ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

BUILDING PERFORMANCE OPTIMIZATION THROUGH DESIGN DECISION PROCESS WITH A HOLISTIC APPROACH

M.Sc. THESIS

Duygu UTKUCU

Energy Science and Technology Division

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Thesis Advisor: Assoc. Prof. Dr. Hatice SÖZER

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

BÜTÜNSEL BİR YAKLAŞIMLA TASARIM SÜRECİ BOYUNCA BİNA PERFORMANS OPTİMİZASYONU

YÜKSEK LİSANS TEZİ

Duygu UTKUCU
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Enerji Bilim ve Teknoloji Anabilim Dalı

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HAZİRAN 2019

Duygu UTKUCU, a M.Sc. student of ITU Institute of Energy, 301161035, successfully defended the thesis entitled "BUILDING PERFORMANCE OPTIMIZATION THROUGH DESIGN DECISION PROCESS WITH A HOLISTIC APPROACH", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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__To my wonderful family,__

FOREWORD

I would like to express my sincere appreciation and thanks to my advisor, Assoc. Prof. Dr. Hatice SÖZER for her constant support, vision and all the valuable and constructive comments. In all manners, I have always motivated by her guidance, understanding, and positive criticisms to work harder. With her provision, new opportunities are created to improve myself.

June 2019 Duygu UTKUCU
(Environmental Engineer)

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ABBREVIATIONS

2D	: Two Dimension
3D	: Three Dimension
4D	: Four Dimension
AEC	: Architecture, Engineering, and Construction
AIA	: American Institute of Architects
API	: Application Programing Interface
ASHRAE	: American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	: Building Information Modeling
CAD	: Computer Aided Design
CFD	: Computational Fluid Dynamics
CURT	: Construction Users Roundtable
DHW	: Domestic Hot Water
DOE	: Department of Energy
DWG	: Drawing
DXF	: Drawing Interchange Format or Drawing Exchange Format
EUI	: Energy Use Intensity
GUI	: Graphical User Interface
HVAC	: Heating, Ventilating, and Air Conditioning
IAI	: International Alliance for Interoperability
IEA	: International Energy Agency
IEQ	: Indoor Environmental Quality
IFC	: Industry Foundation Classes
IGES	: Initial Graphics Exchange Specification
IPD	: Integrated Project Delivery
MDO	: Multidisciplinary Design Optimization
MEP	: Mechanical Electrical Plumbing
NEEAP	: National Energy Efficiency Acton Plan
OECD	: Organization for Economic Cooperation and Development
PD	: Percentage Dissatisfied
PMV	: Predicted Mean Vote
PPD	: Percentage of People Dissatisfied
PV	: Photovoltaic
SAT	: Standard ACIS Text
SIMPLE	: Semi-Implicit Method for Pressure-Linked Equations
TS	: Turkish Standard
VPL	: Visual Programing Language
WWR	: Window Wall Ratio
XML	: eXtensible Markup Language

SYMBOLS

$C_{\varepsilon 1}$	: Empirical Constants
$C_{\varepsilon 2}$	: Empirical Constants
C_{μ}	: Empirical Constants
g_x	: Gravitational Acceleration in x Directions
g_y	: Gravitational Acceleration in y Directions
g_z	: Gravitational Acceleration in z Directions
S_{DR}	: Sources Term for Distributed Resistance in Momentum Equations
S_{ω}	: Sources Term for Rotating Coordinates in Momentum Equations
μ_t	: Eddy Viscosity
σ_k, σ_{ε}	: Turbulent Schmidt Numbers
σ_t	: Turbulent Prandt Number
τ_{ij}	: Reynolds Stress Tensor
μ	: Molecular Viscosity
a	: Original Building
$E_{p,EP}$	: Building Energy Performance
EP	: Building Primary Energy Consumption Per Square Meter
k	: Turbulent Kinetic Energy
p	: Pressure
r	: Reference Building
r, θ, z	: Space Coordinate as Cylindrical
r, θ, ϕ	: Space Coordinate as spherical
t	: Time
U	: Mean Velocity
u,v,w	: Velocity Components Respectively x, y, z Direction
x, y, z	: Space Coordinate as Cartesian
ε	: Turbulent Energy Dissipation
ρ	: Density

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BUILDING PERFORMANCE OPTIMIZATION THROUGH DESIGN DECISION PROCESS WITH A HOLISTIC APPROACH

SUMMARY

The energy consumption is becoming a fundamental subject through the world due to increasing amount of consumption. When comparing to the other economic sectors, the buildings have significant amount of energy consumption which could be differing along countries. However, the energy usage percentage is around 30 and 45 of the global energy request. According to researches, these numbers will be increased in the future, which is depending on growing population, increase of building services and comfort demand. Therefore, the energy efficient buildings at regional, national and international levels are becoming to be prevalent purpose.

The energy efficient buildings have better energy performance. In order to achieve high performance buildings such as low-energy buildings, passive houses, green buildings, net zero-energy buildings, zero-carbon buildings, there is some considerations and tight necessities. During the building design process, the more design alternatives should be examined and should give enlightened multidisciplinary and interdisciplinary decisions by designers to reach high energy performance. For these concerns, there should be an optimization method during development of design objective, which offers an opportunity to design team to select a proper process.

The main objective of building performance optimization should be providing inhabitants better spaces in aspect to better indoor environment quality, thermal comfort and efficient energy usage. On the other hand, it requires detailed evaluations and visualizations in order to achieve the precise construction performance of various design alternatives in the context of the complexity of the Architecture, Engineering and Construction (AEC) processes as well as the integration of newly developed technologies.

Building Information Modeling (BIM) provides a platform to incorporate various stages of the design process for the investigation of buildings' performance. BIM platform includes all the characteristics of the building with its involved disciplines and systems. It offers a suitable platform for co-working between multidisciplinary and interdisciplinary during all process of the project. That supplies the collaborative process to optimize efficiency through building design stages. In addition, the BIM capability of modeling helps architects and engineers to examine various design alternatives. BIM-based interactive design methods is integrated with dynamic architecture in order to suggest a systematic design decision process. When used BIM for building energy performance analysis, it not only saves considerable time and effort but also reduces inconsistencies and mistakes because of BIM conserve necessary information about energy performance analysis. Thus, this method becomes an encouraging way to obtain various design purposes for architects and engineers.

In this study, the aim is to generate the building design optimization method based on BIM. The proposed methodology is applied for building energy performance in aspect to design, thermal comfort, and energy consumption within the various design alternatives. During the implementation of the proposed methodology in a case study, different tools and their applications has been used. Thus, another objective for this study is to emphasize the interoperability between used tools with BIM approach. The proposed methodology is consisted of three design stages, which have different purposes and considerations. Although, each design stages have own purposes and considerations, they are connected and dynamically influenced with each other. To sum up, the proposed methodology within BIM platform is handling as a holistic approach with the consideration of building energy performance optimization through the building design process.

In detail, the proposed building design optimization methodology has the conceptual, schematic, detail design stages. In the conceptual design stage, the building envelope related to windows size and window wall ratio (WWR) optimization is aimed. For this aim, the 3D conceptual model and the dynamic relations according to windows size and WWR have been created. The purpose of the schematic design stage is the model based predicted energy performance and its optimization. In this context, the daylighting and solar radiation analysis have been conducted. Also, the building parameters which are effected building energy performance have been examined according to the divided classes which are insulation integration, lighting & HVAC, and PV integration. Thus, the model based predicted energy performance and its optimization has been occurred on energy use intensity (EUI) results. In the detailed design stage, the investigation of design quality with standards and criteria in respect to indoor air quality, human comfort conditions and energy consumption is the goal. Therefore, the computational fluid dynamics (CFD) analysis and detailed energy analysis has been carried in the detailed design stage. For this goal, the natural ventilation has been examined via CFD analysis. The CFD analysis has its own methodology which contains the integration of 3D building model and CFD model with BIM platform. The main objective in the detailed design analysis is to determine exact energy consumption and building energy class. Owing to this purpose, the detailed energy analysis has been conducted. The results from CFD analysis has been evaluated for the detailed energy analysis as an input. Finally, the calculated building energy performance and the comparison with standard, the building energy class has been figured out.

The results from the implementation of proposed methodology on a case study shown that there were 11664 design alternatives with the consideration of windows size and WWR in the conceptual design stage. The maximum windows size and WWR has been choose for the schematic design which is next design development stage. The daylighting analysis results indicated the possible use of daylighting which passed 75 % at morning and the 27 % of towards the evening. The solar radiation analysis outcomes showed annual solar radiation gains of Niğde house roof surface outcome with average 11 kWh/m^2 thus the PV integration could be beneficial for this building. The model-based predicted energy performance and its optimization exhibited that could be reached up to 75 % of energy saving with the adjustment of building input parameters as insulation integration, lighting & HVAC, and PV integration. The CFD analysis showed that natural ventilation was the acceptable level for the human sensation as PMV between 0 and 3. Therefore, it could be considered that there is no need for the cooling system for in summer times. The detailed energy analysis result was 17865 kWh as annually total energy consumption. The building energy performance should be quantitatively obtained in order to investigate the building design quality within standard. For this reason, the reference building has been developed according to standard and compared the building and reference building as annual primary energy consumption. The detailed energy analysis put forward that the energy performance class of building was in A class. Consequently, the proposed methodology for optimizing the building performance with a holistic approach through the decision making process has been implemented on a two story hypothetical building design. Finally, a high level energy efficient building has been generated.

BÜTÜNSEL BİR YAKLAŞIMLA TASARIM SÜRECİNDE BİNA PERFORMANS OPTİMİZASYONU

ÖZET

Enerji tüketimi, artan tüketim miktarından dolayı dünya genelinde temel bir konu haline gelmektedir. Diğer ekonomik sektörlerle karşılaştırıldığında, binaların enerji tüketimleri yüksek miktarlardadır. Her ne kadar enerji tüketim miktarları ülkeler arasında farklılık gösterse de, binalarda enerji kullanım yüzdesi küresel enerji talebinin yaklaşık 30'u ve 45'i kadardır. Araştırmalara göre, artan nüfus, bina hizmetleri ve konfor talebine bağlı olarak gelecekte bu rakamların artacağını öngörülmektedir. Bu nedenle, bölgesel, ulusal ve uluslararası düzeylerde enerji verimli binalar gün geçtikçe yaygın bir amaç haline gelmektedir.

Enerji verimli binalar, üst seviye enerji performansına sahiptir. Düşük enerjili binalar, pasif evler, yeşil binalar, net sıfır enerjili binalar, sıfır karbonlu binalar gibi yüksek performanslı binalar elde etmek için bazı hususlar ve zorlu gereksinimler vardır. Ayrıca, bina tasarım sürecinde daha fazla tasarım alternatifi incelenmeli ve yüksek enerji performansına ulaşmak için tasarımcılar tarafından aydınlanmış birbirinden farklı çok disiplinli ve disiplinler arası kararların verilmesi gerekmektedir. Bu gereksinimler doğrultusunda, tasarımının geliştirilmesi sırasında tasarım ekibinin uygun bir süreç ve tasarım alternatifi seçmesi için bir optimizasyon yönteminin olması ve en uygun tasarım alternatifini seçmesi gerekmektedir.

En uygun bina tasarım alternatifini seçerken, bina performansı optimizasyonunun temel amacı, daha iyi bir iç ortam kalitesi, ısıl konfor ve verimli enerji kullanımı için sakinlere daha iyi alanlar sağlamak olmalıdır. Öte yandan, mimarlık, mühendislik ve inşaat süreçlerinin karmaşıklığı ve yeni geliştirilen teknolojilerin bu alana entegrasyonu açısından, çeşitli tasarım alternatiflerinin kesin yapım performansını elde etmek için detaylı değerlendirmeler ve görselleştirmelere gereksinim duyulmaktadır.

Bu kapsamda, Yapı Bilgi Modellemesi (BIM), bina performansının araştırılması için tasarım sürecinin tüm aşamalarını içeren bir platform sağlamaktadır. BIM platformu, binanın tüm özelliklerini, ilgili disiplinlerini ve sistemlerini bir arada kapsamaktadır. Projenin tüm süreçlerinde çoklu disiplinler ve disiplinler arası işbirliği için uygun bir platform sunmaktadır. Böylece, bina tasarım aşamalarında verimliliği optimize etmek için uygun işbirliği süreci sağlanır. Ayrıca, BIM'in modelleme yeteneği, mimarların ve mühendislerin çeşitli tasarım alternatiflerini incelemelerine yardımcı olur. BIM tabanlı etkileşimli tasarım yöntemleri, sistematik bir tasarım karar süreci önermek için dinamik mimariyle bütünleştirilir. Bina enerji performansı analizi için BIM kullanıldığında, sadece zaman ve emek tasarrufu sağlamakla kalmaz, aynı zamanda BIM enerji performans analizi hakkında gerekli bilgileri koruduğu için tutarsızlıkları ve hataları da azaltır. Böylece, bu yöntem mimarlar ve mühendisler için çeşitli tasarım amaçlarını oluşturmada cesaretlendirici bir yol haline gelmektedir.

Bu çalışmada amaç, BIM tabanlı bir bina tasarım süreci optimizasyon yönteminin oluşturulmasıdır. Önerilen yöntem bina tasarımında enerji performansı çeşitli tasarım alternatifleri dâhilinde tasarım, ısıl konfor ve enerji tüketimi için uygulanmaktadır. Önerilen bu yöntemin bir vaka çalışmasında uygulanması sırasında, farklı araçlar ve bu araçlara ait uygulamalar kullanılmıştır. Dolayısıyla, bu çalışmanın diğer bir amacı, BIM yaklaşımı ile kullanılan bu araçların arasındaki birlikte çalışabilirliği vurgulamaktır. Önerilen yöntem, farklı amaç ve değerlendirmelere sahip üç tasarım aşamasından oluşmaktadır. Her tasarım aşamasının kendine ait amaçları ve değerlendirmeleri olmasına rağmen, birbirleriyle bağlıdırlar ve birbirlerini dinamik olarak etkilenirler. Özetlemek gerekirse, BIM platformunda önerilen yöntem, bina tasarım süreci boyunca bina enerji performansının optimizasyonunu dikkate alınarak bütüncül bir yaklaşım ile ele almaktadır.

Önerilen yöntem ayrıntılı olarak incelendiğinde, bina tasarımı optimizasyon yöntemi üç ana tasarım sürecini içermektedir bu süreçler kavramsal, şematik, detaylı tasarım aşamalarıdır. Kavramsal tasarım aşamasında, pencerelerin boyutlarını ve pencere duvar oranını (WWR) içermekte olup bina zarfının optimizasyonunu amaçlanmaktadır. Bina zarfı optimizasyonu için, 3B kavramsal model ve bu model üzerinden pencere büyüklüğüne ve pencere duvar oranına bağlı dinamik ilişkiler kurulmuştur. Şematik tasarım aşamasının amacı, model tabanlı öngörülen enerji performansı ve onun optimizasyonudur. Bu kapsamda gün ışığı ve güneş ışınımı analizleri yapılmıştır. Ayrıca, bina enerji performansını etkileyen bina parametreleri yalıtım entegrasyonu, aydınlatma & HVAC ve PV entegrasyonu olarak ayrılmış olan üç sınıfa göre incelenmiştir. Bina giriş parametreleri bu üç sınıf göz önünde bulundurularak değiştirilmiş ve değişime karşılık gelen enerji kullanım yoğunluğuna (EUI) göre inceleme yapılmıştır. Böylece model tabanlı öngörülen enerji performansı ve öngörülen enerji performansının optimizasyonu enerji kullanım yoğunluğu sonuçlarının değişimine göre gerçekleşmiştir. Detaylı tasarım aşamasında ise, tasarım kalitesinin iç mekân hava kalitesi, insan konforu koşulları ve enerji tüketimi ile ilgili standartlar ve ölçütlere göre araştırılması amaçlanmaktadır. Bu nedenle, detaylı tasarım aşamasında CFD analizi ve detaylı enerji analizi yapılmıştır. Bu doğrultuda, doğal havalandırma CFD analizi ile incelenmiştir. CFD analizi, 3B bina modelinin ve CFD modelinin BIM platformuyla entegrasyonunu da kapsayan kendine ait bir metodolojiye sahiptir. Detaylı tasarım analizinde temel amaç, binanın kesin enerji tüketimini belirlenmek binanın enerji sınıfını ortaya koymaktır. Bu amaçla, detaylı enerji analizi yapılmıştır. CFD analizinden elde edilen sonuçlar, ayrıntılı enerji analizi için girdi olarak değerlendirilmiştir. Bu nedenle detaylı enerji analizinin de kendine ait bir yöntemi vardır. CFD analizi ve detaylı enerji analizi yürütülürken, bu analizlere ait kendi yöntemlerini doğrultusunda CFD modeli ve enerji modeli oluşturulmuştur. Bu nedenle çalışmada, önerilen bina tasarım optimizasyonu yönteminin son aşaması olan detaylı tasarım aşamasında gerçekleştirilen CFD ve detaylı enerji analizleri ayrı ayrı bölümler halinde ele alınmıştır. Neticede, hesaplanan kesin bina enerji performansı ve bina enerji performansının standart ile karşılaştırması sonucu bina enerji sınıfı tespit edilmiştir.

Bu çalışma kapsamında önerilen yöntemin bir vaka çalışmasına uygulanmasından elde edilen sonuçlara göre, kavramsal tasarım aşamasında pencerelerin boyutları ve pencere duvar oranı (WWR) arasında kurulan dinamik ilişki dikkate alınarak 11664 tasarım alternatifinin olduğu gözlenmiştir. Bir sonraki tasarım geliştirme aşaması olan şematik tasarım için maksimum pencere boyutu ve pencere duvar oranına (WWR) sahip olan tasarım alternatifi seçilmiştir. Günışığı analizinin sonucuna göre, sabah saat

9’da gün ışığının % 75’i geçmiş ve gün ışığının bina içinde oluşturduğu aydınlanma şiddeti çoğunlukla yaklaşık olarak 1400 lüks ile 2700 lüks arasındadır. Akşamüstü saat 3’te gün ışığının % 27’si geçmiş ve gün ışığının bina içinde oluşturduğu aydınlanma şiddeti 2000 lüks ile 4000 lüks arasındadır. Bu sonuçlar ışığında, gün ışığı kullanımının makul bir seviyede elde edilebileceği ve gün ışığı kullanımının mümkün olduğunu göstermiştir. Güneş radyasyonu analizinin sonuçları ise binanın çatısı yüzeyinde yıllık ortalama 11 kWh / m^2 güneş enerjisi radyasyonu kazanımının olacağını göstermektir, bu sonuçlara göre PV entegrasyonunun bu bina için faydalı olabileceği söylenebilir. Bina giriş parametrelerinin yalıtım entegrasyonuna, aydınlatma & HVAC sistemlerine ve PV entegrasyonuna bağlı olarak değiştirilmesi sonucu model tabanlı öngörülen enerji performansı ve onun optimizasyonu gerçekleştirilmiştir Model tabanlı öngörülen enerji performansı optimizasyonuna göre enerji kullanım yoğunluğunda % 75'e ulaşabilen kümülatif bir enerji tasarrufunun olabileceğini göstermiştir.

Doğal havalandırma incelenmesi için bina zarfı üzerinde bulunan açıklıkların kullanıcılar tarafından yönetildiği varsayılmış ve bu operasyonel bina zarfının optimizasyonu için dört senaryo oluşturulmuştur. Dört senaryo, doğal havalandırma ile sağlanabilecek en uygun iç ortam hava kalitesi ve insan termal koşulu için hava hızı, sıcaklık, PMV ve PPD değerleri bağlamında CFD analizinde incelenmiştir. CFD analizi sonuçlarına göre, doğal havalandırma 0 ile 3 arasında PMV olarak ölçülen insan hissi için senaryo 2’de kabul edilebilir bir seviyede olduğunu göstermiştir. Bu nedenle, bina tasarımına senaryo 2’deki açıklıklar kullanılarak devam edilmiş ve yaz aylarında soğutma sistemine ihtiyaç duyulmayacağı varsayımında bulunulmuştur. Ayrıntılı enerji analizi binanın yıllık toplam enerji tüketiminin 17865 kWh olduğunu göstermiştir. Bina tasarım kalitesini standart dâhilinde incelemek için bina enerji performansı nicel olarak elde edilmelidir. Bu sebeple referans bina “Binalarda Enerji Performansı Ulusal Hesaplama” standarda göre geliştirilmiş ve bina ile referans binanın yıllık birincil enerji tüketimleri karşılaştırılmıştır. Detaylı tasarım aşamasının sonunda, binanın enerji performans sınıfının A sınıfında olduğu ortaya konmuştur.

Sonuç olarak, bina performansını optimize etmek için önerilen yöntem, karar verme süreci boyunca bütünsel bir yaklaşımla iki katlı bir varsayımsal bina tasarımı üzerinde uygulanmıştır ve yüksek düzeyde enerji verimli bir binanın nihai tasarımı oluşturulmuştur. İstenilen performansı elde etmek için farklı araçlar ve uygulamaları kullanılmıştır. BIM yaklaşımı ile birlikte çalışabilirliğin, bu çalışma sırasında kullanılan programlar arasında vurgulanması amaçlanmıştır. Böylece, farklı yazılım entegrasyonunun komplikasyonu BIM bazlı önerilen yöntem ile elimine edilebilir. Çok disiplinli ve çok amaçlı bir yaklaşım olan bina tasarım süreci BIM platformu aracılığıyla optimize edilebilir. Pasif teknikler ve estetik kaygılar içeren bina zarfı tasarımı, önerilen yöntemde mimari açıdan geliştirilebilir ve optimize edilebilir. Ayrıca, CFD yaklaşımı BIM platformunun entegrasyonu ile uygulanılmıştır. CFD analizinin sonuçları dikkate alınarak, tasarım aşamasında uygun soğutma ve havalandırma sistemi binaya entegre edilebilir. Mimarlar ve mühendisler açısından, çok disiplinli bina tasarım süreci BIM platformu ile ele alınmaktadır.

1. INTRODUCTION

The optimization is getting popular along in the architectural, engineering and construction (AEC) industry thanks to the importance of it which helps to figure out the intended properties of buildings designs like making building aesthetic and so on. The optimization process at the beginning of the design stage is said to be most commonly; however, it has the same importance in the late-design stage. The importance of it in the early stage of design is the creation of plenty of alternatives. In the late-design stage, the benefit of it is the best selection of building control depended on model-predictive control strategies [1].

In addition, the simulation based optimization is getting a productive precaution for high performance buildings like low-energy buildings, passive houses, green buildings, net zero-energy buildings, zero-carbon buildings to meet various tight necessity. The simulation-based optimization method during development of design objective for instance indoor environment quality or building energy consumption offers an opportunity to design team to select a proper process that could supplied their time budget, resources and design objectives [2].

There is huge amount of decision parameters when considered building such as building envelope, the heating, ventilating and air conditioning HVAC systems and etc. The main targets of building performance can be listed as the reduction of environmental influences, cost, and equipment size, also maximization of indoor air quality and energy efficiency [3]. For design team, the building design is a comprehensive owing to counterpoise multiple parameters with diverse constraints. Therefore, the performance simulation tools and optimization methods have been used to support a decision. The optimization method could be implemented in several building design problems for instance massing, orientation, façade design, thermal comfort, daylighting, lifecycle analysis, structural design analysis, energy, and cost. [4]. The major areas which center upon optimization and sustainable building design are building envelopes such as construction, and form, building systems as design, control, and lighting, also generation of renewable energy. The building facade and shape are an obstacle for heat, light, and air; so that, it should be cautiously designed to reach upper-level building performance. The shape of a building is not easy indicated as a simple parameter. The HVAC and lighting systems should be carefully configured and efficiently controlled due to the effect of the high amount of energy consumption [5]. Furthermore, when used Building Information Modeling (BIM) for energy performance analysis, it could save considerable time and effort and reduce inconsistencies and mistakes because of BIM conserve necessary information about energy performance analysis [6]. Thus, this method becomes an encouraging way in order to obtain various design goals for architects and engineers.[2].

Consequently, the more concern about environmental aspect also technological developments on computational tools and methods affect designers to build better energy performance building designs. Having an upper-level energy performance to examine more design alternatives and give enlightened decisions by designers could be reached by multidisciplinary simulation-based optimization [7]. BIM can offer a complete and sustainable solution and decisions via digitalization of product and process information to optimize energy efficiency during the entire lifecycle [5]. Further, BIM helps to create energy efficient, healthier, and nature friendly buildings with respect to sustainability thorough the design process.

1.1. Purpose of Thesis

Performance-based building design approach has been investigated to establish a multi and interdisciplinary working skim for the building performance optimization. The main objective of the design process is to provide inhabitants better spaces within their urban context. The complication of Architecture, Engineering, and Construction (AEC) processes, as well as integration of newly developed technologies into it, require detailed assessments and visualizations for achieving precise building performance of various design alternatives. Currently, Building Information Modeling (BIM) provides a platform to incorporate various stages of the design process for the investigation of buildings' performance. In addition, the platform's capability of modeling helps architects and engineers to examine various design alternatives. To this extent, BIM-based interactive design methods can be integrated with dynamic architecture in order to suggest a systematic design decision process that enables buildings to respond to specific seasonal climate changes and integration of new technology. BIM is utilized not just as a model, also as a platform that includes all the characteristics of the building with its involved disciplines and systems. It offers a suitable platform for co-working between multidisciplinary and interdisciplinary during all process of the project. That supplies the collaborative process to optimize efficiency through building design stages.

In this research, the goal is the optimization methods which based on BIM are applied for optimization of the building performance by means of design, thermal comfort, and energy consumption within the different design alternative. Moreover, the interoperability with BIM approach is aimed to emphasize in between used programs during this study. For this purpose, this thesis prepared by following sections.

Chapter 4: Building Design Process Optimization

In the building design process optimization, the main purpose is the optimization of building envelope related to windows size and window wall ratio in the conceptual design stage and the optimization of building energy performance via model-based predicted energy performance and its optimization corresponding with energy use intensity (EUI) in the schematic design stage. Beside model-based predicted energy performance, the daylighting and solar radiation were intended to analyze in the detailed design stage.

Chapter 5: Computational Fluid Dynamic Analysis

In the computational fluid dynamics analysis, natural ventilation has aimed the investigation of design quality with standards and criteria related to human comfort and indoor air quality. In this context, the computational fluid dynamics (CFD) analysis structured to analyze the indoor air quality and thermal comfort conditions in the detailed design stage. In addition, the CFD analysis handled to optimize the building design criteria process on the basis of indoor air quality and thermal comfort conditions as a whole.

Chapter 6: Detailed Energy Analysis

The detailed energy analysis aimed to conduct a quantitative investigation based on design quality with standards and criteria related to energy consumption and building energy class in the detailed design stage. The detailed energy analysis was conducted to examine exact quant energy usage and building energy performance.

2. LITERATURE REVIEW

There is an enormous request to obtain better building energy performance without any sacrificing of comfort, cost, aesthetics, and other performance considerations. Therefore, the improvement of strategies and technologies for the development of energy efficiency are growing. In the early building design stages, there is plenty of decisions impact strongly on building performance during all process. The selection of proper design options and integration is important as well as the building performance related to comfort and energy is getting the significance. Hence, the building simulation abilities are requiring to support decision through the design process [8].

Kalay was explained that performance-based design process. This process obtains the qualitative solution for specific unification of form and function in particular condition rather than process based paradigms. Moreover, the quality could be only detected with multi-criteria and multi-disciplinary performance evaluation [9]. The performance-based design approach has been getting a significance for architecture in order to determine the building energy performance. The design process of existing net zero energy buildings had been depended on performance-based decisions which contain *"all aspects of passive building design, energy efficiency, daylight autonomy, comfort levels, renewable energy installations, HVAC solutions, in addition to innovative solutions and technologies"*. Hence, the various design alternatives and parameters related to performance had been determined in the early design stage for net zero energy buildings [10]. To sum up, the performance-based design considers buildings performance respect to environmental as well as design functions and aesthetics. The performance-based design underlines combination and extensive optimization of diverse measurable building performances [11].

2.1. Building Performance Optimization

The aim of building performance optimization is choosing the optimal solutions along existing alternatives for a design [1]. Indeed, building performance optimization is a multidisciplinary and multi-objective process. The aim of multidisciplinary optimization is finding the optimal value along a set of design variables which are connected with different engineering disciplines. The inputs of one or more than one disciplinary can be as the outputs of others. Also, the opposite of this situation can happen [12]. The multidisciplinary optimization gives a method for performance feedback in the design process, inventive design domain, and making the decision between multiple design parameters [7]. On the other hand, the aim of multi-objective optimization that identification of optimum design which overs minima or maxima of multiple objective functions. The objective of multi objective optimization is the connection of objective function of multiple objectives which could be or not be one or many disciplines. These multiple objective functions have usually included the maximization of performance and the minimization of costs which in case opposite objectives of each other [12].

There are various simulation programs for the detailed building simulation models. All of these tools can simulate building physics phenomena and processes. The data as climatic data, building geometry, materials, occupancy and schedules, HVAC description and operation are often used for inputs. The energy usage, thermal comfort metrics, daylight utility and information about environmental such as the equivalent CO_2 emissions are usually as output [4].

Flager and Haymaker compered the AEC industry and aerospace industry which uses fully multidisciplinary design analysis and optimization processes. The results are indicated that multidisciplinary design optimization (MDO) process needs longer setup time; however, it is more efficient aspect of execution as generating of options and running analyses, management, and reasoning which interpreting results, choosing options [13].

In study of Geyer and Rueckert, they had investigated a prototype to implicate the multidisciplinary optimization process on structural design of a frame hall. The results had showed applicability of multidisciplinary design optimization on load-bearing building structure. It offered backing judgments about how utilization of I-beams or a truss system and utilization of sheet metals as main material or supportive construction. It had helped to choose distance between the frames of the hall [14]. In Flager and coworkers of study, a classroom in San Diego were designed in aspect for design for its structural integrity, energy consumption, daylighting and initial capital and life-cycle costs. The aim of this study was to minimize the capital cost of the building's steel frame and minimize the life-cycle cost for the building's operation. The result of multidisciplinary optimization shows that having best optimal cost design becomes with high capital cost. One of the importance of this study for future case are; how integrate and automate applications such as lighting, computational fluid dynamics (CFD), and other AEC tools [15].

Yang and Bouchlaghem are examined that the pertinence of MDO methodology in building design. According to MDO method which could be decreased time and cost via split a system into smaller subsystems in order to operate efficaciously interactions, they created a framework for assistance of multiple disciplinary tasks and organization of conflict design objectives. Further, they applied this framework on a simple mathematical example. In conclusion, this framework offers a way that two-cycle multilevel structure for complex multidisciplinary optimization problems [16].

To investigate energy efficient design alternative via usage of parametric design and multi-disciplinary design optimization at schematic level, a tool was evolved by Gerber and et al. The aim of this tool was suppling consistently detect design alternatives by a multidisciplinary design. The production and estimation of highly coupled design solution spaces was a dependency of this tool. It was applied on the suppositional and real case studies to show the performance of this tool [17].

The Evolutionary Energy Performance Feedback for Design as a framework was created to promote design decision at early stage via feedback among parameterization, automation, and multi-objective optimization by Lin and Gerber. Two experiments were conducted for the examination of this frame work. The results were concluded as a best practice for designer to measure multiple design alternatives with changed complex performance objectives [18], [19].

There is another study that had investigated to minimize energy usage as well as maximize daylighting level in a residential building via implementation of building performance optimization. Also, it has served a framework for optimization of multiple objectives between multiple disciplines. The outcome of this work shows that applicability of building performance optimization on further studies [7].

