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MASTER THESIS

A DECISION METHOD FOR CONSTRUCTION MATERIAL SELECTION OF NEW APARTMENT BUILDINGS, BASED ON OPTIMIZATION

OBEN KAZIM AKMAZ

THESIS ADVISOR: DR. ILKER KAHRAMAN
CO-ADVISOR: PROF. DR. TAHSİN BAŞARAN

DEPARTMENT OF ARCHITECTURE

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

Jury Members:	**Signature:**
Dr. Ilker KAHRAMAN Yasar University	....
Prof. Tahsin BASARAN Izmir Institute of Technology University	....
Assoc. Prof. Dr. Başak KUNDAKCI Yasar University	....
Dr. Hasan Burak CAVKA Izmir Institute of Technology University	....
Assoc. Prof. Dr. Mujde ALTIN Dokuz Eylul University	....

Prof. Dr. Cuneyt Guzelis

Director of the Graduate School

ABSTRACT

A DECISION METHOD FOR CONSTRUCTION

MATERIAL SELECTION OF NEW APARTMENT

BUILDINGS, BASED ON OPTIMIZATION

AKMAZ, OBEN KAZIM
Msc, in Architecture
Advisor: Dr. İlker KAHRAMAN
Co-Advisor: Prof. Dr. Tahsin BAŞARAN
June 2020

Energy plays an important role in the development and sustainability of humanity. The dependence on energy is increasing day by day with the adaptation of humanity to modern and technological life.

Approximately 40% of the world's final energy consumption is used to provide thermal and visual comfort conditions for heating, cooling, ventilating and lighting buildings. This energy consumption, which is projected to increase gradually, causes serious problems threatening all humanity such as global climate change and environmental destruction. In order to prevent this problem, important steps are taken by campaigns for efficient use of energy, national and international studies and directives are issued. The European Parliament, which was concerned in 2010, published the Energy Performance Directive in Buildings. According to this directive, it is aimed for each state to make its national plans in this regard until December 2020. After December 2020, it has been decided to increase the number of buildings with nearly zero energy, primarily state institution buildings.

In this study, the cost-effective energy consumption optimization of the apartment building consisting of 6 floors and 12 flats to be built in the Izmir region was made. This apartment building is parametrically modeled in the Grasshopper interface of Rhinoceros 3D software. Ladybug, Honeybee plug-ins and EnergyPlus software were used to take energy simulations in the Grasshopper interface, and Octopus plugin was used to manage optimization processes. Thermophysical properties and initial investment costs of the building materials are also defined separately for this model. As a result of the study, the optimum initial investment cost and the energy consumption per square meter of an apartment building targeted to be built in the Izmir region were determined by using which building materials.

Key Words: Apartment Building, Construction Material, Computational Design, Energy Consumption, Energy Simulation, Multi-Objective Optimization, Initial Investment Cost.

ÖZ

YENİ APARTMAN BİNALARININ İNŞAAT MALZEMESİ

SEÇİMİNDE OPTİMİZASYON ÜZERİNE TEMELLENMİŞ

KARAR VERME METHODU

AKMAZ, Oben Kazım
Yüksek Lisans Tezi, Mimarlık Bölümü
Danışman: Dr. İlker KAHRAMAN
Yardımcı Danışman: Prof. Dr. Tahsin BAŞARAN
Haziran 2020

Enerji insanlığın gelişiminde ve yaşantısını devam ettirebilmesi konusunda çok önemli bir role sahiptir. İnsanlığın modern ve teknolojik hayata adapte olması ile birlikte enerjiye olan bağımlılığı da her geçen gün artmaktadır.

Dünya genelinde nihai enerji tüketiminin yaklaşık % 40 gibi büyük bir kısmı binalarda ısıl ve görsel konfor şartlarını sağlayabilmek amacıyla, iç mekanları ısıtmak, soğutmak, havalandırmak ve aydınlatmak için kullanmaktadır. Gittikçe artacağı öngörülen bu enerji tüketimi küresel iklim değişikliği ve çevresel tahribat gibi tüm insanlığı tehdit eden ciddi sorunlara yol açmaktadır. Bu problemin önüne geçebilmek için, enerjinin verimli kullanılmasına dair yürütülen kampanyalar, ulusal ve uluslararası çalışmalar ile direktifler çıkartılarak önemli adımlar atılmaktadır. 2010 yılında toplanan Avrupa Parlamentosu, Binalarda Enerji Performansı Direktifi'ni yayınlamıştır. Bu direktife göre, Aralık 2020'ye kadar her devletin bu konuda Ulusal Planlarını yapması hedeflenmiştir. Aralık 2020'den sonra ise, devlet kurumu binaları öncelikli olmak üzere, yaklaşık sıfır enerjili bina sayılarının arttırılması kararlaştırılmıştır.

Bu çalışmada, İzmir bölgesindeki inşaa edilecek 6 kat, 12 daireden oluşan apartman binasının maliyet etkin enerji tüketimi optimizasyonu yapılmıştır. Bu apartman binası Rhinoceros 3D yazılımının, Grasshopper arayüzünde parametrik olarak modellenmiştir. Grasshopper arayüzünde enerji simülasyonları almak için; Ladybug, HoneyBee eklentileri ile EnergyPlus yazılımı, optimizasyon süreçlerinin yönetimi için ise Octopus eklentisi kullanılmıştır. Hazırlanan bu modele, yapı malzemelerinin termofiziksel özellikleri ve ilk yatırım maliyetleri de ayrı ayrı tanımlanmıştır. Çalışma sonucunda, İzmir bölgesinde yapılması hedeflenen bir apartman binasının; optimum ilk yatırım maliyeti ve metrekare başına düşen enerji tüketim miktarlarını, hangi yapı malzemeleri kullanılarak elde edilebileceği belirlenmiştir.

Anahtar Kelimeler: Apartman Binası, İnşaat Malzemeleri, Hesaplamalı Tasarım, Enerji Tüketimi, Enerji Simülasyonu, Çok Amaçlı Optimizasyon, İlk Yatırım Maliyeti.

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I would also like to thank my co-advisor **Prof. Dr. Tahsin Başaran** for his support and help on my thesis. He is also project consultant of Roadmap of nZEB Turkey project. I also would like to thank **Dr. Burak Hozatlı** for his support and help about building materials and Heating, Ventilating and Air Conditioning (HVAC) system cost calculation. During the model development process of this research, a deep study had been done with Dr. Ilker Kahraman, Prof. Dr. Tahsin Başaran, Dr. Burak Hozatlı and Orçun Koral İşeri. I would like to extend my thankfulness to my friend **Orçun Koral İşeri** who had supported me and also shared his valuable knowledge with me during this study.

I would first like to thank my mother **Songül İşler**, I would never have reached my goals without her support. I also thank my close friends **Sercan Ergezer** and **Alper Altunbaş** for supporting me mentally and always with me.

A special thank you to my wife **Seçil Şencan Akmaz** for always encouraging and supporting me.

Oben Kazım AKMAZ
İzmir, 2020

TEXT OF OATH

I declare and honestly confirm that my study, titled "A Decision Method For Construction Material Selection of New Apartment Buildings, Based on Optimization" and presented as a Master's, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Oben Kazım AKMAZ

Signature

…………………………………..

July 29, 2020

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

EPDB	Energy Performance Directive of Building
nZEB	Nearly Zero Energy Building
GIZ	Gesellschaft für Internationale Zusammenarbeit
MoEU	Ministry of Environment and Urbanization
BepTR	Energy Performance in Buildings Software
TÜİK	Turkish Statistical Institute
TS825	Turkish Standart Number 825
MOO	Multi Objective Optimization
MOEA	Multi Objective Evolutionary Algorithm
HVAC	Heating, Ventilating and Air Conditioning
GA	Genetic Algorithm
NSGA	Non-dominated Sorting Genetic Algorithm
VAV	Variable Air Volume
SBX	Simulated Binary Crossover
NURBS	Non-Uniform Rational B-spline
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
2D	Two-dimensional
3D	Three-dimensional
SDK	Software Development Kit
C++	Software Language
GH	Grasshopper
LB	Ladybug
HB	HoneyBee

API	Application Programming Interface
EP	Energy Plus
PTAC	Packaged Terminal Air Conditioner
ASHRAE	The American Society of Heating Refrigerating and Air Conditioning Engineers
SHGC	Solar Heat Gain Coefficient
VT	Visual Transmittance
EXP	Extruded Polystyrene Foam
EPS	Expanded Polystyrene Foam
EPW	Energy Plus Weather

SYMBOLS:

U	Overall Heat Transfer Coefficient (W/m^2K)
R	Thermal Resistance (m^2K/W)
k	Heat Conduction Coefficient (W/mK)
L	Material Thickness (cm/m)
h_{1-2}	The Individual Convection Heat Transfer Coefficient Each Surface of the Interior and Exterior (W/m^2K)
TL	Turkish Lira

CHAPTER 1

1. INTRODUCTION

In the Energy Performance Directive of Buildings (EPDB, 2010/31/EU), the European Parliament foresees that buildings built after December 2020, which need to be heated or cooled according to their purposes, should be built nearly zero energy buildings (nZEB). In the 9th article of the Energy Performance Directive of Buildings, *" The energy performance of buildings should be calculated on the basis of a methodology that can be differentiated at the national and regional level "*. In this context, each country has started to define the concept of nearly zero energy building for itself. Some countries have given certain energy consumption values per square meter, while some countries have adopted the concept of direct zero energy building.

Determination of nZEB target for the Turkey project was funded by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). This project was realized by Olusum Architecture firm, the results of the project were delivered to the Ministry of Environment and Urbanization (MoEU).

The project team includes Prof. Dr. Mechanical Engineer Tahsin Basaran, Dr. Mechanical Engineer Burak Hozatlı, Dr. Chemical Engineer Emin Selahattin Umdu, Dr. Architect Ilker Kahraman, Architect Orcun Koral Iseri and Architect Oben Akmaz.

The project manager is Ilker Kahraman. Heating and cooling system details, energy consumption values of buildings, thermal conductivity coefficient values of materials are the specialty of Tahsin Basaran. All cost calculations realized in the project were made by Burak Hozatlı. Orcun Koral Iseri and Oben Akmaz performed the parametric building designs, energy simulations, optimization processes and presentation of optimization results.

nZEB project aims to determine the consumption of nearly zero energy building goals of 6 different building typologies in the four climate zones in Turkey. The initial investment costs and thermal conductivity coefficient values prepared for the nZEB project were also used in this study. Since the optimization process was not required in the nZEB project, the studies continued on BepTR software which was started by using Rhinoceros/Grasshopper software. The study method in this thesis is focused on optimization and covers only residential buildings in the Izmir climate region.

1.1. Aim

The main purpose of this thesis is to achieve optimum material data set which guides us to have an apartment building with optimum cost and energy consumption in the Izmir region. As a result of this study, the data of the construction materials, total cost and the amount of energy consumption will be obtained before the buildings are built with the energy simulation and the optimization tools.

1.2. Methodology

This thesis focused on optimization of cost effective energy consumption of apartment buildings to be built in the Izmir climate region and for this thesis a multi-performance computational design model was prepared. The data entered into this prepared model are as follows; *"characteristic features of the apartment building"*, *"costs of opac construction materials"* and *"their overall heat transfer coefficients"*, *"Costs of Window Materials, their Overall Heat Transfer Coefficients"* and *"physical properties"*.

Characteristic Features of the Apartment Building: Design criteria have been established according to data collected by the Turkey Statistical Institute (TUIK). This data shows the most common specifications of apartment buildings in Turkey. The information obtained in this section also determines the performance criteria of the model.

Costs of Construction Materials and Overall Heat Transfer Coefficients: This second module includes a list of most used materials for walls, roofs, floors, exposed floors in Turkey. Also, investment cost and overall heat transfer coefficient values were entered in this module. Each entered data was introduced to the model as a decision variable. When the insulation thickness and type of insulation of the materials to be used are changed, the cost of the material and the overall heat transfer coefficient also change. In this context, in order to insulation thickness limit and the type, the list of insulation materials widely used in Turkey was taken from the Izocam company (https://www.izocam.com.tr/izocam.html). After determining the material combinations to be used in the study, overall heat transfer coefficient values of all materials were calculated according to Turkish Standard 825 (TS825). This standard has been prepared to determine thermal insulation requirements for buildings (http://www1.mmo.org.tr/resimler/dosya_ekler/cf3e258fbdf3eb7_ek.pdf).

Costs of Window Materials, their Overall Heat Transfer Coefficients and physical properties: This module is a continuation of the second module. The window material lists differ in joinery type, glass type and gas type filled between glasses, investment cost, overall heat transfer coefficient, solar heat gain coefficient and visual transmittance values differ. Each window material entered in the model is defined as a decision variable. As the properties specified for window materials change, the cost and insulation properties also differ. In this context, the most widely used types of window glasses are taken from Isıcam company (http://www.isicam.com.tr/tr/). After the window glass type material lists were determined, overall heat transfer coefficient, solar heat gain coefficient and visual transmittance values table were prepared using the Isıcam Performance Calculation system.

1.3. Scope

This thesis is a small part of Turkey nZEB road map project. nZEB Turkey project worked in four different climatic zones (Continental climate, Mediterranean climate, Marmara climate, Blacksea climate), has carried out studies to seven different types of buildings (Single Family House, Apartment Building, Hospital Building, Office Building, Education Building, Hotel Building, Commercial Building). This thesis also deals with apartment buildings to be built in the Izmir region. There are buildings in different districts of Izmir with different storey heights. However, this study has addressed a maximum building area with six-story apartment buildings across Turkey. The base form of the building was considered to be square. While preparing the list of building materials most commonly used materials were selected in Turkey. Cost calculation was made over the initial investment costs of the materials used.

The knowledge embedded in this thesis is an optimization process during the selection of building materials. The writer of this thesis was in charge of this optimization process for the during the project. The writer of this thesis applied the same model to a narrowed climate zone İzmir and with a decided heating cooling equipment. The methodology of this study can be found in Figure 1.1.

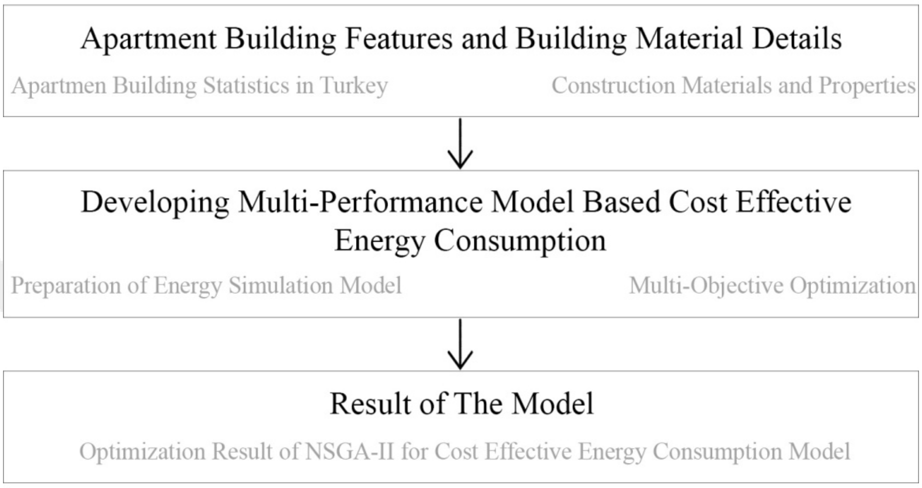


Figure 1.1. Scheme of Research Method

CHAPTER 2

2. ARCHITECTURAL MODELING, ENERGY SIMULATION AND OPTIMIZATION SYSTEMS

In this section, terms such as optimization, history of optimization, genetic algorithm, optimization algorithm, multi objective search will be explained. In addition, information about the use of Rhinoceros, Grasshopper, LadyBug, HoneyBee, EnergyPlus, Octopus tools used in this study will be given.

2.1. Optimization

Optimization is a solution method that enables efficient use of resources such as labor, time processes, raw materials, capacity, equipment that make up a system for specific purposes (Gass, 2000). There is a unique class of problems that can be called optimization problems. This class is a problem with certain constraints that wants to maximize or minimize a mathematical function of various variables. Theoretical and reflective problems can be modeled in this way. Instead of maximizing or minimizing, the term optimizing is often used. The mathematical function to be optimized is generally known as objective function with several variables. General optimization problems can be classified by Sarker and Newton, 2008 as shown in Figure 2.1.

