20	40	20	213.58
20	200	20	45	20	215.02
20	200	20	50	20	216.47
20	200	20	55	20	217.92
20	200	20	60	20	219.36
20	200	20	65	20	221.27
20	200	20	70	20	223.16
20	200	20	75	20	224.14
20	200	20	80	20	225.13
20	200	20	85	20	226.12
20	200	20	90	20	227.10
20	200	20	95	20	228.08
20	200	20	100	20	229.07
20	200	20	20	22	210.10
20	200	20	25	22	211.54
20	200	20	30	22	212.98
20	200	20	35	22	214.42
20	200	20	40	22	215.86
20	200	20	45	22	217.30
20	200	20	50	22	218.75
20	200	20	55	22	220.20
20	200	20	60	22	221.64
20	200	20	65	22	223.55
20	200	20	70	22	225.44
20	200	20	75	22	226.42

Table B.1. Wall Type 1 Unit Prices (cont.).

Gysum Plaster (mm)	**Brick Wall (mm)**	**Cement Plaster (mm)**	**Rock Wool (mm)**	**CB Particle Board (mm)**	**Total Price (TL)**
20	200	20	80	22	227.41

Table B.2. Wall Type 2 Unit Prices.

Gyps. Plaster (mm)	**Brick Wall (mm)**	**Cem. Plaster (mm)**	**EPS (mm)**	**Cement Plaster (mm)**	**Total Price (mm)**
20.00	200.00	20.00	20.00	20.00	154.59
20.00	200.00	20.00	25.00	20.00	155.35
20.00	200.00	20.00	30.00	20.00	156.11
20.00	200.00	20.00	35.00	20.00	156.87
20.00	200.00	20.00	40.00	20.00	157.63
20.00	200.00	20.00	45.00	20.00	158.38
20.00	200.00	20.00	50.00	20.00	159.14
20.00	200.00	20.00	55.00	20.00	159.90
20.00	200.00	20.00	60.00	20.00	160.67
20.00	200.00	20.00	65.00	20.00	161.43
20.00	200.00	20.00	70.00	20.00	162.19
20.00	200.00	20.00	75.00	20.00	162.95
20.00	200.00	20.00	80.00	20.00	163.72
20.00	200.00	20.00	85.00	20.00	164.48
20.00	200.00	20.00	90.00	20.00	165.25
20.00	200.00	20.00	95.00	20.00	166.01
20.00	200.00	20.00	100.00	20.00	166.78

Table B.3. Wall Type 3 Unit Prices.

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	20	20	202.1
20	200	20	20	25	202.9
20	200	20	20	30	203.7
20	200	20	20	35	204.4
20	200	20	20	40	205.2
20	200	20	20	45	205.9
20	200	20	20	50	206.7
20	200	20	20	55	207.5
20	200	20	20	60	208.2
20	200	20	20	65	209
20	200	20	20	70	209.7
20	200	20	20	75	210.5
20	200	20	20	80	211.3
20	200	20	20	85	212
20	200	20	20	90	212.8
20	200	20	20	95	213.6
20	200	20	20	100	214.3
20	200	20	25	20	203.6
20	200	20	25	25	204.3
20	200	20	25	30	205.1
20	200	20	25	35	205.9
20	200	20	25	40	206.6
20	200	20	25	45	207.4
20	200	20	25	50	208.1
20	200	20	25	55	208.9
20	200	20	25	60	209.7

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	25	65	210.4
20	200	20	25	70	211.2
20	200	20	25	75	211.9
20	200	20	25	80	212.7
20	200	20	25	85	213.5
20	200	20	25	90	214.2
20	200	20	25	95	215
20	200	20	25	100	215.8
20	200	20	30	20	205
20	200	20	30	25	205.8
20	200	20	30	30	206.5
20	200	20	30	35	207.3
20	200	20	30	40	208.1
20	200	20	30	45	208.8
20	200	20	30	50	209.6
20	200	20	30	55	210.3
20	200	20	30	60	211.1
20	200	20	30	65	211.9
20	200	20	30	70	212.6
20	200	20	30	75	213.4
20	200	20	30	80	214.2
20	200	20	30	85	214.9
20	200	20	30	90	215.7
20	200	20	30	95	216.4
20	200	20	30	100	217.2
20	200	20	35	20	206.5

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	35	25	207.2
20	200	20	35	30	208
20	200	20	35	35	208.7
20	200	20	35	40	209.5
20	200	20	35	45	210.3
20	200	20	35	50	211
20	200	20	35	55	211.8
20	200	20	35	60	212.5
20	200	20	35	65	213.3
20	200	20	35	70	214.1
20	200	20	35	75	214.8
20	200	20	35	80	215.6
20	200	20	35	85	216.4
20	200	20	35	90	217.1
20	200	20	35	95	217.9
20	200	20	35	100	218.7
20	200	20	40	20	207.9
20	200	20	40	25	208.7
20	200	20	40	30	209.4
20	200	20	40	35	210.2
20	200	20	40	40	210.9
20	200	20	40	45	211.7
20	200	20	40	50	212.5
20	200	20	40	55	213.2
20	200	20	40	60	214
20	200	20	40	65	214.7

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	40	70	215.5
20	200	20	40	75	216.3
20	200	20	40	80	217
20	200	20	40	85	217.8
20	200	20	40	90	218.6
20	200	20	40	95	219.3
20	200	20	40	100	220.1
20	200	20	45	20	209.3
20	200	20	45	25	210.1
20	200	20	45	30	210.9
20	200	20	45	35	211.6
20	200	20	45	40	212.4
20	200	20	45	45	213.1
20	200	20	45	50	213.9
20	200	20	45	55	214.7
20	200	20	45	60	215.4
20	200	20	45	65	216.2
20	200	20	45	70	216.9
20	200	20	45	75	217.7
20	200	20	45	80	218.5
20	200	20	45	85	219.2
20	200	20	45	90	220
20	200	20	45	95	220.8
20	200	20	45	100	221.5
20	200	20	50	20	210.8
20	200	20	50	25	211.6