The conceptual designing of sports facilities has been using multiple engineering performance feedbacks such as the performance of daylighting, energy and structure to make a decision of architectural design. Yang et al. have mainly aimed to examine an operative and productive computational design optimization approach in the conceptual design of sports building envelopes [20].

2.1.1. Obstacles for building performance optimization

It is said that optimization offers a way for the upper-level building performance design. On the other hand, the implementation of optimization is rarely due to its complexity. The enormous multidisciplinary connected parameters for optimization of building performance and the complicated building simulation results bring with complexity. Moreover, this huge number of multidisciplinary interrelated parameters usually could be obscure. In addition to these unknown parameters, the esthetic factor is involved in the optimization process. Because of that the optimization outcomes could be improper [7].

Another objection for usage of building performance optimization is that there is not a suitable tool for it. The interoperability of different software tools has required in order to estimate building performance by designers. Integration of different tools is found insufficient along majority. In other point of simulation based optimization of building performance, it has necessary of severe time due to all of the design alternatives need multiple simulation runs [7]

2.2. Building Performance Simulation

The building simulation programs are used widely by building professionals. Building simulations can be applied in the life cycle analysis of a building which covers building design, construction, operation, maintenance, and management. The multidisciplinary building design covers various professions such as architects, and structural, mechanical and electrical engineers, also different building simulation programs are required at any stages of building [21]. The computer-based model and simulation technology serves a connected way with architectural, mechanical, and civil engineering topics [22].

The building performance simulations which are solving a small subset of the whole subject is getting inadequate for the advanced architectural. With the integrated design approach, the holistic building characteristics can be acquired. In this aspect, a building can be examined by an integrated approach as heating, lighting, ventilation, and acoustics domains to understand complete behavior of building with these different domain interactions [23]. Therefore, an integrated building design system can be useful for integrating different building simulation programs and exchanging data [21].

2.2.1. Multiple domain simulation approach

A building design with a holistic approach is needed a method for prediction of building performance which is occurred by interactions within various technical domain. The integrated design approach was getting a necessity for architectural developments so that the multiple domain methods were defined four program categories as stand-alone, interoperable, coupled or linked, and integrated programs aspect of simulation capability by Citherlet. In the stand-alone programs, simplest multi domain simulation, utilize varied unrelated applications. Therefore, there are different model for each application. The interoperable programs allow the sharing data between different computer tools without interactively exchanging among simulations. The interoperable applications could use a model exchange approach or a model shared approach. *"Model exchange: The applications exchange a model, in whole or part, by using a data exchange facility generally based on a standardized file format. Model sharing: Model sharing allows the domain specific applications to extract the data required for their own purpose from a single data management system that holds both the geometrical and physical parts of the model"* [23]. The major benefits of model exchange approach mentioned to be higher efficiency and less necessary data when creating building model. Though, various unique models by different applications need to be refreshed during project changes. In model shared approach, there is only one building model shared along all applications, therefore; this brings an unspecified task to handle parallel access to the same data source [24]. In coupled or linked programs, there are linked programs related to cooperation during runtime. Usually, there is one control application for simulation and control application evokes others when needed. The significance of this approach is to promote data exchange while simulating, which differ from former approaches. In integrated programs, there are simulating differ domains into same program. Like coupled or linked programs, the data exchange during simulation is also supported by integrated programs. The importance of this approach are easier data management due to only one model for multiple domain simulations. There is not needed exchange file format. If there are some modifications, they should only be applied once [23].

Moreover, there are necessities about consideration of building and its related systems as a whole, instead of summarization of segregated systems, to supply large-scale developments on indoor environment and energy consumption. However, the common issue for performance simulations is to not be a single simulation environment. Further, the levels of shared information for building performance simulation software helping the integration of multiple domains into a simulation environment were defined as "*data and process model integration, data model interoperation, process model interoperation, also data model and process model co-operation*" [25]. Data and process model integration is depended on different subdomains in the same program in order to support simulation of these different domains. Data model interoperation is achieved interoperability level of product model as building and systems. There are two approaches in data model interoperation; one of them is product model data sharing, other is product model data exchange. In product model data sharing, the data is taken out a single data management system which keeps the model geometry and physical parts from specific domain applications according to their own aim. The excess data is prevented with the product model data sharing; however, the inconsistency cannot be eliminated totally. In product model data exchange, the totally or partly data exchange from model is progressed by standardized neutral file format. The model geometry is represented by IGES, Initial Graphics Exchange Specification, or DXF, Drawing Interchange Format or Drawing Exchange Format, format. On the other hand, the model geometry and physical parts are represented with IFC, Industry Foundation Classes, via IAI, International Alliance for Interoperability. Also, the eXtensible Markup Language, XML, is utilized to exchange data of product model over the web [22]. In process model interoperation, the interoperation is carried between physical processes models like thermal and flow. In data model and process model co-operation, the data exchange is reached with the help of cooperated applications during runtime [25].

2.2.2. BIM based optimization approach

When the optimization method with the BIM approach applies to the real building, interdisciplinary thinking arises an important role. The engineering knowledge and methods should be integrated with human-science-based techniques so as to collect data and comment for the building [5]. Asl, Zarrinmehr, and Yan have studied the BIM-based building energy performance analysis and optimization. These energy performance analysis and optimization have mainly focused on the organization of input data for energy simulation, implementation of energy simulation, the invention of a methodology. This methodology contains modeling and algorithms for building energy optimization, and automatization of building energy performance optimization with the BIM-based model [6]. To enabled integration of parametric BIM and improve its usability on innovative, continuous building design via simulation and optimization, the case study was conducted with optimized window sizes. Also, it was ended up with minimized energy utility [6].

Petri et al. have aimed to use BIM for optimization of energy during the operation phase. They had determined the influence of the BIM approach which includes accurate energy monitoring, real-time decision support systems, actuators and identification of consumptions. The optimization sets were defined to maintain the human comfort level. The thermal load simulation tool had generated lighting, daylighting, HVAC, service water heating, and other building performance simulations. This study shows the future potential of BIM for energy efficiency as multi-disciplinary integrative capacity, sustainability design, reaching modeling standards, use of BIM for retrofitting to maximize energy efficiency, monitor building performance and achieve sustainable outcomes [5].

2.3. Building Information Modeling (BIM)

Building Information Modeling (BIM) as a process begins with creating an intelligent 3D design model that features the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories, and project schedule. Also, the entire building life cycle is represented by the model. In the next phase, BIM will not just a model that includes all the features, disciplines and systems. It will allow all design team members to collaborate more accurately. It will supply the collaborative process to reduce waste and optimize efficiency through all phases of the project life cycle [26].

Furthermore, BIM can be thought of as a product, as a collaborative process. As a product, BIM helps to represent each object in the project within 3D models. Therefore, the model would include more information intensive objects during project evolves. Thanks to this visualization model, the physical conflicts could have been reduced before physical project development. Also, this property provides a central data which can be accessed throughout the project at all times by the stakeholders. When considering as a collaborative process, BIM is becoming as a process that covers business drivers, automated process capabilities and information sustainability. By the help of interoperability and information exchange made easy by BIM, it could reduce demanded information from and between stakeholders. Information exchange among stakeholders helps to improve efficiency [27]. Another word, the building performance with the virtual modellings could be simulated for architects and engineers by computer-based product modeling or Building Information Modeling. Many of the performance parameters such as architectural, structural, mechanical as energy aspect, acoustical, lighting, and others could be performed by these models. Moreover, building orientation, massing, and system selections like having an important effect on lifecycle and environment, are adjusted in the early design stage [13].

According to these aspects, BIM is investigated as respect to collaborative process and technology product in project design. The influences of BIM on the multidisciplinary work during the project process and the interoperability of BIM between building performance simulations is enlarged apart in following to understand comprehensively.

2.3.1. BIM and project process

Unlike the conventional project process which attempts to separate disciplines with probable incomplete design objectives, the integrated and collaborated project process is more desirable for sustainable and high energy performance buildings. In this aspect, the Construction Users Roundtable (CURT) offered a collaborated and information integrated project lifecycle procedure for AEC industry. The *"fast, efficient, effective, and cost-bound buildings*" has been aimed with the fully collaborated and information integrated project process. Also, it had offered an effective making decision chance for collaborators with changing analysis, design, and decision-making process. The concept of this project process is shown in Figure 2.1 which represents effort/effects vs conventional design and construction phases [28].

The design effort in conventional process distribution shows that most of the information evolved in construction documentation stage. However, the suggested project proses distribution shows that design information is collected, connected and documented with all in the early design process. Hence, the design information in early design phases gives maximum chance in order to realize the influences such as consumption energy also the assistance of selection optimum decisions [28].

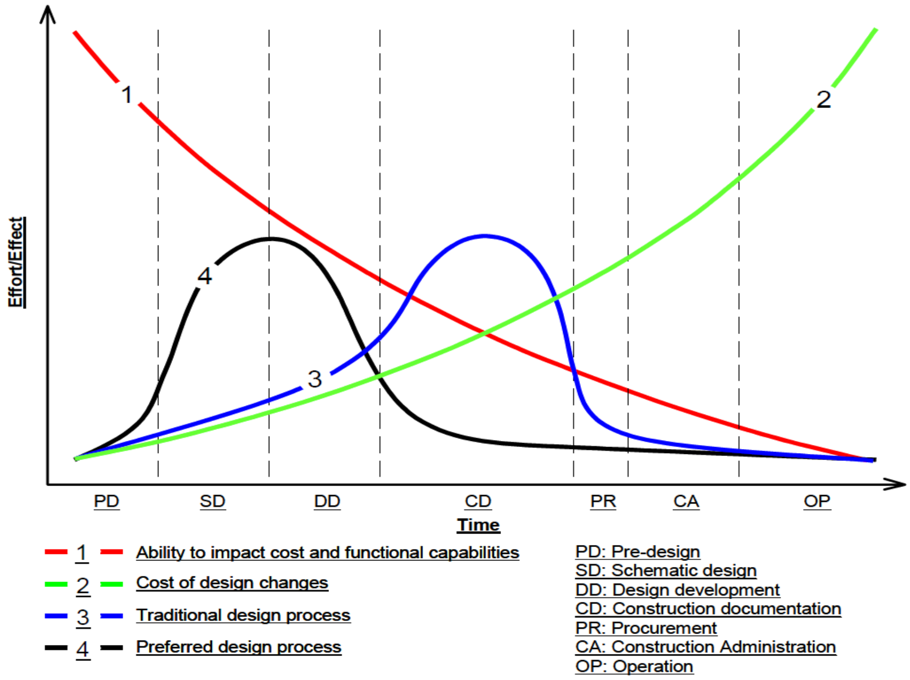


Figure 2.1 : The offered collaborated and information integrated project lifecycle procedure by CURT.

In addition, according to ASHRAE, the easiest way of having a sustainable and high-performance building is that the project objectives and criteria began in the early stage. Because of that, the major opportunity has in the early design, the potential for achieving performance is decreasing with increasing effort throughout the respectively stages, which is represented in Figure 2.2 [29].

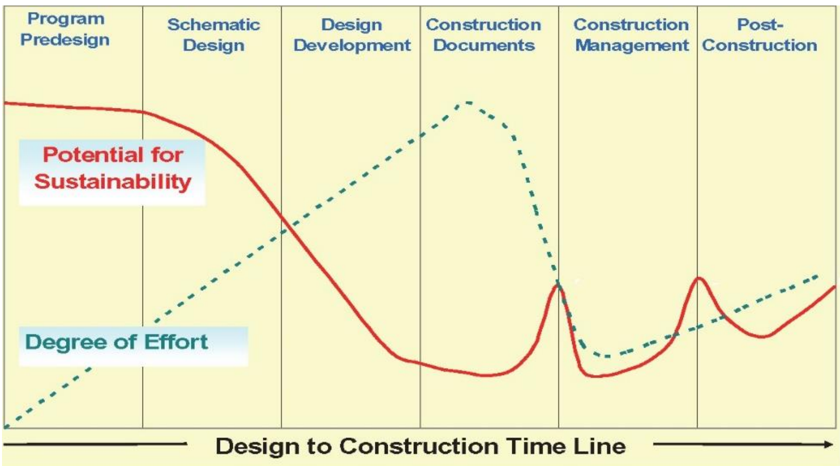


Figure 2.2 : The potential for sustainability and degree of effort during project life cycle.

Besides offered collaborated and integrated project procedure by CURT, Ministry for the Environment in New Zealand published a design method as "*Integrated Whole Building Design*". This design method takes care of building as a whole with the necessity of involved all stakeholders, design team and users. The advantage of this approach is that the realization of design opportunities during early design stage and the addition of this change with easily and cost-effectively way [30]. In addition, Integrated Project Delivery (IPD) approach is unified "*people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction*" [31].

2.3.1.1. BIM as collaborative process in project design

BIM as a process makes possible cooperation and supports combination of all stakeholders' roles in a project. Therefore, there is an opportunity for more efficiency and harmony between stakeholders [32]. The stakeholders which collaborates with BIM is shown in Figure 2.3 [33].

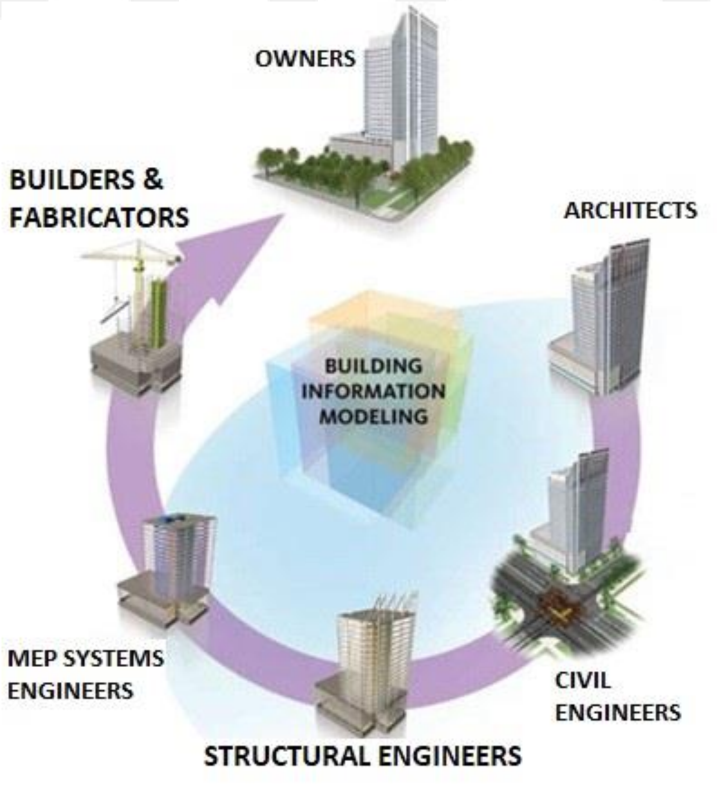


Figure 2.3 : BIM and stakeholders.

BIM is based on two fundamentals which on is communication another is collaboration. Moreover, it promotes the context of Integrated Project Delivery (IPD). Consequently, BIM and integrated projects give chance to connection of "*people, systems, business structures and practices into a collaborative process to reduce waste and optimize efficiency through all phases of the project life cycle*" [32].

BIM as digital three dimensional model with connected project information database is a most suitable platform to promote IPD. BIM can enable the integrate information of design, fabrication, erection instructions, and project management. Further, it supplies a collaboration platform during project design stage to construction stage. Due to being model and database during building life time, BIM could be used for facility management [31]. BIM and project life cycle is represented in Figure 2.4 [34].

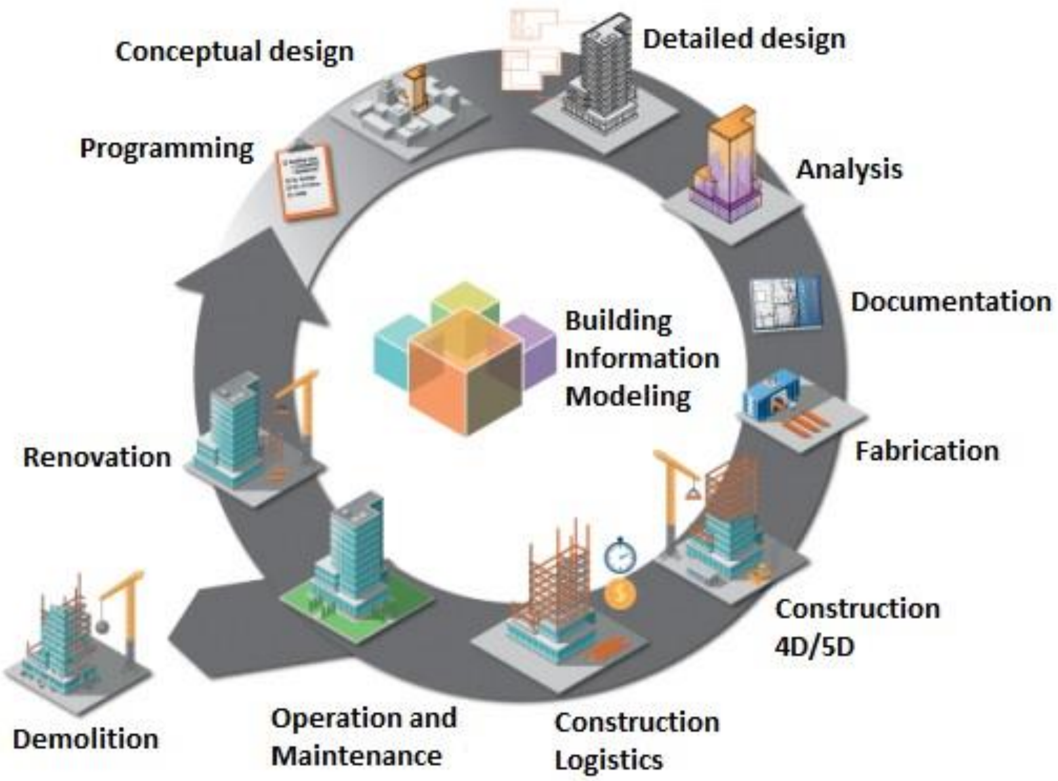


Figure 2.4 : BIM with project life cycle.

2.3.1.2. BIM as product in project design

Through the project life cycle, BIM implementation opportunities have been shown by Azhar. This advantages have been summarized for design stages, which shown in Table 2.1. According to Azhar, BIM implementation in schematic design gives benefits to investigate design options by comparing multiple design alternatives and realistic representation of project. In the detailed design phase, BIM offers a 3D exterior and interior models, analyses building performance like energy models, also analyses structural design. Further, the fabrication drawings, analysis of building systems via clashes, scheduling and 4D phasing are obtained by BIM in construction detailing [32].

Table 2.1 : BIM applications during project design stages.

Schematic Design	Detailed Design	Construction Detailing
Options Analysis	3D Exterior and Interior Models	4D Phasing and Scheduling
Photo Montage	Building Performance Analysis	Building System Analysis
	Structural Analysis and Design	Fabrication Drawings

Taking into considerations of these collaborated and integrated project approaches, BIM serves as a significant way to collaboration of multiple design disciplines. In design stage, coordinated and combined full design model was composed by AEC designers in order to promote better visualization of the project. When the BIM model had created, the stages was respectively architectural, structural, and MEP model. The architectural model was original then adjustments were generated by structural and MEP designers on original model one by one. The Industry Foundation Class (IFC) files were used to collaborate with multi-disciplinary and increase the interoperability. The clashes detection had done until all clashes solved. To see the influence of daylight levels and energy use, the energy and day lighting analyses had been made via Architectural BIM model in design stage [35].

Moreover, the aims of Malaysia case study are determined as reducing energy usage of the building, and defining building alternatives for energy saving by BIM method. The most important key components which influence on energy dissipation examined. After determined baseline building energy usage, the optional building materials were replaced with baseline design in order to examine influences of these alternative materials on energy usage. The modifications were carried on the wall, windows, floor, door, ceiling, and HVAC system. In addition to modifications, sustainable solutions as usage of terraces, reticular walls, and shades on the windows, reduction of the number of windows, and suitable ventilation were proposed. As a consequence, BIM helps to determine best building orientations and designs. The BIM model is a comprehensive method to generate opportunities and enhance the building performances [36].

To sum up, multiple design options can be created and investigated during early design stage with the help of BIM interoperability between available programs which are used to analyze and calculate energy performance [29].

2.3.2. BIM and interoperability

The interoperable, structured and easily extendable data model could occur the advanced interdisciplinary data sharing between in simulation domains. Further, the benefits of this model could be the reduction of the reusing geometric and other data from different models, demolition the manual processes of an error-prone, reduction of time-consuming for erroneous input, enhancement of simulation quality [37].

There are different techniques about an integration of simulation domains; however, the generic data model approach as the most suitable approach for universal interoperability implicates whole required information of definition for Building Information Model (BIM) which has necessary project information like geometric data also materials, cost, and schedules related to each geometric component, and individuals such as spaces, and site [38].

Building Information Models consists of physically represented smart objects and data, which are sharing with all stakeholders. The data flows of BIM along computer systems could be variable that structured / computable as databases, semi-structured for instance spreadsheets or non-structured /non computable data such as images. Having sending and receiving intelligent object information as well as document-based information could be in BIM data flow [39].

It mentioned that the help of BIM interoperability, the required data for building energy performance simulations such as building description, mechanical system like heating, ventilation and air conditioning (HVAC), lighting systems and operating schedules are getting more efficient and reusable. In order to test different data inputs and outputs using different interoperable formats, 3D parametric architectural models and analytical models were optimized on data exchange. In this way, a single life cycle focused energy analysis information exchange has been tried [40].

Another profits of BIM were stated detection of diverse design alternatives and determination of energy strategies and systems at the conceptual design stage. In the predesign stage, designers could have made a decision about energy related topics effected to whole building life cycle. To meet BIM and energy analysis tools with green building certification systems, the integrated methodology has been offered for designers in the early design phase to determine loss or gain energy among different design alternatives to choose best alternative [41].

Commonly used BIM-based simulation tools in the AEC industry were contrasted according to their design parameters and performance outputs, which aim to identify the developments about BIM-based indoor environmental performance analysis. As an advantage of BIM was mentioned that building information could be straightly taken from a model in order to determine building performance that consists of different simulations like solar study, daylighting, building energy use, CFD. Therefore, the implementation of BIM based simulation tools has been offered to achieve sustainable building design [42].

By the aim of automation of exchange data along software platforms and assisting of repetitive energy models, a Building Information Modeling (BIM) workflow had been improved model geometry and parameters exports and energy simulation inputs. Model corrections were made and corrected model exported into energy simulation tool. It could be seen that the workflow concluded as a potential for widen other input files and platforms [43].

A holistic framework based on BIM, thanks to particular building physical and functional characteristics and interoperability of different environmental modeling, has been conducted to improve the sustainable low carbon design on high-rise buildings. The offered framework contained both structural and computational fluid dynamics (CFD) with energy simulation. To determine carbon emission points during building life cycle and to meet minimization of carbon emissions with relevant design improvements are guidelines of this framework in order to compose sustainable built environment [44].

3. METHODOLOGY

The design stages of building architecture could be separated as stage of conceptual design, schematic design and detailed design. It is known that decisions taken during the conceptual design stage would have enormous impact on building's performance [11]. The performance-based optimization process with help of BIM has been conducted in building design process for this study. The building design process conducts as conceptual, schematic, and detail design phases as defined on American Institute of Architects [45] through the project. In this context, the building façade optimization has been performed in conceptual design. After the conceptual design, the predicted energy performance and its optimization have been conducted via model based in schematic design. Finally, the detailed design had been carried out to examine the design quality in the aspect of indoor air quality, human thermal comfort, and exact energy consumption. The proposed methodology for building energy performance optimization through the design process is represented in Figure 3.1.

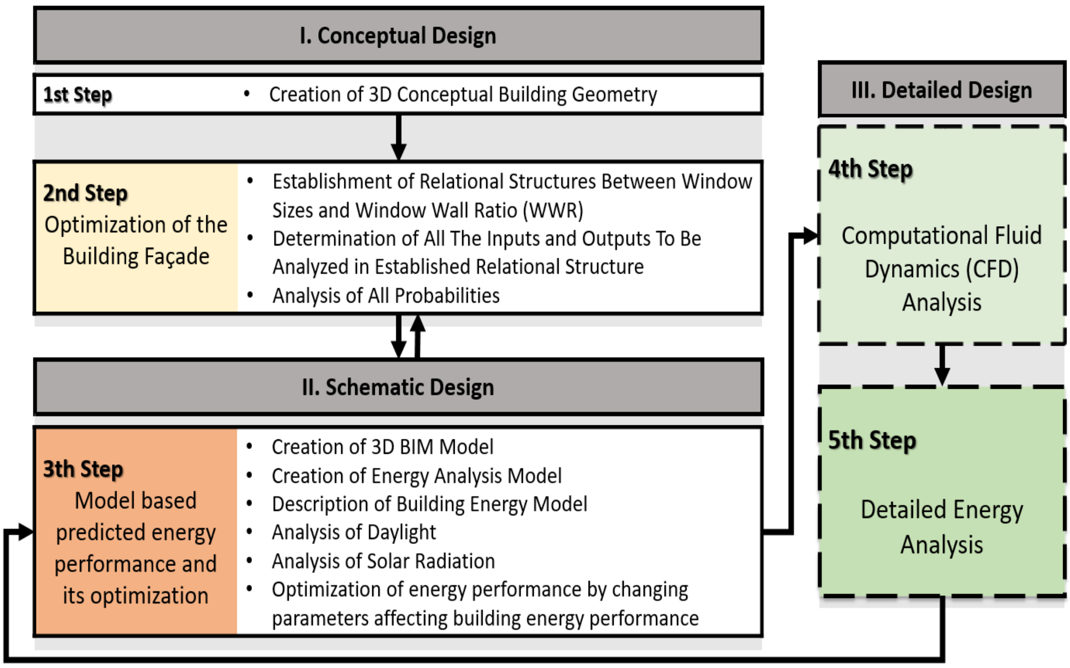


Figure 3.1 : Methodology for building energy performance optimization throughout the design process.

The building design stages are linked to each other and correlated with each other. While the optimization of the building façade is investigating in conceptual design, the conceptual models and schematic models are correlated with each other. Either one of the desired conceptual model can be created 3D BIM model in schematic design or schematic model can be gone back to change conceptual model. After the schematic design, the detailed design stage takes place to evaluate more comprehensively with respect to CFD and energy analysis models. If the building design qualities would not have reached standards and criteria corresponding to indoor air quality, human thermal comfort, and energy consumption, the created building model should have been rearranged. Thus, the required rearrangements will have been done in the schematic stage.

3.1. Proposed Building Energy Performance Optimization Methodology

The proposed methodology for building energy performance optimization through the building design process, which is represented in Figure 3.1, is explained step by step.

3.1.1. Conceptual design

3.1.1.1. 1st step

The 3D conceptual building geometry has been created in order to determine the aim and taken decisions during the conceptual design. The creation of 3D conceptual building model helps to investigate the building further. The conceptual plan of the building has been produced via Autodesk Revit© [46].

3.1.1.2. 2nd step: optimization of the building façade

The purpose of optimization of building façade is to found optimal size and window wall ratio for mainly taking advantage of sun and also consideration of aesthetical view. Therefore, the windows are assigned as a parametric object due to their changing dimensions and ratio. In the created 3D conceptual building geometry, an establishment of relational structures between window sizes and window wall ratio (WWR) is required. Dynamo© [47] has been used to evaluate the relational structures and determine all the inputs and outputs which are analyzed during this process. After the relations for windows sizes and WWR structured, the all parametrical changes will be analyzing within all probabilities in Project Fractal© [48]. Project Fractal© is a cloud computational design solution to ensure project goals and constraints when produces design options. The advantage of these steps are to generate different design alternative and analysis in order to improve the sensibility of design possibilities. The generated design options could also be selected for desired limitations by Project Fractal©.

3.1.2. Schematic design

The determining the building façade by selecting among all possible options is occurred via Dynamo© and Project Fractal©. The obtained outcomes should be organized during the conceptual design. In schematic design, one of the selected design alternative could be extracted to Revit© tool to create 3D BIM model by incorporating information such as location, usage area properties, considered materials. In the schematic design stage Revit© and Insight 360© [49] tools are used in order to evaluate model based predicted energy performance and its optimization. To sum up, the outcome from the conceptual design where used Revit©, Dynamo©, and Project Fractal© will be the inputs for the schematic design where used Revit© and Insight 360©.

3.1.2.1. 3th step: model based predicted energy performance and its optimization

The BIM model for schematic design is also respect to preparation of energy analysis model which means that building energy model will be used to predicted energy analysis. The created energy analysis model is sent to Insight 360©. Insight 360© analyze daylighting calculations which rely on location, sky conditions, surface reflectance and glazing visual transmittance also solar radiation on surfaces which depends on location, orientation, and form of the building is analyzed by it. The daylighting and solar radiation analysis results give us to information about the usage of building spaces and idea about possibilities of an alternative system.

Besides, Insight 360© is used to examine building input parameters. The building design input parameters include the orientation of the building, windows settings for the building such as window wall ratio (WWR), shades, and the glass material. Also, wall construction, roof construction, and insulation materials, lighting efficiency and HVAC systems could be included to building model. Moreover, renewable technologies such as PV systems could be also added. Insight 360© gives changed results automatically as annual energy use intensity (EUI) when the building design inputs are changed. The quick response on energy use intensity (EUI) by varied inputs is the one of the main advantages for optimizing the energy performance. To sum up, the daylighting analysis, solar radiation analysis and the examination of building design input parameters are occurred in Insight 360©. The simultaneously results corresponding to these analyses are shown as energy use intensity. These simultaneously results with energy use intensity (EUI) ensure the model based predicted energy performance and its optimization. Therefore, the beneficial outcomes for optimization based on the energy performance of building is provided.

3.1.3. Detailed design

Firstly, the optimization of building façade conducted by Dynamo and Project Fractal© in the conceptual design, after then the model based predicted energy performance and its optimization occurred by Insight 360© in the schematic design. Finally, the detailed design stage had been carried out.

The detailed design phase contains the computational fluid dynamics (CFD) analysis and the comprehensive energy analysis. The aim of CFD analysis is to understand building indoor quality and human comfort conditions with natural ventilation.

In addition, the goal of detailed energy analysis is to make more certain energy consumption of building. The purpose of detailed design stage is to investigate design quality with standards and criteria related to indoor air quality, human thermal comfort, and energy consumption. For this context, the computational fluid dynamics (CFD) analysis and the detailed energy analysis are separately conducted.

3.1.3.1. 4th step: computational fluid dynamics (CFD) analysis

The CFD analysis has been conducted to evaluate the natural ventilation in respect of indoor air quality and thermal comfort conditions in the detailed design stage. The CFD model has been created depend on the building model from the schematic design. The natural ventilation has been examined by Autodesk CFD© [50]. The outcomes of CFD analysis are temperature, velocity magnitude, predicted mean vote (PMV) and the percentage of people dissatisfied (PPD). According to these results, it has been investigated whether natural ventilation is sufficient to provide indoor air quality and human thermal comfort conditions.

3.1.3.2. 5th step: detailed energy analysis

The detailed energy analysis has been performed to investigate the building energy consumption as monthly and annually. The detailed energy analysis has been examined by eQUEST© [51] building energy performance simulation tool.

The energy analysis model contains mainly inputs of building geometry, weather data, Heating, Ventilation and Air Conditioning (HVAC) systems and components, internal loads, operating strategies and schedules and simulation specific parameters [52].

Hence, the energy analysis model has been generated by the help of building geometry from schematic design stage and the consideration of CFD analysis outcomes for HVAC system. Consequently, the monthly and annually building energy consumption outcomes have been obtained more certainly.