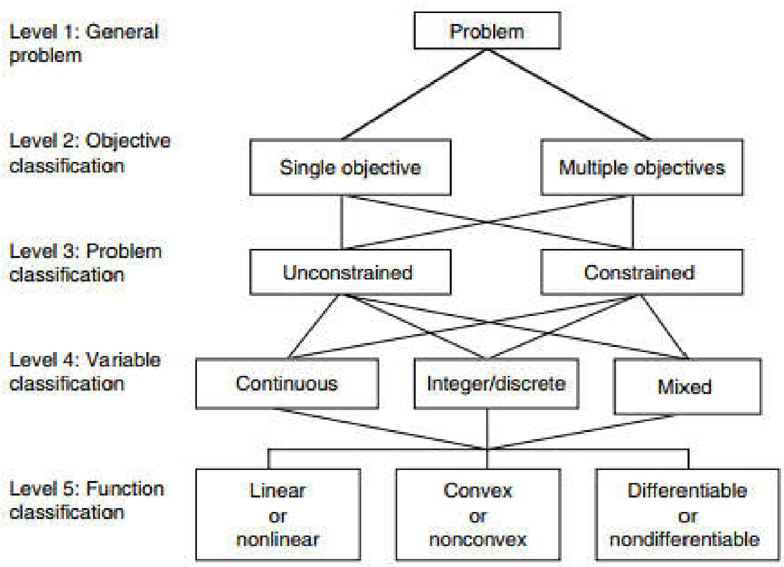


Figure 2.1. Classification of Optimization Problem (Sarker, and Newton, 2008)

The most important part of optimally solving a problem is the creation of a model. This model is also the abstraction or mathematical representation of the problem. Sometimes it is difficult or impossible to create mathematical models that deal with all problems, because problems are often very complex and would not be solved. Researchers and practitioners try to formulate a simplified version of the question or numerous assumptions. They are trying to find the best possible solution to the model or problem prepared as an explanation of the basic optimization concept. In order to achieve this concept, all alternatives should be examined and the selected result proved to be the best results (Sarker, Newton, 2008).

2.1.1. History of Computational building optimization and evolutionary algorithms

N. M. Bouchlaghem and K. M. Letherman combined an optimization technique and a thermal analysis model in the early 1990s (Bouchlanghem, Letherman, 1990). They produced a numerical optimization method applied to the thermal design of non-conditioned buildings. In the continuation of early optimization studies, more complex and multi-objective optimization methods (MOO) were found. In this way, it became clear that several variables or contradictory targets could be evaluated and pareto optimal (non-dominated) solution clusters were found (W. Wang, H. Rivard, R. Zmeureanu, 2005). According to W. Marks *"the basic notions in the formulation of a multicriteria optimization problem are decision variables, constraints and optimization criteria, also called objective functions"* Depending on the objectives used in the optimization process, the designer can choose his preferred solution among several pareto optimal solutions. Building and heating costs, carbon dioxide emission, energy consumption and other parameters may be desirable (W. Marks, 1997).

Systems and techniques such as inheritance, mutation, natural selection and crossover encountered in evolutionary biology have been imitated by evolutionary algorithms to help the solution of multi-objective optimization problems. This mimicry helps to search for the most appropriate set of solutions for a particular question. In the mid-1980's, the first Multi-Objective Evolutionary algorithms were introduced by Schaffer (Schaffer, 2000). After this introduction, Genetic Algorithms, Evolutionary Programming and Genetic Programming, Covariance Matrix Adaptation Evolutionary Strategy, Differential Evolution, Harmony Search, Particle

Swarm Optimization, Ant Colony Optimization and Simulated Annealing studies are added to the literature by both engineers and architects.

Genetic Algorithms of all mentioned Evolutionary Algorithms dominate building design optimization in terms of Renewable Energy Systems, Heating, Ventilating and Air Conditioning (HVAC) and Building Form. Later, thanks to the software developed following the discovery of the biological design process by scientists, tools were produced to meet some of the complexity of design processes. With the development of software such as Octopus Evolutionary Solver and Galapagos Evolutionary Solver, Evolutionary Algorithms are not only used in the academic world laboratories, but also actively used in architecture and engineering applications and student projects worldwide.

2.1.2. Genetic Algorithms

Genetic algorithms (GA) have been successfully used in some areas of study in the mid-1970s at the University of Michigan with the recommendation of John Holland (Holland JH, 1975). These areas include the energy efficiency of architecture and construction, as well as building and components (Attia S, Hamdy M, O'Brien W, Carlucci S, 2013). It is also a family of algorithms based on natural selection in the evolution of species (Goldberg DE, 1989).

Multiobjective issues such as environmental and energy performance have been solved by means of metaheuristics methods (J. López, 2013), including genetic algorithms (J.E. Harding, P. Shepherd, 2017). The path that the genetic algorithm follows to achieve the result is shown in Figure 2.2. As stated by S.J. Russell: particle swarm, hill-climbing, simulated annealing, and genetic algorithms among others has been greatly improved (S.J. Russell, 2016).

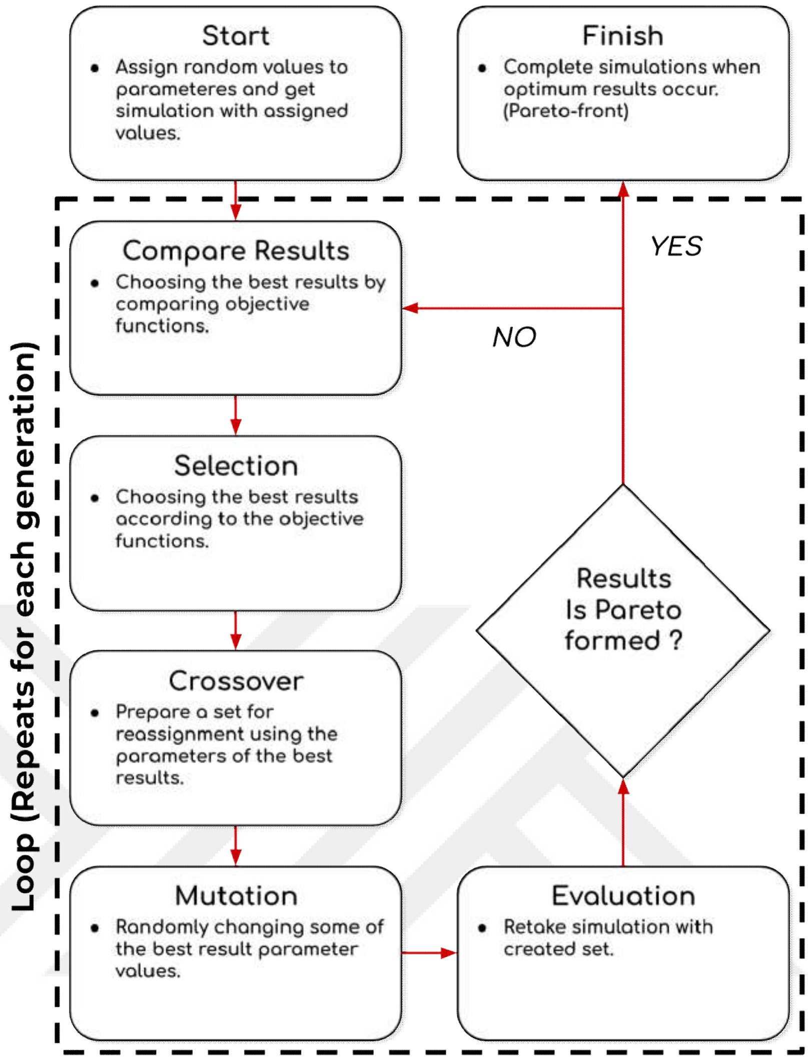


Figure 2.2. Genetic Algorithms Flowchart (Bader, Johannes, Zitzler, Eckart.,2011)

2.1.3. Optimization Algorithm (NSGA-II)

Non-dominated Sorting Genetic Algorithm abbreviation is NSGA. Kalyanmoy Deb and his students developed the NSGA-II, an advanced version of NSGA in 2000 (Deb K., 2001). NSGA-II shares the same dynamics with the Genetic Algorithm (GA). The NSGA-II procedure is also shown in Figure 2.3. As confirmed by Evins, NSGA-II is the most successful multi objective optimization (MOO) algorithm that can be used in building optimization (R. Evins, 2013). Some teams have proven that NSGA-II is more effective and efficient than NSGA. Nassif et al. have found that in the design of simple variable air volume (VAV) systems it performs more effectively in terms of the spread of optimal points and their distance to the pareto front (N. Nassif, L. Kajl, R. Sabourin, 2004). To solve a multi-objective problem with window location, Browlee et al. Found that NSGA-II works more efficiently both in the size of the hyper volume and in the distribution of optimal points (A.E. Brownlee, J.A. Wright, 2001).

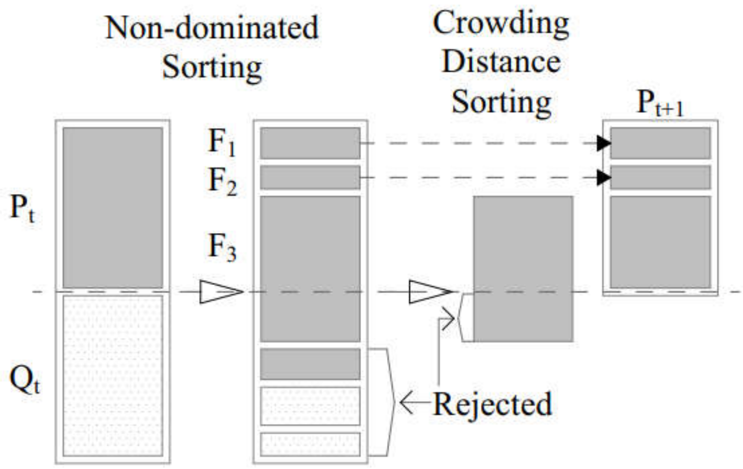


Figure 2.3. NSGA-II Procedure (Deb Et Al.,2002)

The NSGA-II operating system has a main loop, which repeats generation by generation. There is also selection, crossover and mutation operators. These operators are usually prepared to work on multi objective problems.

The steps NSGA-II performs in each generation are as follows;

- First, a random population is created,
- Each individual in the created population is ranked according to their insignificant status, where each individual is given a value (or sequence number)
- NSGA-II quickly lists population members by combining dominant solutions and managed solutions in different populations. Thanks to this listing, members are positioned separately according to the Pareto Ranking.
- Each population member is assigned values, called "Crowd Distance", which create a unique space. This value is calculated separately for each member and shows the distance to the nearest neighbors.
- After the dual selection stage, individuals are selected from the parent population until the mating pool is full. During this election, we first compare the violation of the solutions. In case of a violation of one of the binary solutions, the other is selected. In case of violation of both remedies, the least

infringer is selected. If none violates, the ratings are compared and the one with the largest crowd distance is selected.

- The solution is collected with low rank between selected pairs. If the dominant result cannot be found in this way, the crowd distance is compared and the one with the highest crowd distance is selected.
- Mating pool individuals are subjected to genetic operators in order to form the next generation, they are mutated of simulated binary crossover (SBX) and polynomial.
- The elitism step is performed. In this step, all non-dominant populations members are pooled in different pools and each incoming member is ranked with the highest crowded distance members. For the formation of the elitist population, it is formed by the inclusion of the highest level individuals with a large population size (Deb K., Pratap A., Agarwal S., Meyarivan T., 2002).

2.1.4. Multi-Objective Search

Multi-objective optimization includes multiple and often conflicting objective functions. Multi-objective optimization problems arise in various situations, and when the need for efficient and reliable methods are increasing.

Sometimes a decision maker is needed to determine the solution, to provide additional preference information and to find the most preferred solution. Such information can be given according to the examples used during or after the optimization process. For this reason, optimization and decision support must combine two-way optimization.

The most important difference between single-objective and multi-objective optimization is that there is no single result in multi-objective optimization. At the same time, in multi-objective optimization, a set of equally well-known alternatives known as Pareto Optimal are presented. None of these solutions can be better when there is no other information (M. Karmellos, A. Kiprakis, G. Mavrotas. 2015).

2.2. Tools

In this section, the software and components used in the study will be explained. Names of the software used; Rhinoceros, Grasshopper, Ladybug, Honeybee, Energy Plus and Octopus. Tools flow chart is shown in Figure 2.4.

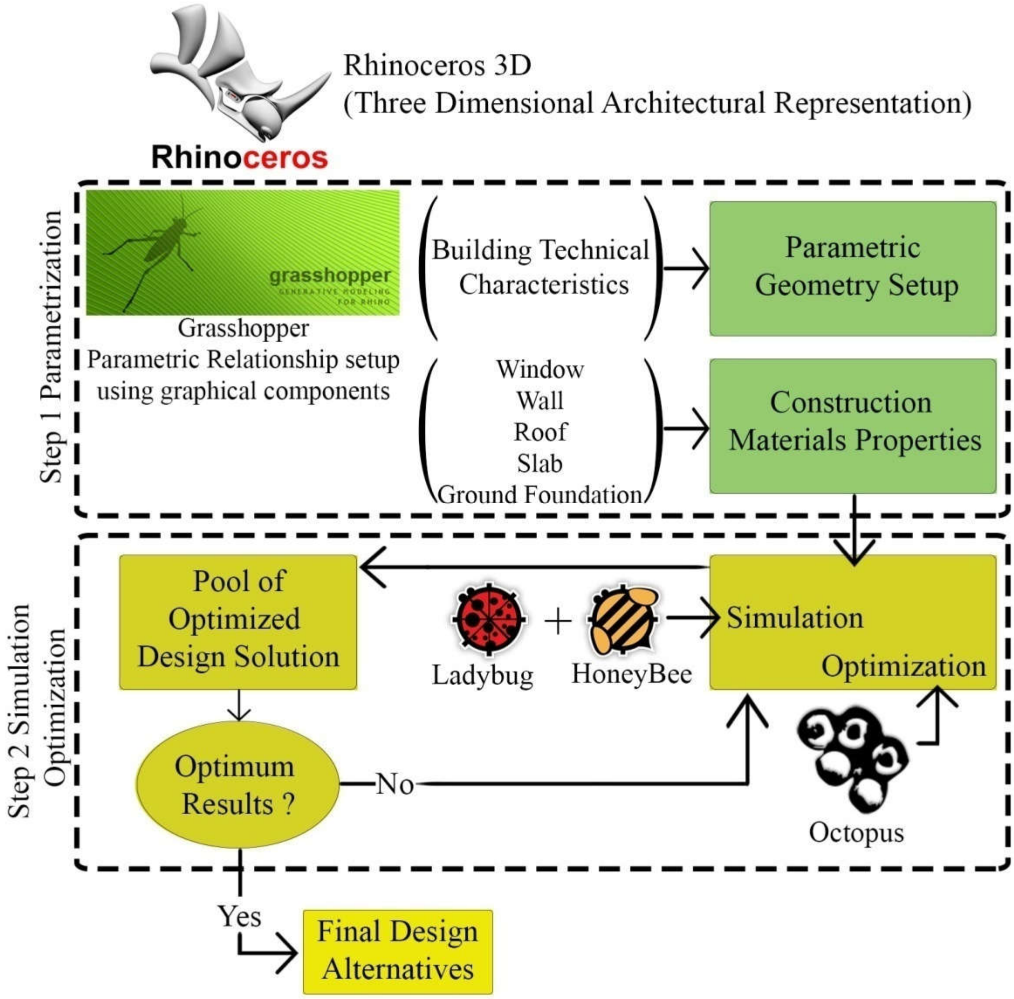


Figure 2.4. Tools Flow Chart

2.2.1. Rhinoceros

Since its first release in 1998, Rhinoceros®, or Rhino®, has become one of the standard 3D modeling tools for designers and architects. Start with a sketch, drawing, physical model, scan data, or only an idea. Rhino provides the tools to accurately model and document your designs ready for rendering, animation, drafting, engineering, analysis, and manufacturing or construction.

Rhino can create, edit, analyze, document, render, animate, and translate NURBS curves, surfaces, and solids with no limits on complexity, degree, or size. Rhino also supports polygon meshes and point clouds. Its accuracy and flexibility makes it possible for students to explore and build their ideas without having to spend much time learning CAD, NURBS, Non-Uniform Rational B-Splines, are mathematical representations of 3-D geometry that can accurately describe any shape from a simple 2-D line, circle, arc, or curve to the most complex 3-D organic free-form surface or solid. Because of their flexibility and accuracy, NURBS models can be used in any process from illustration and animation to manufacturing.

Also, any geometry created in Rhino can be exported to laser cutters, milling machines or 3D printers, and this is really what makes Rhino different from general 3D modelling tools based in polygons, where you can create great images, but without manufacturing precision.

Rhino's open architecture also allows using Rhino as a development platform: C++ SDK and a series of scripting methods (RhinoScript) allow programmers of any level of expertise customize and automate Rhino and extend its capabilities. Today, there are dozens of commercial plug-ins for Rhino for nesting, terrain creation, parametric architecture, rendering, animation, CAM, subdivision modelling, jewelry, mold design, etc.

For this research a student license from Yasar University for modelling software was used (www.rhino3d.com/eval.htm.). Rhinoceros features can also be followed from the same website.

2.2.2. Grasshopper

For designers who are exploring new shapes using generative algorithms, Grasshopper (GH) is a graphical algorithm editor tightly integrated with Rhino's 3-D modeling tools. Unlike RhinoScript, GH requires no knowledge of programming or scripting, but still allows designers to build form generators from the simple to the awe-inspiring.