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	50	30	212.3
20	200	20	50	35	213.1
20	200	20	50	40	213.8
20	200	20	50	45	214.6
20	200	20	50	50	215.3
20	200	20	50	55	216.1
20	200	20	50	60	216.9
20	200	20	50	65	217.6
20	200	20	50	70	218.4
20	200	20	50	75	219.2
20	200	20	50	80	219.9
20	200	20	50	85	220.7
20	200	20	50	90	221.5
20	200	20	50	95	222.2
20	200	20	50	100	223
20	200	20	55	20	212.2
20	200	20	55	25	213
20	200	20	55	30	213.8
20	200	20	55	35	214.5
20	200	20	55	40	215.3
20	200	20	55	45	216
20	200	20	55	50	216.8
20	200	20	55	55	217.6
20	200	20	55	60	218.3
20	200	20	55	65	219.1
20	200	20	55	70	219.8

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	55	75	220.6
20	200	20	55	80	221.4
20	200	20	55	85	222.1
20	200	20	55	90	222.9
20	200	20	55	95	223.7
20	200	20	55	100	224.4
20	200	20	60	20	213.7
20	200	20	60	25	214.4
20	200	20	60	30	215.2
20	200	20	60	35	216
20	200	20	60	40	216.7
20	200	20	60	45	217.5
20	200	20	60	50	218.2
20	200	20	60	55	219
20	200	20	60	60	219.8
20	200	20	60	65	220.5
20	200	20	60	70	221.3
20	200	20	60	75	222
20	200	20	60	80	222.8
20	200	20	60	85	223.6
20	200	20	60	90	224.3
20	200	20	60	95	225.1
20	200	20	60	100	225.9
20	200	20	65	20	215.6
20	200	20	65	25	216.4
20	200	20	65	30	217.1

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	65	35	217.9
20	200	20	65	40	218.6
20	200	20	65	45	219.4
20	200	20	65	50	220.1
20	200	20	65	55	220.9
20	200	20	65	60	221.7
20	200	20	65	65	222.4
20	200	20	65	70	223.2
20	200	20	65	75	224
20	200	20	65	80	224.7
20	200	20	65	85	225.5
20	200	20	65	90	226.3
20	200	20	65	95	227
20	200	20	65	100	227.8
20	200	20	70	20	217.5
20	200	20	70	25	218.2
20	200	20	70	30	219
20	200	20	70	35	219.8
20	200	20	70	40	220.5
20	200	20	70	45	221.3
20	200	20	70	50	222
20	200	20	70	55	222.8
20	200	20	70	60	223.6
20	200	20	70	65	224.3
20	200	20	70	70	225.1
20	200	20	70	75	225.8

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	70	80	226.6
20	200	20	70	85	227.4
20	200	20	70	90	228.1
20	200	20	70	95	228.9
20	200	20	70	100	229.7
20	200	20	75	20	218.5
20	200	20	75	25	219.2
20	200	20	75	30	220
20	200	20	75	35	220.7
20	200	20	75	40	221.5
20	200	20	75	45	222.3
20	200	20	75	50	223
20	200	20	75	55	223.8
20	200	20	75	60	224.5
20	200	20	75	65	225.3
20	200	20	75	70	226.1
20	200	20	75	75	226.8
20	200	20	75	80	227.6
20	200	20	75	85	228.4
20	200	20	75	90	229.1
20	200	20	75	95	229.9
20	200	20	75	100	230.7
20	200	20	80	20	219.5
20	200	20	80	25	220.2
20	200	20	80	30	221
20	200	20	80	35	221.7

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	80	40	222.5
20	200	20	80	45	223.2
20	200	20	80	50	224
20	200	20	80	55	224.8
20	200	20	80	60	225.5
20	200	20	80	65	226.3
20	200	20	80	70	227.1
20	200	20	80	75	227.8
20	200	20	80	80	228.6
20	200	20	80	85	229.3
20	200	20	80	90	230.1
20	200	20	80	95	230.9
20	200	20	80	100	231.6
20	200	20	85	20	220.4
20	200	20	85	25	221.2
20	200	20	85	30	222
20	200	20	85	35	222.7
20	200	20	85	40	223.5
20	200	20	85	45	224.2
20	200	20	85	50	225
20	200	20	85	55	225.8
20	200	20	85	60	226.5
20	200	20	85	65	227.3
20	200	20	85	70	228
20	200	20	85	75	228.8
20	200	20	85	80	229.6

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	Brick Wall (mm)	2 xCement Plaster (mm)	Rock Wool (mm)	EPS (mm)	Total Price (TL)
20	200	20	85	85	230.3
20	200	20	85	90	231.1
20	200	20	85	95	231.9
20	200	20	85	100	232.6
20	200	20	90	20	221.4
20	200	20	90	25	222.2
20	200	20	90	30	222.9
20	200	20	90	35	223.7
20	200	20	90	40	224.5
20	200	20	90	45	225.2
20	200	20	90	50	226
20	200	20	90	55	226.7
20	200	20	90	60	227.5
20	200	20	90	65	228.3
20	200	20	90	70	229
20	200	20	90	75	229.8
20	200	20	90	80	230.6
20	200	20	90	85	231.3
20	200	20	90	90	232.1
20	200	20	90	95	232.8
20	200	20	90	100	233.6
20	200	20	95	20	222.4
20	200	20	95	25	223.2
20	200	20	95	30	223.9
20	200	20	95	35	224.7
20	200	20	95	40	225.4

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	**Brick Wall (mm)**	**2 xCement Plaster (mm)**	**Rock Wool (mm)**	**EPS (mm)**	**Total Price (TL)**
20	200	20	95	45	226.2
20	200	20	95	50	227
20	200	20	95	55	227.7
20	200	20	95	60	228.5
20	200	20	95	65	229.2
20	200	20	95	70	230
20	200	20	95	75	230.8
20	200	20	95	80	231.5
20	200	20	95	85	232.3
20	200	20	95	90	233.1
20	200	20	95	95	233.8
20	200	20	95	100	234.6
20	200	20	100	20	223.4
20	200	20	100	25	224.2
20	200	20	100	30	224.9
20	200	20	100	35	225.7
20	200	20	100	40	226.4
20	200	20	100	45	227.2
20	200	20	100	50	227.9
20	200	20	100	55	228.7
20	200	20	100	60	229.5
20	200	20	100	65	230.2
20	200	20	100	70	231
20	200	20	100	75	231.8
20	200	20	100	80	232.5
20	200	20	100	85	233.3

Table B.3. Wall Type 3 Unit Prices (cont.).