3.2. Definition of Used Tools and Their Applications

In addition to step by step explanation of proposed methodology, the building energy performance optimization methodology through design process has been integrated with BIM platform. It is known that BIM is not a process but also a tool. Further, if one of these properties does not exist the other cannot be the realistically.

BIM supplies an enhanced representation methodology which includes 3D parametric model with plans, sections, elevations, schedules, and perspectives for required documentation and analysis as daylighting, energy consumption. The main importance of BIM for analysis is the interoperability between model geometry and data in applications [53].

This BIM based building energy performance optimization methodology has more than one objectives. In this study, optimization is mainly based on the building façade, predicted energy performance, and also the design quality for in respect to human thermal comfort, indoor comfort conditions, and building energy performances.

To perform this multi-objective optimization, the various kind of tools and their applications has been used during the building design process. Each design stages within the BIM platform and utilized tools are represented on Figure 3.2. These used tools and applications were defined their usage area and functions as well as interoperability between them in following sections.

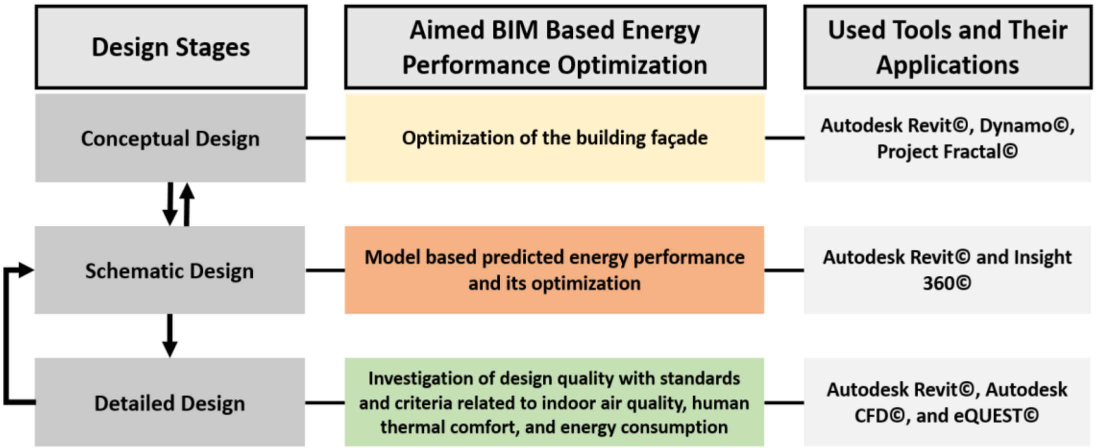


Figure 3.2 : Proposed building design process within the BIM platform and utilized tools.

3.2.1. Autodesk Revit

Autodesk Revit© program as a BIM application allows to generate 3D parametrical models with information. Elements can be governed via parameters in Revit©. The model includes intelligent objects which means that both geometry and data which are decisional information for building during each stage. The whole needed documentations like plans, sections, elevations, perspectives, details, and schedules can be created. Hence, the generated model via Revit© is a live virtual building models [53].

3.2.2. Dynamo

In recent years, the parametric modeling is an increasing trend in architecture due to the exploration of design alternatives and enhancement of the architectural process. During the generation of systems and forms with this method allows dynamic control on geometry and components. Further, the dynamic control supports designers to investigate suitable solutions for complicated problems as well as the evaluation of various variants. Like Dynamo©, the visual programming tools give a chance to perform parametric design via visual logic so that creation of dynamic complicated tasks [54].

Dynamo© which is a visual programming produced by Autodesk has two contexts; one of them is creation of geometry with parametric relations another is to be an external database in related to reading, writing and forming. Dynamo© can read and write data for instance parameter values, family geometry, and family placement from

Revit database via application programing interface (API). Dynamo© is carried out with visual programing language (VPL) which is utilized with nodes and wires instead of text language by users.[55] Using visual programming code is easier to understand for non-programmers because of that visual programming utilizes manipulation of elements via graphically rather than textually [56].

3.2.3. Project Fractal

Project Fractal©, which is a cloud computational design solution, is utilized for obtain project aims, constraints, and generation of design alternatives in order to explore and elaborate. Another saying that, Project Fractal© operates design creations and analysis for enhancement understanding of design possibilities. If users are pleased inputs and outputs in Dynamo© graph, it will be send in Project Fractal©. It has some components in interfaces. Firstly, one of these components is the adjustment of current design input variations. Another of these components is parallel coordinate display which shows inputs as black and outputs as orange. The generated designs are come up with the connection of these input and output series with consideration of input variations [57].

3.2.4. Insight 360

Insight 360© tool can be accessed with plug in Revit© or web link. After energy analysis model has been generated, daylighting calculations, solar radiation analysis, heating and cooling load calculations can be performed with Insight 360©. Also, it can conduct performance impacts feedback with automatically response to building design inputs. These dynamic response result can be energy cost ($\$/m^2/y$) or energy use intensity, EUI, ($kWh/m^2/y$) with +/- 10 % accuracy. Moreover, the building performance results are classified, based on ASHRAE 90, by red, orange, or green which is desired scale for Architecture 2030 benchmark. Consequently, Insight 360© allows the understanding of better design input parameters for whole building life cycle during design process [58].

3.2.5. Autodesk CFD

The computational fluid dynamics program is an important means of sustainability as it helps to make more informed decisions by integrating CFD into energy analysis workflow [59]. Autodesk CFD© program supports quick, correct, and flexible simulation of fluid flow and thermal. It also allows the prediction of product performance, design optimization, and product behavior validation. The advantage of this software for users is easily the exploration and comparison of design options. In order to generate fluid flow and thermal analysis, Autodesk CFD is linked with CAD systems [60].

In this study, Autodesk CFD© is used with AutoCAD© [61] which is a 2D and 3D CAD program to create external volume thus analyze simulation domain. The detail information about computational fluid dynamics analysis for this work to evaluate indoor air quality and human thermal comfort is explained in Chapter 5.

3.2.6. eQUEST

eQUEST© allows building performance analysis as a whole which means that a building composed of "system of systems" also energy sensitive design is a process which is integration of interacting system performance like envelope, fenestration, lighting, heating ventilating and air conditioning (HVAC), also domestic hot water (DHW). In the backstage of eQUEST©, the DOE simulation engine is worked to actualize building simulation [62].

When using eQUEST©, there are substantial properties should be described which are exact space definitions, numerical characteristics for instances occupancy, lighting power, and equipment power densities, and also references fields like occupancy, lighting, equipment, and infiltration schedules [63]. When wanted detailed energy analysis eQUEST© is usually one of common utilized tool [64]. The more specific information about detailed energy analysis with eQUEST© is mentioned in Chapter 6.

3.3. Interoperability between BIM Tools and Applications

Due to the fact that, interoperability is able the data transition among applications and the collectively contribution of multiple applications in work. Interoperability, which is expressed as capability of data exchange among applications, helps to improve workflows. Besides, the requirement of manual copied data from previously created application is eliminated via interoperability. The manually copy data for a fraction of project limits repetition to figure out best solution for complicated subjects like energy design. Also, this copied data causes definitely some inconsistency level [65]. Consequently, interoperability can eliminate these issues such as limitation of design repetition and inconsistency due to manually copy data.

The ways of interoperability can be the conventionally file exchange formats which is restiricted to geometry.The common exchange formats as image, 2D vector, 3D surface and shape, and finally 3D object exchange in AEC applications were meantioned by C. Eastman, P. Teicholz, R. Sacks, and K. Liston [65]. However, these formats were summarized related with utilized formats for this study, in Table 3.1.

Table 3.1 : Common exchange formats in AEC applications.

Common Exchange Formats in AEC Applications		
2D Vector Format	DWG	"Vector formats vary regarding compactness, line formatting, color, layering and types of curves supported."
3D Surface and Shape Formats	SAT, DWG	"3D surface and shape formats vary according to the types of surfaces and edges represented, whether they represent surfaces and/or solids, material properties of the shape, or viewpoint information."

Moreover, interoperability can be the direct links depended on Application Programming Interfaces (APIs) which is a system to take out data from application and write data using the reception application [65].

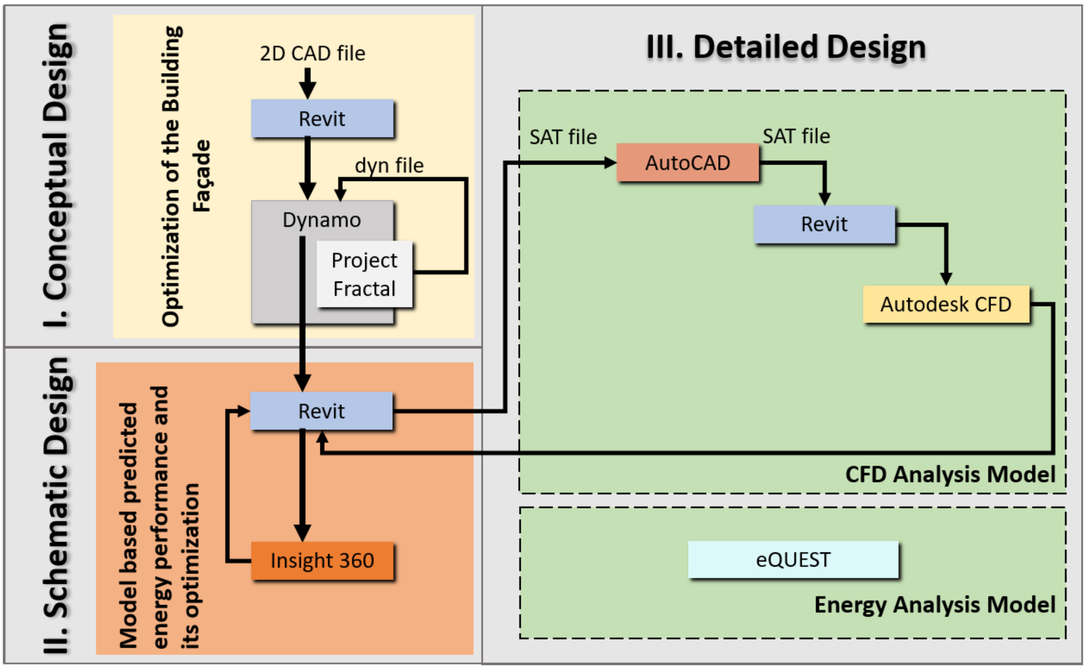


Figure 3.3 : The interoperability diagram-optimization process.

In this study, the used exchanged formats were DWG as 2D CAD file, and SAT as 3D surface and shape format. Also, the application of Dynamo© file was dyn which could be read and write in also Project Fractal©. Furthermore, Dynamo© utilized Revit© Application Programming Interface (API) to read and write data which can be about anything like values for parameter, family geometry, placement of family etc. [55]. Dynamo© and Project Fractal© were linked together also. Like Dynamo©, also Insight 360© was directly connected with Revit©. To sum up, the data exchange would have obtained for geometric information as 2D and 3D via DWG and SAT formats. Also, thanks to direct link among used programs, the interoperability had been reached. Throughout the building design process, the interoperability diagram between the used tools and their applications is represented in Figure 3.3.

4. BUILDING DESIGN PROCESS OPTIMIZATION

In the previous chapter, the proposed building energy performance optimization methodology through the building design process is defined. The building design process has been considered According to this methodology and applied on one hypothetical building. The aim of the application of the proposed methodology on the hypothetical building is to obtain high building performance as well as reach better thermal comfort condition and indoor air quality.

The hypothetical building is considered as a duplex single family house and located in the central part of Turkey, city called Niğde. The weather information for Niğde, the description of the hypothetical building and also the application of the proposed methodology is extensively explained in following.

4.1. Weather Information

It is necessary to determine the weather data before starting to determine optimal building design. The information about temperature, wind, and humidity are crucial to analyze the energy usage and natural ventilation in terms of indoor air quality and thermal comfort of the building, located in Niğde.

Table 4.1 : Monthly temperature values.

Month / Temp.	1	2	3	4	5	6	7	8	9	10	11	12
Avg. Temperature (°C)	-0.3	0.6	5.2	10.8	15.3	19.7	22.9	22.7	18.2	12.4	6.0	1.7
Avg. Max. Temperature (°C)	4.9	5.9	11.2	16.9	21.5	26.0	29.4	29.7	25.9	19.7	12.5	7.0
Avg. Min. Temperature (°C)	-4.5	-3.8	0	4.8	8.6	12.3	15.2	14.9	10.7	6.4	1.2	-2.5

During summer season, the average maximum temperature values are 26°C, 29.4°C, and 29.7°C respectively June, July, and August. In contrast to average maximum temperature, the average minimum temperature values are -2.5°C, -4.5°C, and -3.8°C respectively December, January, and February which indicates winter season. The monthly temperature values with average, maximum, and minimum is shown in Table 4.1 [66].

In addition to monthly temperature values, the monthly design data for temperature is important. The monthly design temperature information with 2 percentage of threshold [67], which is represented in Figure 4.1, are taken consideration.

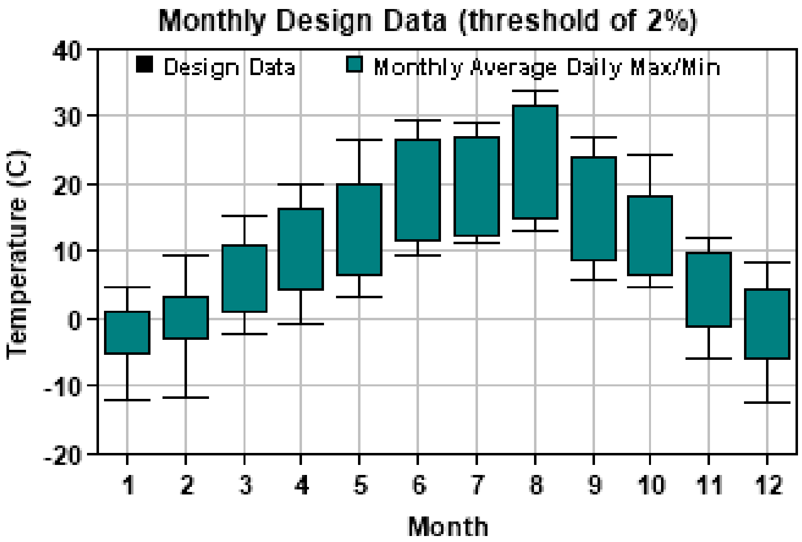


Figure 4.1 : Monthly design data with 2 % threshold for temperature.

The monthly wind speed range with observed days [68] is mainly said between 5 and 19 km/h, which seen in Figure 4.2.

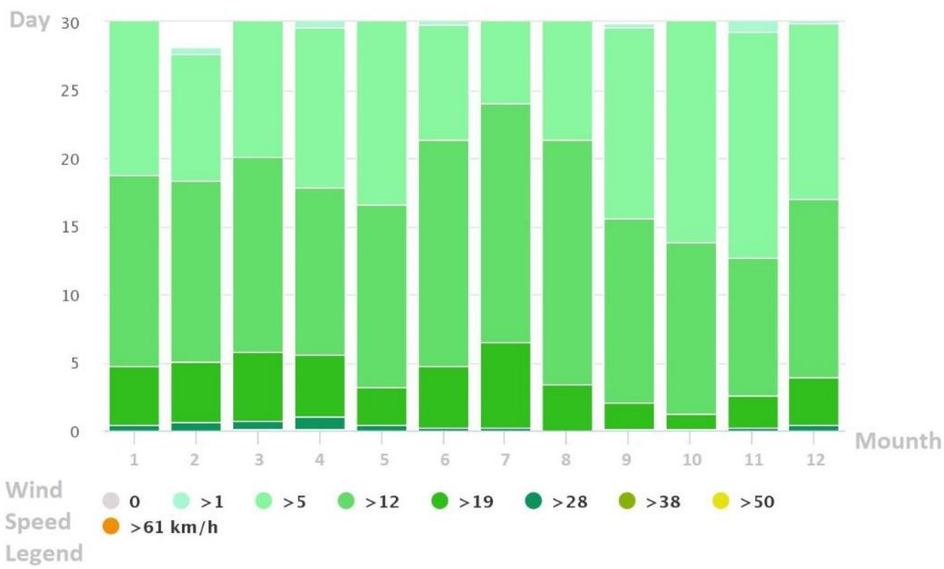


Figure 4.2 : The monthly wind speed range with observed days.

On the other hand, the annual wind speed at 10 m [69] is between 5 and 10 km/h. The wind rose for Niğde is shown in Figure 4.3.

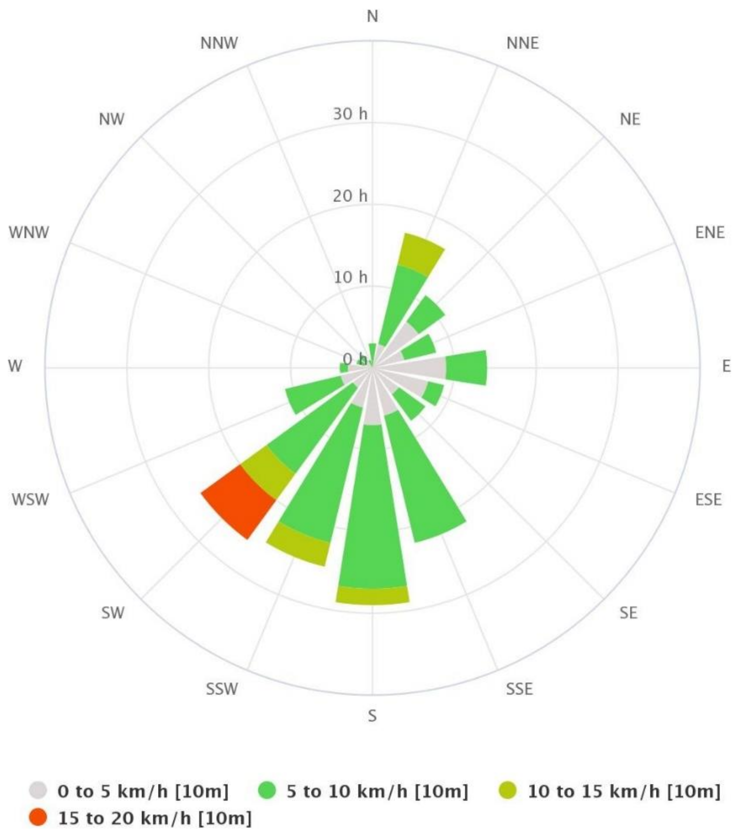


Figure 4.3 : Wind rose.

The annual relative humidity distribution for Niğde [67] is changing, which seen in Figure 4.4, but the main three ranges are 40-50 %, 50-60 %, and 60-70 %.

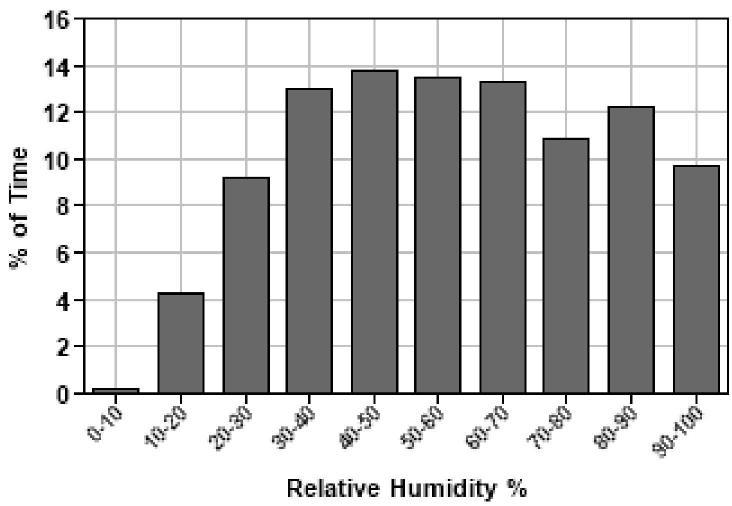


Figure 4.4 : Annual relative humidity frequency distribution.

4.2. Project Description of the Hypothetical Building

The hypothetical building has been supposed to be a two-story residential building which is located at Niğde, in Turkey. The ground floor has two bedrooms, one bathroom and one restroom, a kitchen, one study room, a living room, and a sunroom using a terrace. The upper floor has three bedrooms and two bath rooms. The living room at ground floor is a gallery for the upper floor. There has been planning a fireplace located in the middle of the living room for heating. Also, there has been assumed no cooling equipment in the building, it has been aimed the air ventilation occurs by naturally. Further, this concrete structure would have a small wind turbine on the chimney to take advantage of wind. The walls of both terrace and living room will be covered with windows due to taking advantage of sunlight. Beside to wall, the roof of terrace and living room will be composed of solar windows for the same purpose. The hypothetical building floor plan and space usage with assumed strategies for taking advantage of nature is shown in Figure 4.5.

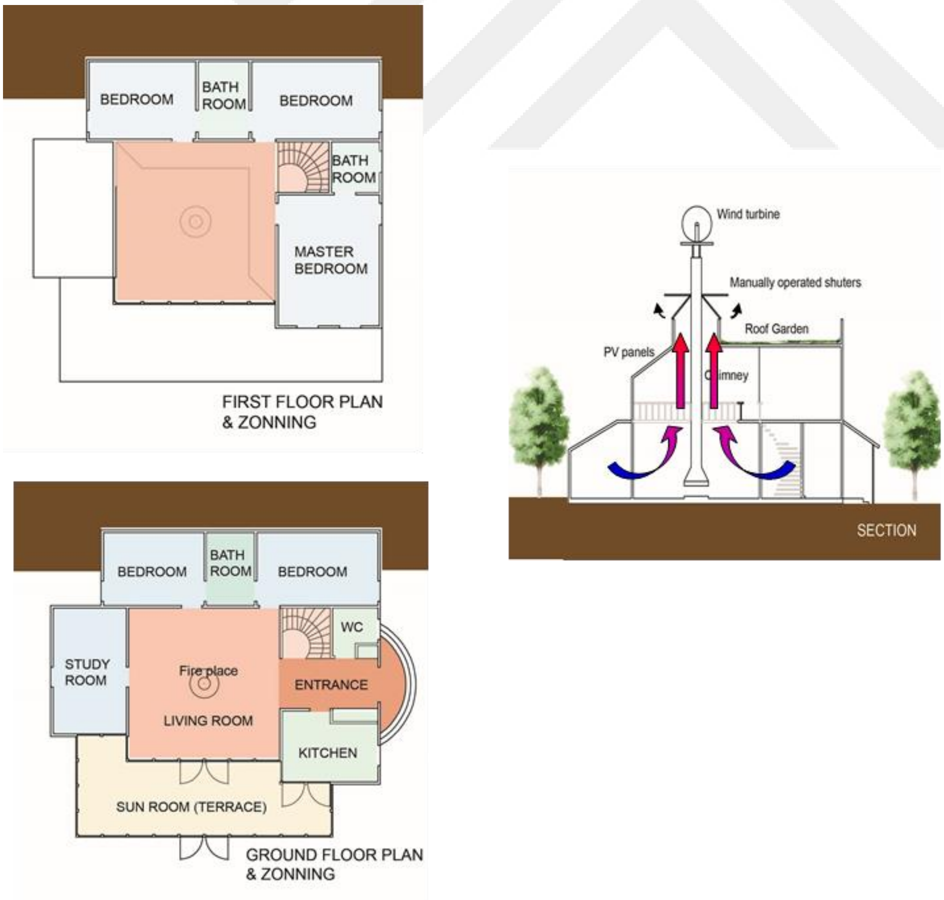


Figure 4.5 : Hypothetical building floor plan with space usage and planning strategies.

4.3. Application of Proposed Methodology

4.3.1. Conceptual design

According to the hypothetical building considerations which aimed to take advantage of natural source as sun and wind, the 2D drawings of building was represented in Figure 4.6.

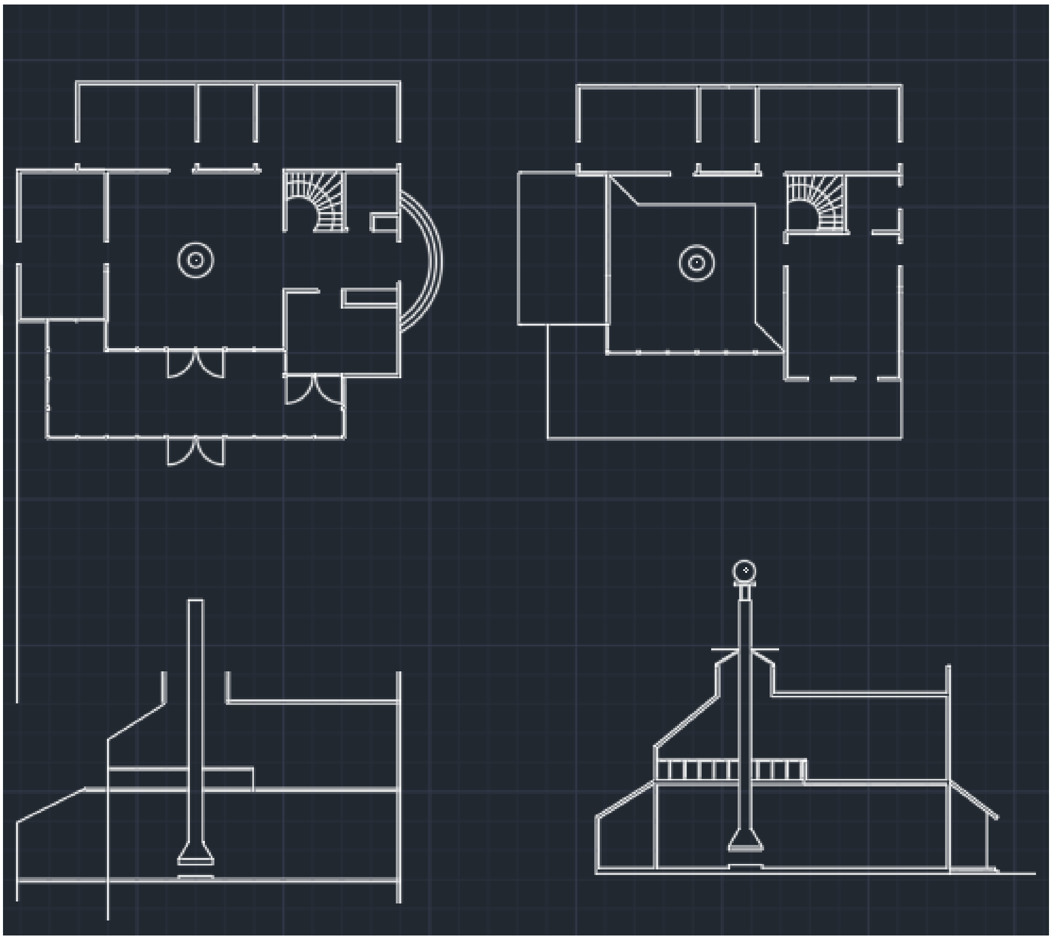


Figure 4.6 : 2D drawing for conceptual building.

The desired passive technics which are influence building energy performance had been assumed to implement on terrace room, living room and study room. Hence, the main considered usage places had been these places.

4.3.1.1. 1st step

In order to analyze optimum window size and window wall ratio, firstly the conceptual 3D model had been created in Autodesk Revit© for these 3 places, which is shown in Figure 4.7.

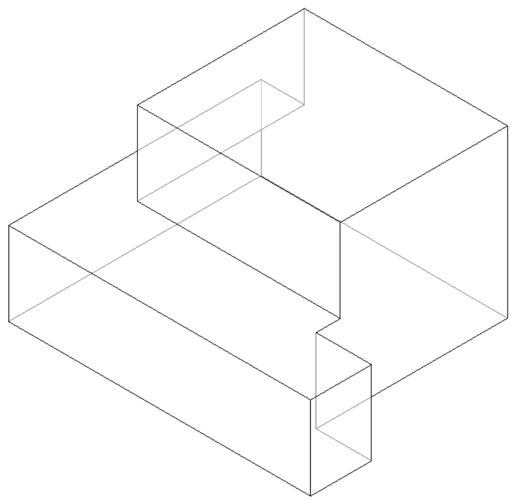
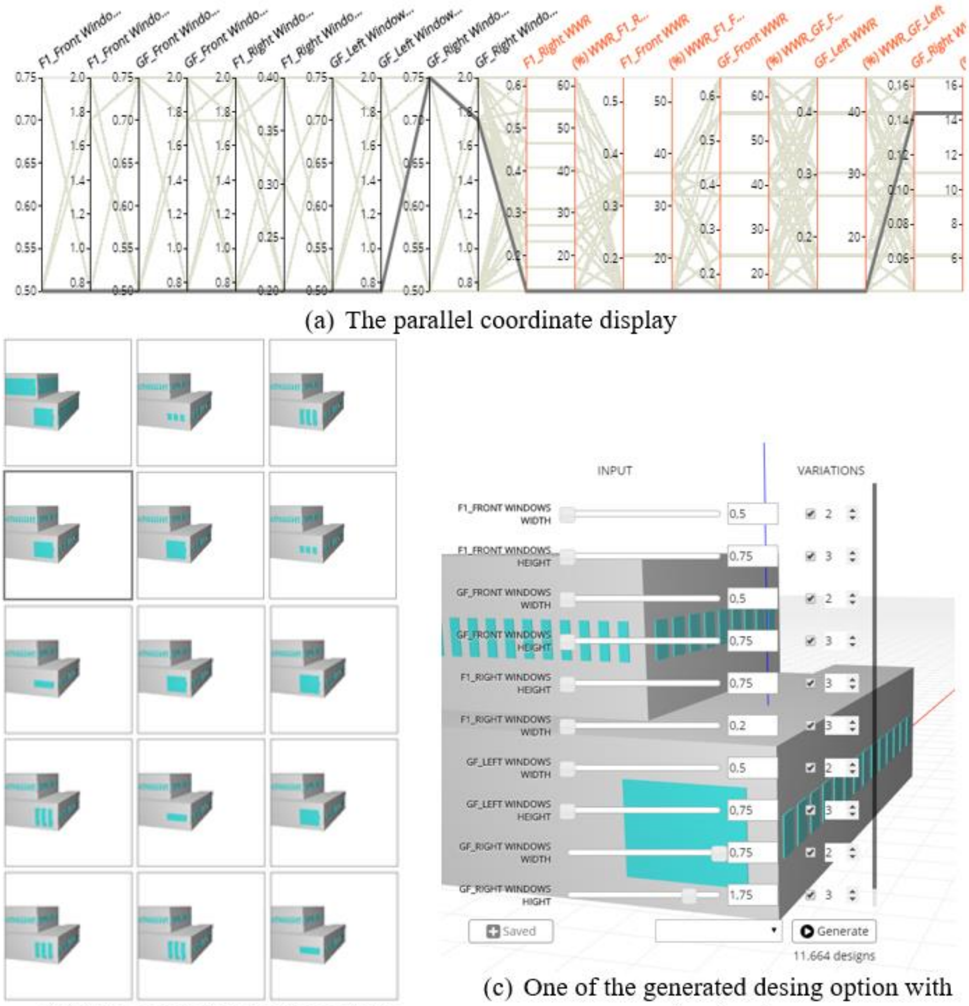


Figure 4.7 : 3D conceptual building geometry for terrassa, living room and study room.

4.3.1.2. 2nd step: optimization of building façade

To determination window size and window wall ratio, this conceptual building model was extracted Dynamo© tool, which could be standalone or plug in Revit©, via SAT file. The relational structures along window sizes, which respect of heigh and wide, and window wall ratio (WWR) was establieshed with the help of Dynamo© nodes. The goal of relational structeres was to build a dynamic response corellated with changing window sizes along window wall ratio (WWR). In order to obtaine dynamic response, also the desired all inputs and outputs of relational structures should be determined in Dynamo©.