Instead of using programming languages, it uses a lego-like interface. Using simple lego blocks, a designer can easily create parametric designs. Grasshopper is fast growing to become an important platform for architects and designers to experiment with new ways of representing design ideas. More than a tool or software, it presents a way of thinking for design issues, a "method" called Parametric or Associative these days (Zubin Khabazi, 2011). To put it more simple: Grasshopper's ease of use enables architects to play with the concept of Parametric or Associative design without the need to be an expert in scripting/programming. Therefore, architects can focus on the "why" instead of the "how". The first version of Grasshopper was designed by David Rutten in September, 2007. Grasshopper was developed by Robert McNeel and associates as a plug-in for Rhinoceros in April, 2014.

The core features of Grasshopper are its components. The components are the building-blocks for your model. Each component consists of two or three elements:

- one or more inputs
- the action; what it does with the input
- one or more outputs

There are different types of components in Grasshopper panels or components menu which are available. You can find them under ten different tabs called: Params, Logic, Scalar, Vector, Curve, Surface, Mesh, Intersect, XForm and Complex. Each tab has multiple panels and different objects, and commands are sorted between these panels. There are objects in these panels to draw geometry like lines and circles and there are also lots of commands to move, rescale, divide and deform these geometries. So some objects draw geometry and generate data, some of them manipulate the already existing geometry or data. Parameters are objects that represent data, like a point or line. Components are objects that do actions like move, copy, and add. Even more components can be added by installing various for Grasshopper.

Using the in- and outputs the components can be linked together forming a larger network. The canvas in Grasshopper is a visual representation of components used and their internal relation. It can be compared to writing a script, but with the use of predefined sets of code but more visual which makes it more sensible and usable in the designer's hand. The network always works downstream.

2.2.3. Ladybug

Ladybug Tool is a collection of free computer applications that support environmental design and education. Of all the available environmental design software packages, Ladybug Tool is among the most comprehensive, connecting 3D CAD interfaces to a host of validated simulation engines. Ladybug features are as follows;

- Is built on top of several validated simulation engines: Radiance, EnergyPlus/OpenStudio, Therm/Window and OpenFOAM.

- Is the only open source interface that unites all of its underlying open source engines. Like these engines, it evolves through the consensus of an open community of experts.
- Is supported by a passionate and diverse community from around the world.
- Runs within 3D modeling software and allows data transfer between its simulation engines. So all geometry creation, simulation and visualization happen within one interface.
- Is composed of modular components, making it flexible across different stages of design and capable of answering a variety of research questions.
- Runs within parametric visual scripting interfaces, enabling the exploration of design spaces and the automation of tasks.
- By harnessing capabilities of CAD interfaces, Ladybug tools produce a variety of interactive 3D graphics, animations and data visualizations.
- Is written programming language in Python, which can be run on virtually any operating system and plugged into any geometry engine (provided the geometry library is translated).

2.2.4. Honeybee

Honeybee supports detailed daylighting and thermodynamic modeling that tends to be most relevant during mid and later stages of design. Specifically, it creates, runs and visualizes the results of daylight simulations using Radiance, energy models using EnergyPlus/OpenStudio, and heat flow through construction details using Berkeley Lab Therm/Window.

It accomplishes this by linking these simulation engines to CAD and visual scripting interfaces such as Grasshopper/Rhino and Dynamo/Revit plugins. It also serves as an object-oriented Application Programming Interface (API) for these engines. For this reason, Honeybee is one of the most comprehensive plugins presently available for environmental design.

2.2.5. Energy Plus

EnergyPlus™ (EP) is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumptions for heating, cooling, ventilation, lighting and plug and process loads and water use in buildings. Some of the notable features and capabilities of EnergyPlus include:

- Integrated, simultaneous solution of thermal zone conditions and HVAC system response that does not assume that the HVAC system can meet zone loads and can simulate unconditioned and under-conditioned spaces.
- Heat balance-based solution of radiant and convective effects that produce surface temperatures thermal comfort and condensation calculations.
- Sub-hourly, user-definable time steps for interaction between thermal zones and the environment; with automatically varied time steps for interactions between thermal zones and HVAC systems. These allow EnergyPlus to model systems with fast dynamics while also trading off simulation speed for precision.
- Combined heat and mass transfer model that accounts for air movement between zones.
- Advanced fenestration models include controllable window blinds, electrochromic glazings, and layer-by-layer heat balances that calculate solar energy absorbed by window panes.
- Illuminance and glare calculations for reporting visual comfort and driving lighting controls.
- Component-based HVAC that supports both standard and novel system configurations.
- A large number of built in HVAC and lighting control strategies and an extensible runtime scripting system for user-defined control.
- Functional Mockup Interface import and export for co-simulation with other engines.
- Standard summary and detailed output reports as well as user definable reports with selectable time-resolution from annual to sub-hourly, all with energy source multipliers.

EnergyPlus is a console-based program that reads input and writes output to text files. It ships with a number of utilities including IDF-Editor for creating input files using a simple spreadsheet-like interface, EP-Launch for managing input and output files and performing batch simulations, and EP Compare for graphically comparing the results of two or more simulations. Several comprehensive graphical interfaces for EnergyPlus are also available. DOE does most of its work with EnergyPlus using the OpenStudio software development kit and suite of applications.

2.2.6. Octopus

Octopus was originally made for Multi-Objective Evolutionary Optimization. It allows the search for many goals at once, producing a range of optimized trade-off solutions between the extremes of each goal. It is used and works similar to David Rutten's Galapagos, but introduces the Pareto-Principle for Multiple Goals. Based on SPEA-2 and HypE algorithm from ETH Zurich. Also based on David Rutten's Galapagos User Interface. Christoph Zimmel added the custom user interface and the hypervolume approximation (https://www.food4rhino.com/app/octopus). It is determined by scientific studies that Octopus plugin gives more effective results than other plugins in multi objective optimization processes For this reason, Octopus plugin was used in this study. Octopus features can also be followed from the same website. The features of Octopus are as follows;

- Search for a single goal + diversity of solutions.
- Search for best trade offs between 2 to any number of goals.
- Improve solutions by similarity-goals
- Choose preferred solutions during a search
- Change objectives during a search
- Solutions' 3D model in objective space for visual feedback.
- Recorded history.
- Save all search data within the Grasshopper document.
- Save a solution as a Grasshopper State.
- Export to text or text files.

CHAPTER 3

3. APARTMENT BUILDING FEATURES AND BUILDING MATERIAL DETAILS

In this section, based on information received from Turkey Statistical Institute (TÜIK) apartment building statistics in Turkey (2019), the apartment building technical characteristic and acceptance used in this study, axonometric view of the apartment building, building materials used list and details of these materials (window, wall, roof, slap, exposed floor), overall heat transfer coefficient value (U) calculation example details will be explained.

3.1. Apartment Building Statistics In Turkey

Turkish Statistical Institute (TÜİK) compiles, evaluates, analyzes and publishes statistics in the fields of economy, social issues, demography, culture, environment, science and technology, and in the other required areas. The subject of this study is cost-effective energy consumption in apartment buildings, so the need was felt to statistical data of apartment buildings in Turkey. This data was requested for the GIZ supported nZEB project from TÜİK. With this data, up to a construction area of apartment building type has been identified in Turkey. Figure 3.1 shows the construction areas according to the total number of floors. As a result, a 6-storey building with a construction area of 1.400 m^2 was chosen for the energy simulation modeling.

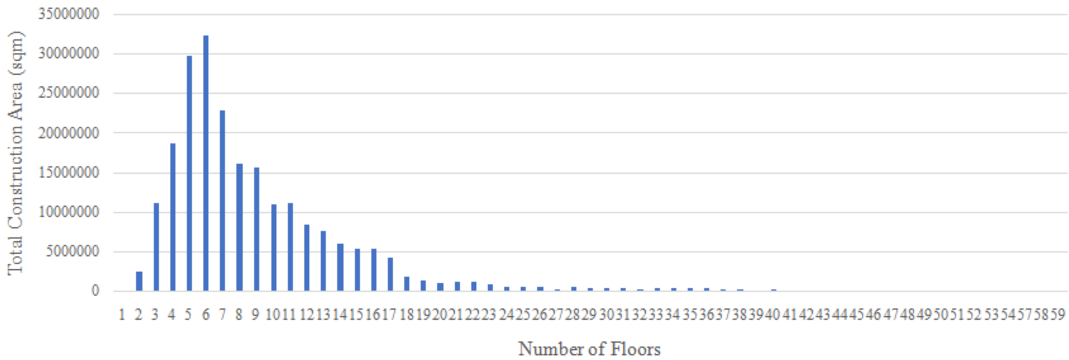


Figure 3.1. Apartment Building Construction Area with Number of Floors in Turkey (TÜİK)

3.2. Apartment Building Technical Characteristic and Acceptances

Simulations were made according to the climatic conditions of Izmir and weather information between 2003-2017 was used. The details of the apartment building are as follows;

- 6 Floors, 12 flats
- Construction area 1400,00 m^2
- Apartment area 111,78 m^2
- Floor area 233,00 m^2
- Side length 15,27 m
- Story height 2,80 m
- Slab thickness 0,15 m
- Facade area 1.026,16 m^2
- Wall area 872,23 m^2
- Window area 153,92 m^2
- Window to wall ratio 0,15
- Staircases dimensions 3,60 m x 2,60 m (without lift)

Each apartment has 3 rooms, 1 living room, 1 kitchen, 1 bathroom. It is assumed that 4 people live in each apartment. These are considered a mother, father, and children. The user profile has not been diversified by age. Scenarios are prepared according to human burden of age range 0-65. There are 7 LED lights in each apartment and 1 LED lighting in the staircase areas. Each LED has a 10 Watt and 300 lux illuminance value. The unit prices of the construction materials used in the cost calculation were taken from the unit cost price list of the Ministry of Environment and Urbanization (https://webdosya.csb.gov.tr/db/yfk/icerikler/insaat-birim-fiyatlari-2019-turkce.pdf).

In order to have a comfortable time in closed areas, thermal comfort must be provided. This thermal comfort can be achieved by heating and cooling zones with certain HVAC systems. Different HVAC systems can be used according to each climate zone and building type. Thanks to the Honeybee plugin used in this study, 17 different HVAC systems can be defined to the model to be simulated. The use of these systems differs according to building typologies and the climate. Since this study is based on apartment buildings in İzmir region, Packaged Terminal Air Conditioner (PTAC) was defined as an HVAC system for the energy simulation model. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines the PTAC system in energy standards (90.1-2007) in this way; "*a factoryselected wall sleeve and separate unencased combination of heating and cooling components, assemblies, or sections. It may include heating capability by hot water, steam, or electricity and is intended for mounting through the wall to serve a single room or zone.*" This standard also recommends PTAC HVAC systems for residential buildings above 5 floors. PTAC system performs cooling with direct expansion system using electricity and heating with a hot water boiler, using fossil fuel. The schedule of the system, heating and cooling set points temperatures are explained in Chapter 4.

3.3. Axonometric View of Apartment Building

Figure 3.2 shows the apartment building. Window to wall ratio is 0,15 and each window is thought to be a single piece of walls on different facades and zones. According to the Ministry of Environment and Urbanization (MoEU) regulations, the sloping roof is defined as 0,33 degrees.

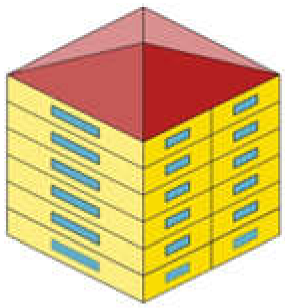


Figure 3.2. Axonometric View of Apartment Building

3.4. Apartment Building Construction Materials and Properties

Building materials such as glass, wall, slab, ground foundation and roof must be brought together to build a structure. Each building material has many types and characteristics. The material types differ according to their thickness, thermal conductivity and cost value. In the following section, details of the type of building materials, overall heat transfer coefficients and cost values are given.

Overall heat transfer coefficient value (U) is the value that shows how much a material conducts heat and this value is different for each material. These values are defined in TS825 "Heat Insulation Rules in Buildings" standard. The smaller overall heat transfer coefficient value of a material, the less it transmits heat. In heat insulation materials, it is preferred that this value be close to zero. Because as this value gets smaller, the overall heat transfer coefficient performance of the material increases that much. Calculation of the U value example determined by using Eq. 3.1 is given in Figure 3.3.

In this study, overall heat transfer coefficient values are not given in a certain value range. These values are calculated separately for each material combinations and integrated into the simulation model.

Heat Lose Surface	Building Materials	Material Thickness	Heat Conduction Coefficient	Thermal Resistance	Overall Heat Transfer Coefficient
		L	k	R	U
		(m)	(W/mK)	(m^2K/W)	(W/m^2K)
WALL	Interior Convection			0,130	
	Interior Plaster	0,02	0,7	0,029	
	Brick	0,19	0,5	0,380	
	Exterior Plaster	0,03	1,4	0,021	
	Isolation Material	0,04	0,04	1,000	
	Exterior Convection			0,040	
Total				1,600	0,625

Figure 3.3. Calculation of U Value Example

$$U = \left(\frac{1}{h_1} + \frac{L}{k} + \frac{1}{h_2}\right)^{-1}$$

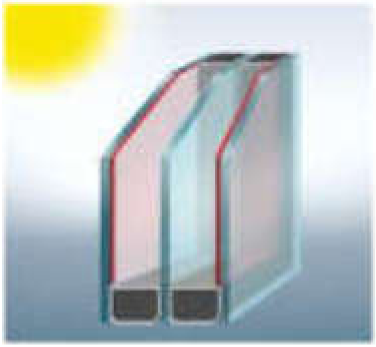
Equation 3.1. U Value Calculation Formula

3.4.1. Window Material

Window has a very important role for decreasing energy consumption of buildings by using natural light and heating cooling systems. The use of many glass combinations such as single glass, double glass, triple glass with aluminum or pvc frames gives us many options. However, according to company sales reports ISICAM was determined to be the most widely used kinds of glass in Turkey (http://www.isicam.com.tr/tr).

The properties of glass that affect energy simulation are overall heat transfer coefficient (U value), solar heat gain coefficient (SHGC) and visual transmittance (VT) values. These values are calculated from Sisecam Energy Performance Calculation webpage (https://www.sisecamduzcam.com/tr/faaliyet-alanlarimiz/mimari-camlar/performans-hesaplayici). An example of double-glazed performance calculation is given in Figure 3.4.

ŞİŞECAM / DÜZCAM
Performance Calculator



Glass Configuration

OUTER PANE	: Şişecam Low-E Glass 4 mm Neutral
CAVITY 1	: 16 mm Cavity (Air)
MIDDLE PANE	: Şişecam Clear Float Glas 4 mm Clear
CAVITY 2	: 16 mm Cavity (Air)
INNER PANE	: Şişecam Low-E Glass 4 mm Neutral

Daylight Properties (EN 410)	Daylight Transmittance	: 70%
	Daylight Reflectance Outdoor	: 14%
	Daylight Reflectance Indoor	: 14%
Solar Energy Properties (EN 410)	Solar Energy Direct Transmittance	: 40%
	Solar Energy Reflectance Outdoor	: 30%
	Solar Energy Absorption	: 31%
	Solar Heat Gain Coefficient	: 48%
	Shading Coefficient	: 0.55
	UV Transmission	: 14%
Thermal Conductivity (EN 673)	U Value W/(m2K)	: 0.7
Sound Insulation Calue (En 12758)	Rw (C; Ctr) dB	: 35 (-1; -6)

Figure 3.4. Sisecam Energy Performance Calculation Example

Another value added to the optimization account is the cost of these materials. Unite price costs of glass materials were obtained from ISICAM company in 2019. Window materials data is given in Table 3.1. In this table, there are 32 different window combinations with 16 aluminum and 16 PVC frames. 24 of these combinations were evaluated as double glass and 8 as triple glass.