Gysum Plaster (mm)	**Brick Wall (mm)**	**2 xCement Plaster (mm)**	**Rock Wool (mm)**	**EPS (mm)**	**Total Price (TL)**
20	200	20	100	90	234.1
20	200	20	100	95	234.8
20	200	20	100	100	235.6

Table B.4. Wall Type 4 Unit Prices.

Gyp. Plaster (mm)	**Brick Wall (mm)**	**Cement Plaster (mm)**	**EPS (mm)**	**Aluminium Composite Panel (mm)**	**Total Price (TL)**
20.00	200.00	20.00	20.00	4.00	241.56
20.00	200.00	20.00	25.00	4.00	242.32
20.00	200.00	20.00	30.00	4.00	243.08
20.00	200.00	20.00	35.00	4.00	243.84
20.00	200.00	20.00	40.00	4.00	244.60
20.00	200.00	20.00	45.00	4.00	245.35
20.00	200.00	20.00	50.00	4.00	246.11
20.00	200.00	20.00	55.00	4.00	246.87
20.00	200.00	20.00	60.00	4.00	247.64
20.00	200.00	20.00	65.00	4.00	248.40
20.00	200.00	20.00	70.00	4.00	249.16
20.00	200.00	20.00	75.00	4.00	249.92
20.00	200.00	20.00	80.00	4.00	250.69
20.00	200.00	20.00	85.00	4.00	251.45
20.00	200.00	20.00	90.00	4.00	252.22
20.00	200.00	20.00	95.00	4.00	252.98
20.00	200.00	20.00	100.00	4.00	253.75

Table B.5. Roof Type 1 Unit Prices.

Gypsum Plaster (mm)	Concrete Slab (mm)	2 x Leveling Concrete (mm)	XPS (mm)	Gravel (mm)	Total Price (TL)
20.00	200.00	50.00	20.00	50.00	666.91
20.00	200.00	50.00	25.00	50.00	668.28
20.00	200.00	50.00	30.00	50.00	669.66
20.00	200.00	50.00	35.00	50.00	671.03
20.00	200.00	50.00	40.00	50.00	672.41
20.00	200.00	50.00	45.00	50.00	673.79
20.00	200.00	50.00	50.00	50.00	675.17
20.00	200.00	50.00	55.00	50.00	676.54
20.00	200.00	50.00	60.00	50.00	677.92
20.00	200.00	50.00	65.00	50.00	679.30
20.00	200.00	50.00	70.00	50.00	680.68
20.00	200.00	50.00	75.00	50.00	682.05
20.00	200.00	50.00	80.00	50.00	683.43
20.00	200.00	50.00	85.00	50.00	684.80
20.00	200.00	50.00	90.00	50.00	686.18
20.00	200.00	50.00	95.00	50.00	687.55
20.00	200.00	50.00	100.00	50.00	688.93

Table B.6. Roof Type 2 Unit Prices.

Concrete Slab (mm)	Leveling Screed (mm)	XPS (mm)	Screed (mm)	Total Price (TL)
200	50	20	50	672.36
200	50	25	50	673.73
200	50	30	50	675.11
200	50	35	50	676.48
200	50	40	50	677.86
200	50	45	50	679.24
200	50	50	50	680.62
200	50	55	50	681.99
200	50	60	50	683.37
200	50	65	50	684.75
200	50	70	50	686.13
200	50	75	50	687.50
200	50	80	50	688.88
200	50	85	50	690.25
200	50	90	50	691.63
200	50	95	50	693.00
200	50	100	50	694.38

Table B.7. Roof Type 3 Unit Prices.

XPS (mm)	**Rock Wool (mm)**	**Protective Concrete (mm)**	**Total Price (TL)**
20	20	50	713.69
20	25	50	715.13
20	30	50	716.57
20	35	50	718.01
20	40	50	719.45
20	45	50	720.89
20	50	50	722.34
20	55	50	723.79
20	60	50	725.23
20	65	50	727.14
20	70	50	729.03
20	75	50	730.01
20	80	50	731
20	85	50	731.99
20	90	50	732.97
20	95	50	733.95
20	100	50	734.94
25	20	50	715.06
25	25	50	716.5
25	30	50	717.94
25	35	50	719.38
25	40	50	720.82
25	45	50	722.26
25	50	50	723.71
25	55	50	725.16
25	60	50	726.6

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	Rock Wool (mm)	Protective Concrete (mm)	Total Price (TL)
25	65	50	728.51
25	70	50	730.4
25	75	50	731.38
25	80	50	732.37
25	85	50	733.36
25	90	50	734.34
25	95	50	735.32
25	100	50	736.31
30	20	50	716.44
30	25	50	717.88
30	30	50	719.32
30	35	50	720.76
30	40	50	722.2
30	45	50	723.64
30	50	50	725.09
30	55	50	726.54
30	60	50	727.98
30	65	50	729.89
30	70	50	731.78
30	75	50	732.76
30	80	50	733.75
30	85	50	734.74
30	90	50	735.72
30	95	50	736.7
30	100	50	737.69
35	20	50	717.81