In the Project Fractal© had been evaluated all alternatives depended on created relations and variations; thus, the model directly sends to Project Fractal© via Dynamo©. Before stared analysis of possibilities, the variations for inputs was specified the height of windows for three variations as minimum, average, and maximum, the wide of windows for two variations as minimum and maximum. According to the relation structure and variations, the possibilities of building envelope in respect to windows size, height and wide, and corresponding to window wall ratio was started to generate in Project Fractal©. After the creation had been done, the generated design options, which some of them represented in Figure 4.9.b, could be seen in interfaces. The generation all probabilities with parallel coordinate display with input as black and outputs as orange color is shown in Figure 4.9.a. In addition, if one of the design options was selected, the input values for it could be seen like Figure 4.9.c.



(a) The parallel coordinate display

(b) The generated design options

(c) One of the generated desing option with input values

Figure 4.8 : The parallel coordinate displays, generated design options, and one of the generated design option with inputs.

Although there were various design options, these options should be eliminated from some considerations such as aesthetical view. The selected option was the one with the maximum input values for both the window height and width.

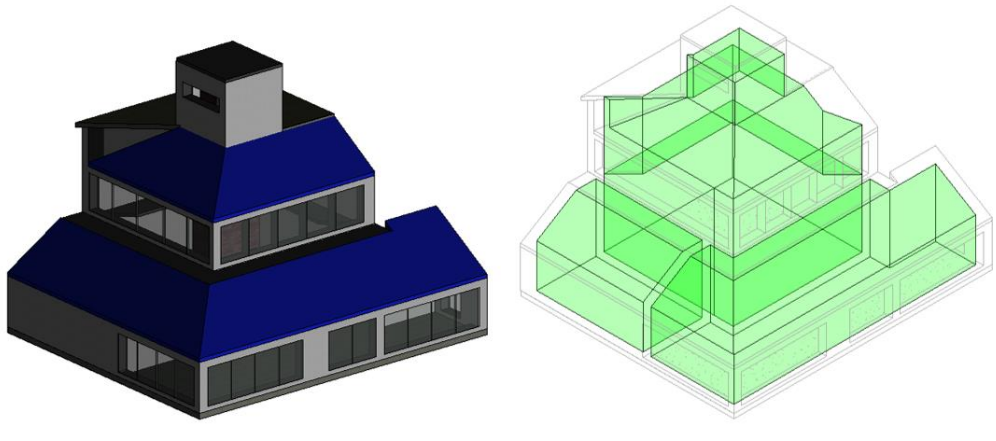
4.3.2. Schematic design

After the determination of building envelope, the 3D BIM model was created in Revit© for schematic design stage. For this purpose, firstly the 3D building geometry was built and then the required information for energy analysis as location, space definitions, and used materials was added to the model in Revit©. The location selected as Niğde and the spaces were determined for study room, living room, and terrace. Besides, the materials for hypothetical building were defined for floor, wall, and roof as concrete, also windows, and roof of atrium and terrace as glass. The defined information for energy analysis model in schematic design is shown in Table 4.2.

Table 4.2 : Defined information in BIM model for energy analysis model in schematic design.

Defined Information		
Location	Niğde	
Defined Spaces	Study Room, Living Room, and Terrace	
Materials	Floor	200 mm Concreate
	Wall	300 mm Concreate
	Roof	150 mm Concreate
	Roof of Atrium and Terrace	Glass
	Windows	Glass

To sum up, the 3D BIM model and energy analysis model are represented in Figure 4.10.



(a) 3D BIM Model (b) Energy Analysis Model

Figure 4.9 : The 3D BIM model and energy analysis model.

4.3.2.1. 3th step: model based predicted energy performance and its optimization

To conduct model based predicted energy performance and its optimization, the energy analysis model should be described in Insight 360© by the way of Revit© plugin. When finished the activation of model, the lighting, solar radiation, and optimization of energy performance by changing parameters affecting building energy performance could be actualized.

The daylighting calculation in Insight 360© depended on location, sky conditions, surface reflectance, and glazing transmittance [58]. The setting for environment had been adjusted before analysis started. In the environmental settings, the daylighting duration determined 21 September between at 9 am and 3 pm. The other required information was automatically come from weather data which determined when had been selected location in Revit© for energy analysis model.

In addition to daylighting, the solar radiation on surface calculated depended on location, orientation and form of building [58]. Once the surfaces which were desired to analyze solar radiation had been selected, the study settings were adjusted. Like daylight analysis, weather data was come from the earlier selection. Also, the result settings for virtualization could be adjusted before analysis started.

The model based predicted energy performance and its optimization in schematic design phase, the building parameters were divided by three classes in aspects of understanding more clearly the effect of these classified classes on energy performance. These three groups were the insulation integration, lighting & HVAC related different systems, and PV integration as the consideration of taking advantage of sun. In this context, the examined building parameters with classes are represented in Table 4.3.

Table 4.3 : The divided classes to examine building input parameters.

Classes	Building Input Parameters
Insulation Integration	Wall Construction
	Roof Construction
Lighting & HVAC	Lighting Efficiency
	Daylight & Occupancy Control
	Plug Load Efficiency
	HVAC
	Operating Schedule
PV Integration	PV Surface Cover
	PV Payback Limit

In Insight 360©, there were input adjustment tiles which were represented for each specific design elements. When firstly initiated input adjustment tiles, they shown current range for specific element. The significance of input adjustment tiles is that capability of creation a unique result with the combination of various adjustments which were in related to design and the interrelated results [58].

If one of the input adjustment tile with related to one of the building parameter is selected, the parameter range will show for current situation as triangular and for other options as dot. According to setting of parameter range, the energy use intensity (EUI) will be spontaneously updated.

In light of this situation, the insulation integration, lighting & HVAC, and PV integration classes input parameters were setting correlated to dynamic response of annual energy use intensity (EUI). For insulation integration, the wall and roof construction were adjusted, which shown in Figure 4.11.

In addition to insulation integration, the lighting efficiency, daylighting & occupancy control, plug load efficiency, HVAC, and operating schedule were setting for lighting & HVAC input parameters, in Figure 4.12.

Finally, the consideration of take advantage of sun The PV panel were assumed to place on terrace and living room roof surface. Hence, the surface cover and payback limit parameters were set for PV integration.

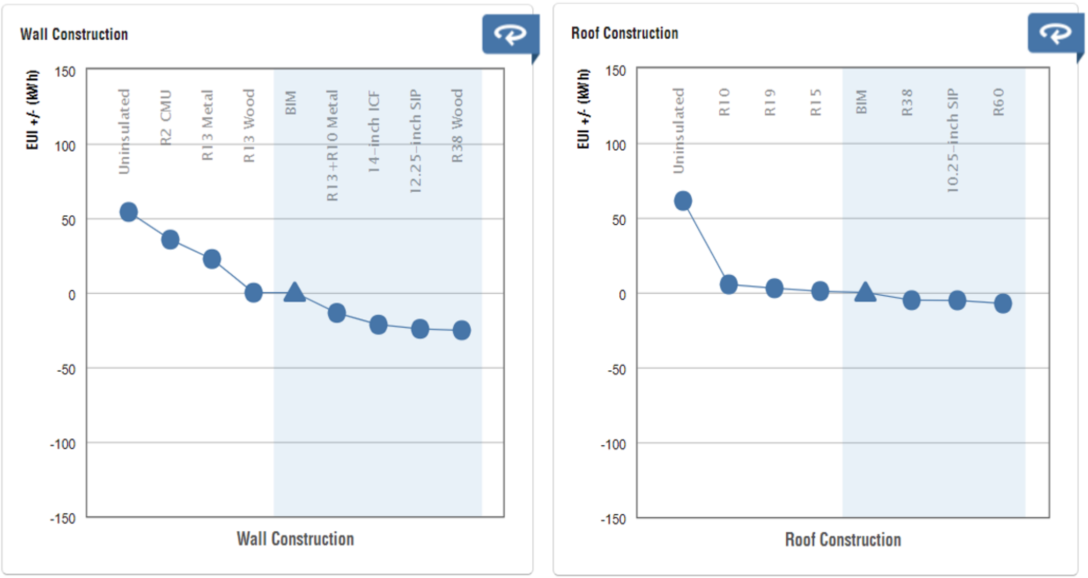


Figure 4.10 : The adjustment of wall and roof construction for insulation integration.

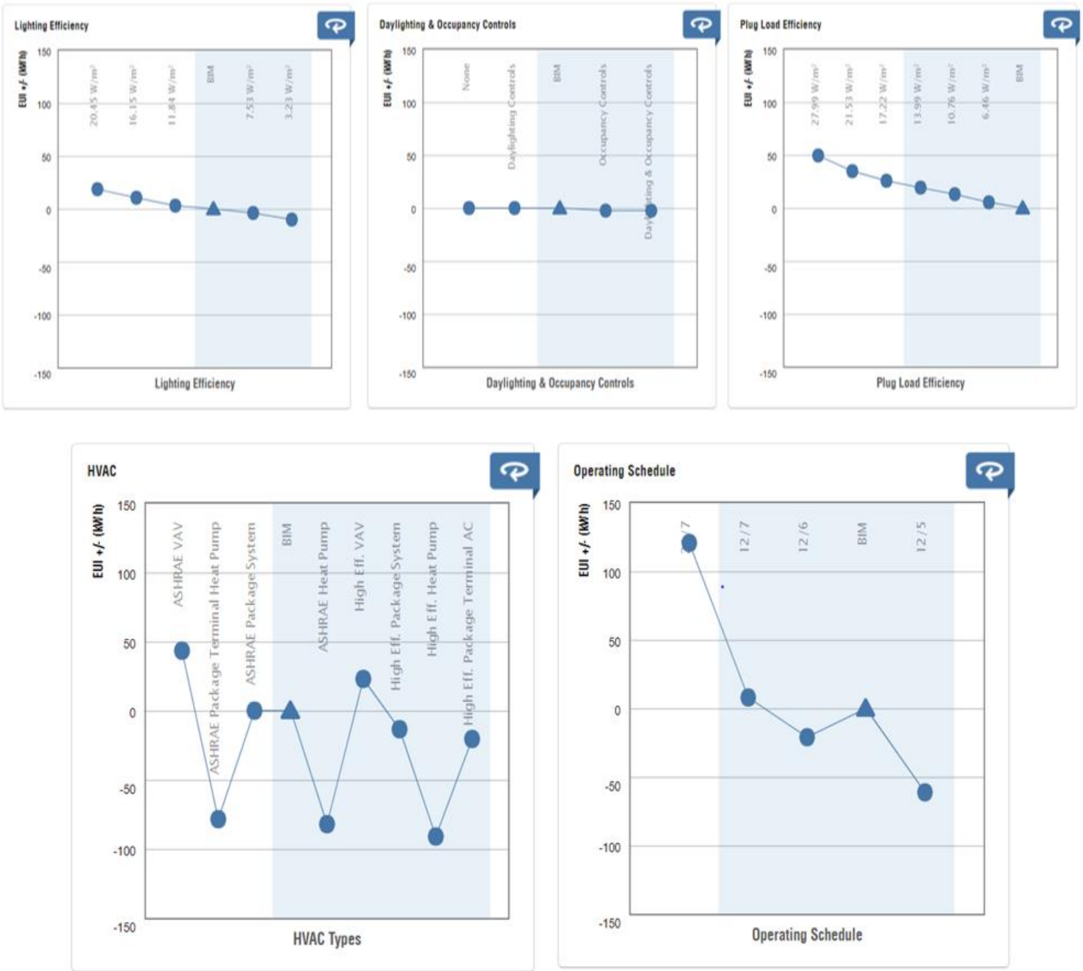


Figure 4.11 : The adjusted lighting & HVAC input parameters.

The adjusted range for surface cover and payback limit is shown in Figure 4.13.

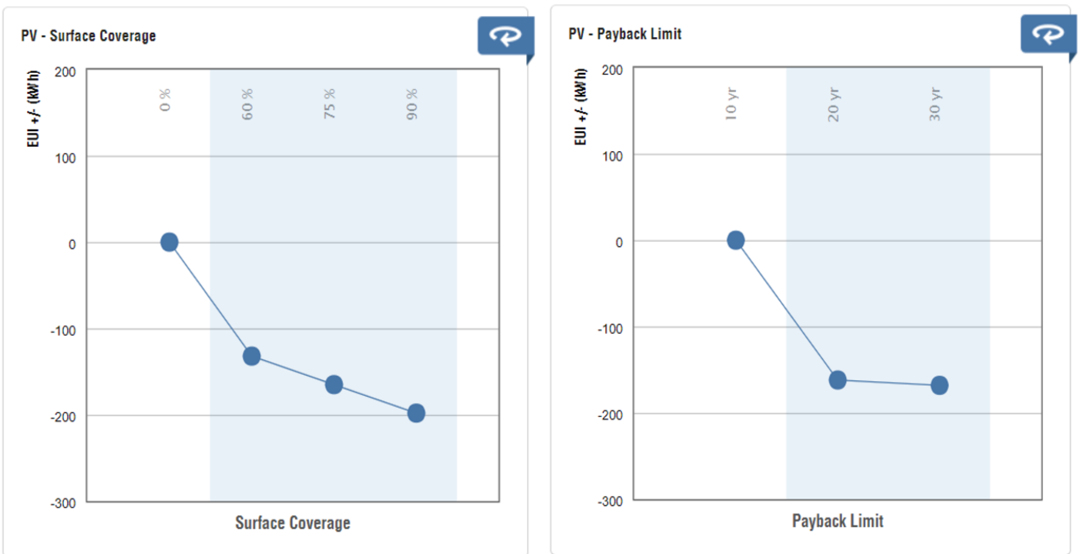


Figure 4.12 : The adjusted PV integration input parameters.

Taking all building input parameter range adjustment consideration, the model based predicted energy performance and its optimization were conducted. The building geometry had been examined aspect of optimization of the building façade and dynamic responce between predicted energy performance optimization and building input parameters for three main spaces as terrace, living room, and study room up till now.

4.3.3. Detailed design

The conceptual and schematic design stages have been applied on the hypothetical building design in Niğde untill now. For the further study, detailed analysis could be conducted as represented on Figure 3.1 which includes detailed CFD and energy analysis that we represented respectively in Chapter 5 and Chapter 6.

4.3.3.1. 4th step: computational fluid dynamics (CFD) analysis

The CFD analysis has been examined in comprehensively in Chapter 5 with its own analysis methodology.

4.3.3.2. 5th step: detailed energy analysis

The detailed energy analysis has been extensively investigated with its own analysis methodology in Chapter 6.

4.4. Building Design Process Optimization Result and Discussion

After the created conceptual building geometry for terrace, living room, and study room in Revit©, the structural relations between window sizes and window wall ratio were established in Dynamo© to examine building façade alternatives due to effect on building energy performance.

The façade properties affect space heating and cooling, also lighting demand substantially. Therefore, the optimum façade properties, which is one of the crucial parametric element for building performance, are very important in order to reduce energy need [70].

The generated building envelope alternatives via Project Fractal© gave 11664 design alternatives depending on structured relations for windows sizes and window wall ratio. However, the maximum input values of window height and width were selected due to consideration to advance more daylighting. Thus, the schematic model for next design stage had been developed over this selected alternative. The daylighting analysis was conducted on 21 September between at 9 am and 3 pm.

According to the useful daylight illuminance scheme, which was depended on a survey that implemented in non-residential where glare on visual display devices was a widespread issue, the daylight range between 300 and around 3000 lux is generally seen as desirable or at least tolerable. Moreover, the useful daylight illuminances in between 300 to 3000 lux is called as autonomous which means that there would not be required supplementary artificial lighting [71].

In this aspect, the illuminance value was set between 300 and 3000 lux for the daylighting analysis. The daylight was passed 75 %, whose rest of was 14% below threshold, which means lower than 300 lux, and 11% above threshold, which means higher than 3000 lux, at 9 am. Besides, the daylight was passed 27 % within the threshold at 3 pm, which the rest of was 11 % of below 300 lux, and 62% of above 3000 lux.

When examined the floor area with the consideration of daylight, the result of the second floor was no value due to the living room acted as an atrium thus there was no available floor area for examination.

However, the ground floor area was totally included for daylight examination. The outcome for ground floor area was 75 % of daylight within threshold at 9 am, and 27 % of daylight within threshold at 3 pm. Also, the outcomes of daylighting for floor area is shown in Table 4.4.

In addition, the daylight analysis with taking account of each room is represented in Table 4.5. All rooms were included in daylighting. The daylight passed 100% with threshold into the living room at 9 am but at 3 pm the daylight was 100 % above the threshold.

In terrace, the majority of daylight passed with threshold both at 9 am and 3 pm. On the other hand, the predominance of daylight was below the threshold not only at 9 am but also 3 pm in the study room.

To see more clearly the daylight analysis, the visual representation with daylight value range is shown in Figure 4.14 for 9 am and in Figure 4.15 for 3 pm.

Table 4.4 : The daylight analysis with consideration of floor area.

	Total Floor Area	Floor Area Included in Daylighting	9am threshold results						3pm threshold results					
			within threshold		above threshold		below threshold		within threshold		above threshold		below threshold	
			%	area	%	area	%	area	%	area	%	area	%	area
Level 1	75 m^2	75 m^2	75	57 m^2	11	8 m^2	14	10 m^2	27	20 m^2	62	47 m^2	11	8 m^2

Table 4.5 : The results of room based daylight analysis.

	Room Area	Include in Daylighting	9am threshold results						3pm threshold results					
			within threshold		above threshold		below threshold		within threshold		above threshold		below threshold	
			%	area	%	area	%	area	%	area	%	area	%	area
Study Room	13 m^2	YES	17	2 m^2	0	0	83	10 m^2	33	4 m^2	0	0	67	8 m^2
Terrace	30 m^2	YES	73	22 m^2	27	8 m^2	0	0	55	16 m^2	45	13 m^2	0	0
Living Room	33 m^2	YES	100	33 m^2	0	0	0	0	0	0 m^2	100	33 m^2	0	0

The dominant range of daylighting at 9 am was approximately between 1400 lux and 2700 lux, which is represented as green color, in living room and part of terrace.

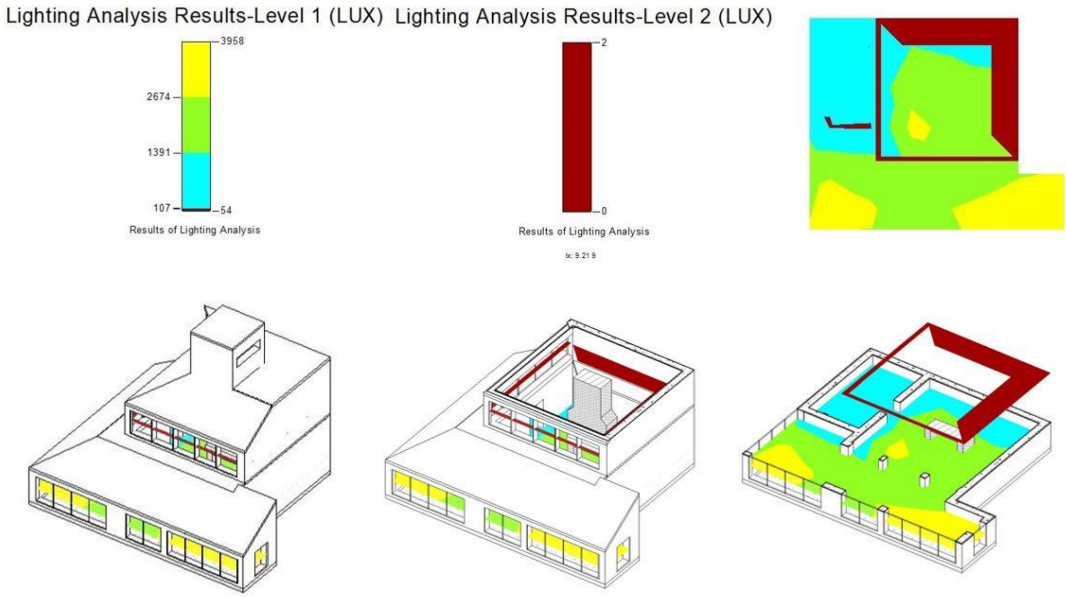


Figure 4.13 : Daylighting representation for 9 am.

Furthermore, the primary range of daylighting at 3 pm was almost between 2000 lux and 4000 lux, which is represented as green color, in terrace and part of living room. Therefore, it could be said that daylight would greatly influence the terrace in the afternoon.

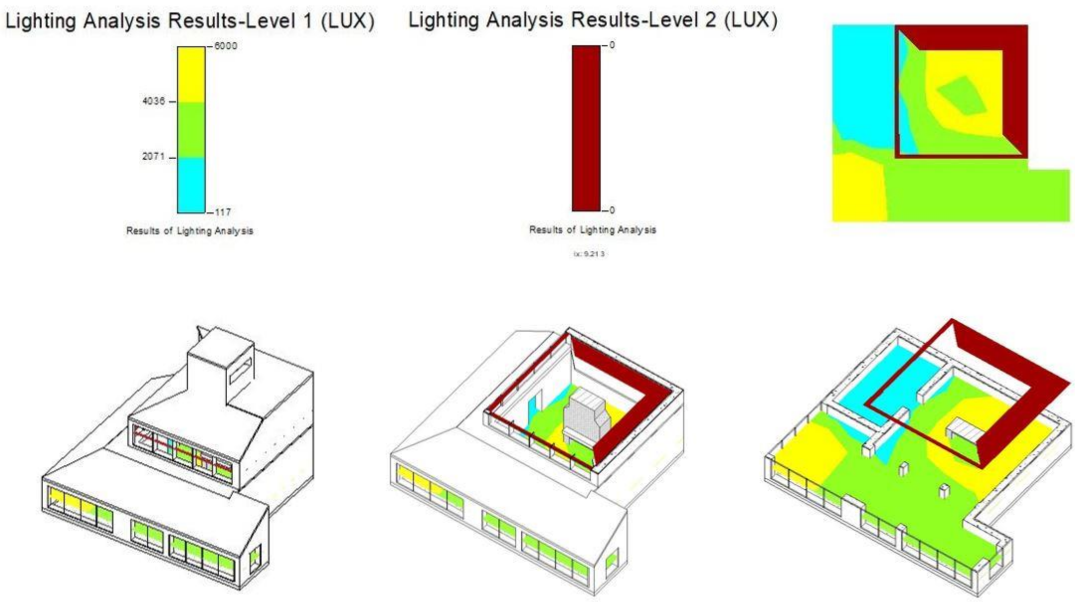


Figure 4.14 : Daylighting representation for 3 pm.

After the daylighting analysis, the solar radiation analysis was implemented during a year which was started on 21 September and finished on 21 September following year. The sun path for a year in Niğde is shown in Figure 4.16.

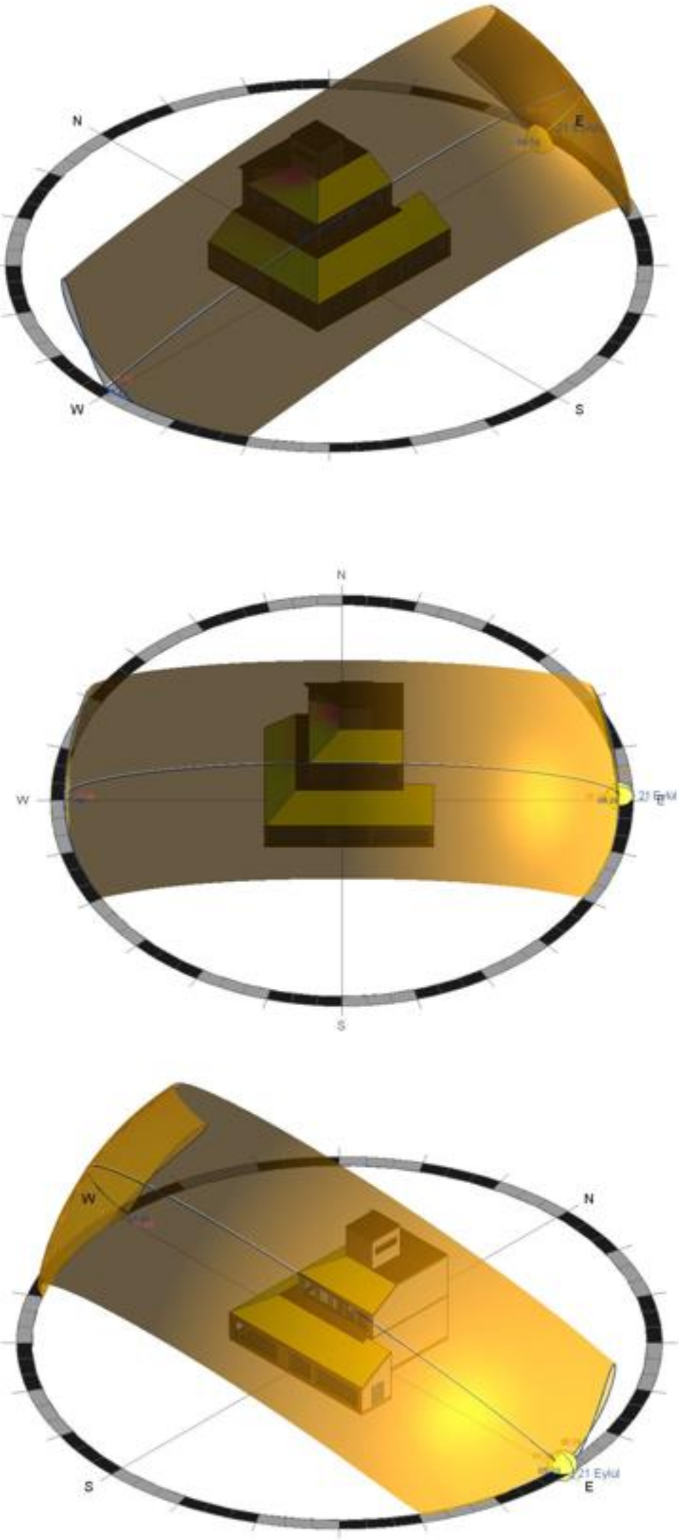


Figure 4.15 : The sun path between examined days.

One of the main significant assistance for surface and volumetric energy balance throughout daylight is the solar radiation. In particular, residential buildings, solar radiation is the chief impact on heat gains. Also, the saving of electricity usage due to use of daylight for the creation of high indoor quality can be obtained [72]. In this aspect, the annual solar radiation gains of Niğde house roof surface outcome with average 11 kWh/m^2 as 778 kWh, in Figure 4.17. Therefore, the PV integration would be beneficial for Niğde house.

Figure 4.16 : The result of annual solar radiation analysis.

For the examination how influenced energy use intensity with building input parameters, the input parameters had been divided three classes. It means that there were three scenarios which were insulation integration, lighting& HVAC, and finally PV integration. After the changed input parameters with related classes, the cumulative outcomes are shown in Table 4.6.

Table 4.6 : The model based predicted energy performance and its optimization in respect of EUI and saving.

	Energy Use Intensity (kWh/m^{2}y)	Saving of EUI (%)
Baseline	279	-
Insulation Integration	232	0.17
Lighting & HVAC	181	0.35
PV Integration	69.1	0.75

When initialized the created energy model in Insight 360© without changed input parameters, which called Baseline, the energy use intensity was respectively as 279 kWh/ m^2y. The energy use intensity is a substantial indicator for building energy performance and its saving potential. It calculates as annual energy usage divided by total floor area. Thus it represents the building energy utilization in the aspect of functionality, size, and characteristics of the building. The EUI can be useful for owners and designers because it allows a comparable energy saving aim [70]. Consequently, after baseline values, the scenarios were developed depended on the baseline with changing the input parameters which were classed and also the outcomes as EUI were compared between each scenario.

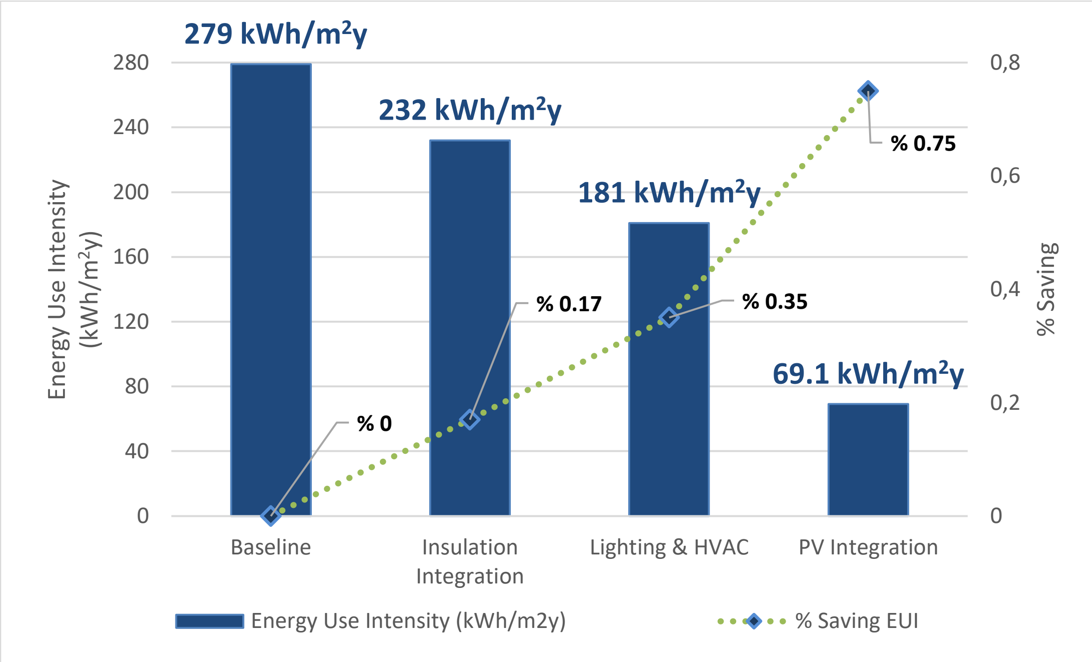


Figure 4.17 : The model based predicted energy performance and its optimization in respect of EUI and saving.

The EUI values were decreased up to 69.1 kWh/ m^2y in final. The final saving for EUI was 75 % which is cumulatively. The cumulative outcomes are also represented on Figure 4.18 in order to underline each building input parameters which were divided by three classes.

4.5. Building Design Process Optimization Conclusion

During the design building, the proposed methodology is comprised by three main stages which are conceptual, schematic, and detailed design phases. There are different considerations for the design stages. In the conceptual design, the optimization of building façade is the main consideration. For this purpose, the different building envelope design alternatives have been examined via the integration of Revit©, Dynamo©, and Project Fractal© within BIM platform. There were 11664 different outcomes from the Project Fractal©, however, one of the design alternatives, which has the maximum window sizes and window wall ratio, has been selected to conduct next design stages.

In the schematic design stage, the main concern is to evaluate the model based predicted energy performance and its optimization. For this goal, the daylighting analysis, solar radiation analysis, and also, the examination of the influences of building input parameters on energy use intensity are conducted. All of these analyses has been done in Insight 360© and Revit© within BIM platform. The daylighting and solar radiation analysis shown the efficiency of the selected conceptual model envelope design. The building façade efficiency is come from the daylighting results as 75 % at morning and 27 % at evening, as well as the annual solar radiation of roof surface outcome as average 11 kWh/m^2. With the examination of the influences of building input parameters on energy use intensity, the predicted energy performance obtained. The possible cumulative saving on building energy use intensity reached 232 kWh/ m^2y with insulation integration, 181 kWh/ m^2y with lighting and HVAC, almost 69 kWh/ m^2y with PV integration.