Table 3.1. Window Material List

Type	Name	U Value (W/mK)	SHGC (%)	VT (%)	Total Material Area (m2)	Unit Cost (TL/m2)	Total Cost (TL)
AL	Ordinary Glass-Air (4-12-4)	3,0	0,78	0,82	154,00	1119,98	172476,92
AL	Ordinary Glass-Air (4-16-4)	2,8	0,78	0,82	154,00	1134,42	174700,68
AL	Ordinary Glass-Argon (4-12-4)	2,8	0,78	0,82	154,00	1126,48	173477,92
AL	Ordinary Glass-Argon (4-16-4)	2,7	0,78	0,82	154,00	1140,92	175701,68
AL	Sisecam-LowE-Air (4-12-4)	1,9	0,55	0,79	154,00	1135,73	174902,42
AL	Sisecam-LowE-Air (4-16-4)	1,7	0,55	0,79	154,00	1138,36	175307,44
AL	Sisecam-LowE-Argon (4-12-4)	1,7	0,55	0,79	154,00	1142,23	175903,42
AL	Sisecam-LowE-Argon (4-16-4)	1,5	0,55	0,79	154,00	1144,86	176308,44
AL	Sisecam-SolarLowE-Air (4-12-4)	1,9	0,44	0,72	154,00	1154,11	177732,94
AL	Sisecam-SolarLowE-Air (4-16-4)	1,7	0,44	0,72	154,00	1159,36	178541,44
AL	Sisecam-SolarLowE-Argon (4-12-4)	1,7	0,44	0,72	154,00	1160,61	178733,94
AL	Sisecam-SolarLowE-Argon (4-16-4)	1,5	0,44	0,72	154,00	1165,86	179542,44
AL	Sisecam-SolarLowE-Air (4-12-4-12-4)	1,4	0,39	0,64	154,00	1327,40	204419,60
AL	Sisecam-SolarLowE-Air (4-16-4-16-4)	1,2	0,39	0,64	154,00	1333,40	205343,60
AL	Sisecam-LowE-Air (4-12-4-12-4)	1,4	0,48	0,70	154,00	1322,40	203649,60
AL	Sisecam-LowE-Air (4-16-4-16-4)	1,2	0,48	0,70	154,00	1327,40	204419,60
PVC	Ordinary Glass-Air (4-12-4)	2,8	0,78	0,82	154,00	651,05	100261,70
PVC	Ordinary Glass-Air (4-16-4)	2,6	0,78	0,82	154,00	665,49	102485,46
PVC	Ordinary Glass-Argon (4-12-4)	2,6	0,78	0,82	154,00	657,55	101262,70
PVC	Ordinary Glass-Argon (4-16-4)	2,5	0,78	0,82	154,00	671,99	103486,46
PVC	Sisecam-LowE-Air (4-12-4)	1,7	0,55	0,79	154,00	666,80	102687,20
PVC	Sisecam-LowE-Air (4-16-4)	1,5	0,55	0,79	154,00	669,43	103092,22
PVC	Sisecam-LowE-Argon (4-12-4)	1,5	0,55	0,79	154,00	673,30	103688,20
PVC	Sisecam-LowE-Argon (4-16-4)	1,4	0,55	0,79	154,00	675,93	104093,22
PVC	Sisecam-SolarLowE-Air (4-12-4)	1,7	0,44	0,72	154,00	685,18	105517,72
PVC	Sisecam-SolarLowE-Air (4-16-4)	1,5	0,44	0,72	154,00	690,43	106326,22
PVC	Sisecam-SolarLowE-Argon (4-12-4)	1,5	0,44	0,72	154,00	691,68	106518,72
PVC	Sisecam-SolarLowE-Argon (4-16-4)	1,4	0,44	0,72	154,00	696,93	107327,22
PVC	Sisecam-SolarLowE-Air (4-12-4-12-4)	1,2	0,39	0,64	154,00	780,40	120181,60
PVC	Sisecam-SolarLowE-Air (4-16-4-16-4)	1,0	0,39	0,64	154,00	786,40	121105,60
PVC	Sisecam-LowE-Air (4-12-4-12-4)	1,2	0,48	0,70	154,00	775,40	119411,60
PVC	Sisecam-LowE-Air (4-16-4-16-4)	1,0	0,48	0,70	154,00	780,40	120181,60

3.4.2. Wall Material

Walls are the most common area of the buildings that usually come into contact with the weather. For this reason, the role of reducing the heating and cooling loads on the walls can not be underestimated.

In ancient times, building walls were generally built of wood, mudbrick and stone. The materials available were limited. Nowadays, with the development of the technology, material options that make up the main structure of the wall and different insulation material options are produced and used. Thus, there are many walls and insulation materials.

Each climate zone can use different thickness walls and insulation materials according to their conditions. Detail sections of the wall types are shown in Figure 3.5. Three different wall material details are given as Brick (19cm), Autoclaved Aerated Concrete Block (19,9cm - 24,9cm) and Pumice Block (18,9cm - 24,9cm).

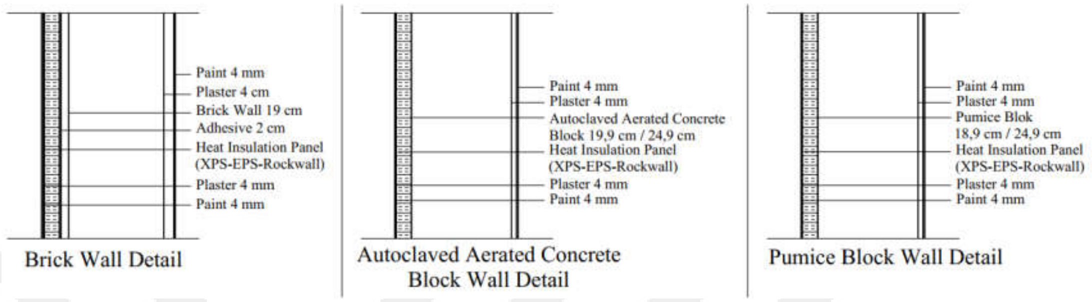


Figure 3.5. Wall Types Detail Section

Wall materials data is given in Table 3.2. In this table, 135 different wall simulation models are defined by using XPS, EPS and rockwool insulation materials in 3cm, 5cm, 6cm, 7cm, 8cm, 9cm, 10cm, 11cm and 12cm thicknesses for each wall type. The properties of the wall and the insulation material widely used in Turkey; thickness, heat transfer coefficient and unit cost price are given in Table 3.2. The heat transfer coefficient value of the materials is regulated according to TS825 regulation and the unit cost price is arranged according to the data determined by the Ministry of Environment and Urbanization (MoEU). Equation 3.1 is used for each case where U values of opaque materials are calculated. In this equation, thermal resistance is calculated depending on the insulation material thickness and heat transmission coefficient values. According to this thermal resistance, the U values differ for each material combination. These costs also include labour unit prices.

Table 3.2. Wall Material List

Type	Name	Insulation Type	Thickness (cm)	U Value (W/mK)	Total Material Area (m2)	Unit Cost (TL/m2)	Total Cost (TL)
	B_BrickWall_Ext_Thermal_Ins						
Brick	Heat Insulation	XPS	3 cm	0,555	872,14	259,09	225963,79
Brick	Heat Insulation	XPS	5 cm	0,405	872,14	266,97	232836,28
Brick	Heat Insulation	XPS	6 cm	0,357	872,14	270,91	236272,53
Brick	Heat Insulation	XPS	7 cm	0,319	872,14	274,84	239700,06
Brick	Heat Insulation	XPS	8 cm	0,288	872,14	278,78	243136,30
Brick	Heat Insulation	XPS	9 cm	0,263	872,14	282,72	246570,37
Brick	Heat Insulation	XPS	10 cm	0,242	872,14	286,66	250004,44
Brick	Heat Insulation	XPS	11 cm	0,224	872,14	290,59	253438,51
Brick	Heat Insulation	XPS	12 cm	0,208	872,14	294,53	256872,57
Brick	Heat Insulation	EPS	3 cm	0,603	872,14	253,78	221332,70
Brick	Heat Insulation	EPS	5 cm	0,448	872,14	258,11	225109,09
Brick	Heat Insulation	EPS	6 cm	0,398	872,14	260,28	227001,64
Brick	Heat Insulation	EPS	7 cm	0,357	872,14	262,44	228885,47
Brick	Heat Insulation	EPS	8 cm	0,324	872,14	264,61	230778,02
Brick	Heat Insulation	EPS	9 cm	0,297	872,14	266,78	232666,76
Brick	Heat Insulation	EPS	10 cm	0,273	872,14	268,94	234555,50
Brick	Heat Insulation	EPS	11 cm	0,254	872,14	271,11	236444,23
Brick	Heat Insulation	EPS	12 cm	0,236	872,14	273,27	238332,97
Brick	Heat Insulation	Rockwool	3 cm	0,603	872,14	268,09	233813,08
Brick	Heat Insulation	Rockwool	5 cm	0,448	872,14	276,23	240912,34
Brick	Heat Insulation	Rockwool	6 cm	0,398	872,14	280,36	244514,29
Brick	Heat Insulation	Rockwool	7 cm	0,357	872,14	285,74	249206,43
Brick	Heat Insulation	Rockwool	8 cm	0,324	872,14	288,57	251674,59
Brick	Heat Insulation	Rockwool	9 cm	0,297	872,14	292,71	255280,36
Brick	Heat Insulation	Rockwool	10 cm	0,273	872,14	296,84	258886,13
Brick	Heat Insulation	Rockwool	11 cm	0,254	872,14	300,97	262491,91
Brick	Heat Insulation	Rockwool	12 cm	0,236	872,14	305,11	266097,68
	C_Autoclaved_Aerated_Concrete_Block						
Concrete	Heat Insulation	XPS	3 cm	0,469	872,14	281,49	245499,81
Concrete	Heat Insulation	XPS	5 cm	0,357	872,14	289,37	252372,31
Concrete	Heat Insulation	XPS	6 cm	0,319	872,14	293,31	255808,56
Concrete	Heat Insulation	XPS	7 cm	0,288	872,14	297,24	259236,08
Concrete	Heat Insulation	XPS	8 cm	0,263	872,14	301,18	262672,33
Concrete	Heat Insulation	XPS	9 cm	0,242	872,14	305,12	266106,40
Concrete	Heat Insulation	XPS	10 cm	0,224	872,14	309,06	269540,46
Concrete	Heat Insulation	XPS	11 cm	0,208	872,14	312,99	272974,53
Concrete	Heat Insulation	XPS	12 cm	0,195	872,14	316,93	276408,60
Concrete	Heat Insulation	EPS	3 cm	0,502	872,14	276,18	240868,73
Concrete	Heat Insulation	EPS	5 cm	0,390	872,14	280,51	244645,11
Concrete	Heat Insulation	EPS	6 cm	0,351	872,14	282,68	246537,67
Concrete	Heat Insulation	EPS	7 cm	0,319	872,14	284,84	248421,50
Concrete	Heat Insulation	EPS	8 cm	0,292	872,14	287,01	250314,05
Concrete	Heat Insulation	EPS	9 cm	0,270	872,14	289,18	252202,79
Concrete	Heat Insulation	EPS	10 cm	0,251	872,14	291,34	254091,52
Concrete	Heat Insulation	EPS	11 cm	0,234	872,14	293,51	255980,26
Concrete	Heat Insulation	EPS	12 cm	0,219	872,14	295,67	257869,00

Concrete	Heat Insulation	Rockwool	3 cm	0,502	872,14	290,49	253349,11
Concrete	Heat Insulation	Rockwool	5 cm	0,390	872,14	298,63	260448,36
Concrete	Heat Insulation	Rockwool	6 cm	0,351	872,14	302,76	264050,32
Concrete	Heat Insulation	Rockwool	7 cm	0,319	872,14	308,14	268742,45
Concrete	Heat Insulation	Rockwool	8 cm	0,292	872,14	310,97	271210,62
Concrete	Heat Insulation	Rockwool	9 cm	0,270	872,14	315,11	274816,39
Concrete	Heat Insulation	Rockwool	10 cm	0,251	872,14	319,24	278422,16
Concrete	Heat Insulation	Rockwool	11 cm	0,234	872,14	323,37	282027,93
Concrete	Heat Insulation	Rockwool	12 cm	0,219	872,14	327,51	285633,70
Concrete	Heat Insulation	XPS	3 cm	0,424	872,14	295,16	257422,02
Concrete	Heat Insulation	XPS	5 cm	0,330	872,14	303,04	264294,52
Concrete	Heat Insulation	XPS	6 cm	0,298	872,14	306,98	267730,77
Concrete	Heat Insulation	XPS	7 cm	0,271	872,14	310,91	271158,29
Concrete	Heat Insulation	XPS	8 cm	0,248	872,14	314,85	274594,54
Concrete	Heat Insulation	XPS	9 cm	0,229	872,14	318,79	278028,61
Concrete	Heat Insulation	XPS	10 cm	0,213	872,14	322,73	281462,67
Concrete	Heat Insulation	XPS	11 cm	0,199	872,14	326,66	284896,74
Concrete	Heat Insulation	XPS	12 cm	0,187	872,14	330,60	288330,81
Concrete	Heat Insulation	EPS	3 cm	0,451	872,14	289,85	252790,94
Concrete	Heat Insulation	EPS	5 cm	0,358	872,14	294,18	256567,32
Concrete	Heat Insulation	EPS	6 cm	0,325	872,14	296,35	258459,87
Concrete	Heat Insulation	EPS	7 cm	0,298	872,14	298,51	260343,71
Concrete	Heat Insulation	EPS	8 cm	0,274	872,14	300,68	262236,26
Concrete	Heat Insulation	EPS	9 cm	0,254	872,14	302,85	264124,99
Concrete	Heat Insulation	EPS	10 cm	0,237	872,14	305,01	266013,73
Concrete	Heat Insulation	EPS	11 cm	0,222	872,14	307,18	267902,47
Concrete	Heat Insulation	EPS	12 cm	0,209	872,14	309,34	269791,21
Concrete	Heat Insulation	Rockwool	3 cm	0,451	872,14	304,16	265271,32
Concrete	Heat Insulation	Rockwool	5 cm	0,358	872,14	312,30	272370,57
Concrete	Heat Insulation	Rockwool	6 cm	0,325	872,14	316,43	275972,53
Concrete	Heat Insulation	Rockwool	7 cm	0,298	872,14	321,81	280664,66
Concrete	Heat Insulation	Rockwool	8 cm	0,274	872,14	324,64	283132,83
Concrete	Heat Insulation	Rockwool	9 cm	0,254	872,14	328,78	286738,60
Concrete	Heat Insulation	Rockwool	10 cm	0,237	872,14	332,91	290344,37
Concrete	Heat Insulation	Rockwool	11 cm	0,222	872,14	337,04	293950,14
Concrete	Heat Insulation	Rockwool	12 cm	0,209	872,14	341,18	297555,91
	D_Pumice_Block						
Pumice	Heat Insulation	XPS	3 cm	0,584	872,14	249,70	217774,36
Pumice	Heat Insulation	XPS	5 cm	0,420	872,14	257,58	224646,85
Pumice	Heat Insulation	XPS	6 cm	0,369	872,14	261,52	228083,10
Pumice	Heat Insulation	XPS	7 cm	0,328	872,14	265,45	231510,62
Pumice	Heat Insulation	XPS	8 cm	0,296	872,14	269,39	234946,87
Pumice	Heat Insulation	XPS	9 cm	0,269	872,14	273,33	238380,94
Pumice	Heat Insulation	XPS	10 cm	0,247	872,14	277,27	241815,01
Pumice	Heat Insulation	XPS	11 cm	0,228	872,14	281,20	245249,07
Pumice	Heat Insulation	XPS	12 cm	0,212	872,14	285,14	248683,14
Pumice	Heat Insulation	EPS	3 cm	0,637	872,14	244,39	213143,27
Pumice	Heat Insulation	EPS	5 cm	0,467	872,14	248,72	216919,66
Pumice	Heat Insulation	EPS	6 cm	0,412	872,14	250,89	218812,21
Pumice	Heat Insulation	EPS	7 cm	0,369	872,14	253,05	220696,04
Pumice	Heat Insulation	EPS	8 cm	0,334	872,14	255,22	222588,59
Pumice	Heat Insulation	EPS	9 cm	0,305	872,14	257,39	224477,33
Pumice	Heat Insulation	EPS	10 cm	0,280	872,14	259,55	226366,07
Pumice	Heat Insulation	EPS	11 cm	0,259	872,14	261,72	228254,80
Pumice	Heat Insulation	EPS	12 cm	0,241	872,14	263,88	230143,54
Pumice	Heat Insulation	Rockwool	3 cm	0,637	872,14	258,70	225623,65
Pumice	Heat Insulation	Rockwool	5 cm	0,467	872,14	266,84	232722,90
Pumice	Heat Insulation	Rockwool	6 cm	0,412	872,14	270,97	236324,86
Pumice	Heat Insulation	Rockwool	7 cm	0,369	872,14	276,35	241016,99
Pumice	Heat Insulation	Rockwool	8 cm	0,334	872,14	279,18	243485,16
Pumice	Heat Insulation	Rockwool	9 cm	0,305	872,14	283,32	247090,93
Pumice	Heat Insulation	Rockwool	10 cm	0,280	872,14	287,45	250696,70
Pumice	Heat Insulation	Rockwool	11 cm	0,259	872,14	291,58	254302,47
Pumice	Heat Insulation	Rockwool	12 cm	0,241	872,14	295,72	257908,24

Pumice	Heat Insulation	XPS	3 cm	0,536	872,14	258,84	225745,75
Pumice	Heat Insulation	XPS	5 cm	0,395	872,14	266,72	232618,25
Pumice	Heat Insulation	XPS	6 cm	0,349	872,14	270,66	236054,50
Pumice	Heat Insulation	XPS	7 cm	0,313	872,14	274,59	239482,02
Pumice	Heat Insulation	XPS	8 cm	0,283	872,14	278,53	242918,27
Pumice	Heat Insulation	XPS	9 cm	0,259	872,14	282,47	246352,34
Pumice	Heat Insulation	XPS	10 cm	0,238	872,14	286,41	249786,40
Pumice	Heat Insulation	XPS	11 cm	0,221	872,14	290,34	253220,47
Pumice	Heat Insulation	XPS	12 cm	0,206	872,14	294,28	256654,54
Pumice	Heat Insulation	EPS	3 cm	0,580	872,14	253,53	221114,67
Pumice	Heat Insulation	EPS	5 cm	0,436	872,14	257,86	224891,05
Pumice	Heat Insulation	EPS	6 cm	0,388	872,14	260,03	226783,60
Pumice	Heat Insulation	EPS	7 cm	0,349	872,14	262,19	228667,44
Pumice	Heat Insulation	EPS	8 cm	0,317	872,14	264,36	230559,99
Pumice	Heat Insulation	EPS	9 cm	0,291	872,14	266,53	232448,72
Pumice	Heat Insulation	EPS	10 cm	0,269	872,14	268,69	234337,46
Pumice	Heat Insulation	EPS	11 cm	0,249	872,14	270,86	236226,20
Pumice	Heat Insulation	EPS	12 cm	0,233	872,14	273,02	238114,94
Pumice	Heat Insulation	Rockwool	3 cm	0,580	872,14	267,84	233595,05
Pumice	Heat Insulation	Rockwool	5 cm	0,436	872,14	275,98	240694,30
Pumice	Heat Insulation	Rockwool	6 cm	0,388	872,14	280,11	244296,26
Pumice	Heat Insulation	Rockwool	7 cm	0,349	872,14	285,49	248988,39
Pumice	Heat Insulation	Rockwool	8 cm	0,317	872,14	288,32	251456,56
Pumice	Heat Insulation	Rockwool	9 cm	0,291	872,14	292,46	255062,33
Pumice	Heat Insulation	Rockwool	10 cm	0,269	872,14	296,59	258668,10
Pumice	Heat Insulation	Rockwool	11 cm	0,249	872,14	300,72	262273,87
Pumice	Heat Insulation	Rockwool	12 cm	0,233	872,14	304,86	265879,64

3.4.3. Roof Material

There are 2 different roof types usually used in Turkey. One of them is called a flat terrace roof and the other one is called an angle/sloped roof. Flat terrace roof is more affordable in terms of cost. The terrace roof transmits cold or hot air faster than the angle/sloped roof. The most important reason for this is the gap created by the sloped roof. Hot/cold air coming to the sloped roof is stored in the space between the top floor of the building and the roof. This reduces the effect of incoming air. As a result, this situation affects the energy consumption of the top floor apartments. In addition, since the floor material of the roof is directly exposed to bad weather conditions, there is a need to repair the material before the end of its economic life.