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	Rock Wool (mm)	Protective Concrete (mm)	Total Price (TL)
35	25	50	719.25
35	30	50	720.69
35	35	50	722.13
35	40	50	723.57
35	45	50	725.01
35	50	50	726.46
35	55	50	727.91
35	60	50	729.35
35	65	50	731.26
35	70	50	733.15
35	75	50	734.13
35	80	50	735.12
35	85	50	736.11
35	90	50	737.09
35	95	50	738.07
35	100	50	739.06
40	20	50	719.19
40	25	50	720.63
40	30	50	722.07
40	35	50	723.51
40	40	50	724.95
40	45	50	726.39
40	50	50	727.84
40	55	50	729.29
40	60	50	730.73
40	65	50	732.64

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	**Rock Wool (mm)**	**Protective Concrete (mm)**	**Total Price (TL)**
40	70	50	734.53
40	75	50	735.51
40	80	50	736.5
40	85	50	737.49
40	90	50	738.47
40	95	50	739.45
40	100	50	740.44
45	20	50	720.57
45	25	50	722.01
45	30	50	723.45
45	35	50	724.89
45	40	50	726.33
45	45	50	727.77
45	50	50	729.22
45	55	50	730.67
45	60	50	732.11
45	65	50	734.02
45	70	50	735.91
45	75	50	736.89
45	80	50	737.88
45	85	50	738.87
45	90	50	739.85
45	95	50	740.83
45	100	50	741.82
50	20	50	721.95
50	25	50	723.39

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	**Rock Wool (mm)**	**Protective Concrete (mm)**	**Total Price (TL)**
50	30	50	724.83
50	35	50	726.27
50	40	50	727.71
50	45	50	729.15
50	50	50	730.6
50	55	50	732.05
50	60	50	733.49
50	65	50	735.4
50	70	50	737.29
50	75	50	738.27
50	80	50	739.26
50	85	50	740.25
50	90	50	741.23
50	95	50	742.21
50	100	50	743.2
55	20	50	723.32
55	25	50	724.76
55	30	50	726.2
55	35	50	727.64
55	40	50	729.08
55	45	50	730.52
55	50	50	731.97
55	55	50	733.42
55	60	50	734.86
55	65	50	736.77
55	70	50	738.66

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	Rock Wool (mm)	Protective Concrete (mm)	Total Price (TL)
55	75	50	739.64
55	80	50	740.63
55	85	50	741.62
55	90	50	742.6
55	95	50	743.58
55	100	50	744.57
60	20	50	724.7
60	25	50	726.14
60	30	50	727.58
60	35	50	729.02
60	40	50	730.46
60	45	50	731.9
60	50	50	733.35
60	55	50	734.8
60	60	50	736.24
60	65	50	738.15
60	70	50	740.04
60	75	50	741.02
60	80	50	742.01
60	85	50	743
60	90	50	743.98
60	95	50	744.96
60	100	50	745.95
65	20	50	726.08
65	25	50	727.52
65	30	50	728.96

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	**Rock Wool (mm)**	**Protective Concrete (mm)**	**Total Price (TL)**
65	35	50	730.4
65	40	50	731.84
65	45	50	733.28
65	50	50	734.73
65	55	50	736.18
65	60	50	737.62
65	65	50	739.53
65	70	50	741.42
65	75	50	742.4
65	80	50	743.39
65	85	50	744.38
65	90	50	745.36
65	95	50	746.34
65	100	50	747.33
70	20	50	727.46
70	25	50	728.9
70	30	50	730.34
70	35	50	731.78
70	40	50	733.22
70	45	50	734.66
70	50	50	736.11
70	55	50	737.56
70	60	50	739
70	65	50	740.91
70	70	50	742.8
70	75	50	743.78

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	**Rock Wool (mm)**	**Protective Concrete (mm)**	**Total Price (TL)**
70	80	50	744.77
70	85	50	745.76
70	90	50	746.74
70	95	50	747.72
70	100	50	748.71
75	20	50	728.83
75	25	50	730.27
75	30	50	731.71
75	35	50	733.15
75	40	50	734.59
75	45	50	736.03
75	50	50	737.48
75	55	50	738.93
75	60	50	740.37
75	65	50	742.28
75	70	50	744.17
75	75	50	745.15
75	80	50	746.14
75	85	50	747.13
75	90	50	748.11
75	95	50	749.09
75	100	50	750.08
80	20	50	730.21
80	25	50	731.65
80	30	50	733.09
80	35	50	734.53

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	**Rock Wool (mm)**	**Protective Concrete (mm)**	**Total Price (TL)**
80	40	50	735.97
80	45	50	737.41
80	50	50	738.86
80	55	50	740.31
80	60	50	741.75
80	65	50	743.66
80	70	50	745.55
80	75	50	746.53
80	80	50	747.52
80	85	50	748.51
80	90	50	749.49
80	95	50	750.47
80	100	50	751.46
85	20	50	731.58
85	25	50	733.02
85	30	50	734.46
85	35	50	735.9
85	40	50	737.34
85	45	50	738.78
85	50	50	740.23
85	55	50	741.68
85	60	50	743.12
85	65	50	745.03
85	70	50	746.92
85	75	50	747.9
85	80	50	748.89

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	Rock Wool (mm)	Protective Concrete (mm)	Total Price (TL)
85	85	50	749.88
85	90	50	750.86
85	95	50	751.84
85	100	50	752.83
90	20	50	732.96
90	25	50	734.4
90	30	50	735.84
90	35	50	737.28
90	40	50	738.72
90	45	50	740.16
90	50	50	741.61
90	55	50	743.06
90	60	50	744.5
90	65	50	746.41
90	70	50	748.3
90	75	50	749.28
90	80	50	750.27
90	85	50	751.26
90	90	50	752.24
90	95	50	753.22
90	100	50	754.21
95	20	50	734.33
95	25	50	735.77
95	30	50	737.21
95	35	50	738.65
95	40	50	740.09