In some building design process, the proposed conceptual and schematic design stages in respect of the building façade optimization and the model based predicted energy performance and its optimization could be adequate. However, in this study, the detailed design stage is applied to investigate building design quality with standards and criteria related to indoor air quality, human thermal comfort, and final energy consumption. In this context, the CFD analysis and detailed energy analysis based on the detailed design stage in the proposed methodology is conducted in Chapter 5 and Chapter 6. In addition to proposed methodology, the CFD analysis and detailed energy analysis has own analyze models and methods.

On the other hand, the conceptual and schematic design has been carried out in a single model with BIM platform. Thanks to, the interoperability between Revit©, Dynamo©, Project Fractal©, and Insight 360©, this single building model has been evolved through the conceptual and schematic design.

5. COMPUTATIONAL FLUID DYNAMIC (CFD) ANALYSIS

The performance of building, as a complex system via multiple interacting physical processes, has multi-criteria such as energy performance, indoor environment for human comfort and health, environmental degradation, economic aspects during analyzing performance [73]. The indoor environmental quality (IEQ) contains indoor climate integration with thermal environment and indoor air quality, and health, safety and comfort aspects like ergonomics, acoustics, and lighting [74]. On the other hand, thermal comfort is affected by factors such as ambient and radiant temperature, relative humidity, air movement, building characteristics, occupancy levels, and individuals [75].

Building energy usage, which is one of the highest contributions related to energy consumption, depends on various factors like lighting, dwellers' behavior, heating, ventilation, and air conditioning (HVAC) systems. Through all building services, HVAC systems are one of the most effective factors on building energy usage [74]. Furthermore, one of the crucial aspect in the HVAC systems is the ventilation to supply proper indoor air quality. Ventilation is a process that supplies fresh air, which could be naturally, mechanically or integration of both. The natural ventilation is affected by the location, opening's sizes, weather conditions and outdoor air quality[75]. Unlike the mechanical ventilation, the natural ventilation has a significance on air supply, energy saving, CO_2 emission reduction [74].

The physical models, which is one of the current methods for building thermal behavior, depended on heat transfer equations that could be used for various needs of building such as space heating, natural ventilation, HVAC systems, integration of renewables, economic, behavior of dwellings, climatic conditions, and so on. The physical model needs particular information about building design like exact geometry, material properties, and energy service systems. One of the physical model approach is the CFD as an entire method of thermal building simulation, which is permitting to specify various flows fields such as airflow, and pollution in three-dimensional. The building zone is divided by many of the discrete control volumes with homogeneous or heterogeneous global mesh; therefore, the minimized local mesh of specific parts simplifies work on complicated building geometry [76].

In deeply, CFD programs allow the exhaustive estimation on thermal comfort and indoor air quality via the dispersion of air velocity, temperature, relative humidity, and contaminant concentrations, also these dispersions are linking to the indicator such as predicted mean vote (PMV), the percentage of people dissatisfied (PPD), the percentage dissatisfied (PD) for thermal comfort and indoor air quality. The dispersion of temperature, coefficients for convective heat transfer, natural ventilation rate due to effect of wind, stack, or both can completely identify by CFD [77].

5.1. Literature Review for Computational Fluid Dynamics

Initially, the usage of the CFD method has been applied in high-technology engineering fields such as aeronautics and astronautics and then it has been adapting to solve complex problems for modern engineering studies [78],[79]. The usage area for CFD has been started to enrich for different disciplines such as process, chemical, civil, and environmental engineering [78]–[80]. In additionally, CFD usage fields are getting widen for instance it can be applying on marine engineering, electrical and electronic engineering, biomedical engineering, wind engineering, hydrology, oceanography, meteorology, and nuclear power [81]. Furthermore, the CFD usage has been successfully implemented on building design and analyses such as the examination of building indoor environment and interactivity of the indoor environment and building surface, and the investigation of outdoor environment [81].

5.1.1. CFD analysis for buildings

With the purpose of CFD usage for building design and analysis, the recent works have been examined. It has been emphasized that the CFD implementation on outdoor environment, whose spotting points are "*pedestrian wind environment around buildings, wind-driven rain on building facades, convective heat transfer coefficients at exterior building surfaces and air pollutant dispersion around buildings*" had significant benefits. These advantages had been come from the supplied detailed flow field data which has completely control conditions and no similarity constraints via CFD [82]. Besides the investigation of outdoor environment, the natural ventilation has been examined by CFD, for instance, a full-scale natural ventilation for atrium, which offers a flow way along the building, has been analyzed. The outcome showed that proper atrium design for outlet geometry to the outdoor environment has been needed [83]. Also, the building prototypes have been optimized via CFD with aspect to the three parameters as geometry, orientation and street height and width ratio. The consequences of this research was highlighted the CFD simulations dependability on estimation of natural ventilation which related to human health and energy efficiency [84]. Additionally, the estimation of a whole building internal air temperature for long term such as a year was conducted with CFD simulation in order to determine the accuracy of CFD simulation. When the simulation results were compared to the real temperature data which measured in building, the consequences were shown that simulation results had 92 percentage of accuracy [85]. In another point coming with Zero-Energy Buildings, it has been mentioned that the heat flows among the building parts and spaces should be understood. Therefore, it was underlined that the examination of indoor thermal environment with simulation software has been a necessity. In order to examine the indoor thermal design, the mean radiant temperature maps were calculated with CFD [86]. Consequently, there are various investigations on building energy performance because of its multi-objective structure. The thermal behavior for particular requirements of the building, like space heating and/or cooling, natural ventilation, air conditioning systems, indoor and/or outdoor environment, is modelled via the physical model which is currently using Computational fluid dynamics (CFD). The CFD can implement all kinds of aero-thermal events such as natural and/or mechanical ventilation, air, pollutants, and heat dissipation in buildings indoor and/or outdoor environments.

5.1.2. The utilization of CFD and BIM for buildings

When considering building design, the integration of building performance analysis with design process uses the all possibility of computational methods. These methods could be used for both creation of building forms and design of better building [87]. The CFD simulation approach, which used BIM based CFD tools, was offered to investigate wind environment for high-rise building at early design phase. BIM based analysis for building designs had benefits on time saving with usage of design alternative and building information in early design phase [88]. Moreover, Cai and Kang explained a Chilled Beam simulation to show how effectively the Building Information Model could be utilized to generate a CFD model. They have mentioned that the definition of space geometry had major time consuming among many required steps for CFD analysis, also the process for building up CFD input could be accelerated with the help of BIM. The BIM based CFD model had a crucial step which was removing, simplifying, and reorganizing of Building Information Models due to complex and redundant for CFD simulation. The crucial step for BIM based CFD model was removal, simplification, and reorganization of Building Information Models which contains complexity and redundancy for CFD simulation [89]. Further, the passive heating and cooling techniques on studies were conducted with care of Building Information Modelling (BIM) and Computational Fluid Dynamics (CFD) software to decrease energy usage with desired thermal comfort conditions [90]. For the handling the complex objects and environments, the Level of Detail for Object Simplification had been expressed to assist importation and set-up of complex models by the way of selectively reducing. Consequently, the CFD capacity for the analysis processes of design and safety had been advanced via interoperation between CFD and BIM – CAD [91].

5.2. Computational Fluid Dynamics Methodology

The offered methodology consists of mainly three steps, which are the development of detailed 3D building to provide data for the BIM platform, the development of detailed CFD analysis to evaluate natural ventilation within the BIM platform, and the optimization process for accurate results as represented on Figure 5.1.

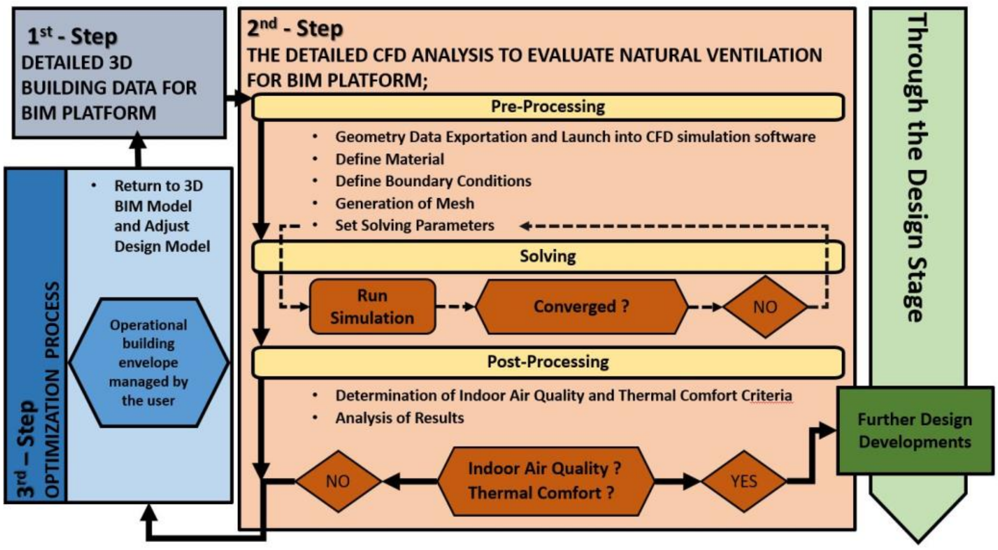


Figure 5.1 : CFD analysis methodology.

5.2.1. 1st step: detailed 3D building data for BIM platform

The methodology starts with the generation of 3D building model which contains information of building geometry, space usage, and materials. Also, this information will have utilized for further steps.

5.2.2. 2nd step: the detailed CFD analysis to evaluate natural ventilation for BIM platform

The detailed CFD analysis to evaluate natural ventilation for BIM platform includes all CFD simulation steps that are pre-processing, solving, and post-processing. In the pre-process stage has geometry description and launch descripted geometry into CFD simulation software, after than the determination of materials, boundary conditions, meshes, and set solving parameters are occurred, which are into CFD software environment. After the pre-process which is important part for preparation of CFD model to solve, the CFD simulation is initiated and calculations are performed in the background of the CFD simulation program as a solving step. If the simulation solution is not reach to convergence, the solving parameters should be check and then re-run the CFD simulation. In the post-process the converged solution results are collected and analyzed to evaluate whether they meet the Indoor Air Quality and Thermal Comfort criteria as air temperature, air velocity, PMV, and PPD determined by ASHRAE Standard.

5.2.2.1. Geometry data exportation and launch into CFD simulation software

The starting point of solving a CFD problem is a two-dimensional (2D) or three-dimensional (3D) drawing geometry system. The geometry system can often include details which are not desired in CFD [80]. According to simulation goal, the details of the geometry should be ignored or simplified because the detailed geometry can district the mesh quality and influence results as more or less conservative [92]. During the simplification of geometry, it should be ensured that CAD drawings provide the flow simulation [93]. Another issue in this step is that the generation of the CAD model for the investigated environment has to be. Because this environment is covered by computational domain which cut off the surroundings represented by approximate boundary conditions [92]. The computational domain is related to the area which displays via simulation. Domain should be large enough to avoid reflecting of fluid streams, which may cause abnormal pressure fields around the model. There are many recommended domain dimensions in the literature, but all of them are case specific. Therefore, the creation of an appropriate domain aspect to physical and computational terms for low-rise buildings relates dimension of the building [94].

Taking into account about geometry considerations, the steps of geometry data exportation and launch into CFD simulation software are represented on Figure 5.2. Firstly, the building geometry, which was already created with a BIM model, was simplified via extraction of unessential parts according to simulation aim. After, an air volume which covers building was created to consider natural ventilation and wind loads. It is recommended that the air volume is formed in the CAD model so that the air volume is co-plane with the ground plane of building [95].

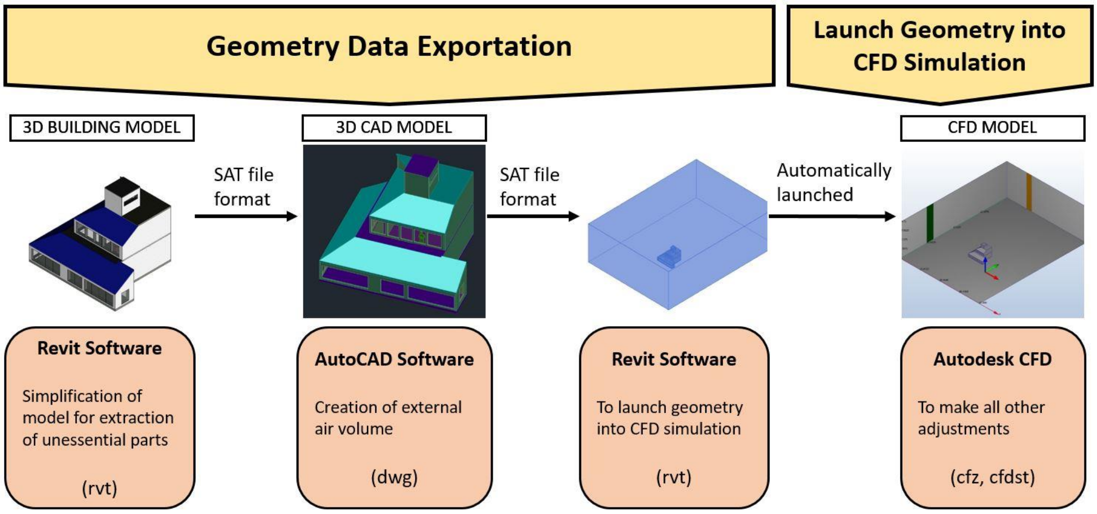


Figure 5.2 : Geometry data exchange from BIM model to CFD model.

Further, the created external volume had to be dimensional to protect the calculation domain from artificially accelerated flows. The advised dimensions for natural ventilation into CFD simulation is shown in Figure 5.3 [95]. Renewal of the model in Revit© is caused to advance useful exportation to Autodesk CFD© [59]. Therefore, CFD model had been launched from Revit©.

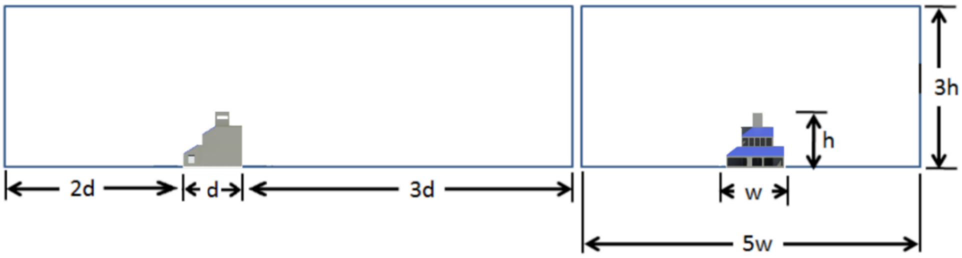


Figure 5.3 : External volume diameters.

5.2.2.2. Define material

Materials which are physical objects in each kind of analysis are determined into two main classes as Fluids or Solids for CFD analysis [96]. In CFD simulation for AEC applications, the primitive physical material is air as a fluid [97]. Therefore, the particular properties like viscosity, density, temperature, pressure etc. about fluid should be defined [80]. Moreover, heat flow along the building material medium is related to the material's thermal properties and nature. The building component materials as solid materials are generally utilized to describe the building materials such as brick, gypsum board, hardwood and softwood, steel, glass, and other physical solids [97]**.** The CFD software databases have these physical properties; besides, CFD programs allow to make adjustments on physical properties [80]**.** Also, there is a possibility about creation of materials via adjusting of feature like density, viscosity, conductivity, specific heat, emissivity, and so on [59].

5.2.2.3. Define boundary conditions

The significance of the indication of boundary conditions is the solving of the physical problem via CFD which is represented with the definition of boundary conditions. In more specifically, the correct described boundary conditions are important for modelling CFD in indoor environments [98]. Moreover, the initial conditions are needed for iterative process utilized for solving. Prior to solution, almost all properties of flow have to be determined as initial conditions. Even if the initial conditions could be arbitrary, the good determined ones are vital for getting benefits on iterative process. There are two subjects in recommending usage of proper initial conditions; one of them is that the results with faster converged and lesser computed time would be when used closer initial conditions to solution of steady-state.

5.2.2.4. Generation of mesh

The turbulence flow and heat transfer models solve in CFD with help of finite intervals which are discretized continuous time and space. Also, the calculations have occurred at grid points [98]. Thus the computational outcome is drastically related to grids using for discretization of the computational domain [92]. When generating the mesh, if the cell counts are bigger the CFD outcome will be better and more accurate. However, the more cell count will also affect the computation time and storage of computer as increased. Consequently, the numerical grids should be satisfactory to obtain geometric resolution and expected flow behavior. Also, the mesh should be precise [94].

5.2.2.5. Set solving parameters

The prediction precision and computational speed for CFD simulations could be affected by plenty of factors for instance numerical method, turbulent model, mesh quality, discretization scheme, and algorithms of pressure and velocity [99]. Despite of being various factors for prediction precision and computational speed for CFD simulations, when using the CFD approach, the main considerations are mentioned as turbulence modelling, discretization method, and algorithm development. [94], [100].

Turbulence Model

One of the chief factor influencing CFD simulation estimation is turbulence modelling due to developing a set of constitutive relations for turbulent flow whose behavior is fluctuating and agitated motion. There are many turbulence modelling techniques in the literature. These techniques are related to the approximations of Navier-Stokes equations. The governing equations for flow have been developed via mathematically expression of three essentially physical principles; conservation of mass as continuity equation, Newton's second law as momentum equation, and conservation of energy as energy equation. In order to have more geometry resolution, the governing equations can be written with space coordinates as Cartesian (x, y, z), cylindrical (r, θ, z) or spherical (r, θ, ϕ) [101]. The two equation models are seen that the popular model in the commonly engineering analysis and research fields. In this model, the turbulence length scale and the turbulent kinetic energy have been independently ensured via transport equations. When using the two equations models, there is not needed supplementary turbulence data for flow [100]. One of the universal two equation eddy-viscosity turbulence models is k-epsilon model which contains two transport equation for description of turbulent flow behaviors. The transport variables of k-epsilon model are turbulent kinetic energy, k determining energy in the turbulence, and turbulent energy dissipation, ε determining the scale of the turbulence. The beneficial of k-epsilon model is to calculate convection and diffusion of turbulent energy. When derivation the k-ε model, the flow is assumed fully turbulent and the influences of molecular viscosity are ignored, so that this model is suitable for only fully turbulent flows [94]. In the standard k-ε model equations are shown.

Continuity Equation [102];

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}+\frac{\partial \rho w}{\partial z}=0 \tag{5.1}$$

X- Momentum Equation [102];

$$\rho\frac{\partial u}{\partial t}+\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}+\rho w\frac{\partial u}{\partial z} = \rho g_x-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[2\mu\frac{\partial u}{\partial x}\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right]+S_\omega+S_{DR} \tag{5.2}$$

Y- Momentum Equation [102];

$$\rho\frac{\partial v}{\partial t}+\rho u\frac{\partial v}{\partial x}+\rho v\frac{\partial v}{\partial y}+\rho w\frac{\partial v}{\partial z} = \rho g_y-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial y}\left[2\mu\frac{\partial v}{\partial y}\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+S_\omega+S_{DR} \tag{5.3}$$

Z- Momentum Equation [102];

$$\rho\frac{\partial w}{\partial t}+\rho u\frac{\partial w}{\partial x}+\rho v\frac{\partial w}{\partial y}+\rho w\frac{\partial w}{\partial z} = \rho g_z-\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[2\mu\frac{\partial w}{\partial z}\right]+S_\omega+S_{DR} \tag{5.4}$$

There are two sources term in momentum equations which are S_{DR} *which is for distributed resistance and* S_ω *which is for rotating coordinates. The variables are* g_x,g_y, g_z *as gravitational acceleration with coordinates, p as pressure, t as time, μ as viscosity, and ρ as density. The velocity components* u, v, w *respectively x, y, z-direction are also variables.*

Turbulent Kinetic Energy (k) Equation [100];

$$\rho\frac{\partial k}{\partial t}+\rho U_j\frac{\partial k}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+\tau_{ij}\frac{\partial U_i}{\partial x_j}-\rho\varepsilon \tag{5.5}$$

Turbulent Energy Dissipation (ε) Equation [100];

$$\rho\frac{\partial\varepsilon}{\partial t}+\rho U_j\frac{\partial\varepsilon}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{\varepsilon 1}\frac{\varepsilon}{k}\tau_{ij}\frac{\partial U_i}{\partial x_j}-C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k} \tag{5.6}$$

Eddy Viscosity [100];

$$\mu_t=\frac{C_\mu\rho k^2}{\varepsilon} \tag{5.7}$$

The k- ε equations variables are; density (ρ), time (t), mean velocity (U), molecular viscosity (μ), eddy viscosity (μ_t), Reynolds stress tensor (τ_{ij}). σ_k as 1 and σ_ε as 1.3 are turbulent Schmidt numbers, $C_{\varepsilon 1}$ as 1.44 and $C_{\varepsilon 2}$ as 1.92 are empirical constants. σ_t is a turbulent Prandt number as 1, and C_μ as 0.09 is an emprical constant [102].

Discretization Method

Discretization method is important to solve the flows described by partial differential equations and get an approximate numerically solution. The discretization method approximates these differential equations with a set of algebraic equations which could be solved by a computer. The approximations are implemented on small domains in space and/or time; therefore, the outcomes of numerical solution give discrete locations in space and time. The outcomes of numerical solutions are related to the utilized discretization quality [79].

Algorithm

The problem about governing partial differential equations with computational fluid dynamics is that there is not explicit pressure equation for incompressible flows [103]. To solve missing pressure equation, the most appropriate method is seen semi-implicit method for pressure-linked equations, called as SIMPLE, and its variations. In the CFD simulation program, SIMPLE-R technique is used [103].The SIMPLER derives the pressure field from velocity field, unlike SIMPLE which estimates the pressure field. It means that, if the velocity field is correctly, then the pressure field will be correct; thus it will be no anymore required iterations. In other words, the obtained pressure correction equation by velocity fields, and the pressure equation which is extracted from the consequence of velocity field are concluded with the faster converged solution [104].

Other Solving Parameters

After the determination of major considerations about usage of computational fluid dynamics, there is needed to set some other solving parameters such as solve physics parameters, and solve control parameters. Furthermore, before the simulation run, some required result quantity parameters should be adjusted, for instance, thermal comfort parameters should be determined when important to see heat transfer. Final step before run the simulation is the placing of monitor points, where placed specifically to flow the track trends and convergence throughout analysis, into the model.

5.2.2.6. Determination of indoor air quality and thermal comfort criteria

The measurable main comfort criteria for indoor air quality are; temperature which influences straightly on indoor air quality, humidity, air velocity which is a sign for air distribution along the building, ventilation helping entrance of fresh air, vibration, and noise [105]. In the ASHRAE Standard 55, the comfortable range of temperature in summer and winter season and the comfortable range of humidity have been determined, which is shown in Figure 5.4 [106].

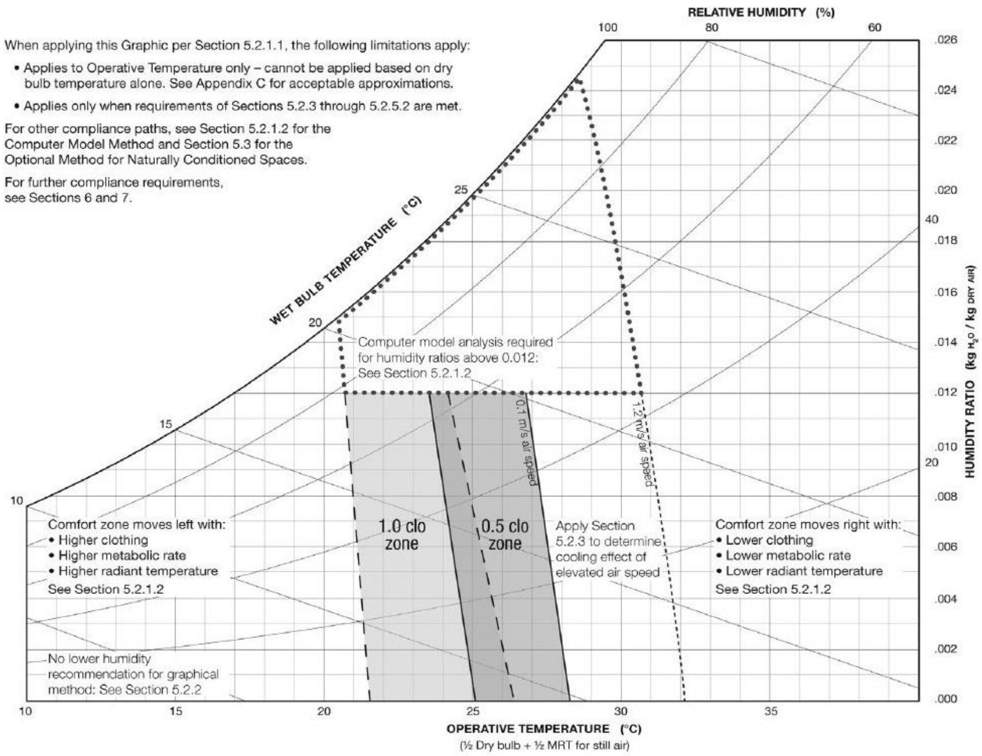


Figure 5.4 : Acceptable range of operative temperature and humidity for spaces.

Besides, ASHRAE connects temperature and humidity in order to supply a measurable thermal comfort. The aim of linking is to reach a proper occupant comfort level in terms of temperature and humidity at the same time controlling energy usage [105].

When considering thermal comfort, the required parameters for thermal comfort conditions are mentioned as four major environmental factors which are "*Mean air temperature around the human body, Mean radiant temperature in relation to the body, Mean air velocity around the body, and Water vapor pressure in ambient air*". In addition to these environmental factors, activity level and Thermal resistance of clothing are effects the thermal comfort conditions [107]. According to ASHRAE standard, the thermal sensation of human has been expressed as a scale, which is represented in Table 5.1 [106]**.**

Table 5.1 : The ASHRAE thermal sensation scale.

Value	Sensation
+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

The computer model method for general indoor application covers predicted mean vote (PMV) model and predicted percentage of dissatisfied (PPD) index. Predicted mean vote (PMV) model is comprised a heat balance principle which is corresponding to thermal comfort conditions and people thermal sensation response. In other words, the PMV model is determined with related metabolic rate, clothing insulation, air speed, and humidity as well as responded air temperature and mean radiation temperature. Unlike PMV, predicted percentage of dissatisfied (PPD) index, in Figure 5.5, is depended on a simplification around a neutral PMV, which estimates people are dissatisfied where thermal sensation scale is +3, +2, -2, and -3 [106].

Furthermore, the thermal comfort zone could be determined with recommended PMV values, which is generated by computer model, and combination of thermal comfort factor which are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. The recommended PMV values are between -0.5 and +0.5, therefore PPD value is lower than 10 [106].

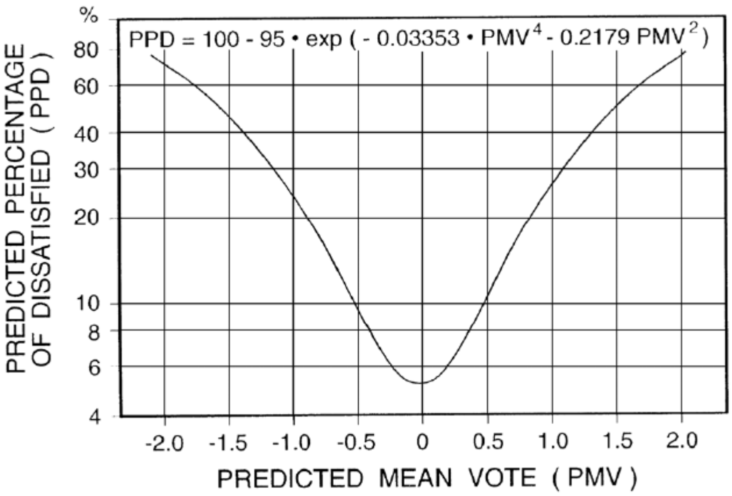


Figure 5.5 : Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV).

5.2.2.7. Analysis of results

In the post-process stage, the simulation results should be collected in order to investigate achieved or not the indoor air quality and thermal comfort criteria. During collection of CFD results, there are plenty of computer graphic techniques which are assisted users for analyzing and representing the fluid flow problem in terms of physical characteristics. These different techniques could be X-Y plots, vector plots, contour plots and other plots, data report and output, even animation [108].

5.2.3. 3rd step: optimization process

The optimization process takes place when the collected results do not reach the standard and when there is human control on the openings. Due to the human control on indoor air quality and thermal comfort, four scenarios are created for this study. According to the scenarios, the adjustments in model geometry are conducted on BIM model for existing building.

5.2.3.1. Return BIM model and adjust design model

One of the main behavior among humans is to have an under a controlled environment [109]. When someone feels discomfort from an environment, the person acts to recreate the comfort zone, which mentions as an adaptive approach. Thus, the indoor air quality can be changed by occupants whether consciously or not [110]. The preliminary factor of windows opening or closing behavior has been seen that air temperature as a physical environmental driven force. Furthermore, human behavior on opening or closing windows is not continuous action. [109]. Taking into account human control on building openings, there could be required some adjustments to the openings positions related to design study.

5.3. Computational Fluid Dynamics Analysis Application for Niğde House

5.3.1. 1st step: detailed 3D building data for BIM platform

In this study, it is aimed to investigate natural ventilation related to thermal comfort and indoor air quality. For this purpose, the main place which are most effected by wind was considered. These places were the terrace, the living room and the study room. Besides, these places were generated in the previous section which is at Chapter 4 building design optimization. However, the previously created 3D BIM model, in Figure 4.10.a, has many detail information. Therefore, some requirements such as simplification of BIM model had been appeared. The considerations during simplification of 3D BIM model to CFD model;

- ✓ The windows and doors were simplified.
- ✓ Since the fireplace would not be used in summer condition, it is also ignorable.
- ✓ The manually operable shutters, which is represented in Figure 12, were simplified as opening on chimney.

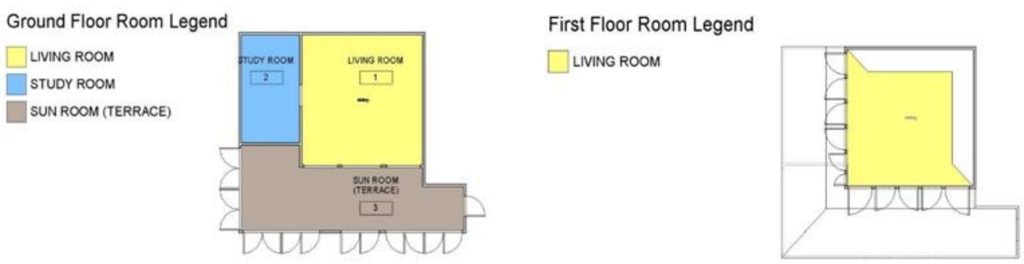


Figure 5.6 : Simplified building geometry with space usage.

The simplified 3D model with its perspective is shown on Figure 5.6 and Figure 5.7.

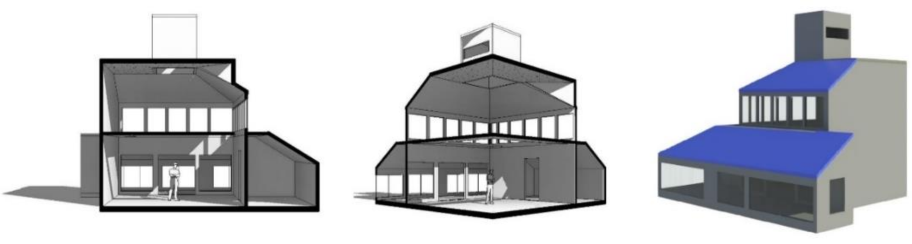


Figure 5.7 : Simplified building perspective and simplified 3D BIM model.