The aim of this study is to reduce the energy consumption in apartment buildings Therefore, only the sloped roof is defined in our energy model. The detailed section of the sloped roof is shown in Figure 3.6.

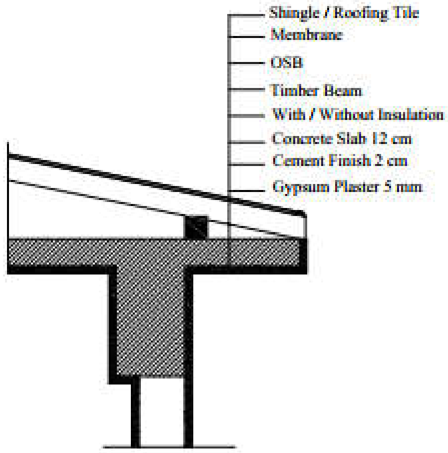


Figure 3.6. Sloped Roof Detail Section

Sloped roof material details are given in Table 3.3. In this table, two types of sloped roofing material are used. For this roofing materials, 5cm, 8cm, 10cm and 12cm thicknesses XPS, EPS, Rockwool and Glasswool insulation materials were used. A total of 32 different sloped roof types were defined to the simulation model.

Table 3.3. Sloped Roof Material List

Type	Name	Insulation Type	Thickness (cm)	U Value (W/mK)	Total Material Area (m2)	Unit Cost (TL/m2)	Total Cost (TL)
	C_Slooped_Roof_Roofing_Tile						
Tile	Board Insulation	XPS	5cm	0,510	233,17	298,13	69516,13
Tile	Board Insulation	XPS	8cm	0,338	233,17	310,33	72360,81
Tile	Board Insulation	XPS	10cm	0,276	233,17	318,47	74258,81
Tile	Board Insulation	XPS	12cm	0,233	233,17	326,61	76156,82
Tile	Board Insulation	EPS	5cm	0,580	233,17	297,47	69362,24
Tile	Board Insulation	EPS	8cm	0,387	233,17	309,28	72115,98
Tile	Board Insulation	EPS	10cm	0,317	233,17	317,16	73953,36
Tile	Board Insulation	EPS	12cm	0,269	233,17	325,03	75788,41
Tile	Board Insulation	Rockwool	5cm	0,580	233,17	295,42	68884,24
Tile	Board Insulation	Rockwool	8cm	0,387	233,17	297,84	69448,51
Tile	Board Insulation	Rockwool	10cm	0,317	233,17	300,21	70001,13
Tile	Board Insulation	Rockwool	12cm	0,269	233,17	302,61	70560,74
Tile	Board Insulation	Glasswool	5cm	0,580	233,17	287,52	67042,20
Tile	Board Insulation	Glasswool	8cm	0,387	233,17	293,64	68469,20
Tile	Board Insulation	Glasswool	10cm	0,317	233,17	295,48	68898,23
Tile	Board Insulation	Glasswool	12cm	0,269	233,17	297,32	69327,27

D_Slooped_Roof_Shingle						
Shingle Board Insulation	XPS	5cm	0,510	233,17	281,73	65691,07
Shingle Board Insulation	XPS	8cm	0,338	233,17	293,91	68532,06
Shingle Board Insulation	XPS	10cm	0,276	233,17	302,04	70427,61
Shingle Board Insulation	XPS	12cm	0,233	233,17	310,17	72323,15
Shingle Board Insulation	EPS	5cm	0,580	233,17	281,07	65537,38
Shingle Board Insulation	EPS	8cm	0,387	233,17	292,87	68287,55
Shingle Board Insulation	EPS	10cm	0,317	233,17	300,74	70122,55
Shingle Board Insulation	EPS	12cm	0,269	233,17	308,60	71955,22
Shingle Board Insulation	Rockwool	5cm	0,580	233,17	279,02	65060,00
Shingle Board Insulation	Rockwool	8cm	0,387	233,17	281,44	65623,54
Shingle Board Insulation	Rockwool	10cm	0,317	233,17	283,81	66175,44
Shingle Board Insulation	Rockwool	12cm	0,269	233,17	286,20	66734,32
Shingle Board Insulation	Glasswool	5cm	0,580	233,17	271,13	63220,34
Shingle Board Insulation	Glasswool	8cm	0,387	233,17	277,25	64645,50
Shingle Board Insulation	Glasswool	10cm	0,317	233,17	279,08	65073,97
Shingle Board Insulation	Glasswool	12cm	0,269	233,17	280,92	65502,45

3.4.4. Slab Material

The building is divided into floors by adding a structural element called flooring which is foreseen to be at least 12 cm between each floor.

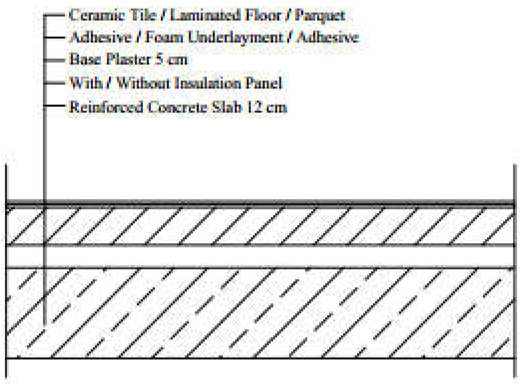


Figure 3.7. Slab Detail Section

Wood, steel, concrete slab types are available. As is common in Turkey for use in reinforced concrete floor apartments. For this reason, only concrete slab types are defined in the energy model. Reinforced concrete slabs consist of reinforced concrete insulation and coating material. Detail section of the slab is shown in Figure 3.7. Slab material details are given in Table 3.4. In this table, three types of flooring materials are used. For these flooring materials, 3cm, 5cm, 6cm and 7cm thicknesses, XPS, EPS and rockwool insulation materials were used. Heat exchange in floorings is not considered very important relatively, therefore an uninsulated option is also added for each type of flooring. A total of 39 different flooring types are defined to simulation models.

Table 3.4. Slab Material List

Type	Name	Insulation Type	Thickness (cm)	U Value (W/mK)	Total Material Area (m2)	Unit Cost (TL/m2)	Total Cost (TL)
	A_RC_Slab_12cm_Ceramic_On_Top						
Ceramic	NoInsulation			2,169	1.165,86	112,01	130587,98
Ceramic	Extrude Polystyren Foam Board Insulation	XPS	3cm	0,684	1.165,86	126,42	147388,02
Ceramic	Extrude Polystyren Foam Board Insulation	XPS	5cm	0,470	1.165,86	134,56	156878,12
Ceramic	Extrude Polystyren Foam Board Insulation	XPS	6cm	0,406	1.165,86	138,62	161611,51
Ceramic	Extrude Polystyren Foam Board Insulation	XPS	7cm	0,358	1.165,86	142,70	166368,22
Ceramic	Foam Board Insulation	EPS	3cm	0,759	1.165,86	151,85	177035,84
Ceramic	Foam Board Insulation	EPS	5cm	0,529	1.165,86	132,59	154581,38
Ceramic	Foam Board Insulation	EPS	6cm	0,460	1.165,86	136,26	158860,08
Ceramic	Foam Board Insulation	EPS	7cm	0,406	1.165,86	139,94	163150,45
Ceramic	Rockwool Foam Board Insulation	Rockwool	3cm	0,759	1.165,86	126,16	147084,90
Ceramic	Rockwool Foam Board Insulation	Rockwool	5cm	0,529	1.165,86	134,04	156271,87
Ceramic	Rockwool Foam Board Insulation	Rockwool	6cm	0,460	1.165,86	136,84	159536,28
Ceramic	Rockwool Foam Board Insulation	Rockwool	7cm	0,406	1.165,86	141,91	165447,19
	B_RC_Slab_12cm_Laminated_Flooring						
Laminated	NoInsulation			1,953	1.165,86	210,22	245087,09
Laminated	Extrude Polystyren Foam Board Insulation	XPS	3cm	0,661	1.165,86	224,63	261887,13
Laminated	Extrude Polystyren Foam Board Insulation	XPS	5cm	0,459	1.165,86	232,77	271377,23
Laminated	Extrude Polystyren Foam Board Insulation	XPS	6cm	0,398	1.165,86	236,83	276110,62
Laminated	Extrude Polystyren Foam Board Insulation	XPS	7cm	0,351	1.165,86	240,91	280867,33
Laminated	Foam Board Insulation	EPS	3cm	0,730	1.165,86	250,06	291534,95
Laminated	Foam Board Insulation	EPS	5cm	0,515	1.165,86	230,80	269080,49
Laminated	Foam Board Insulation	EPS	6cm	0,449	1.165,86	234,47	273359,19
Laminated	Foam Board Insulation	EPS	7cm	0,398	1.165,86	238,15	277649,56
Laminated	Rockwool Foam Board Insulation	Rockwool	3cm	0,730	1.165,86	224,37	261584,01
Laminated	Rockwool Foam Board Insulation	Rockwool	5cm	0,515	1.165,86	232,25	270770,99
Laminated	Rockwool Foam Board Insulation	Rockwool	6cm	0,449	1.165,86	235,05	274035,39
Laminated	Rockwool Foam Board Insulation	Rockwool	7cm	0,398	1.165,86	240,12	279946,30
	C_RC_Slab_12cm_Solid_Parquet						
SolidParquet	NoInsulation			1,808	1.165,86	249,64	291045,29
SolidParquet	Extrude Polystyren Foam Board Insulation	XPS	3cm	0,644	1.165,86	264,05	307845,33
SolidParquet	Extrude Polystyren Foam Board Insulation	XPS	5cm	0,450	1.165,86	272,19	317335,43
SolidParquet	Extrude Polystyren Foam Board Insulation	XPS	6cm	0,392	1.165,86	276,25	322068,83
SolidParquet	Extrude Polystyren Foam Board Insulation	XPS	7cm	0,347	1.165,86	280,33	326825,53
SolidParquet	Foam Board Insulation	EPS	3cm	0,709	1.165,86	289,48	337493,15
SolidParquet	Foam Board Insulation	EPS	5cm	0,505	1.165,86	270,22	315038,69
SolidParquet	Foam Board Insulation	EPS	6cm	0,441	1.165,86	273,89	319317,40
SolidParquet	Foam Board Insulation	EPS	7cm	0,392	1.165,86	277,57	323607,76
SolidParquet	Rockwool Foam Board Insulation	Rockwool	3cm	0,709	1.165,86	263,79	307542,21
SolidParquet	Rockwool Foam Board Insulation	Rockwool	5cm	0,505	1.165,86	271,67	316729,19
SolidParquet	Rockwool Foam Board Insulation	Rockwool	6cm	0,441	1.165,86	274,47	319993,59
SolidParquet	Rockwool Foam Board Insulation	Rockwool	7cm	0,392	1.165,86	279,54	325904,50

3.4.5. Ground Foundation Material

Each building has a surface in contact with soil, rocks and similar materials on the floor. This surface is called the ground foundation. As with the roof and the wall, the heat exchange of the floor of the building depends on the weather conditions. For this reason, it is necessary to apply different insulation and material in the floor covering. A detailed section of the ground foundation is shown in Figure 3.8.

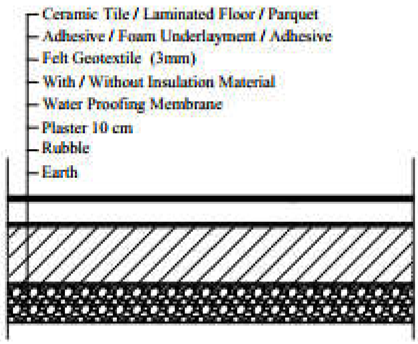


Figure 3.8. Ground Foundation Detail Section

foundation details are given in Table 3.5. In this table, two types of ground foundation materials are used. For these ground foundation materials, XPS and EPS insulation materials in 3cm, 5cm, 6cm, 7cm, 8cm, 9cm, 10cm, 11cm and 12cm thicknesses are used. In ground foundation, heat exchange is not considered very important, therefore an uninsulated option has been added for each type of flooring. A total of 38 different ground foundation types are defined to the simulation models.

Table 3.5. Ground Foundation Material List

Type	Name	Insulation Type	Thickness (cm)	U Value (W/mK)	Total Material Area (m2)	Unit Cost (TL/m2)	Total Cost (TL)
	A_Ground_Foundation_Ceramic_On_Top						
Ceramic	NoInsulation			3,690	233,17	164,32	38314,49
Ceramic	Foam Board Insulation	XPS	3cm	0,787	233,17	178,73	41674,47
Ceramic	Foam Board Insulation	XPS	5cm	0,516	233,17	186,87	43572,48
Ceramic	Foam Board Insulation	XPS	6cm	0,440	233,17	190,93	44519,15
Ceramic	Foam Board Insulation	XPS	7cm	0,384	233,17	195,01	45470,48
Ceramic	Foam Board Insulation	XPS	8cm	0,340	233,17	199,07	46417,15
Ceramic	Foam Board Insulation	XPS	9cm	0,306	233,17	203,14	47365,86
Ceramic	Foam Board Insulation	XPS	10cm	0,277	233,17	207,21	48314,57
Ceramic	Foam Board Insulation	XPS	11cm	0,254	233,17	211,28	49263,28
Ceramic	Foam Board Insulation	XPS	12cm	0,234	233,17	215,35	50211,99
Ceramic	Foam Board Insulation	EPS	3cm	0,887	233,17	177,55	41399,33
Ceramic	Foam Board Insulation	EPS	5cm	0,588	233,17	184,90	43113,13
Ceramic	Foam Board Insulation	EPS	6cm	0,504	233,17	188,57	43968,87
Ceramic	Foam Board Insulation	EPS	7cm	0,440	233,17	192,25	44826,93
Ceramic	Foam Board Insulation	EPS	8cm	0,391	233,17	195,92	45682,67
Ceramic	Foam Board Insulation	EPS	9cm	0,352	233,17	199,60	46539,57
Ceramic	Foam Board Insulation	EPS	10cm	0,320	233,17	203,27	47396,47
Ceramic	Foam Board Insulation	EPS	11cm	0,293	233,17	206,95	48253,37
Ceramic	Foam Board Insulation	EPS	12cm	0,270	233,17	210,62	49110,27

	B_Ground_Foundation_Laminated_Flooring						
Laminated	NoInsulation			3,106	233,17	262,53	61214,12
Laminated	Foam Board Insulation	XPS	3cm	0,756	233,17	276,94	64574,10
Laminated	Foam Board Insulation	XPS	5cm	0,503	233,17	285,08	66472,10
Laminated	Foam Board Insulation	XPS	6cm	0,431	233,17	289,14	67418,77
Laminated	Foam Board Insulation	XPS	7cm	0,377	233,17	293,22	68370,11
Laminated	Foam Board Insulation	XPS	8cm	0,335	233,17	297,28	69316,78
Laminated	Foam Board Insulation	XPS	9cm	0,301	233,17	301,35	70265,49
Laminated	Foam Board Insulation	XPS	10cm	0,274	233,17	305,42	71214,20
Laminated	Foam Board Insulation	XPS	11cm	0,251	233,17	309,49	72162,91
Laminated	Foam Board Insulation	XPS	12cm	0,231	233,17	313,56	73111,62
Laminated	Foam Board Insulation	EPS	3cm	0,848	233,17	275,76	64298,96
Laminated	Foam Board Insulation	EPS	5cm	0,571	233,17	283,11	66012,76
Laminated	Foam Board Insulation	EPS	6cm	0,491	233,17	286,78	66868,49
Laminated	Foam Board Insulation	EPS	7cm	0,431	233,17	290,46	67726,56
Laminated	Foam Board Insulation	EPS	8cm	0,383	233,17	294,13	68582,29
Laminated	Foam Board Insulation	EPS	9cm	0,346	233,17	297,81	69439,19
Laminated	Foam Board Insulation	EPS	10cm	0,315	233,17	301,48	70296,09
Laminated	Foam Board Insulation	EPS	11cm	0,289	233,17	305,16	71152,99
Laminated	Foam Board Insulation	EPS	12cm	0,267	233,17	308,83	72009,89

CHAPTER 4

4. OPTIMIZATION MODEL ACCORDING TO APARTMENT BUILDING AND CONSTRUCTION

Based on the previous chapters, this chapter describes the preparation steps of the energy and optimization model of the apartment building. Grasshopper is a parametric form tool and an add-on for Rhinoceros software. This plugin is very effective for architects and designers to solve complex forms. There is a plugin called LadyBug to support this plugin with environmental analysis. LadyBug can transfer Energy Plus Weather (.EPW) files to Grasshopper and provides the interaction necessary to carry out building form generation, energy analysis studies. The grasshopper interface provides graphic visualization, shortening the analysis process and automatic completion of the desired calculations.