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	Rock Wool (mm)	Protective Concrete (mm)	Total Price (TL)
95	45	50	741.53
95	50	50	742.98
95	55	50	744.43
95	60	50	745.87
95	65	50	747.78
95	70	50	749.67
95	75	50	750.65
95	80	50	751.64
95	85	50	752.63
95	90	50	753.61
95	95	50	754.59
95	100	50	755.58
100	20	50	735.71
100	25	50	737.15
100	30	50	738.59
100	35	50	740.03
100	40	50	741.47
100	45	50	742.91
100	50	50	744.36
100	55	50	745.81
100	60	50	747.25
100	65	50	749.16
100	70	50	751.05
100	75	50	752.03
100	80	50	753.02
100	85	50	754.01

Table B.7. Roof Type 3 Unit Prices (cont.).

XPS (mm)	**Rock Wool (mm)**	**Protective Concrete (mm)**	**Total Price (TL)**
100	90	50	754.99
100	95	50	755.97
100	100	50	756.96

Table B.8. Roof Type 4 Unit Prices.

Gypsum Plaster (mm)	Concrete Slab (mm)	XPS (mm)	Protective Concrete (mm)	Roof Tiles (mm)	Total Price (TL)
20	200	20	50	40	734.46
20	200	25	50	40	735.83
20	200	30	50	40	737.21
20	200	35	50	40	738.58
20	200	40	50	40	739.96
20	200	45	50	40	741.34
20	200	50	50	40	742.72
20	200	55	50	40	744.09
20	200	60	50	40	745.47
20	200	65	50	40	746.85
20	200	70	50	40	748.23
20	200	75	50	40	749.6
20	200	80	50	40	750.98
20	200	85	50	40	752.35
20	200	90	50	40	753.73
20	200	95	50	40	755.1
20	200	100	50	40	756.48

Table B.9. Slab Type 1 Unit Prices.

Screed (mm)	**2 x Leveling Concrete (mm)**	**Foundation Slab (mm)**	**Blockage (mm)**	**Total Price (TL)**
50.00	50.00	500.00	150.00	826.759

Table B.10. Slab Type 2 Unit Prices.

Screed (mm)	**Rock Wool (mm)**	**Slab (mm)**	**Lean Concrete (mm)**	**Blockage (mm)**	**Total Price (TL)**
50.00	40.00	500.0	100.00	150.00	869.90
50.00	45.00	500.0	100.00	150.00	871.34
50.00	50.00	500.0	100.00	150.00	872.79
50.00	55.00	500.0	100.00	150.00	874.24
50.00	60.00	500.0	100.00	150.00	875.68
50.00	65.00	500.0	100.00	150.00	877.59
50.00	70.00	500.0	100.00	150.00	879.48
50.00	75.00	500.0	100.00	150.00	880.46
50.00	80.00	500.0	100.00	150.00	881.45
50.00	85.00	500.0	100.00	150.00	882.44
50.00	90.00	500.0	100.00	150.00	883.42
50.00	95.00	500.0	100.00	150.00	884.40
50.00	100.0	500.0	100.00	150.00	885.39

Table B.11. Window Unit Prices (Without Joints).

	Glass	Space Between Glasses (mm)	Glass Thickness (mm)	Total Price (TL)
Without Joints	Single Glazing	0.00	4	49.67
	Double Glazing	6.00	8	68.50
		9.00	8	75.00
		12.00	8	81.50
		16.00	8	90.03
	Double Glazing Low E	6.00	8	94.65
		9.00	8	97.92
		12.00	8	101.19
		16.00	8	104.46

Table B.12. Window Unit Prices (Woodwork Joints).

	Glass	Space Between Glasses (mm)	Glass Thickness (mm)	Total Price (TL)
Woodwork	Single Glazing	0.00	4	180.42
	Double Glazing	6.00	8	199.25
		9.00	8	205.75
		12.00	8	212.25
		16.00	8	220.78
	Double Glazing Low E	6.00	8	225.40
		9.00	8	228.67
		12.00	8	231.94
		16.00	8	235.21

Table B.13. Window Unit Prices (PVC 2c Joints).

	Glass	**Space Between Glasses (mm)**	**Glass Thickness (mm)**	**Total Price (TL)**
PVC 2o Joint	Single Glazing	0.00	4	199.35
	Double Glazing	6.00	8	216.14
		9.00	8	222.64
		12.00	8	229.14
		16.00	8	237.68
	Double Glazing Low E	6.00	8	230.99
		9.00	8	234.99
		12.00	8	238.99
		16.00	8	244.24

Table B.14. Window Unit Prices (PVC 3c Joints).

	Glass	**Space Between Glasses (mm)**	**Glass Thickness (mm)**	**Total Price (TL)**
PVC 3o Joint	Single Glazing	0.00	4	209.25
	Double Glazing	6.00	8	226.04
		9.00	8	232.54
		12.00	8	239.04
		16.00	8	247.58
	Double Glazing Low E	6.00	8	240.89
		9.00	8	244.89
		12.00	8	248.89
		16.00	8	254.14

Table B.15. Window Unit Prices (Aluminium Joints).

	Glass	Space Between Glasses (mm)	Glass Thickness (mm)	Total Price (TL)
Aluminium Joint	Single Glazing	0.00	4	409.45
	Double Glazing	6.00	8	426.24
		9.00	8	432.74
		12.00	8	439.24
		16.00	8	447.78
	Double Glazing Low E	6.00	8	441.09
		9.00	8	445.09
		12.00	8	449.09
		16.00	8	454.34

Table B.16. Window Unit Prices (Aluminium Joint With Insulation Bridge).