5.3.2. 2nd step: the detailed CFD analysis to evaluate natural ventilation for BIM platform

In the second step, there was seven sub-steps which had been applied on detailed CFD analysis to evaluate natural ventilation for BIM platform. These substeps explained one by one.

5.3.2.1. Geometry data exportation and launch into CFD simulation program

For the purpose of simplification of previously created 3D BIM model had been carried out in Revit© software. 3D model was exported as SAT format to create external air volume into 3D CAD software.

After the creation of dimensional external air volume, the CAD model imported into Revit© as a SAT file format in order to make final adjustments and launch into Autodesk CFD© as a CFD simulation software.

5.3.2.2. Define material

All the physical objects in the model as the fluid or solid should be assigned. In this study air as a fluid was the main physical material. Even if internal air was not created in the CAD or BIM model, it has been created in the CFD model automatically.

To investigate the natural ventilation and heat distribution, air was selected as variable position with other physical properties such as density, viscosity, conductivity and so on.

In the same investigation approach, the structural materials as solid class were assigned materials in CFD database with their physical properties. Also desired material was created and saved in CFD database. The solid clay material as green roof was created and saved in CFD database.

The building components were defined as concrete for wall and floor, as solid clay for top roof, as solar windows for windows and roof of atrium and terrace. In order to investigate thermal comfort, there was a human body in the building, which represents occupants.

Besides air and structural materials, it is necessary for the human body to assign materials as a solid class with thermo-physical properties. Hence, the defined all materials with physical properties is shown in Table 5.2.

Table 5.2 : Defined all materials with physical properties.

Building Components	Materials	Type	Physical Properties			
			Density (kg/m^3)	Spec. Heat (J/kgK)	Conductivity (W/mK)	Emissivity
Wall	Concrete	Fixed Solid	2306	837	1.1	0.92
Floor	Concrete	Fixed Solid	2306	837	1.1	0.92
Top Roof	Brick	Fixed Solid	1600	890	0.14	0.92
Roof of atrium and terrace	Window Solar	Fixed Solid	2700	840	0.78	0.92
Windows	Window Solar	Fixed Solid	2700	840	0.78	0.92
External and Internal Volume	Air	Variable Fluid	1.1644	1004	0.02563	1
Occupant	Human Body	Fixed Solid	998	4182	50	0.98

5.3.2.3. Define boundary conditions

For the inlet boundary conditions, velocity was specified as normal for the front side of the external domain, and as Cartesian components (Vy) for the top and lateral sides of the external domain due to the dominant air velocity was Y direction. Also, the air temperature was defined for the flow inlet boundary condition. The applied velocity and temperature values had been determined with consideration of meteorological data in section 4.1.Weather Information. The applied velocity value as the inlet flow parameter was taken from the meteorological data for annual wind speed at 10 m as average 7 km/h. Also, the temperature value, which is other inlet flow parameter, was taken as the maximum design temperature during summer season as 30^{o}C. For the outlet boundary condition, static gage pressure was assigned as 0 value. Total heat generation, which contains the volumetric heat loads so that heat loads could not be separated, is applied to the human body as a heat source.

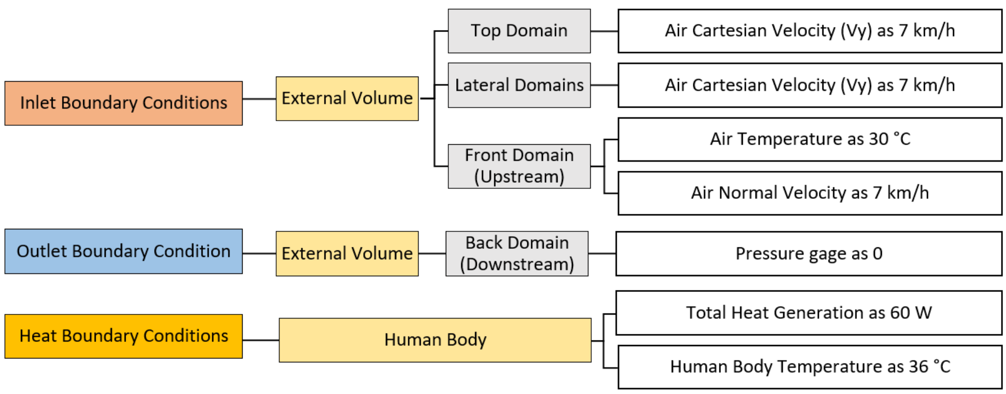


Figure 5.8 : Applied boundary conditions.

To get more converged and less computing time, the initial conditions are determined for building components. When assigning initial conditions on building components, the consideration was that the temperature values for all the building materials are related to the summer weather conditions. Consequently, the applied boundary conditions and initial conditions is shown in respectively Figure 5.8 and Figure 5.9.

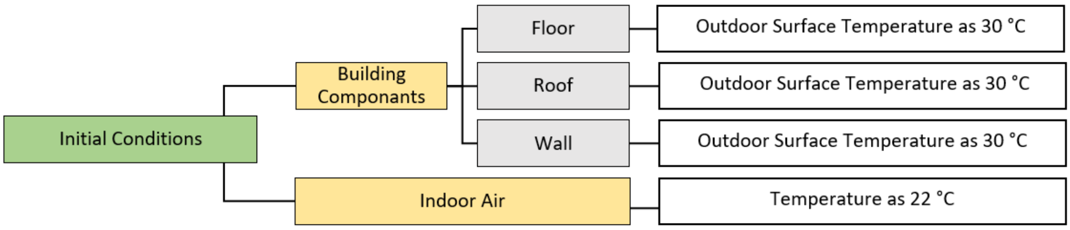


Figure 5.9 : Applied initial conditions.

5.3.2.4. Generation of mesh

During mesh creation, firstly mesh was generated by automatically, which means that mesh distribution in the model were examined all edges, surfaces, and volumes [96]. In order to improve automatically created mesh, small edges and surface were being diagnosed by CFD simulation software. The problematic edges, whose length change had higher degrees of magnitude, were adjusted by minimum refinement length as a threshold edge size so that they were mesh with a node. The problematic surfaces were first identified and then refined from the model. The benefits of this mesh creation way, the automatically creation of mesh and after then adjustment of them, were quicker and efficient mesh distribution. On the Figure 5.10 represent generated mesh distribution respectively for CFD model, building, and inside of building.

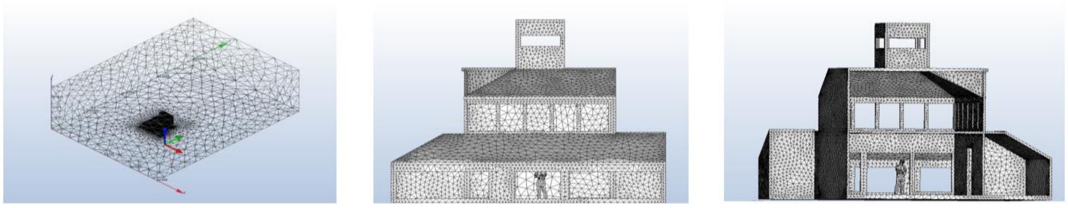


Figure 5.10 : Mesh distribution for CFD model, on building, and into building.

5.3.2.5. Set solving parameters

For the natural convection, the flow section, as well as heat transfer section, should be on. The heat transfer as conduction and convection has been considered. The k-ε turbulence model was selected. When determining the flow properties, internal flows, containing enter and pass along a solid structure, and external flows, having an immersed body inflow and flow moves according to the solid body, have been considered. In natural ventilation simulation model, the flow properties have been selected as internal and external incompressible flow. It is important to reach comfort level by correlating air movement and behavior with time in this study, thus the solution mode was selected as transient which is time depended. Therefore, the parameters for transient analysis as time step, stop time, inner iteration were determined. Beside the default result quantities, the thermal comfort has been selected for visualization of analysis result. With the consideration of recommended values for metabolic rates, and clothing in ASHRAE, the metabolic rate and clothing had been selected as 60 W/m^2 (1.03 met) and 0.5 clo. For the solution control, the advection, which is the numerical mechanism of transporting a quantity through the solution domains scheme was chose Modified Petrov-Galerkin. Consequently, all selected solving parameters for analysis is shown in Table 5.3.

Table 5.3 : All selected solving parameters for analysis.

Solve Physics Parameters		Solve Control Parameters	
Parameters	Selected Value	Parameters	Selected Value
Flow	Select	Solution Mode	Transient
Turbulence	Selected as Turbulent	Time Step Size	2
Turbulence Model	k- epsilon	Stop Time	10800
Compressibility	Incompressible	Inner Iterations	1
Heat	Select	Solver Computer	Cloud
Gravity Method	Earth	Thermal Comfort	Selected
Gravity Direction	0,0,-1	Metabolic Rate	60 W/m2
		Clothing	0,5 clo
		Humidity	76%
		Solution Control	ADV 5 (Modified Petrov- Galerkin)

In order to observe the behaviors of trends and convergence, the monitor points were placed into the model before running analysis. These points were determined by the correlated to air flow path. The air flow path was considered as a way where air entered and exited. It was considered as air entry place first point, air exit place last point. The first point as entry place was selected ground floor middle window which is front of the human body. The last point as exit place was selected chimney cover. Other points that form a path for the air moving towards the human body were also among these two points.

Table 5.4 : Location of monitor points into the CFD model.

Point Number	Located Coordinates (x, y, z)
Point 1	-11.35, 4.5, 0.6
Point 2	-11.35, 7, 0.8
Point 3	-11.35, 8, 1.25
Point 4	-11.35, 8.75, 2
Point 5	-11.35, 9.25, 3
Point 6	-11.35, 9.75, 5
Point 7	-11.35, 10.05, 7.25

The determined exact locations with Cartesian coordinates for monitor points in Table 5.4 were shown in the building in Figure 5.11.

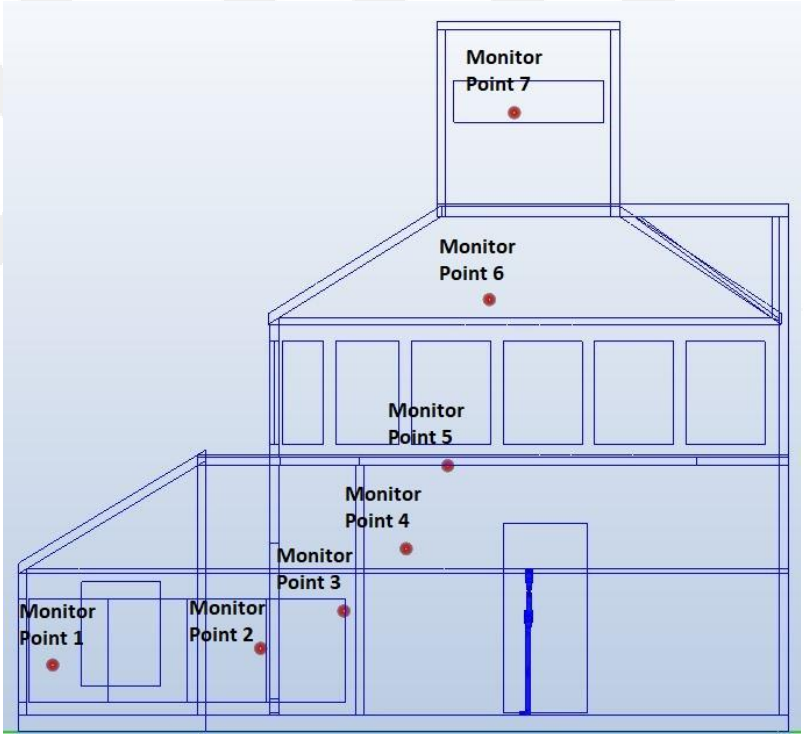


Figure 5.11 : Monitor point in building.

After the all solving parameters are set, the CFD simulation will be started. During the CFD simulation program is running, the calculation steps with segregated solution method, which separately solved all governing equations with explicit pressure equation, and iteration technique, which assumed only one unknown for each equation and solved in a repeating cycle unless all equations are met, in background of software are shown in Table 5.5 [111].

Table 5.5 : Overall solution sequence flowchart.

Overall Solution Sequence Flowchart	
1. Read in geometry, boundary conditions, and analysis data	
2. Create data structures	
3. Solve x-momentum equation	Equation (5.2)
4. Solve y-momentum equation	Equation (5.3)
5. Solve z-momentum equation	Equation (5.4)
6. Solve pressure equation and correct velocities	
7. Solve energy equation	
8. Solve turbulent kinetic energy equation	Equation (5.5)
9. Solve turbulent energy dissipation equation	Equation (5.6)
10. Check convergence (go to step 3)	
11. Perform output calculations	
12. Write out data	
13. Exit	

5.3.2.6. Determination of indoor air quality and thermal comfort criteria

For the indoor air quality, the major measurable criteria have been specified as temperature, humidity, air velocity, ventilation, vibration, and noise. However, the considered ones are temperature, humidity, air velocity, and natural ventilation in this study. During the evaluation of thermal comfort criteria, the main criteria for thermal comfort conditions which are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity are integrated with the PMV values. The major dependencies aspects of both indoor air quality and thermal comfort can be considered as temperature and air velocity. In addition to temperature and air velocity, the PMV and PPD are significant considerations for thermal comfort in this study.

5.3.2.7. Analysis of results

Collecting the analysis data, the X-Y Plots were generally used to see air velocity magnitude, indoor air distribution, and PMV. Also, the vector plots were used to more detail understanding of air velocity direction. Besides temperature, velocity, and PMV, the analysis data reports and outputs at monitor points, where had been adjusted in the model before the simulation run, were collected with respect to each iteration.

5.3.3. 3rd step: optimization process

The building model should be adjusted with the dependencies of human control on building openings. Therefore, there were planned as four scenarios which were related to the human control on openings.

5.3.3.1. Return BIM model and Adjust Design Model

During creating scenarios, the position of windows or shutters were considered as opened or closed.

- Scenario 1 was, if all windows from the ground and second-floor had been opened and the shutters had been semi-opened (two sided).
- Scenario 2 was, if all windows from the ground and second-floor had been opened and the shutters had been fully-opened (four sided).
- Scenario 3 was, what if second-floor windows had been closed, windows at the ground had been opened and the shutters had been semi-opened (two sided).
- Scenario 4 was, what if second-floor windows had been closed, windows at the ground had been opened and the shutters had been fully-opened (four sided).

The required adjustments with corresponding to scenarios should be rearranged in the simplified BIM model.

5.4. Computational Fluid Dynamics Analysis Results and Discussion

The air temperature, air velocity, PMV, and PPD are main considerations for air indoor quality and thermal comfort criteria in this study. Therefore, these criteria with indicated AA and BB sections were obtained by CFD simulation for each scenario. The monitor points where located in building were collected to see results of air temperature and air velocity point by point. For all scenarios, the temperature range was from 22^0C to 36^0C. The previous temperature had been selected as initial temperature of indoor air, and second temperature had been determined human body temperature. Also, the air velocity range was set between 0 and 1.2 m/s for each scenarios.

To understand the relation between temperature and air velocity, the literature has been investigated. For this purpose, the nearest value in the TS EN ISO 7730 to this study is the activity level 58 W/m^2 and the clothing 0.5 clo. If the operative temperature and relative air velocity are increasing together, the predicted mean vote is getting closer to zero. For instance, while air velocity is increasing to 0.5 m/s at 28^0C, the PMV is 0.14. However, while air velocity is increasing to 1 m/s at 30^0C, the PMV is 0.86. [112]. Moreover, the total heat loss over time depending on the ambient air velocity during constant relative humidity and temperature has been examined by Atmaca.

It was underlined that if the velocity was increasing, there would be more heat transfer and the skin temperature would be decreased over time.[113]. Furthermore, the acceptable air movement levels have been examined in Brazil which is hot humid climates. The results have been shown that the minimum air velocity were 0.4 m/s and 0.9 m/s where the temperature respectively 26^{0}C and 30^{0}C. [114].

In the light of these studies, the relationship between temperature and velocity value should tend to increase together. In this study, the results of scenario 2 and 4 match this trend. In the scenario 3 had opposite of this trend. Further, the results of scenario 1 had inconsistent data for evaluation of relationship between temperature and velocity.

- Scenario 1;

When the simulation finished for scenario 1, the mean temperature value was 30.87^{0}C. The indoor temperature range was between 26^{0}C and 32^{0}C for the AA and BB sections, which shown in Figure 5.12. The mean velocity magnitude was 0.26 m/s. The velocity magnitude in the sections had more variations than temperature. The maximum velocity magnitude was in the second floor shutters was 1.2 m/s. And the minimum value of velocity magnitude was 0 m/s in some spots of study room in the ground floor.

With the air passing through the second floor windows openings, air velocity was decreasing. The air movement was dominantly entered from second floor and left from the ground floor and shutters openings, therefore the air was circulated inside building. Velocity magnitude and air direction on AA and BB sections are shown in Figure 5.12.

The monitor point 1 and 2 had lower temperature value than others. The air movement around this two monitor points was trend from inside to outside. Hence, the air temperature was lower in terrace room rather than the living room. According to the temperature and velocity magnitude, the PMV value for this scenario was between 2 and 3 which means that the human sensation was warm to hot. PMV and PPD ranges for scenario 1 are shown on Figure 5.16.

When considered 30^{0}C outside temperature, inside of the building on the ground level temperature drop down average 1.5^{0}C to almost 28^{0}C with the velocity reached 0.33 m/s on the living room, could not be favorable.

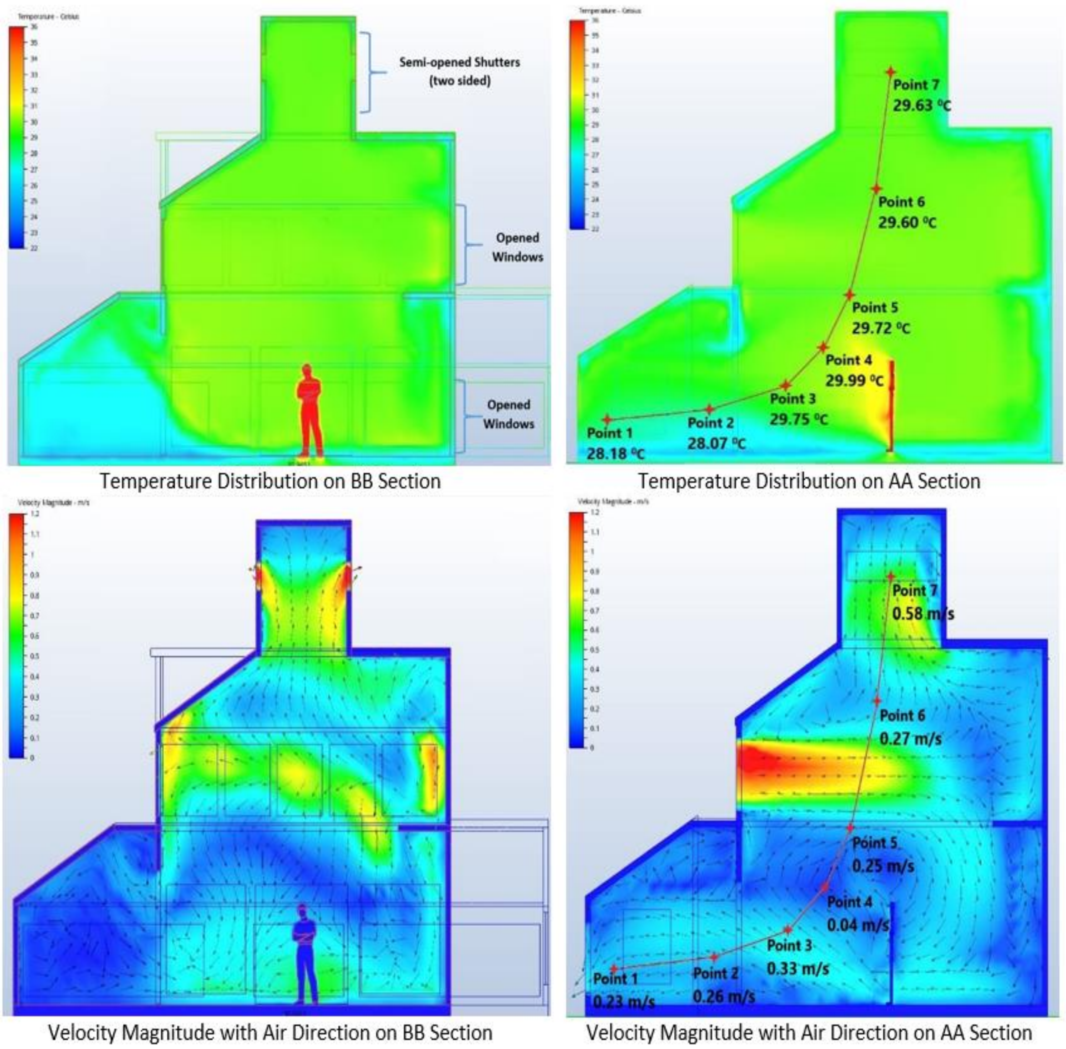


Figure 5.12 : Temperature distribution and velocity magnitude with air direction on BB and AA section for scenario 1.

- Scenario 2;

The mean temperature for second scenario was 28.18^0C. When compared first scenario, the temperature value was lower in the second scenario. The indoor temperature on AA and BB sections was approximately 27^0C at ground floor and 30^0C at second floor. The temperature distributions on sections is shown on Figure 5.13.

The mean velocity magnitude was 0.45 m/s, after all iterations had done. When investigate the air velocity in sections which is represented on Figure 5.13, the air direction was shown more clearly. The air was entered from both ground and second floor windows openings and leaved from shutters openings which were located four side of chimney. Therefore, the highest velocity values as range from 0.6 m/s to 1.2 m/s were in second floor windows and shutters openings.

To obtain more detailed results in the building, the temperature and velocity magnitude in each monitor point for Scenario 2 was collected. Till the last two monitor points temperature was around 28^{0}C. In monitor point 6, temperature was increased as 29^{0}C, and final monitor point was almost 30^{0}C. The velocity value was 0.16 m/s as minimum in first monitor point, and 0.75 m/s as maximum in final monitor point. The individual value of temperature and velocity in monitor points also supported the temperature and velocity range in the sections.

Having lower temperature and velocity magnitude in ground floor, the human sensation for second case was more adequate than first case. The PMV value of second case was between 0 and 3. Some of body parts such as neck, arm, and foot were still at hot sensation level. Because of the more pleasured PMV value, the PPD value was dominantly range between 0 and 40. The PMV and PPD ranges for scenario 2 is shown Figure 5.16.

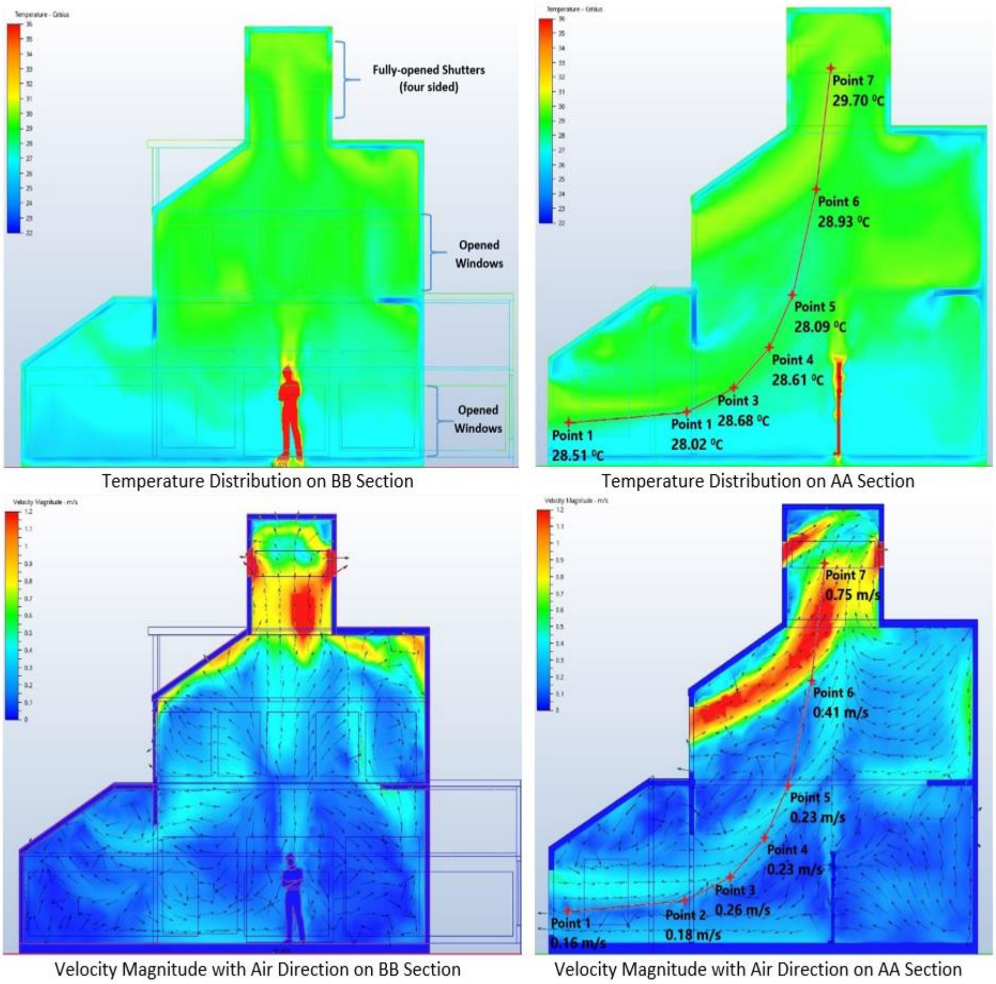


Figure 5.13 : Temperature distribution and velocity magnitude with air direction on BB and AA section for scenario 2.

Temperature and air velocity has distributed evenly inside of house, the temperature drop down 2^0C to almost 28^0C and air velocity comes to 0.26 m/s while it reaches to 0.4 m/s on the second level. Because of balanced air temperature and velocity distribution the PMV level reached to an acceptable level.

- Scenario 3;

The mean temperature value was 27.66^0C. The temperature range in the sections was between 23^0C and 30^0C, which is seen in Figure 5.14. For the third scenario air was entering from only ground floor windows with 30^0C.

While entering hot outdoor air from the windows, the temperature reached the peak value in the terrace room. The temperature for remaining of building spaces was getting lower value. The behavior could be explained by the fact that the hot outdoor air stayed in the terrace room as it moves through the building. Moreover, it would be meant that the terrace room was acted as a buffer zone aspect to the protection of temperature.

The mean velocity magnitude was 0.48 m/s. The only way for entrance of air was the ground floor windows openings and for exit of air was shutters openings which located two side of chimney in third scenario. Because of this entrance and exit openings, the air movement through the building presented like a path. In this path the velocity magnitude of air was between almost 0.6 m/s and 0.9 m/s. The peak value as 1.2 m/s was in the shutters openings. The velocity magnitude and air direction on sections shown in Figure 5.14.

In the sections, temperature and velocity ranges were larger, thus the values of temperature and velocity in monitor points would bring more specific results. The temperature was decreased in each monitor point. However, the velocity values would be changed in the points. Furthermore, the PMV range was varied in the third scenario. The PMV range was from the 0 to 3, which is represented Figure 5.16. The body parts as the neck, arms, and ankle had highest value of PMV. The sensation of the upper body part had hotter than the legs. Like PMV value variation, PPD range was also differed which seen in Figure 5.16.

In this scenario temperature drop down average 3^0C and reached to almost 27^0C on the living room and 26^0C on the second floor. While velocity reached to 0.64 m/s evenly on the first and second floor. Therefore, PMV level is in tolerable range.

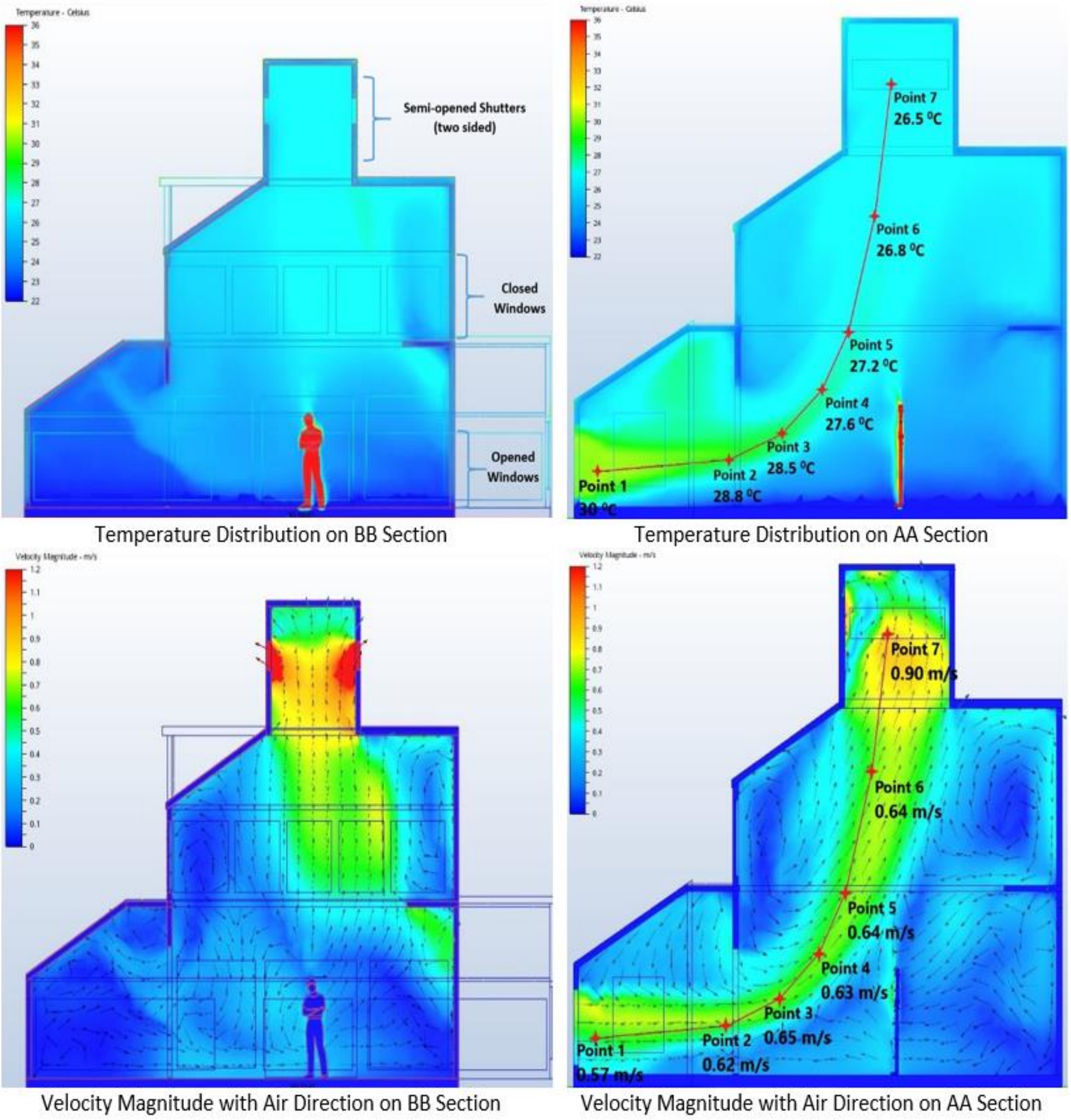


Figure 5.14 : Temperature distribution and velocity magnitude with air direction on BB and AA section for scenario 3.