4.1. Steps of the Energy Simulation Model

4.1.1. Create Building Geometry

The first step is to determine the geometry of the building. The floor area obtained in this study was considered as a rectangle and a model was started to be formed on a square floor. The grasshopper definition is given Figure in 4.1. According to the need, this form can be a circle, triangle, L form and so on.

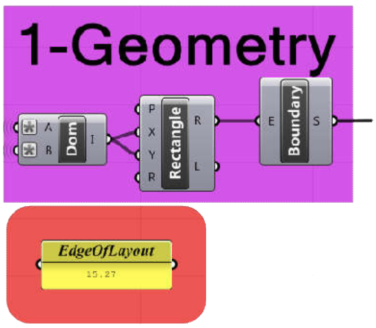


Figure 4.1. Building Geometry Definition on Grasshopper

4.1.2. Generating Floor Layout

In this step, the floor layout plan is created. The flat dimensions on the floor and the area allocated for the building circulation are determined. The grasshopper definition is given Figure 4.2. In this study, there are 2 flats on each floor and a building circulation area measuring 3,60 meters by 2,60 meters.

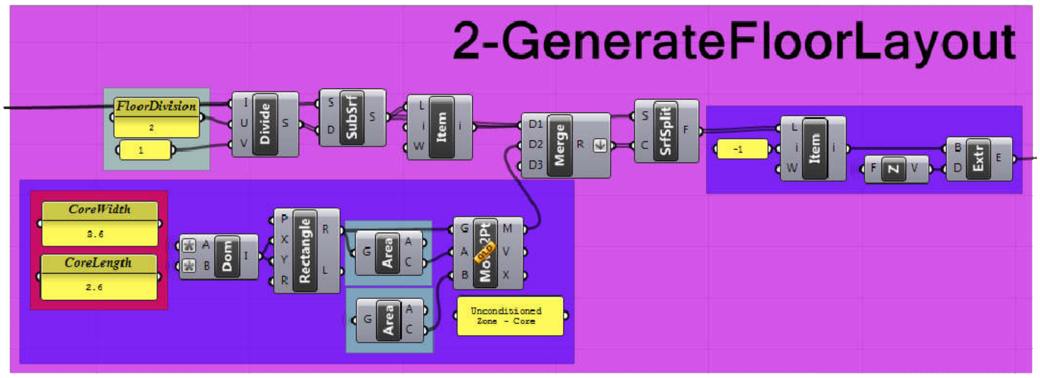


Figure 4.2. Floor Layout Definition on Grasshopper

4.1.3. HoneyBee Zone Generation

In this step, name of the zone, separation of the zones according to the usage, degree of the roof with slope used, window to wall ratio and the list of window material details are entered into the model. HoneyBee zone generation grasshopper definition is given Figure 4.3.

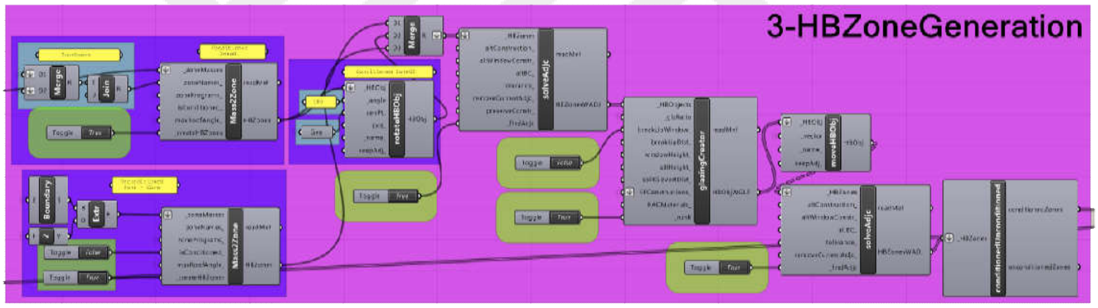


Figure 4.3. HoneyBee Zone Generation Definition on Grasshopper

The zone name is mentioned as the naming of the model studied. Separation of zones according to usage is to introduce the difference of flat and corridor to the model. If the roof of the apartment building is sloping, the slope degree of the roof formed should also be specified in this section. The glazing creator component is also used in this step. It is necessary to introduce the window to wall ratio and window material details to the model through this component. Window materials Grasshopper definition is given in Figure 4.4.

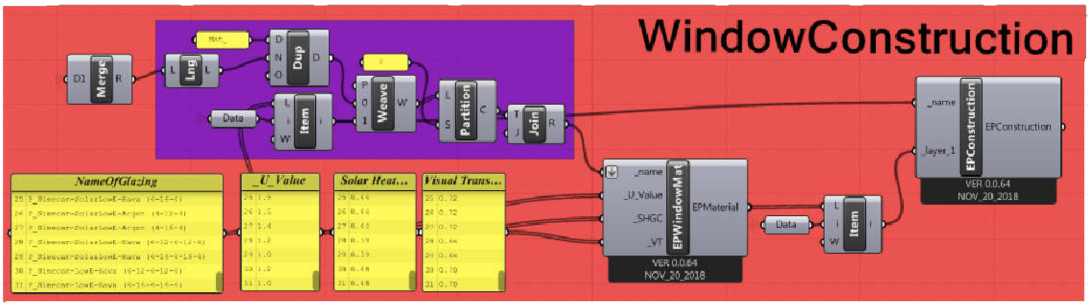


Figure 4.4. Window Material List Definition on Grasshopper

4.1.4. Zone Thermal Characterization

In this step, building material details, zone loads, building schedules, natural ventilation details and threshold values are entered into the model. Lists made of wall, roof, slab and exposed floor materials are introduced to the model. In these lists, there are 135 walls, 32 roofs, 39 slab, 27 exposed floor types. Building materials Grasshopper definition is given in Figure 4.5.

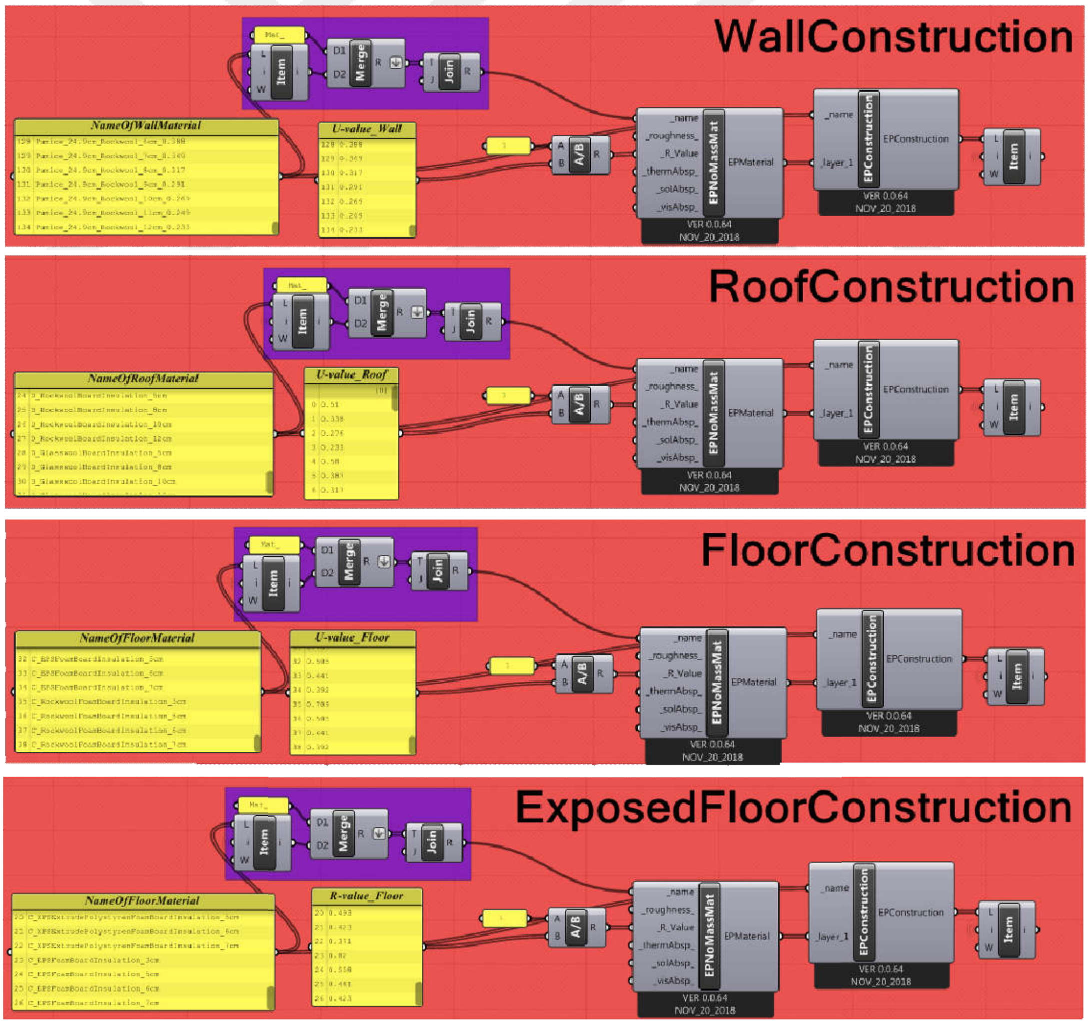


Figure 4.5. Building Material List Definition on Grasshopper

Equipment, infiltration, lighting and occupancy rate per square meter are entered as zone loads. Equipment load is assumed as 1 W/m^2, and the infiltration value is defined as 0,0006 m^3/s per m^2 facade (ASHRAE). For the lighting load, considering that 7 units of 10 Watt LEDs are used in each flat, 0,62 W/m^2 is calculated by dividing the total LED load by the square meter of the flat. In this study, it is assumed that 4 people live in each flat. To calculate the occupancy rate per square meter, dividing the number of people by the square meter of the flat, the value of 0,035 ppl/m^2 is defined for the model. Zone load Grasshopper definition is given Figure in 4.6.

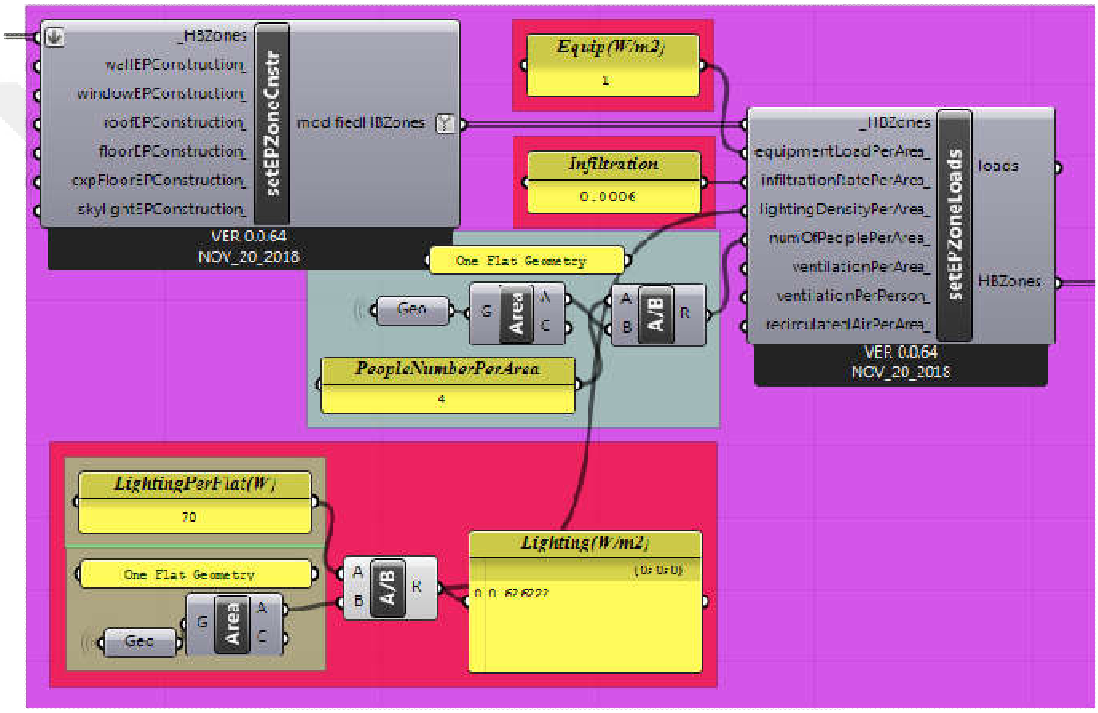


Figure 4.6. Zone Loads Definition on Grasshopper

Grasshopper performs energy simulation calculations with EnergyPlus. On the EnergyPlus infrastructure, there are different type schedules according to ASHRAE standards. However, schedules in accordance with the conditions of Turkey in this study were prepared and introduced to the model again. 2 different schedules have been prepared. One of them is for lighting load and the other is for occupancy and the equipment load. Schedule definition is given Figure in 4.7.

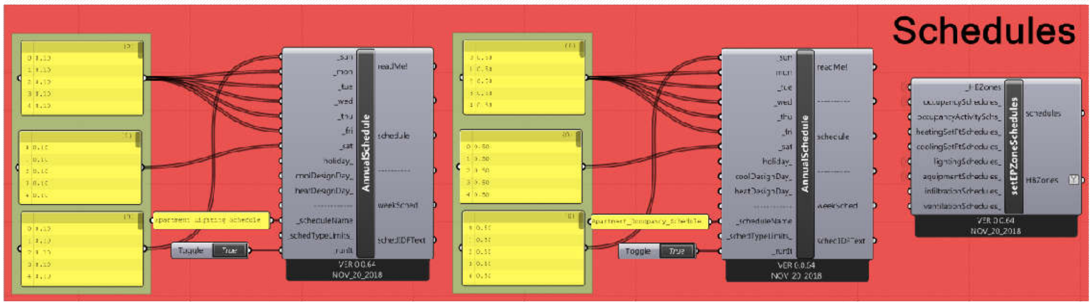


Figure 4.7. Schedules Definition on Grasshopper

After the scenarios, the natural ventilation details in the building are entered. In the software, 4 different types of natural ventilation can be defined. In this study, it is accepted that natural ventilation is made by opening the windows at a maximum rate of 50%. Natural ventilation definition is given Figure in 4.8.