	Glass	Space Between Glasses (mm)	Glass Thickness (mm)	Total Price (TL)
Aluminium Joint With Insulation Bridge	Single Glazing	0.00	4	437.45
	Double Glazing	6.00	8	454.24
		9.00	8	460.74
		12.00	8	467.24
		16.00	8	475.78
	Double Glazing Low E	6.00	8	469.09
		9.00	8	473.09
		12.00	8	477.09
		16.00	8	482.34

APPENDIX C: PARAMETRIC RUNS

Table C.1. Exterior Wall - Parametric Runs

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
1	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	25520	81303
10	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26185	59224
20	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	25750	73374
30	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26309	55875
40	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	25974	65493
50	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26402	53445
60	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26145	60241
70	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	25671	75944
80	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26279	56603
90	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	25923	67143
100	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26382	53972
100	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26382	53972
110	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26103	61361
120	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	25577	78866
130	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26246	57390
140	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26112	61023
150	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26578	48467
160	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26442	52448
170	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26674	46319
180	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26552	49499
190	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26302	55918
200	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26625	47511
210	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26474	51677
220	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26682	46029
230	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26569	48997
240	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26347	54768

Table C.1. Exterior Wall - Parametric Runs (cont.).

X1	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**Cooling Load (KWh)**	**Heating Load (KWh)**
250	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26639	47174
260	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26498	50988
270	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26687	45762
280	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26585	48537
290	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26386	53762
300	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26650	46808
310	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26524	50344
320	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26698	45492
330	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26610	48086
340	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26732	44448
350	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26666	46476
360	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26545	49764
370	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26702	45253
380	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26622	47692
390	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26738	44238
400	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26677	46174
410	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26562	49238
420	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26717	44998
430	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26632	47326
440	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26749	44022
450	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26379	54130
459	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26633	47374

Table C.2. Roof - Parametric Runs.

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	1	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27109	53762
153	10	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26755	48567
153	20	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27389	52484
153	30	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27352	46837
153	40	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27220	49747
153	50	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27173	47389
153	60	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27206	48408
153	70	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27217	49987
153	80	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27163	47544
153	90	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27198	48600
153	100	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27113	46870
153	110	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27150	47705
153	120	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27192	48795
153	130	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27099	47016
153	140	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27141	47864
153	150	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27047	46421
153	160	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27088	47157
153	170	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27007	45958
153	180	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27034	46540
153	190	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27082	47288
153	200	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26996	46056
153	210	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27026	46645
153	220	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26986	45629
153	230	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26988	46150
153	240	1	36	92.38	92.4	64.84	64.41	0.2	0.2	27025	46751
153	250	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26978	45704
153	260	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26983	46232
153	270	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26980	45310

Table C.2. Roof - Parametric Runs (cont.)

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	280	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26971	45777
153	290	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26981	46310
153	300	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26974	45372
153	310	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26967	45850
153	320	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26983	45041
153	330	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26710	50389
153	340	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26779	46794

Table C.3. Slab – Parametric Runs.

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26635	47320
153	17	2	36	92.38	92.4	64.84	64.41	0.2	0.2	39662	25269
153	17	3	36	92.38	92.4	64.84	64.41	0.2	0.2	40400	24592
153	17	4	36	92.38	92.4	64.84	64.41	0.2	0.2	41054	24002
153	17	5	36	92.38	92.4	64.84	64.41	0.2	0.2	41624	23517
153	17	6	36	92.38	92.4	64.84	64.41	0.2	0.2	42123	23072
153	17	7	36	92.38	92.4	64.84	64.41	0.2	0.2	42580	22687
153	17	8	36	92.38	92.4	64.84	64.41	0.2	0.2	42968	22327
153	17	9	36	92.38	92.4	64.84	64.41	0.2	0.2	43319	22018
153	17	10	36	92.38	92.4	64.84	64.41	0.2	0.2	43641	21737
153	17	11	36	92.38	92.4	64.84	64.41	0.2	0.2	43923	21493
153	17	12	36	92.38	92.4	64.84	64.41	0.2	0.2	44179	21276
153	17	13	36	92.38	92.4	64.84	64.41	0.2	0.2	44414	21071
153	17	14	36	92.38	92.4	64.84	64.41	0.2	0.2	44626	20872

Table C.4. Windows – Parametric Runs.

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	17	1	10	92.38	92.4	64.84	64.41	0.2	0.2	30761	98472
153	17	1	11	92.38	92.4	64.84	64.41	0.2	0.2	28120	69410
153	17	1	12	92.38	92.4	64.84	64.41	0.2	0.2	28349	65156
153	17	1	13	92.38	92.4	64.84	64.41	0.2	0.2	28467	63044
153	17	1	14	92.38	92.4	64.84	64.41	0.2	0.2	28711	58855
153	17	1	15	92.38	92.4	64.84	64.41	0.2	0.2	25492	65975
153	17	1	16	92.38	92.4	64.84	64.41	0.2	0.2	26072	55369
153	17	1	17	92.38	92.4	64.84	64.41	0.2	0.2	26205	53324
153	17	1	18	92.38	92.4	64.84	64.41	0.2	0.2	26490	49313
153	17	1	19	92.38	92.4	64.84	64.41	0.2	0.2	30669	100696
153	17	1	20	92.38	92.4	64.84	64.41	0.2	0.2	28009	71553
153	17	1	21	92.38	92.4	64.84	64.41	0.2	0.2	28234	67280
153	17	1	22	92.38	92.4	64.84	64.41	0.2	0.2	28467	63044
153	17	1	23	92.38	92.4	64.84	64.41	0.2	0.2	28588	60947
153	17	1	24	92.38	92.4	64.84	64.41	0.2	0.2	25388	68148
153	17	1	25	92.38	92.4	64.84	64.41	0.2	0.2	25943	57433
153	17	1	26	92.38	92.4	64.84	64.41	0.2	0.2	26072	55369
153	17	1	27	92.38	92.4	64.84	64.41	0.2	0.2	26345	51307
153	17	1	28	92.38	92.4	64.84	64.41	0.2	0.2	30854	96250
153	17	1	29	92.38	92.4	64.84	64.41	0.2	0.2	28234	67280
153	17	1	30	92.38	92.4	64.84	64.41	0.2	0.2	28467	63044
153	17	1	31	92.38	92.4	64.84	64.41	0.2	0.2	28711	58855
153	17	1	32	92.38	92.4	64.84	64.41	0.2	0.2	28837	56776
153	17	1	33	92.38	92.4	64.84	64.41	0.2	0.2	25600	63822
153	17	1	34	92.38	92.4	64.84	64.41	0.2	0.2	26205	53324
153	17	1	35	92.38	92.4	64.84	64.41	0.2	0.2	26345	51307
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26635	47320
153	17	1	37	92.38	92.4	64.84	64.41	0.2	0.2	30041	116350