- Scenario 4;

The mean temperature was 28.18^{0}C. The temperature range was from 24^{0}C and 30^{0}C in AA and BB sections, which could see in Figure 5.15. The outdoor air was entering majorly from ground floor windows and slightly from shutters opening, and exiting from four sides of shutters. While the hot air was passing from the terrace room to atrium, the temperature would be decreased. But when the air rose up to the chimney, it would be crossed with the hot outdoor air again. Therefore, like the third scenario, there was an observable air path. However, the path was closer to the human body in final scenario. Also, the temperature of the path was warmer than the third scenario.

The mean velocity magnitude for the final scenario was 0.40 m/s. When the velocity magnitude in the sections, the range of velocity look was same as third scenario. The velocity magnitude and air direction on sections shown in Figure 5.15.

The velocity magnitude reached maximum value as 1.2 m/s at shutters openings. Also, the same velocity ranges of air movement path for third scenario observed. However, the air flow path was differing between last two scenarios.

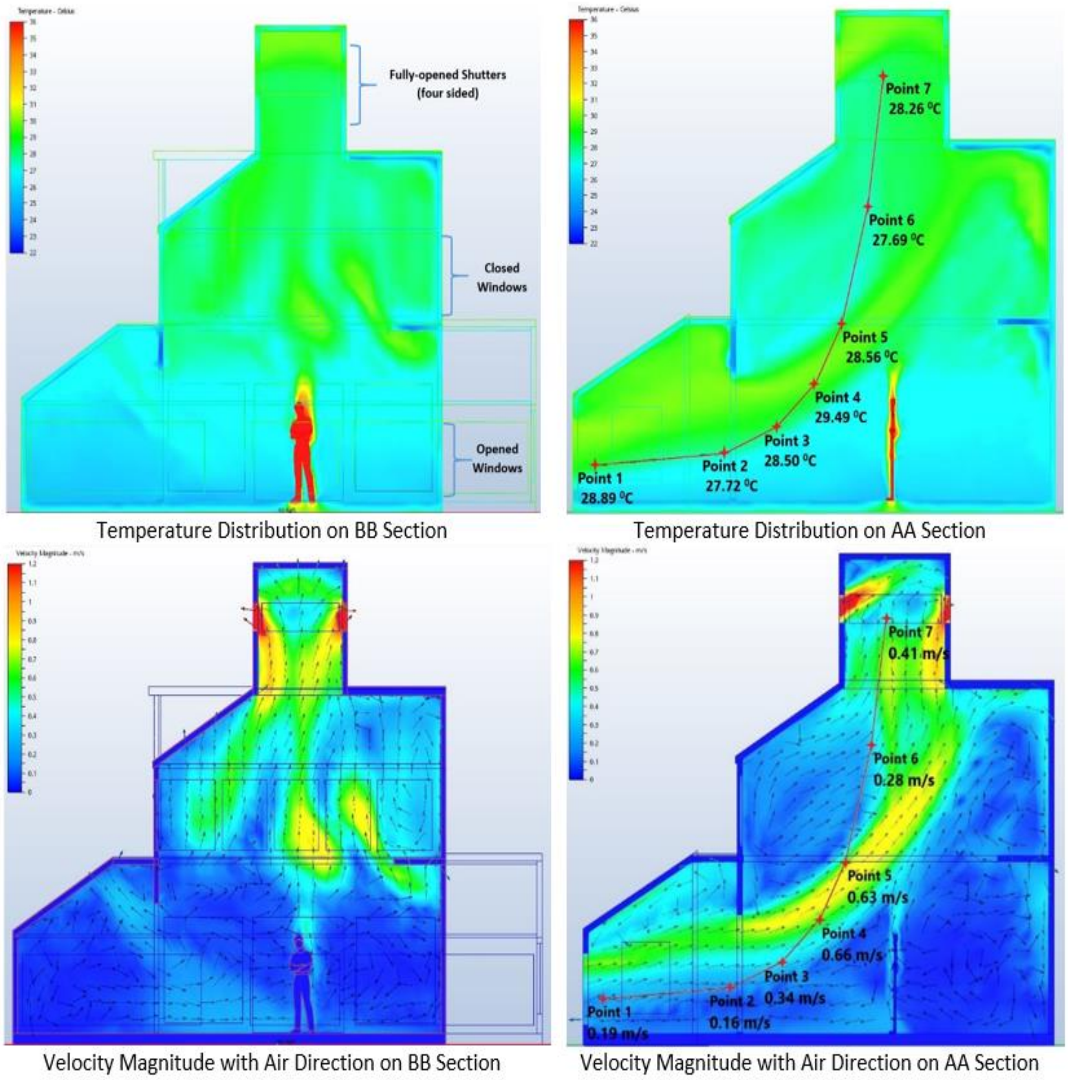


Figure 5.15 : Temperature distribution and velocity magnitude with air direction on BB and AA section for scenario 4.

The PMV range was from -0.5 to 3. The lowest value was on the foot, and the highest value was on the arms and neck. Due to this larger range for PMV, the PPD had also various value on human body. Both PMV and PPD are respectively represented in Figure 5.16.

The temperature drops reach to almost 3^0C on the sunroom while come back to average 1^0C on the living room while velocity also has variable distribution from 0.67 m/s to 0.66 m/s. On the other hand, PMV level could be tolerated.

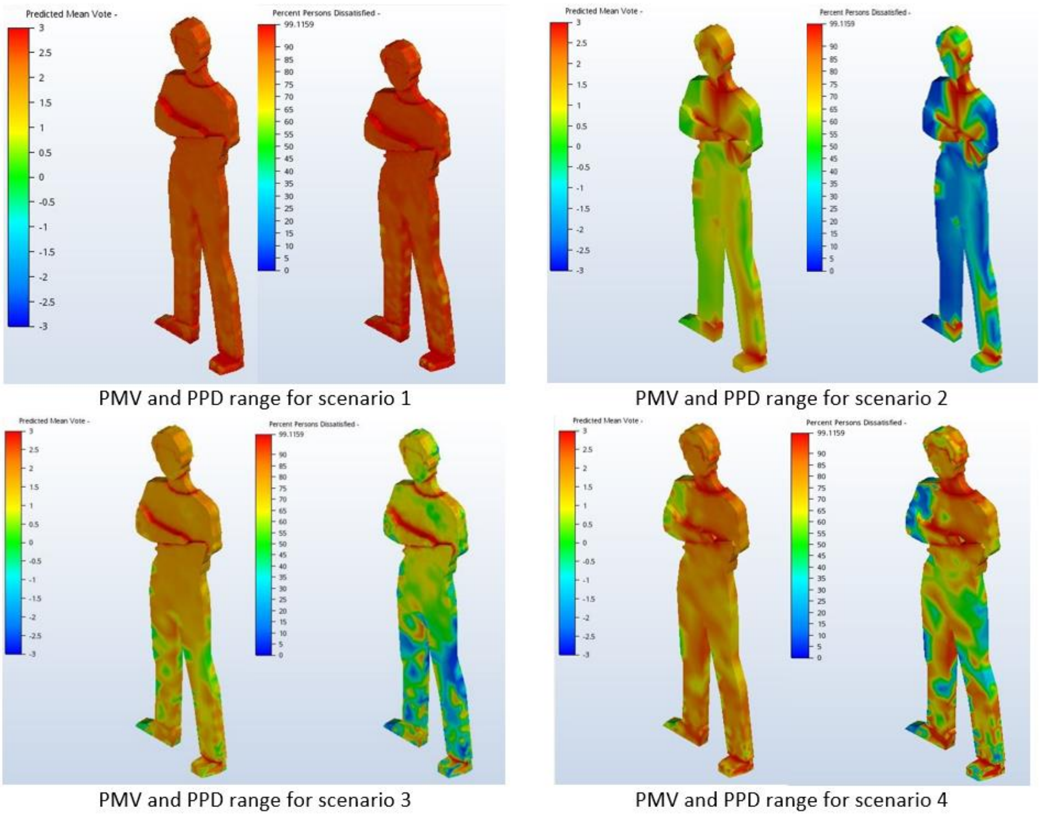


Figure 5.16 : PMV and PPD ranges for all scenarios.

When summarized mean temperature and velocity value for all scenarios in Table 5.6, scenario 1 had the maximum mean temperature value and scenario 3 had the minimum mean temperature. The mean temperature value for scenario 2 and 4 had same value, however their standard deviation of temperature had been different. The standard deviations were 1.76 for scenario 2 and 2.20 for scenario 4. It means that the standard deviation, gave the information about distribution of values, for scenario 4 had been have more inconsistent data than scenario 2. The maximum mean velocity magnitude was in scenario 3 and the minimum velocity magnitude was in scenario 1.

Table 5.6 : Mean temperature and mean velocity values for scenarios.

	Mean Temperature(Celsius)	Mean Velocity Magnitude(m/s)
Scenario 1	30.87	0.26
Scenario 2	28.18	0.45
Scenario 3	27.66	0.48
Scenario 4	28.18	0.40

In the same aspect in Table 5.7, the temperature and velocity magnitude have been evaluated for each monitor points of each scenario.

Table 5.7 : The temperature and velocity magnitude in each monitor points.

Monitor Points	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Temp. (Celsius)	Velocity Magnitude (m/s)	Temp. (Celsius)	Velocity Magnitude (m/s)	Temp. (Celsius)	Velocity Magnitude (m/s)	Temp. (Celsius)	Velocity Magnitude (m/s)
1	28.18	0.23	28.51	0.16	30.00	0.57	28.89	0.19
2	28.07	0.26	28.02	0.18	28.78	0.62	27.72	0.16
3	29.75	0.33	28.68	0.26	28.51	0.65	28.50	0.34
4	29.99	0.04	28.61	0.23	27.56	0.63	29.49	0.66
5	29.72	0.25	28.09	0.23	27.18	0.64	28.56	0.63
6	29.60	0.27	28.93	0.41	26.82	0.64	27.69	0.28
7	29.63	0.58	29.70	0.75	26.51	0.90	28.26	0.41

To see more clearly temperature and velocity values in monitor points, all scenarios values were represented in graphically in Figure 5.17.

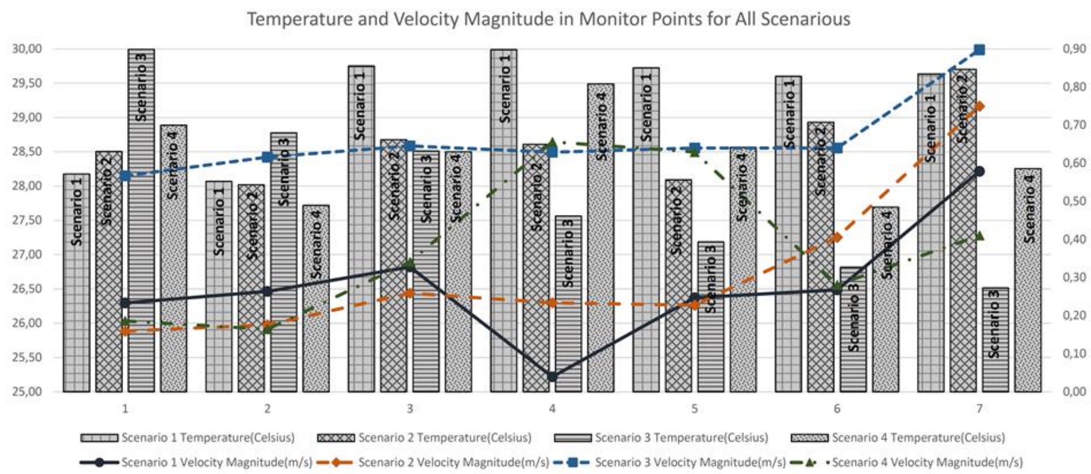


Figure 5.17 : Temperature and velocity magnitude in monitor points for all scenarios.

There was no clear trend like increasing or decreasing of temperature except scenario 3. In the scenario 3, temperature occurred in a decreasing trend. Also, the most consistent value was in scenario 2 as temperature was around 28^{0}C. Further, the velocity magnitudes in monitor point 7 were higher for all scenarios because the monitor point 7 located at chimney openings which acted as an exit for air place. For scenario 2 and 3 had no dramatic changes in monitor points except point 7. The velocity magnitude for scenario 2 and 3 were changed respectively around 0.2 and 0.6 m/s. Also, the maximum velocity magnitude was in scenario 3 due to velocity value around 0.6 m/s string. On the other hand, the drastic decrease was in scenario 1 at monitor point 4. In oppositely, the dramatic increasing was in scenario 4 at monitor point 4 and 5.

Beside investigate separately temperature and velocity values, the integration of them had been also examined at each monitor point for all scenarios in Figure 5.18, Figure 5.19, Figure 5.20, and Figure 5.21.

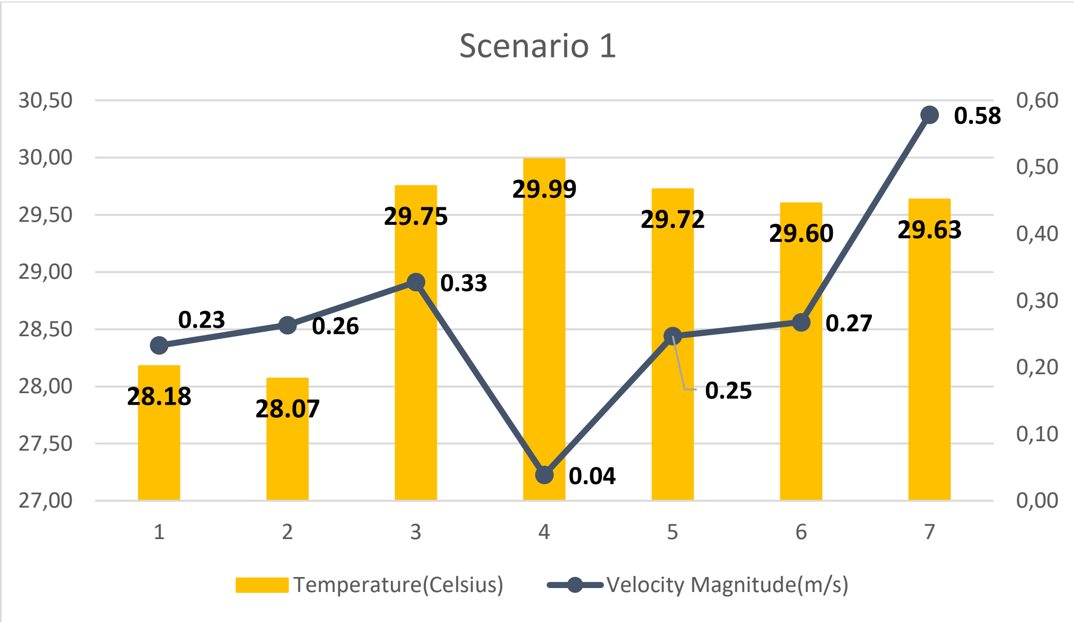


Figure 5.18 : Temperature and velocity magnitude in monitor points for scenario 1.

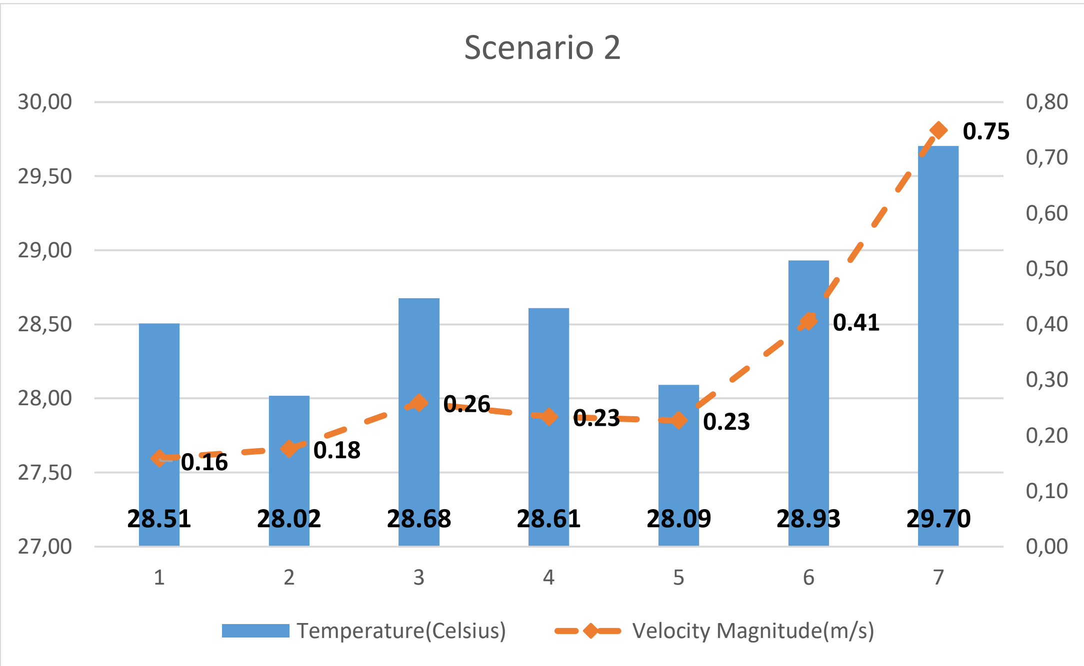


Figure 5.19 : Temperature and velocity magnitude in monitor points for scenario 2.

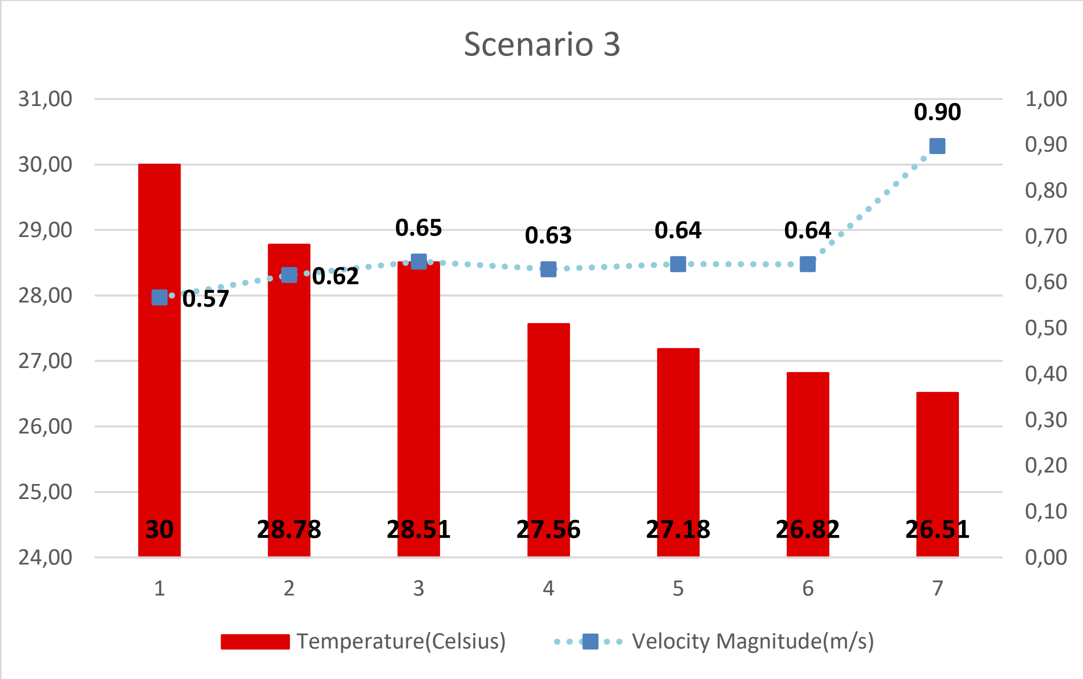


Figure 5.20 : Temperature and velocity magnitude in monitor points for scenario 3.

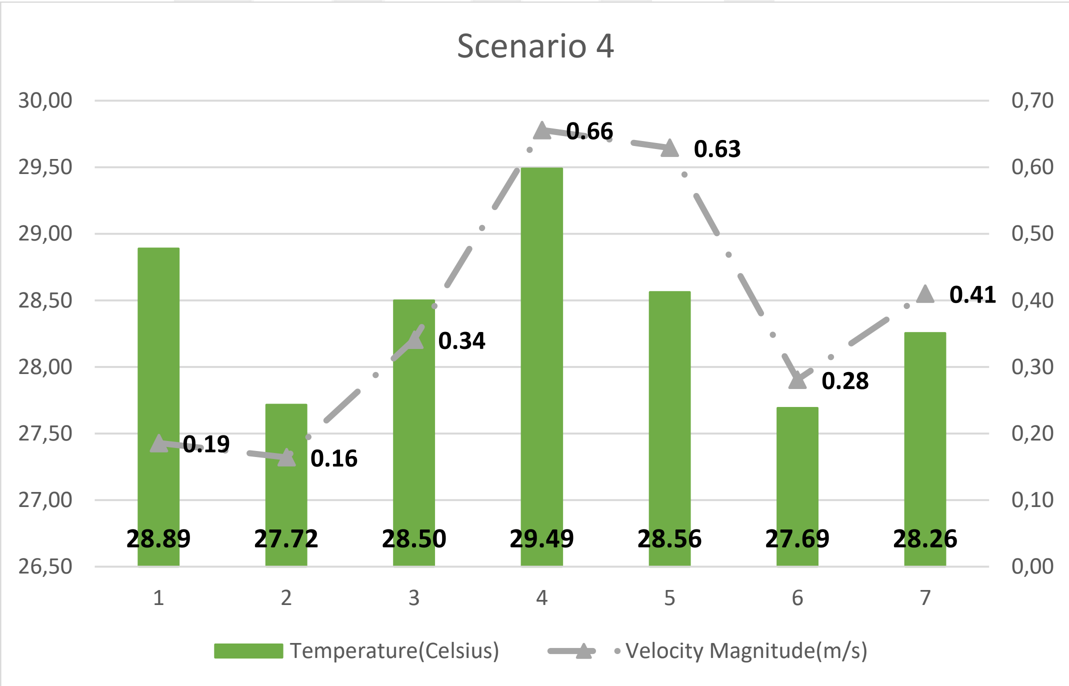


Figure 5.21 : Temperature and velocity magnitude in monitor points for scenario 4.

When compared the result based on the defined path line which shows the temperature and velocity distribution come to the acceptable level on scenario 2 and scenario 3, even scenario 4 have temperature drops considering 30^{0}C outside temperature and tolerable air velocity by the help of design strategy. On the other hand, when PMV level considered inside of the living room except scenario 1 all scenarios were reached to acceptable level while scenario 2 could be considered as the best one.

5.5. Computational Fluid Dynamics Analysis Conclusion

The aim of this study is to assess the hypothetical building design quality in aspect of indoor air quality and human thermal comfort conditions for occupants with the generated CFD analysis methodology. The optimization of building design quality is compared with standards and criteria related to evaluating air temperature, air velocity, PMV, and PPD. Beside, different scenarios were created to evaluate the optimization process including geometry, material, boundary conditions, CFD analysis model, internal and external conditions, and human behavior.

The importance of this study is the combination of an architectural structure and computational fluid mechanics in order to analyze indoor air quality and thermal comfort conditions via natural ventilation. During the integrating the 3D building model and CFD model within the BIM platform to analyze CFD, three different programs were used which are Revit©, AutoCAD©, and Autodesk CFD©. Also, the data exchange was occurred in these different programs. The 3D model was developed and simplified by Revit©, the adding the external volume around the model was occurred by CAD, and the CFD model was analyzed by Autodesk CFD©.

The advantage of BIM based CFD model had been taken in creation geometry and exportation geometry data step. Revit based BIM platform was provided easier and quicker approaches during this process. However, since only the geometry transfer was made from the 3D model, the materials of building components had to be defined again in the CFD program. Although this process seems to be a time consuming step, the CFD program includes its own material database and the desired changes as additions, edits, or recreations can be made in this database. Since the new materials are stored in the database, it is not difficult to assign material to all scenarios again.

In the CFD analysis was performed in summer season, the air temperature was chosen at maximum value and this value was preserved. Also, the four scenarios were created in aspect of human control with different combinations of building openings. According to temperature, air velocity, PMV and PPD results, the natural ventilation could be tolerable for the summer comfort in the scenario 2 where human sensation as

PMV ranges from 0 to 2, the mean temperature as 28.18^{0}C, and the mean air velocity as 0.45 m/s.

Furthermore, the outcomes from scenario 2 has shown that there is no additional need for cooling. Hence, design developments could be continued without mechanical cooling. In the next Chapter, the detailed energy analysis performs in the light of the CFD analysis outcome for evaluating the building design quality.

6. DETAILED ENERGY ANALYSIS

The energy consumption is getting increase in worldwide with concerning on issues such as supply difficulties, energy resource exhaustion, and great environmental effect like depletion of ozone layer, global warming, and climate change and so on [115]. Despite other economic sectors, the buildings have a major energy usage percentage, which can differ among countries, as around between 30 and 45 of the global energy request [116]. In addition, it is assumed that the energy consumption will be increased in the future due to growing population, increase of building services and comfort demand which brings more time spent in building. Owing to these facts that the preliminary purpose in these days is energy efficient buildings at regional, national and international levels [115]. Thus, energy efficiency and savings strategies are becoming a preliminary object for energy policies through countries due to the increase in energy usage and CO_2 emissions for built places [116].

According to the International Energy Agency (IEA), the global CO_2 emissions via buildings has been rising by almost 1% annually and global electricity usage of buildings has been increasing by average 2.5% annually in OECD also approximately 6% annually in non-OECD countries since 2010. With the acceptance and application of building codes and building efficiency standards, the energy intensity of buildings, which refers as final energy per square meter, decreased globally 1.3% per year along 2010 and 2014. The policies about the progress of buildings energy performance, however, global average energy usage per person is still constant onwards 1990. Thus, there is required pretentious action throughout the world to evolve global energy consumption per person up to 10 % in 2025 [117].

In respect to National Energy Efficiency Action Plan (NEEAP) in Turkey, the average annual energy demand in the building sector has been increased by 4.4 % from 2000 to 2015 also contributed to 32.8 % percent of final energy consumption in 2015. In Turkey, the Energy Efficiency Law, performed in 2007 with Law No. 5627, was aimed to utilize efficiently energy, prevent waste, alleviate the charge of energy costs on the economy, and preserve the environment with the improvement of consumption efficiency and energy [118]. The Energy Performance Regulation on Buildings, which based on the Energy Efficiency Law No. 5627 and Energy Performance Directive of Buildings 2002/91 / EC, entered into force in 2009 [119]. Besides, The National Climate Change Strategy of 2010-2023, The Energy Efficiency Strategy of 2012-2023, the Tenth Development Plan of 2014-2018, the 2015-2019 Strategic Plan of the Ministry of Energy and Natural Resources have included the energy efficiency goals, the set of policies and actions in order to achieve these aims [118].

Consequently, it is obvious that there is growing concern about energy use. Related to this concern, energy consumption in buildings, which is one of the sectors with the most energy use, is becoming more important day by day. In addition, energy consumption in buildings has great potential for energy efficiency and conservation.

6.1. Literature View for Building Energy Performance Analysis

It can be said that the reduction of building energy consumption is started with better building design. In this content, the tools of energy modeling and simulation are utilized through the building design phases in order to predict building energy performance [120]. However, building energy performance is a comprehensive system. It is subject to diverse parameters which are connected to the characteristics of the building, the equipment and systems, also the weather properties [121]. Besides, the energy consumption of building is highly depended on the building operation, the space usage properties, and the building occupant behavior [122]. Consequently, there are several sets of inputs required to evaluate building energy performance. These inputs are composed of building geometry and shape, internal loads, HVAC systems, occupant schedules, and etc. [121].

The building energy simulation tools provide an understanding of the building characteristic with the help of visualization of design, analyzing performance and energy usage. There are various building energy performance tools which have different Graphical User Interface (GUI), calculation engines, properties, and abilities [123]. One of the building performance simulation tools is eQUEST which is aimed at all design members and design stages. The outcomes from eQUEST have high accuracy due to the DOE simulation engine in it. On the other hand, the data for input should be the detailed and technical orient [124]. The building energy simulation depending upon walls, windows, glass, people, plug loads, and ventilation occurs by

DOE in eQUEST. Moreover, the simulation engine performs the performance of the energy consuming devices such as fans, pumps, chillers, boilers. The creation of multiple simulations and visualization of alternative outcomes in side by side graphical representation are provided in eQUEST [125]. The strongest benefit of eQUEST can be said that the comparison of design alternatives. Also, it provides the evaluation of different energy efficiency measures [124]. Some usage fields of eQUEST building energy performance simulation tool is mentioned in below.

6.1.1. eQUEST usage fields

The eQUEST simulation tool had been used both to analyze the influence of building envelope design on energy saving of air conditioner and to see the energy saving strategies on electric consumption of air conditioner [126]. In another study, the office buildings had been investigated with respect to air conditioner systems. The building annual performance had been analyzed via eQUEST. The results from energy performance simulation shown the energy saving probability of air conditioner system [127]. In addition to analyzing the effect of air conditioner on building energy consumption, the influences of different glazing systems on energy consumption had been examined via eQUEST. With this purpose, the eQUEST building simulation tool had been used to calculate energy consumption for a commercial office building in the aspect of different glazing systems [128].

The building energy consumption analysis and correlation of building redesign for a University building in Taiwan had been carried out by eQUEST as a BIM technology. The simulation results had been verified and the influence of energy saving on building envelope design had been examined [129]. In North China, public buildings as the office, school, and hospital had been examined building characteristics related to their energy consumption. The primary factors for energy consumption were analyzed via eQUEST. The outcome of the study showed that the air conditioning system, lighting density, and building envelope had been the main influence on building energy usage [130]. Besides, the Mosque, which they have characteristic functions and operating schedules, in Kingdom of Saudi Arabia had been investigated electricity consumption with the design approach. In order to enforce detailed energy analysis for this complicated building energy consumption, three cases were simulated via eQUEST. The outcomes from simulation enlightened some significant energy conservation techniques which should be implemented in the construction stage [131]. In another study, the retrofitting measures which were based on the solar system for an office building in United States had been examined via building energy model in eQUEST. eQUEST had been used to analyze the economic and environmental influence [132].

6.2. Detailed Energy Analysis Methodology

According to the offered methodology of building energy performance optimization for building design process within the BIM platform, which is shown in Figure 3.1, the final step is the detailed energy analysis. The aim of detailed energy analysis is to figure out final energy consumption and to evaluate building energy performance efficiency. The detailed energy analysis methodology is comprised of mainly four steps which are interacting with each other. The offered methodology for detailed energy analysis is represented in Figure 6.1.

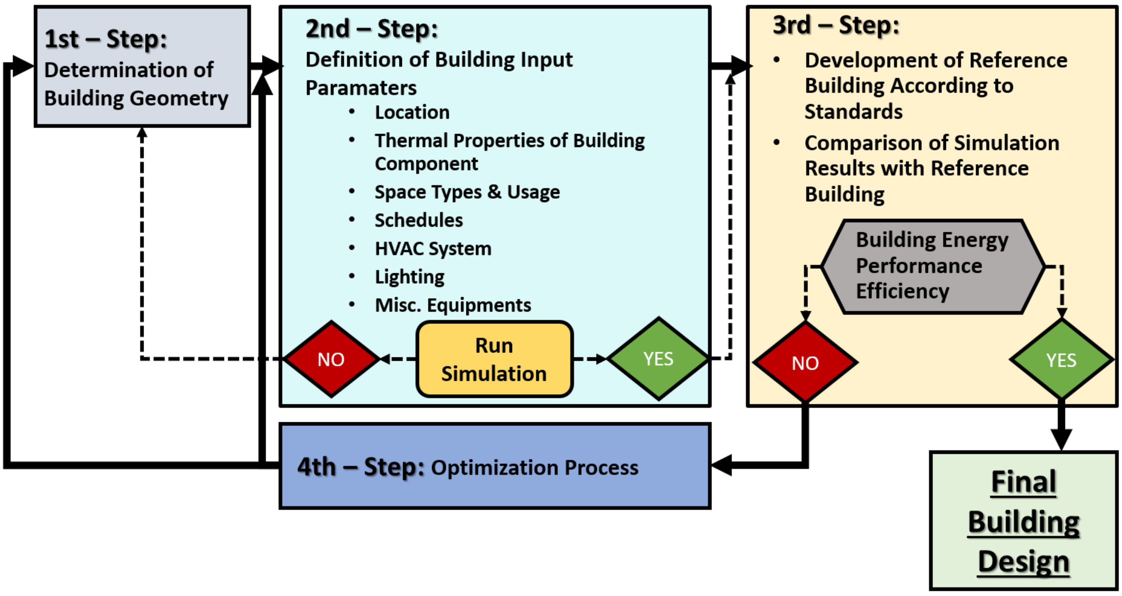


Figure 6.1 : Detailed energy analysis methodology.