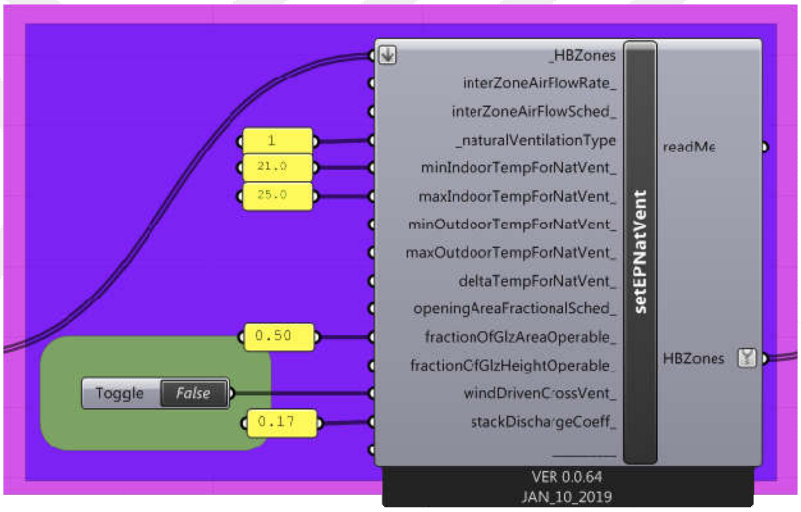


Figure 4.8. Natural Ventilation Definition on Grasshopper

In this step, threshold values need to be defined. It is the step where the illuminance values of the heating set point (20,0°C), heating set back (10,0°C), cooling set point (26,0°C), cooling set back (28,0°C) and illuminance (300 lux) values are determined. Heating set point, set back and cooling set point, set back values are taken from Bep-TR methodology (https://www.resmigazete.gov.tr/eskiler/2017/11/20171101M1-1.htm). This software was produced by the Ministry of Environment and Urbanization. Threshold definition is given in Figure 4.9.

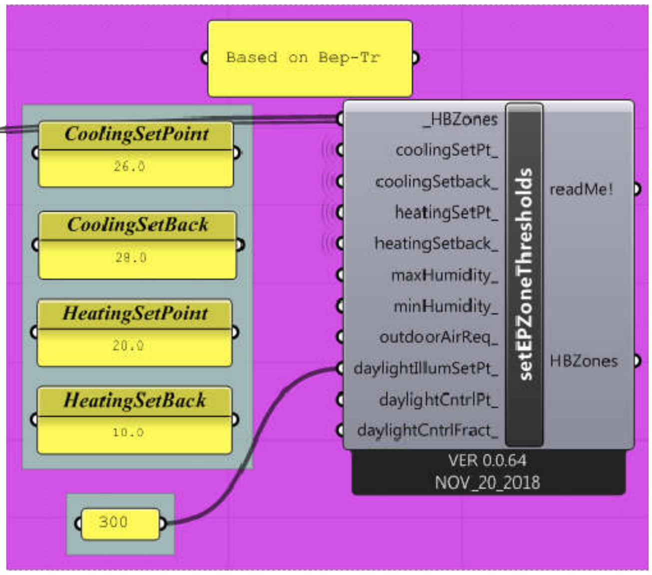


Figure 4.9. Threshold Definition on Grasshopper

4.1.5. Zone Conditioning (HVAC Type)

Thanks to HoneyBee plugin, 17 different HVAC systems can be added to the energy simulation model. Also, new systems can be added by entering different heating and cooling details from existing HVAC systems in software. As explained in Chapter 3, in this study, PTAC was chosen as the heating and cooling system. PTAC system performs cooling with direct expansion using electricity and heating with a hot water boiler using fossil fuel. In addition, ASHRAE standards recommend using this system in residential buildings above 5 floors. HVAC system definition is given Figure in 4.10.

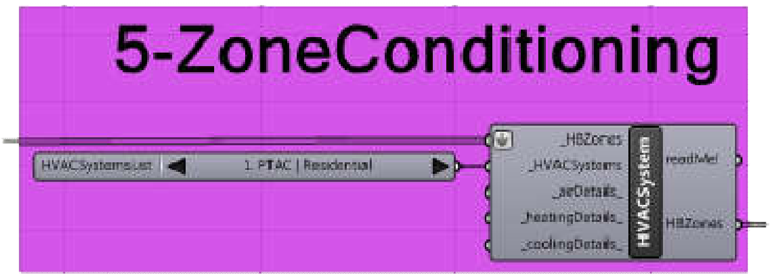


Figure 4.10. HVAC System Definition on Grasshopper

4.1.6. Unconditioned Zone

When preparing the energy simulation model of a building, it is important to identify places where heating and cooling are undesirable. If these areas are not separated, the resulting energy consumption will be inaccurate. These building zones are divided into Conditioned Zones and Unconditioned Zones sections. Unconditioned zones were defined as circulation areas and sloped roof gaps. Unconditioned zones definition is given Figure in 4.11.

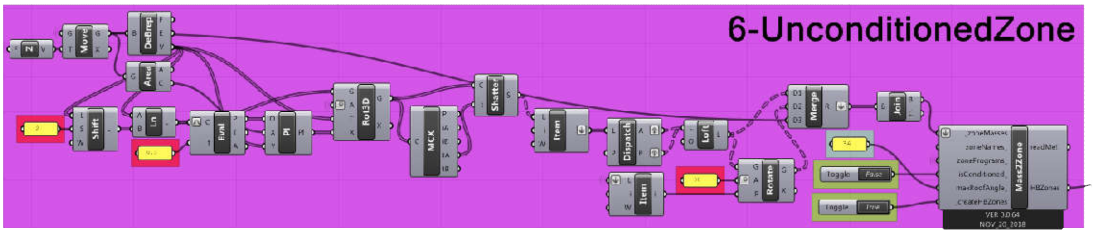


Figure 4.11. Unconditioned Zone Definition on Grasshopper

4.1.7. Combine Zones

Before starting the simulation, it is necessary to define the model as a single mass. In this step, conditioned and unconditioned zones are combined. Load values of unconditioned zones are entered as zero (0). For the circulation area, a 10 Watt LED lighting fixture load was added to the staircase of each floor. At the end of this step, all zones are combined and the building model is ready for the simulation. Combine zone definition is given in Figure 4.12.

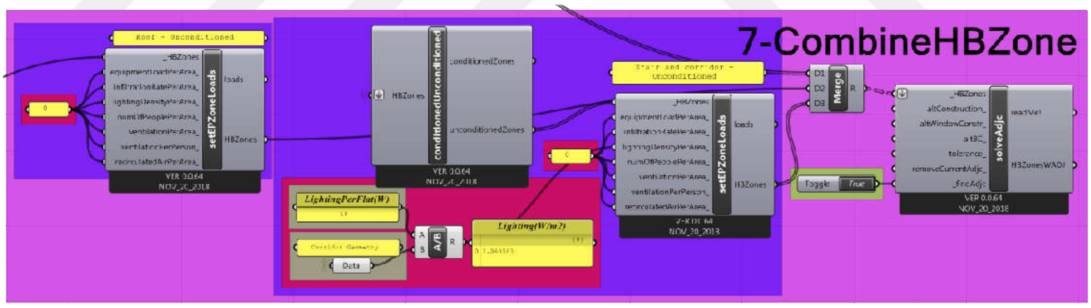


Figure 4.12. Combine Zone Definition on Grasshopper

4.1.8. Run the Simulation

In this step, the final details of the simulation are determined. These details are such as load type, time step, terrain type, epw file. There are 3 types of load, these are total, sensible and latent loads. In this study, calculations are made on the total load. The software can simulate it at different time steps according to the desired results. There are 4 different time steps, hourly, daily, monthly and annual. The annual time step was used in this study. If the building has a special location while taking simulation, it can be selected in this step. There are 4 different options in the terrain section. These are city, suburb, country and ocean. In this study, simulations were completed by selecting the country location. Grasshopper takes energy simulation by working with Energy Plus software. Therefore, files in EnergyPlus Weather format are used (.EPW file). These files, which are specially designed for most locations in the world, can be accessed at "http:// climate.onebuilding.org/default.html". The ladybug plugin was used to add an energy plus weather data file to the model. Simulation definition is given in Figure 4.13.

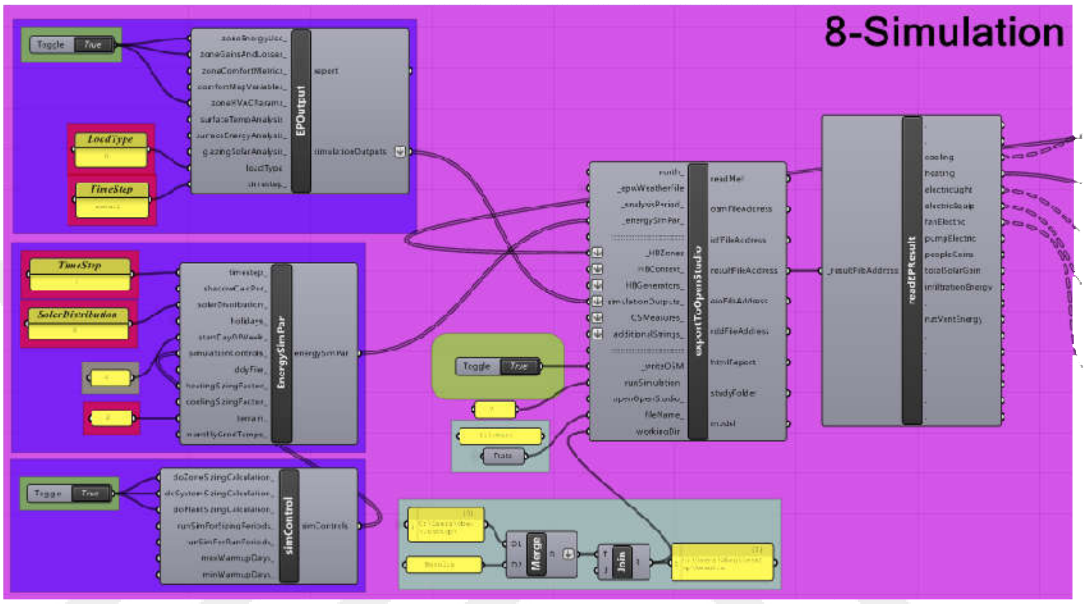


Figure 4.13. Run Simulation Definition on Grasshopper

4.1.9. Simulation Results

After running the simulation, reading the results is an important step. The first results show the annual total loads such as heating, cooling and lighting in kWh/m^2. However, since energy consumption per square meter is required in this study, additional components such as in Figure 4.14 were used.

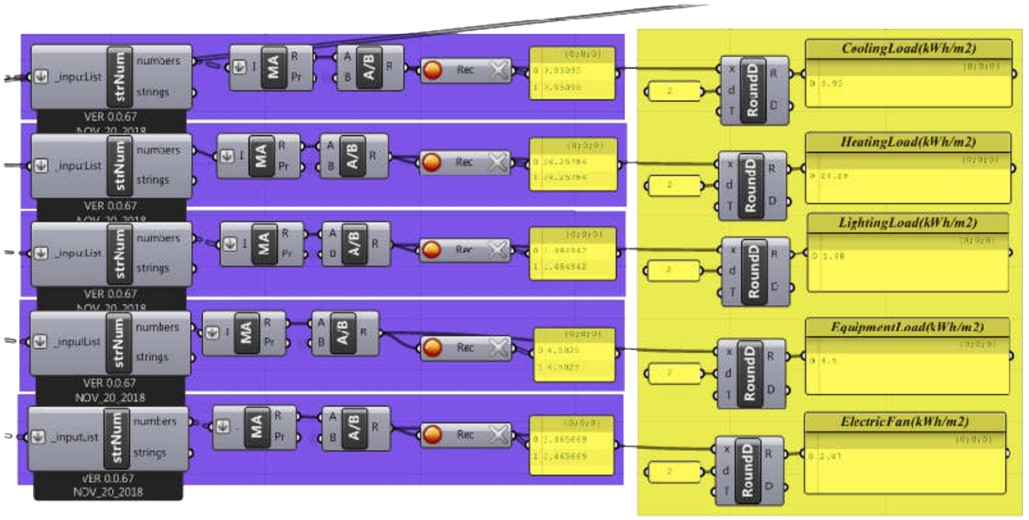


Figure 4.14. Energy Consumption Details Definition on Grasshopper

The total investment cost of the materials used with the energy consumption results is also calculated at this step. The image of the material cost list and calculations in the grasshopper interface is shown in Figure 4.15.

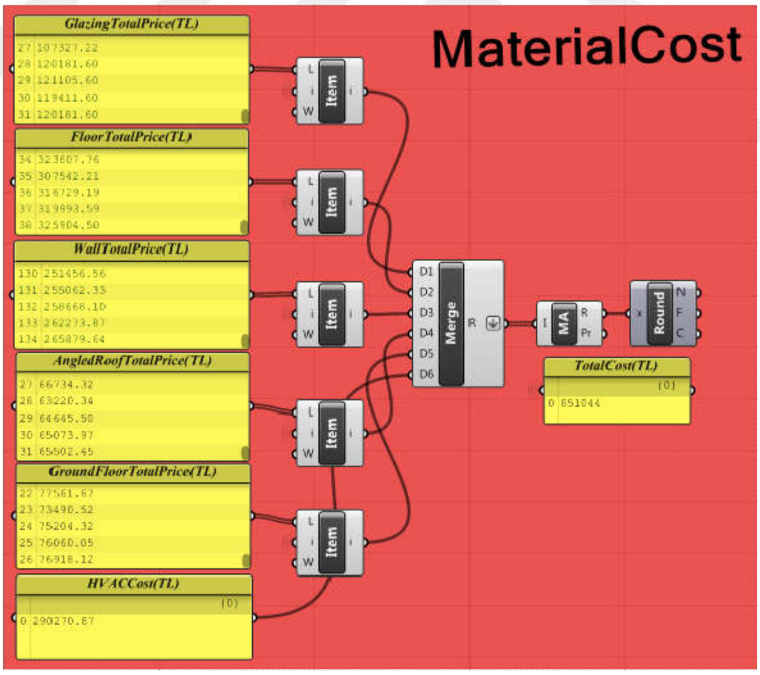


Figure 4.15. Material Cost List Definition on Grasshopper

The sum of the heating and cooling energy consumption and the initial investment cost are the objectives of this project. Objectives and result examples are given in Figure 4.16.

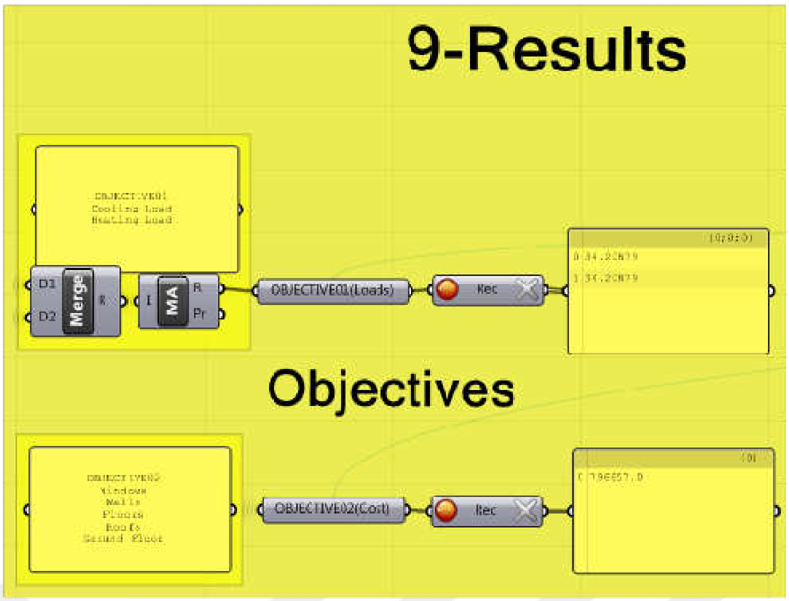


Figure 4.16. Result and Objective Example Definition on Grasshopper

4.1.10. Decision Variables and Optimization

In this study, the Octopus plugin was used for the optimization. The optimization component has 2 data entries; one of which is the objectives and the other decision variables. One of the objectives is the initial investment cost of the building, the other is the heating and cooling energy consumption per square meter of the building. The decision variables of this study are building materials and there are 5 different building material lists. These are the window, wall, roof, slab and exposed floor. More detailed lists are given in Chapter 3.2. Figure 4.17 shows the decision variable lists and the octopus component. The decision variables table shows the building materials. The numbers shown in these tables refer to a material in the list of building materials. The materials selected as a result of a simulation are recorded in this step.