Table C.4. Windows – Parametric Runs (cont.).

X1	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**Cooling Load (KWh)**	**Heating Load (KWh)**
153	17	1	38	92.38	92.4	64.84	64.41	0.2	0.2	27393	84630
153	17	1	39	92.38	92.4	64.84	64.41	0.2	0.2	27489	82421
153	17	1	40	92.38	92.4	64.84	64.41	0.2	0.2	27689	78038
153	17	1	41	92.38	92.4	64.84	64.41	0.2	0.2	27792	75864
153	17	1	42	92.38	92.4	64.84	64.41	0.2	0.2	24720	83627
153	17	1	43	92.38	92.4	64.84	64.41	0.2	0.2	25188	72531
153	17	1	44	92.38	92.4	64.84	64.41	0.2	0.2	25287	70337
153	17	1	45	92.38	92.4	64.84	64.41	0.2	0.2	25492	65975
153	17	1	46	92.38	92.4	64.84	64.41	0.2	0.2	30669	100700
153	17	1	47	92.38	92.4	64.84	64.41	0.2	0.2	28009	71553
153	17	1	48	92.38	92.4	64.84	64.41	0.2	0.2	28234	67280
153	17	1	49	92.38	92.4	64.84	64.41	0.2	0.2	28467	63044
153	17	1	50	92.38	92.4	64.84	64.41	0.2	0.2	28588	60947
153	17	1	51	92.38	92.4	64.84	64.41	0.2	0.2	25388	68148
153	17	1	52	92.38	92.4	64.84	64.41	0.2	0.2	25943	57433
153	17	1	53	92.38	92.4	64.84	64.41	0.2	0.2	26072	55369
153	17	1	54	92.38	92.4	64.84	64.41	0.2	0.2	26345	51307

Table C.5. Surface 1 Window Area – Parametric Runs

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	17	1	36	90	92.4	64.84	64.41	0.2	0.2	26577	47265
153	17	1	36	100	92.4	64.84	64.41	0.2	0.2	26819	47460
153	17	1	36	110	92.4	64.84	64.41	0.2	0.2	27061	47655
153	17	1	36	120	92.4	64.84	64.41	0.2	0.2	27299	47857
153	17	1	36	130	92.4	64.84	64.41	0.2	0.2	27536	48065
153	17	1	36	140	92.4	64.84	64.41	0.2	0.2	27774	48279
153	17	1	36	150	92.4	64.84	64.41	0.2	0.2	28009	48500
153	17	1	36	160	92.4	64.84	64.41	0.2	0.2	28243	48728
153	17	1	36	170	92.4	64.84	64.41	0.2	0.2	28475	48955
153	17	1	36	180	92.4	64.84	64.41	0.2	0.2	28702	49187
153	17	1	36	190	92.4	64.84	64.41	0.2	0.2	28926	49388
153	17	1	36	200	92.4	64.84	64.41	0.2	0.2	29150	49600
153	17	1	36	210	92.4	64.84	64.41	0.2	0.2	29370	49817
153	17	1	36	220	92.4	64.84	64.41	0.2	0.2	29586	50002
153	17	1	36	230	92.4	64.84	64.41	0.2	0.2	29803	50201
153	17	1	36	240	92.4	64.84	64.41	0.2	0.2	30020	50415
153	17	1	36	250	92.4	64.84	64.41	0.2	0.2	30236	50655
153	17	1	36	260	92.4	64.84	64.41	0.2	0.2	30451	50896
153	17	1	36	270	92.4	64.84	64.41	0.2	0.2	30664	51129
153	17	1	36	280	92.4	64.84	64.41	0.2	0.2	30880	51390
153	17	1	36	290	92.4	64.84	64.41	0.2	0.2	31097	51669
153	17	1	36	300	92.4	64.84	64.41	0.2	0.2	31313	51951
153	17	1	36	310	92.4	64.84	64.41	0.2	0.2	31529	52229
153	17	1	36	320	92.4	64.84	64.41	0.2	0.2	31738	52536

Table C.6. Surface 2 Window Area – Parametric Runs

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	17	1	36	92.38	90	64.84	64.41	0.2	0.2	26494	47182
153	17	1	36	92.38	100	64.84	64.41	0.2	0.2	27081	47768
153	17	1	36	92.38	110	64.84	64.41	0.2	0.2	27668	48354
153	17	1	36	92.38	120	64.84	64.41	0.2	0.2	28255	48942
153	17	1	36	92.38	130	64.84	64.41	0.2	0.2	28840	49535
153	17	1	36	92.38	140	64.84	64.41	0.2	0.2	29424	50130
153	17	1	36	92.38	150	64.84	64.41	0.2	0.2	30006	50739
153	17	1	36	92.38	160	64.84	64.41	0.2	0.2	30593	51364
153	17	1	36	92.38	170	64.84	64.41	0.2	0.2	31174	52000
153	17	1	36	92.38	180	64.84	64.41	0.2	0.2	31756	52627
153	17	1	36	92.38	190	64.84	64.41	0.2	0.2	32333	53237
153	17	1	36	92.38	200	64.84	64.41	0.2	0.2	32909	53860
153	17	1	36	92.38	210	64.84	64.41	0.2	0.2	33484	54473
153	17	1	36	92.38	220	64.84	64.41	0.2	0.2	34060	55090
153	17	1	36	92.38	230	64.84	64.41	0.2	0.2	34634	55718
153	17	1	36	92.38	240	64.84	64.41	0.2	0.2	35206	56354
153	17	1	36	92.38	250	64.84	64.41	0.2	0.2	35777	56993
153	17	1	36	92.38	260	64.84	64.41	0.2	0.2	36346	57632
153	17	1	36	92.38	270	64.84	64.41	0.2	0.2	36914	58274
153	17	1	36	92.38	280	64.84	64.41	0.2	0.2	37480	58933
153	17	1	36	92.38	290	64.84	64.41	0.2	0.2	38045	59590
153	17	1	36	92.38	300	64.84	64.41	0.2	0.2	38608	60252
153	17	1	36	92.38	310	64.84	64.41	0.2	0.2	39171	60919
153	17	1	36	92.38	320	64.84	64.41	0.2	0.2	39731	61586

Table C.7. Surface 3 Window Area – Parametric Runs.

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	17	1	36	92.38	92.4	60	64.41	0.2	0.2	26565	46924
153	17	1	36	92.38	92.4	70	64.41	0.2	0.2	26709	47742
153	17	1	36	92.38	92.4	80	64.41	0.2	0.2	26852	48562
153	17	1	36	92.38	92.4	90	64.41	0.2	0.2	26991	49372
153	17	1	36	92.38	92.4	100	64.41	0.2	0.2	27128	50188
153	17	1	36	92.38	92.4	110	64.41	0.2	0.2	27262	51011
153	17	1	36	92.38	92.4	120	64.41	0.2	0.2	27393	51838
153	17	1	36	92.38	92.4	130	64.41	0.2	0.2	27521	52671
153	17	1	36	92.38	92.4	140	64.41	0.2	0.2	27648	53507
153	17	1	36	92.38	92.4	150	64.41	0.2	0.2	27771	54349
153	17	1	36	92.38	92.4	160	64.41	0.2	0.2	27892	55193
153	17	1	36	92.38	92.4	170	64.41	0.2	0.2	28010	56040
153	17	1	36	92.38	92.4	180	64.41	0.2	0.2	28125	56893
153	17	1	36	92.38	92.4	190	64.41	0.2	0.2	28240	57756
153	17	1	36	92.38	92.4	200	64.41	0.2	0.2	28352	58624
153	17	1	36	92.38	92.4	210	64.41	0.2	0.2	28463	59497
153	17	1	36	92.38	92.4	220	64.41	0.2	0.2	28571	60375
153	17	1	36	92.38	92.4	230	64.41	0.2	0.2	28677	61254

Table C.8. Surface 4 Window Area – Parametric Runs.

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	17	1	36	92.38	92.4	64.84	60	0.2	0.2	26095	48355
153	17	1	36	92.38	92.4	64.84	70	0.2	0.2	27328	45951
153	17	1	36	92.38	92.4	64.84	80	0.2	0.2	28605	43612
153	17	1	36	92.38	92.4	64.84	90	0.2	0.2	29933	41311
153	17	1	36	92.38	92.4	64.84	100	0.2	0.2	31306	39140
153	17	1	36	92.38	92.4	64.84	110	0.2	0.2	32723	37012
153	17	1	36	92.38	92.4	64.84	120	0.2	0.2	34202	35109
153	17	1	36	92.38	92.4	64.84	130	0.2	0.2	35746	33414
153	17	1	36	92.38	92.4	64.84	140	0.2	0.2	37363	32012
153	17	1	36	92.38	92.4	64.84	150	0.2	0.2	39051	30861
153	17	1	36	92.38	92.4	64.84	160	0.2	0.2	40786	29920
153	17	1	36	92.38	92.4	64.84	170	0.2	0.2	42553	29096
153	17	1	36	92.38	92.4	64.84	180	0.2	0.2	44346	28303
153	17	1	36	92.38	92.4	64.84	190	0.2	0.2	46150	27519
153	17	1	36	92.38	92.4	64.84	200	0.2	0.2	47970	26856
153	17	1	36	92.38	92.4	64.84	210	0.2	0.2	49834	26344
153	17	1	36	92.38	92.4	64.84	220	0.2	0.2	51712	25877
153	17	1	36	92.38	92.4	64.84	230	0.2	0.2	53601	25415

Table C.9. Wall Absorption Coefficient – Parametric Runs.

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26635	47320
153	17	1	36	92.38	92.4	64.84	64.41	0.3	0.2	27338	45862
153	17	1	36	92.38	92.4	64.84	64.41	0.4	0.2	28038	44364
153	17	1	36	92.38	92.4	64.84	64.41	0.5	0.2	28739	42849
153	17	1	36	92.38	92.4	64.84	64.41	0.6	0.2	29447	41350
153	17	1	36	92.38	92.4	64.84	64.41	0.7	0.2	30163	39889
153	17	1	36	92.38	92.4	64.84	64.41	0.8	0.2	30881	38437
153	17	1	36	92.38	92.4	64.84	64.41	0.9	0.2	31601	36997
153	17	1	36	92.38	92.4	64.84	64.41	1	0.2	32327	35582

Table C.10. Roof Absorption Coefficient – Parametric Runs.

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Cooling Load (KWh)	Heating Load (KWh)
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.2	26635	47320
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.3	27079	46663
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.4	27521	45996
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.5	27960	45305
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.6	28398	44581
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.7	28831	43837
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.8	29264	43090
153	17	1	36	92.38	92.4	64.84	64.41	0.2	0.9	29697	42343
153	17	1	36	92.38	92.4	64.84	64.41	0.2	1	30130	41602