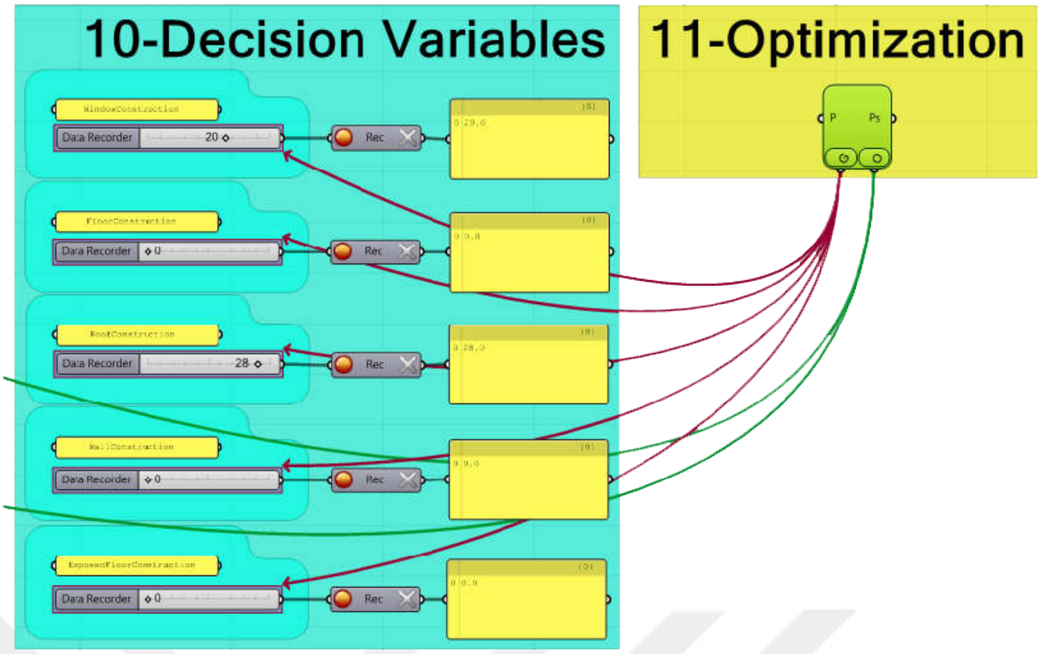


Figure 4.17. Decision Variables and Optimization Definition on Grasshopper

The parametric model prepared in this study is shown in Figure 4.18 in the environment of a Grasshopper.In this complex-looking model, color adjustment has been made to make the steps more understandable and easier to work with. These steps are as follows; input, steps, sub-steps, info, boolean, variable, objective (result).

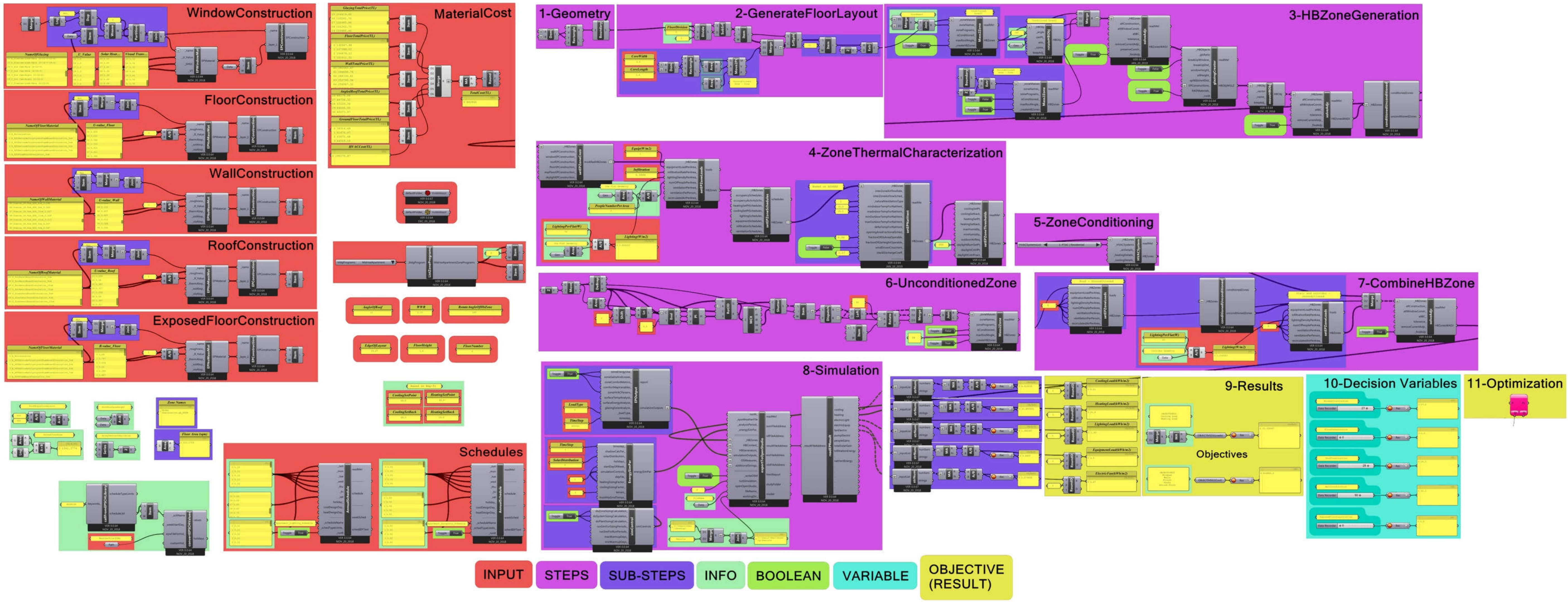


Figure 4.18. Complete Grasshopper Model

CHAPTER 5

5. DISCUSSION OF ENERGY EFFICIENT COST OPTIMIZATION RESULTS OF APARTMENT BUILDING CONSTRUCTION MATERIALS

In this section, the NSGA-II optimization algorithm has been performed and the results of the optimization have been specified in detail. In addition, this study shows how effective the choice of materials is on energy consumption and initial investment cost before the building is built.

5.1. Results of the Model

Based on the previous statements, the NSGA-II version of Octopus has optimized the cost-effective energy consumption calculation for one hundred generations with a population size of one hundred among the building materials detail and initial investment cost defined in the energy model. A total of 10073 simulations were taken and the optimization process was completed.

Out of 100 generations, 99th is the last cluster generation results were evaluated. Because the best results are seen in the latest generation. There are a total of 12 results in the 99th generation cluster. These results are shown in Figure 5.1 in details of the Octopus interface. Since the decision variables are discrete, 12 results were reached in 100 generations.

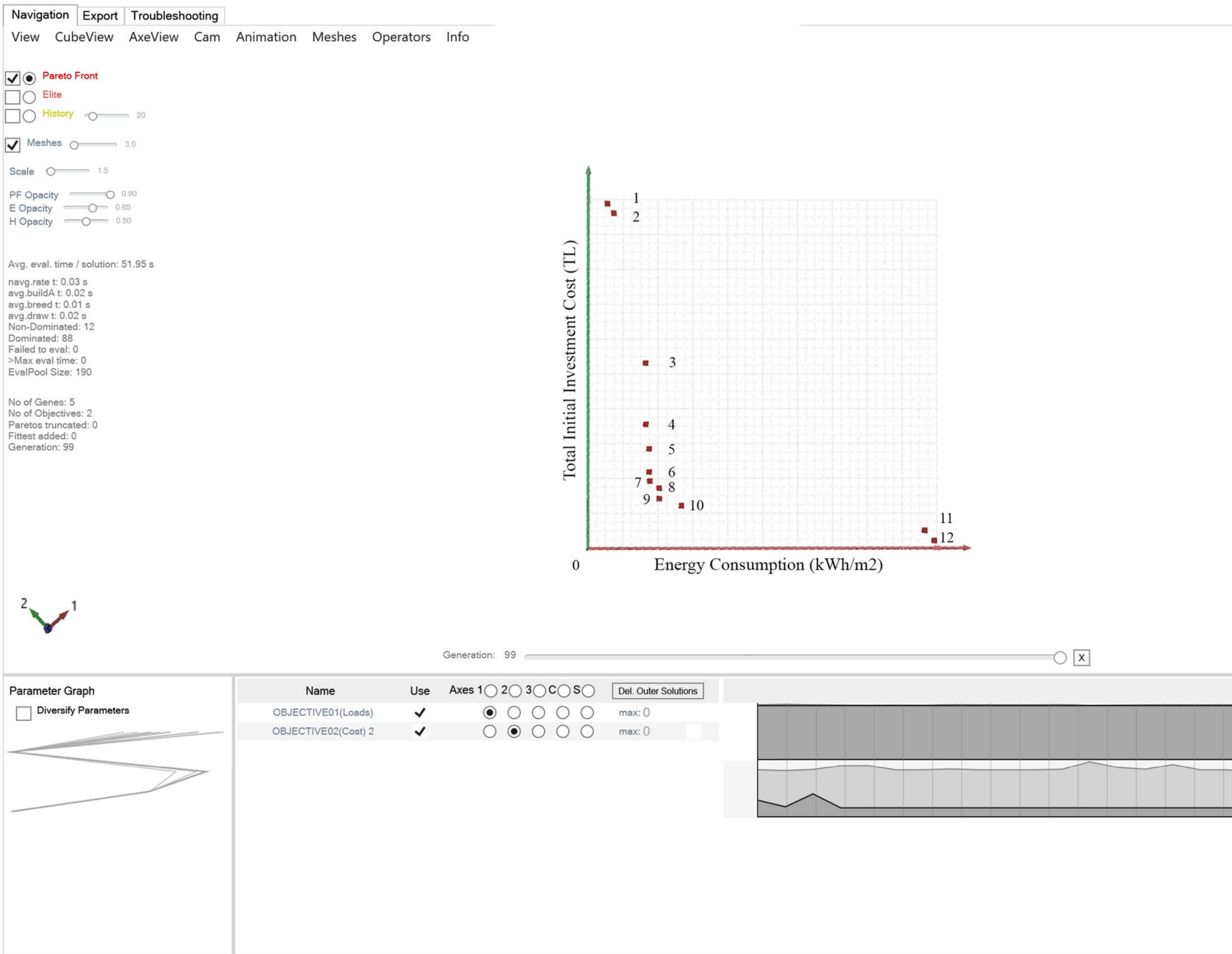


Figure 5.1. 99th Generation Non-Dominated Optimum Result in Octopus Interface

A clear pareto line can be obtained when it is desired to find results in the limit values range. However, in this study, costs and overall heat transfer coefficient values are not given between certain ranges and integrated into the energy model as net values. Therefore, a clear pareto line has not been obtained.

This study has 2 objectives. The first is the total heating and cooling loads, the second is the initial investment cost. In Figure 5.1, 99th generation non-dominated optimum results are shown graphically, and the numerical details of these results are given in Table 5.1.

Table 5.1. 99th Generation Objective and Refractions Result

	Objectives		Refractions	
	Energy Consumption Heating + Cooling (kWh/m2)	Initial Investment Cost (TL)	Cooling Load (kWh/m2)	Heating Load (kWh/m2)
1	32,0454	855718	9,0442	23,0012
2	32,6245	854948	9,0239	23,6006
3	33,3439	846378	9,5073	23,8376
4	33,3488	842864	9,5075	23,8412
5	33,4239	841469	9,9690	23,4549
6	33,4506	841055	9,9740	23,4767
7	33,4513	839630	9,9786	23,4727
8	33,6522	839225	9,9613	23,6909
9	33,6549	838629	9,9562	23,6987
10	34,1566	838224	9,9530	24,2037
11	39,6652	836799	13,9556	25,7096
12	39,9662	835798	13,9777	25,9892

According to these results, the building with the highest energy consumption consumes 39,96 kWh/m^2 annual energy and has an initial investment cost 835798 TL. The building with the lowest energy consumption consumes 32,04 kWh/m^2 annual energy and has an initial investment cost of 855718 TL. These two results are shown in Table 5.2. Between these two results; There is 7,92 kWh/m^2 annual energy consumption difference and 19920 TL initial investment cost difference. Considering the energy consumption for all apartments of the building (111,78*12=1341,36m^2) at 1341,36 m^2, the difference of 7,92 kWh/m^2 creates an annual energy consumption difference of 10624,64 kWh per year.

Table 5.2. 99th Generation Best and Worst Result

	Objectives		Refractions	
	Energy Consumption Heating + Cooling (kWh/m2)	Initial Investment Cost (TL)	Cooling Load (kWh/m2)	Heating Load (kWh/m2)
1	32,0454	855718	9,0442	23,0012
12	39,9662	835798	13,9777	25,9892

Thanks to this method, it has been calculated that an annual energy consumption of an apartment building can be reduced by 10624,64 kWh per year with an initial investment cost difference of 19920 TL. Considering that the kWh of the energy used in residential buildings in 0,50 cent, it will profit from an annual energy consumption of (10624,64 x 0,50=532,332 TL) 532,332 TL for a residential building.

As a result, by consuming less energy, less harm is done to the world on an urban scale and the price to be paid for energy consumption is reduced to benefit the family budget. In Table 5.3, the materials details of the 99th generation results are shown. This table includes material names and shows the overall heat transfer coefficient values. According to this list, PVC window frames, double and triple glazing are used. Air and argon gas differences were also observed in the spaces between the glazing. When the combinations of materials available in the 99th generation options are examined, it is seen that the most effective material that directly affects energy consumption and initial investment cost is windows. Details of window materials can be examined from Table 3.1.

Table 5.3. 99th Generation Decision Variable Details

	Decision Variables									
	Window Construction		Slab Construction		Roof Construction		Wall Construction		Ground Foundation Construction	
	Name	U Value (W/(m2K)	Name	U Value (W/(m2K)	Name	U Value (W/(m2K)	Name	U Value (W/(m2K)	Name	U Value (W/ (m2K)
1	P_Sisecam-LowE - Air (4-16-4-16-4)	1,0	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
2	P_Sisecam-LowE - Air (4-12-4-12-4)	1,2	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
3	P_Sisecam - SolarLowE - Argon (4-16-4)	1,4	A_No Insulation	2,169	D_Rockwool Board Insulation 12cm	0,47	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
4	P_Sisecam - SolarLowE - Argon (4-16-4)	1,4	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
5	P_Sisecam - LowE - Argon (4-16-4)	1,4	A_No Insulation	2,169	D_Rockwool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
6	P_Sisecam - LowE - Argon (4-16-4)	1,4	A_No Insulation	2,169	D_Glasswool Board Insulation 8cm	0,387	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
7	P_Sisecam - LowE - Argon (4-16-4)	1,4	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
8	P_Sisecam - LowE - Argon (4-12-4)	1,5	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
9	P_Sisecam - LowE - Air (4-16-4)	1,5	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
10	P_Sisecam - LowE - Air (4-12-4)	1,7	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
11	P_Ordinary Glass - Argon (4-12-4)	2,6	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69
12	P_Ordinary Glass - Air (4-12-4)	2,6	A_No Insulation	2,169	D_Glasswool Board Insulation 5cm	0,58	Pumice_18.9cm EPS 3cm	0,637	A_No Insulation	3,69

In the flooring materials that divide the flats, the use of uninsulated flooring was preferred because it is cost-effective and does not have much effect on the heating and cooling load. The thickness of this material is 12 cm and it is covered with ceramic on top, the details can be examined from Table 3.4.

In most options for the sloped roof material, 5 cm glasswool board insulation material was chosen under the shingle coating. This material is also seen to be balanced in terms of cost and overall heat transfer coefficient values. Details of the sloped roof materials can be examined from Table 3.3.

In all options for the wall material, 18,9 cm pumice block and 3 cm EPS heat insulation board material were chosen. According to these results, the wall type suitable for the İzmir climate region has been specified in terms of cost and overall heat transfer coefficient values from the defined wall options. Details of the wall materials can be examined from Table 3.2.

In the selection of ground foundation material, uninsulated material was chosen because it is cost-effective and not having much effect on the heating and cooling load throughout the building. Two types of ground foundation covering are defined, these are laminate and ceramic materials. The coating of the selected flooring material is ceramic as it is cost-effective. Details of the ground foundation materials can be examined from Table 3.5.

CHAPTER 6

6. CONCLUSIONS AND FUTURE WORK

Thanks to this study, the initial investment cost, total heating and cooling loads of the building were calculated before the construction of an apartment building in the Izmir climate region. This proposal can be applied in different climate zones and different building typologies. If implemented, it will improve the field and increase the variety of studies. In this way, faster and healthier progress will be made regarding the decisions to be made before the buildings are built. In addition, information about the energy consumption of buildings will be obtained.

When this application is desired to be applied in different regions, the details such as building characteristics, HVAC system, building materials lists and building schedules should change.

In different building typologies and climatic zones, studies can be made on which HVAC system can achieve optimum energy consumption and cost results. For this, it is necessary to include HVAC system details and cost information in the optimization process. After this information is added, it can be decided which HVAC system is the optimum based on the result of the optimization process.

There are no shading elements in or around the apartment building in this study. It is also possible to take a simulation of a building surrounded by buildings or with shading elements with different material combinations. Energy consumption and cost calculations can be made for a building with buildings around it and a building an empty space. In this way, it is decided which situation is beneficial.

In addition, in this study, total cost calculation was made using the initial investment costs of building materials and HVAC systems. However, for building materials and HVAC systems, different results will be obtained if building life cycle costs are used. For example, considering the building life cycle cost for HVAC systems, heat pumps with high initial investment costs and low energy consumption will be used. Because the low energy consumption of heat pumps compensates the high initial investment cost in the life cycle cost calculation.

Today, the carbon footprints of the materials, the energy spent while producing and the values of volatile organic compounds can be seen. In terms of developing this study, adding these values of the materials to be used in the next stages as a variable to the optimization process will show that the study area is more valuable.

With this method, energy consumption and cost results of different building types and construction material combinations in different locations can be obtained. Thanks to the acquisition of these values before the construction begins, decision making processes in many subjects become faster and easier. Finally, and most importantly, the studies carried out in this way include a scientific approach.

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