6.2.1. 1st step: the determination of building geometry

Due to the fact that the building geometry is the major input for a building energy simulation [133]. First of all, the determination of building geometry should be done. The building geometry for energy simulation tool differs from the real building model. The geometry should be simplified from real building geometry [133]. Therefore, the CAD drawing of the building geometry is used for energy simulation.

6.2.2. 2nd step: the definition of building input parameters

The determination of building input parameters is significant because the accuracy of results from building energy simulation is depended on the inputs [133]. After determining building geometry, the main building input parameters are weather data for a specific location, the specific parameters for thermal properties of building component, space types and usage profiles, operating strategies and schedules, HVAC systems and components, also the internal loads such as lighting and miscellaneous equipment. After then the definition of building input parameters, the simulation of detailed building energy analysis will be initiated. If the simulation does not start to run properly, it will be returning to the first step and the inputs will be checking. On the other hand, if the simulation runs properly, it will go directly next step.

6.2.3. 3rd step

In this step is covers two sub-steps in order to evaluate building energy performance efficiency in standards. After obtaining building energy simulation results, the results should be compared to standards. Therefore, the development of reference building according to standards should primarily occur. In this study, the reference building is developed depending on the standard of natural calculation of energy performance in buildings, which published by the Ministry of Public Works and Settlement in Turkey [134]. The second step is the comparison of simulation results with reference building to determine the building energy performance class. If the outcome from the comparison is efficient for building energy performance, it is reached the final building design. On the other side, if the building energy performance is not efficient at the end of the comparison, the optimization process will be begun.

6.2.4. 4th step: optimization process

In the optimization process, the building geometry and the building input parameters can be changed and adjusted to get better building energy performance efficiency. This step continues until the building energy performance reaches the desired efficiency.

6.3. Detailed Energy Analysis Application for Niğde House

The detailed energy analysis has been applied on Niğde House based on the detailed energy analysis methodology.

6.3.1. 1st step: the determination of building geometry

Up till now the design stages which are in the conceptual design, schematic design and also CFD analysis part is based on the three usage places of the building. These places are terrace room, living room and study room. However, the detailed energy analysis is comprised whole building geometry. The hypothetical building geometry in Figure 4.5 had been preserved and used for the whole building geometry. Therefore, the 2D drawing of building geometry in the Figure 4.6 has been used the determination of the building geometry for eQUEST©.

6.3.2. 2nd step: the definition of building input parameters

After the building geometry determined, the definition of building input parameters has been taking place. For the purpose of the determination of building input parameters, weather data for a specific location, the specific parameters for thermal properties of building component, space types and usage profiles, operating strategies and schedules, HVAC systems and components, also the internal loads such as lighting and miscellaneous equipment were defined step by step.

- Location was set to Niğde, in Turkey
- The weather file for Niğde was taken from the Green Building Studio© [135] via bin file.
- The thermal transmittance values for building component were taken from TS 825 standard with considered to region containing Niğde [136]. In TS 825 standard, the provinces are divided 5 different zones according to the degree days. The degree days are a measure that the location is how cold and hot [137].

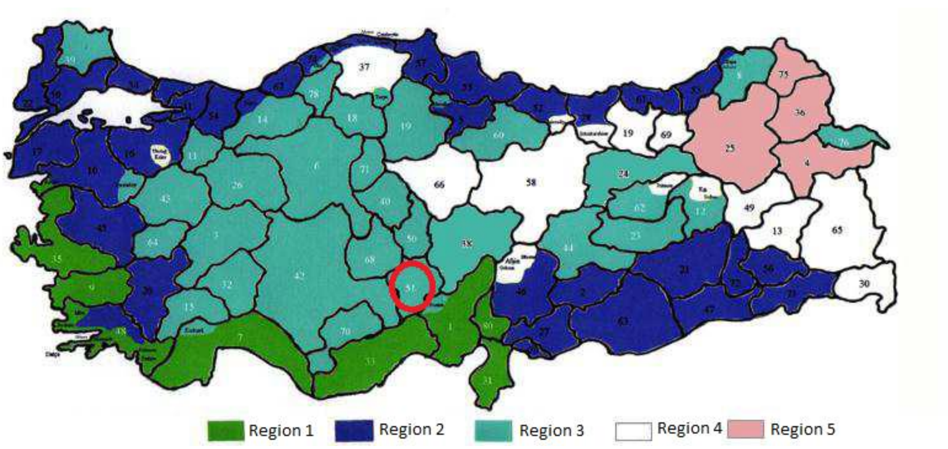


Figure 6.2 : The provinces according to the degree day regions.

The provinces according to the degree day regions are shown on Figure 6.2. Niğde is remarked on Figure 6.2 in red circle. The thermal transmittance values for building components as exterior wall, window, ground floor, and roof is shown in Table 6.1.

Table 6.1 : The thermal transmittance values for building components.

Thermal Transmittance	W/m^2K
Exterior Wall	0.48
Window	1.80
Ground Floor	0.43
Roof	0.28

- The building space types and usage has been determined as in Figure 4.5.
- The building usage scheduling has been adjusted as 24/7.
- For the HVAC system, the CFD analysis results in the previous Chapter have been taking into account. The outcome from CFD analysis for Niğde house has been shown that the natural ventilation could be enough in Scenario 2 during the summer season. Thus, it assumed that there was no need for a cooling system. Consequently, the HVAC system for detailed energy analysis model has been based only heating system. The heating system has been defined as a fireplace located in the middle of the living room, which was planning in the project description section. The heating system has been also supported the domestic hot water.

The quantity of internal loads, such as loads from people, lights and equipment, for a specific space should be indicated in the energy simulation during the building design [133]. In this context, the restrooms, kitchen as a food preparation area, and corridors were taken account of lighting power densities using the space by space method in ASHRAE 90.1. [138]. The bedrooms, terrace, living room, and study room were assumed as residential places for multifamily. The lighting power densities for usage places are represented in Table 6.2.

Table 6.2 : The lighting power densities for usage places.

Lighting	W/m^2
Bedroom	6.5
Restroom	10.5
Corridor	7.1
Kitchen (Food Prep.)	10.7
Terrace	6.5
Living Room	6.5
Study Room	6.5

- The washing machine, refrigerator, dishing washer, and television were considered as the miscellaneous equipment. Also, the miscellaneous equipment power loads as high efficient were established [139] on Table 6.3.

Table 6.3 : The miscellaneous equipment power loads.

Miscellaneous. Equipment	W/m^2
Washing Machine	4.9
Refrigerator	5.9
Dish. Washer	5.5
Television	0.6

After the definition of building input parameters for detailed energy analysis model, the simulation was started. If errors are observed while the simulation is running, the model should be checked in related to building geometry as well as input parameters. Therefore, if errors appeared in the model, the detailed energy analysis methodology returns to the first step. Otherwise, the third step will be followed.

6.3.3. 3rd step

As mentioned in the detailed energy analysis methodology, the third step consisted of two sub-steps. In order to evaluate building design quality, the reference building should firstly be developed according to standard of natural calculation of energy performance in buildings, which published by the Ministry of Public Works and Settlement in Turkey [134]. After then, the comparison of the simulation results between reference building and hypothetical building should be done.

During the evaluating the reference building, the considerations in the standard [134] are listed.

- The reference building should locate in the same location.
- The reference building should have the same building geometry with the real building which is aimed to figure out energy class. In this study, the real building is the hypothetical Niğde house.
- The reference building should have minimum conformity to existing building regulations for the thermal properties of the building shell. The thermal properties of the reference building have been taken from TS 825 Standard, which was the same with hypothetical Niğde house.

- The HVAC system for reference building should be the central heating with natural gas and the split air conditioner for cooling. Also, natural ventilation should be assumed in.

After the evaluated the reference building, the energy performance for reference building has been simulated. Further, the simulation results have been compared between the reference building and hypothetical Niğde house. While comparing simulation results, the used formulation, which is based on the standard of natural calculation of energy performance in buildings [134], is shown below.

$$E_{p,EP} = 100\ (EP_a\ /EP_r\ ) \quad (6.1)$$

"Ep" represents the energy performance of the building. "EP" means the amount of energy consumption per square meter of the building converted into primary energy (kWh / m^2-year). "r" is for reference building, and "a" is for the original building.

According to this formulation, the simulation results should be converted to primary energy consumption. In order to convert annual building energy consumption from simulation results to primary energy, the conversion factor should be used. The conversion factor for natural gas and electricity is respectively 1.294 and 2.944. These conversion factors were taken from SimaPro© which is a life cycle assessment software package includes many life cycle inventory databases[140]. The energy classes in respect to the energy performance range of building is shown in Table 6.4 [134].

Table 6.4 : The energy classes in respect to the building energy performance range.

Energy Classes	Energy Performance (Ep) Ranges
A	0-39
B	40-79
C	80-99
D	100-119
E	120-139
F	140-174
G	175-…

If the building energy performance efficiency has been satisfied with the building energy class, the detailed energy analysis methodology ends up with the consequence of final building design. In the contrary case, if the building energy performance has been not satisfied with the building energy class, the improvements for building design should be continued. Thus, the optimization process, which is fourth step in the detailed energy analysis methodology, will be take placed. The optimization process was not taken part in the application of detailed energy analysis methodology on Niğde house due to satisfy the building energy performance.

6.4. Detailed Energy Analysis Results and Discussion

After the CFD analysis for adequate natural ventilation in the aspect of indoor air quality and human thermal comfort condition, the detailed energy analysis of the whole building has been evaluated. The CFD analysis chapter results has been considered and used during the generation of the detailed energy analysis model in eQUEST©. The detailed energy analysis model via eQUEST© is represented on Figure 6.3.

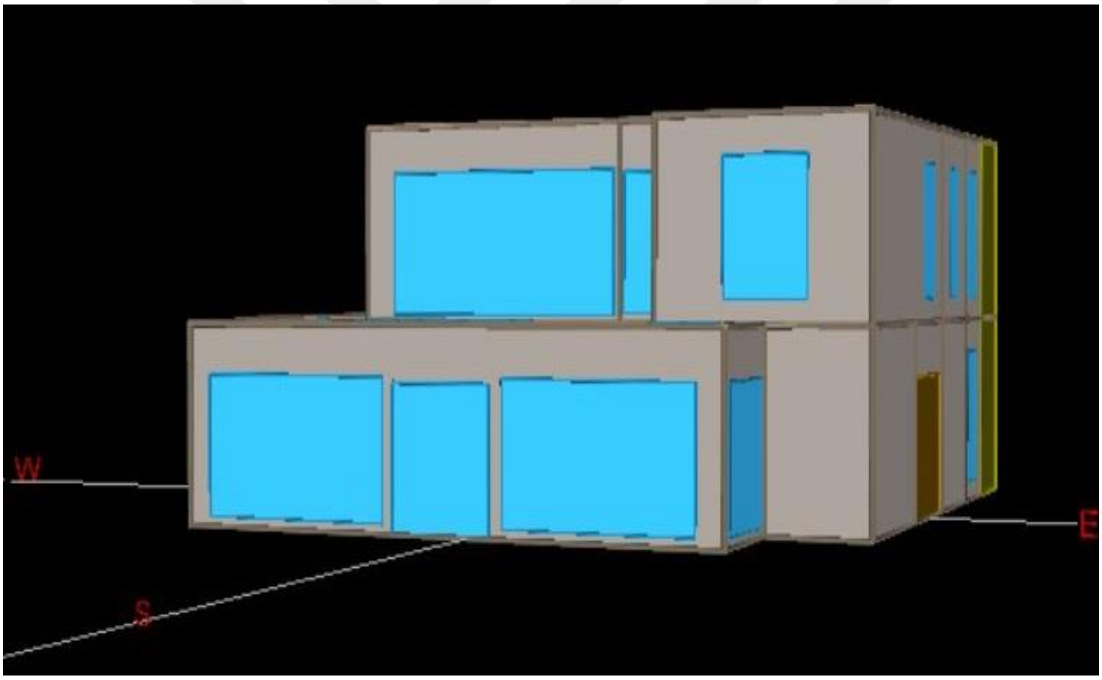


Figure 6.3 : The detailed energy analysis model via eQUEST©.

The detailed energy analysis results can give the annual and monthly building energy consumption. The total energy consumption was annually 17865 kWh. According to annual energy consumption result of hypothetical Niğde house, the total gas consumption for heating was 13467 kWh and the total electricity consumption was 4399 kWh. Thus, the main consumption had in the total gas consumption as 75 %. The building energy consumption distribution as annual gas and electricity is represented in Figure 6.4.

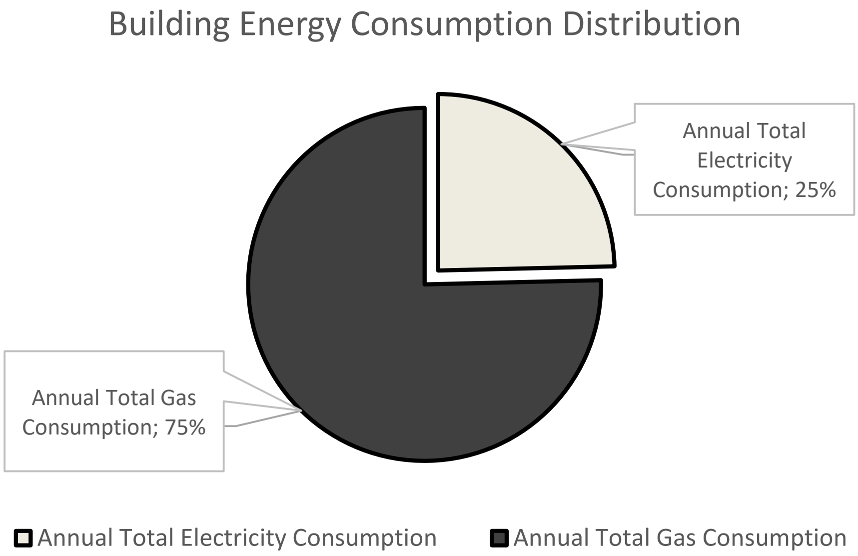


Figure 6.4 : The building energy consumption distribution.

Moreover, the detailed energy analysis results can show the energy consumption as each load items. In this context, the cooling load was not taken into account in the calculation of electricity consumption in the detailed energy analysis due to the adequate natural ventilation on the human sensation. However, lighting loads, pumps & auxiliary power loads, miscellaneous equipment loads, space heating loads, and loads for hot water were considered. The detailed energy analysis results with the consumption of each item are represented on Table 6.5.

When account each item to influence on the building energy consumption, the major influence has been observed from the space heating as 66% of total energy consumption. The annual energy consumption for space heating was 11743 kWh. And the second major contributor was lighting as 19 percent of energy consumption. The annual energy consumption for lighting was 3456 kWh. On the other side, the minor effects on building energy consumption were in pumps and auxiliary power loads, also miscellaneous equipment. The contribution percentages for pumps & auxiliary power loads and miscellaneous equipment were respectively 1% and 4%. The distribution for contributors of the total energy consumption is shown on Figure 6.5.

Beside the distribution of annual total energy consumption contributors, the distribution of contributors has been defined in respect to annual total electricity consumption. The significant contributor was lighting with 3456 kWh as 79% of annual total electricity consumption. The contribution of miscellaneous equipment for total electricity consumption was 764 kWh as 17%. The third contributor for total electricity consumption was in pumps and auxiliary power loads which had 179 kWh as 4%. The distribution for contributors of total energy electricity consumption is represented on Figure 6.6.

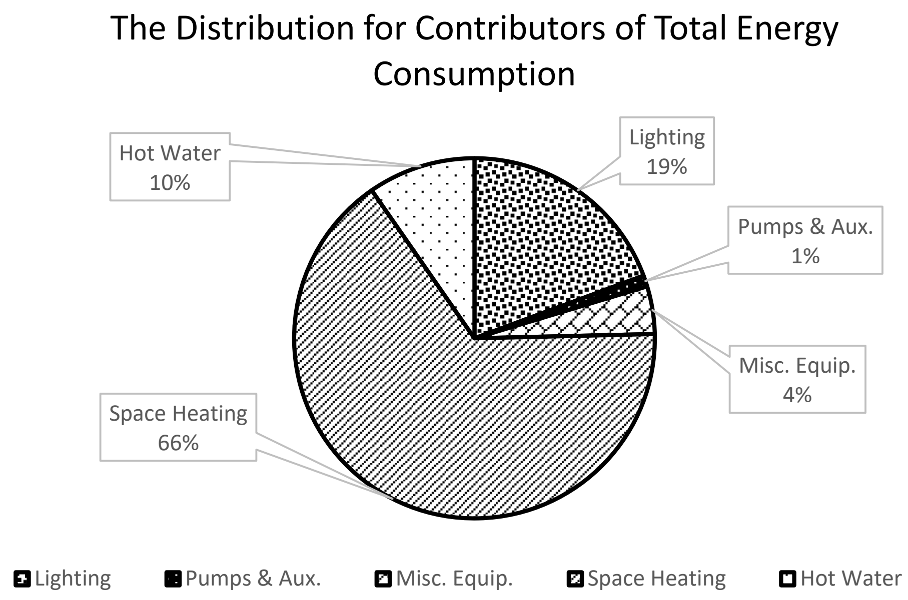


Figure 6.5 : The distribution for contributors of total energy consumption.

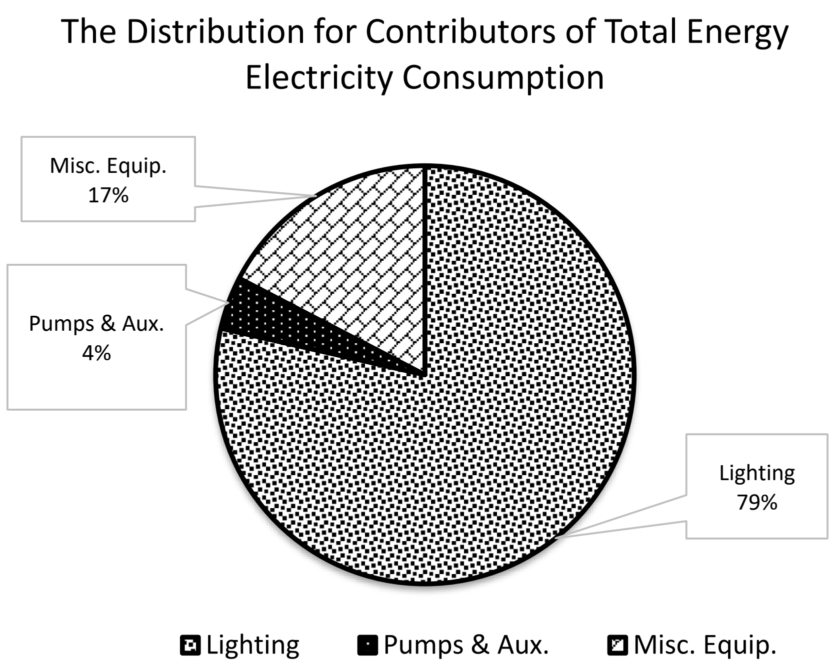


Figure 6.6 : The distribution for contributors of total energy electricity consumption.

Table 6.5 : Monthly and annual energy consumption for each item.

Mount / Item Consumption (kWh)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Lighting	302	271	305	276	276	282	282	282	291	292	289	315	3456
Pumps & Aux.	32	29	32	20	3	0	0	0	0	2	30	32	179
Misc. Equip.	64	59	66	62	64	64	64	64	64	64	63	66	764
Space Heating	3373	2368	1225	569	56	0	0	0	0	47	1351	2755	11743
Hot Water	170	161	179	164	152	135	135	135	111	123	135	158	1723
Annual Total Electricity Consumption (kWh)													4399
Annual Total Gas Consumption (kWh)													13467
Annual Total Consumption (kWh)													17865

After the investigated the annual energy consumption of hypothetical building, the results should be converted to primary energy consumption in order to determine building energy class with compare to the reference building. The building energy performance calculated as annual primary energy consumption per square meter which is 210 m^2. The annual primary energy consumption, building energy performance which is primary energy consumption per square meter, and the building energy class is shown in Table 6.6.

Table 6.6 : The annual primary energy consumption, building energy performance, and building energy class.

	Total Annual Primary Energy Consumption	Primary Energy Consumption per square meter (EP)	Building Energy Performance ($E_{p,EP}$)	Building Energy Class
Reference Building	94868 kWh	452 kWh / m^2-year	100	
Niğde House	30375 kWh	145 kWh / m^2-year	32	A

According to the building energy performance comparison between the reference building and hypothetical Niğde house, the hypothetical Niğde building energy class was in A. Building energy performance was satisfied with the design quality of the building. Therefore, the final building design has been reached and there is no need to perform the optimization process which is included in the detailed energy analysis methodology. Moreover, the whole building design, which has been generated in Revit© to introduced more architectural view, is represented in Figure 6.7, 6.8, 6.9, and 6.10.

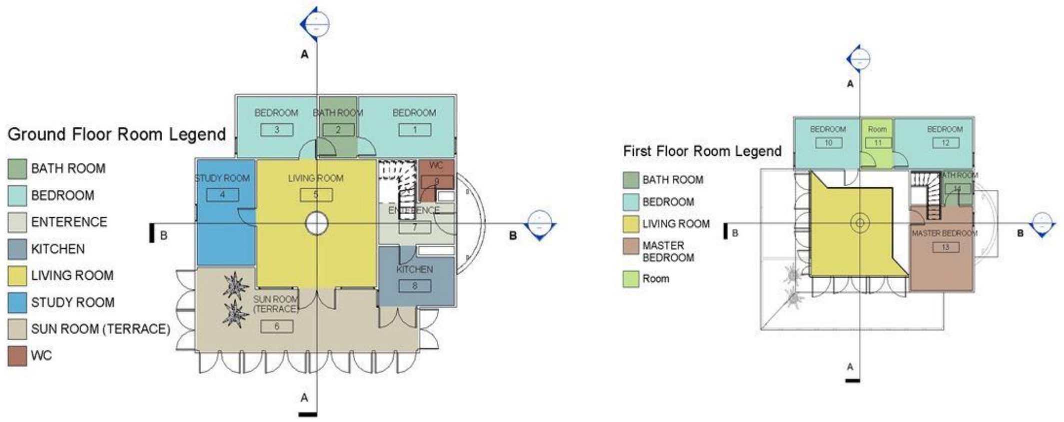


Figure 6.7 : Ground floor and first floor plan and space usage.

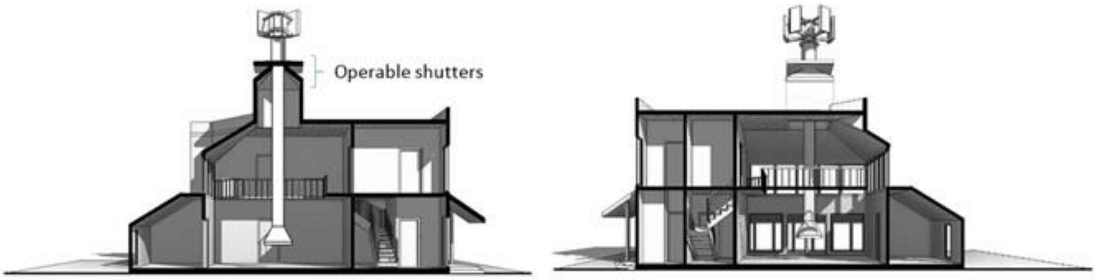


Figure 6.8 : Perspective of building (BB section).

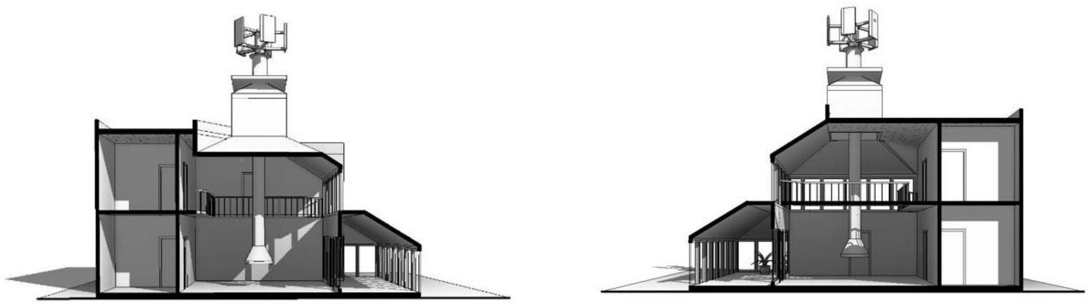


Figure 6.9 : Perspective of building (AA section).

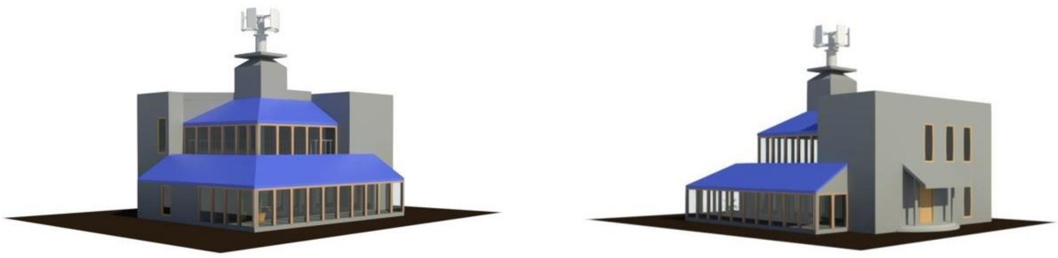


Figure 6.10 : 3D BIM model for schematic building design.

6.5. Detailed Energy Analysis Conclusion

The importance of detailed energy analysis is to make high energy performance building design. Thus, the detailed energy analysis has been integrated with the building design process. The proposed methodology includes detailed energy analysis as the final design phase. Moreover, the goal of the detailed energy analysis in this study is to investigate building design quality. The building design quality has been investigated in aspect to exact building energy consumption as well as building energy class.

The comparison of simulation results between the reference building and hypothetical Niğde house also highlighted the main influences on energy consumption is the cooling load. The natural ventilation examined in the CFD analysis, the outcome shown that natural ventilation was satisfy with respect of the indoor air quality and thermal comfort conditions. Therefore, there was no need cooling system in the hypothetical building. This situation brings the significant difference between reference building and hypothetical Niğde house.

To sum up, the building quality has been evaluated and evolved in each building design stage. Finally, the quantity of building quality has been ascertainment with detailed energy analysis in detailed design. With the dependencies of the quantity of building design quality, the final building design could be generated.

The detailed energy analysis has been conducted via eQUEST©, which is a building energy simulation program. The outcomes shown that the annual and monthly building energy consumption. The annual building energy consumption was 17865 kWh. The major contributors to energy consumption was the space heating as 11743 kWh and lighting as 3456 kWh. According to the standard of natural calculation of energy performance in buildings, the building energy class was determined with comparison of the reference building as annual primary energy consumption. The energy class of hypothetical Niğde house was A.

7. RESULT AND DISCUSSION

The building design is a comprehensive and complicated process which comprises of several design stages as well as is a multidisciplinary area including architects, and engineers. Moreover, the high-performance energy-efficient building design is becoming more significant with their requirements in the early design stage. [141]. The considerations on building design such as energy demand and environmental aspect are growing substantially. Therefore, the optimization of various criteria like energy, indoor air quality, materials, life cycle has been required to obtain for designers. The significance of early design stage, where has the major influence on ultimate performance, is to support decision making and reaching high performance. Besides, the holistic design approach encourages to assess the extensive performance indicators [142].

In this study, the building design process has been handled and offered a BIM-based methodology in respect of handling building with a holistic approach during the building design process. The proposed methodology has been included three design stages, which is based on design stages from American Institute of Architects [45]. These three design stages were the conceptual design, schematic design, and finally detailed design stage. In each design stage, there was different considerations and restrictions, which are also correlated with each other's. If the examined design alternative is not meet the criteria and/or standards, the implemented methodology allows recreation or reselection of alternative and then all analysis would be applied on this newly selected design option. The behavior for return of design alternative is helped via BIM-based methodology.

7.1. Conceptual Design;

The aim was to find out most appropriate building envelope in the conceptual design. Thus the optimization of building façade has been conducted in this stage. The building envelope isolates the building from its surround thus it is the outstanding design characteristic for the building. Also, it has an important impact on building performance. Generally, the building envelope is determined in early design stage and the envelope is probably continued with little changes up till design process end [143]. Due to this fact, the building design alternatives with regard to windows sizes and WWR ratio were generated via Revit©, Dynamo©, and Project Fractal©. There were 11664 design alternatives from the optimization of building façade, and the maximum window size and WWR ratio has been selected between various design alternatives to evaluate next design stage.

7.2. Schematic Design

The high performance building design is created by architectural principles with taking into account physical environmental conditions. Building model can be analyzed mainly in the areas of daylight intake, solar and shade relations, radiation acquisition, wind and natural ventilation, which in the context of sustainability [144]. In this study, the daylighting analysis and solar radiation analysis has been conducted via Insight 360© and Revit© in schematic stage. The natural ventilation has been investigated comprehensively in detailed stage.

The daylighting analysis results indicated the possible use of daylighting which passed 75 percent with the majority range of approximately between 1400 lux and 2700 lux at 9 am. Also, towards the evening, the 27 percentage of daylight passed corresponding with almost between 2000 lux and 4000 lux. Therefore, the available level for daylight use was obtained.

The solar radiation analysis outcomes showed annual solar radiation gains of Niğde house roof surface outcome with average 11 kWh/m2 thus the PV integration could be beneficial for this building.

The energy analysis is not considered to calculate in early design stage because of the time consuming energy model [143]. However, this study has been implemented the model based predicted energy performance and its optimization to estimate energy performance in early design process. In respect to this, the influence of building input parameter on energy use intensity was investigated by Insight 360© and Revit©. The model-based predicted energy performance and its optimization exhibited that could be reached up to 75 % of energy saving with the adjustment of building input parameters as insulation integration, lighting & HVAC, and PV integration.

7.3. Detailed Design

The computational fluid dynamics and detailed energy analysis has been conducted respectively to evaluate natural ventilation and enlighten exact consumption in the detailed design stage. These two analysis had their own model and methodology; thus, they were comprehensively examined in this study.

The CFD analysis methodology was structured to investigate natural ventilation during the detailed design stage. The indoor air quality and thermal comfort conditions has been evaluated and optimized in terms of temperature, velocity magnitude, predicted mean vote (PMV) and the percentage of people dissatisfied (PPD). These process has been conducted with developing and integrating detailed 3D model and CFD model. During the integration between two different models, three different program which are Revit©, AutoCAD©, and Autodesk CFD© has been used. After the generation of CFD model, Autodesk CFD© program has been used to conduct analysis. The operational characteristics of the building in respect of windows and shutters, managed by user, have important effects on indoor quality and thermal comfort. Therefore, manually operated building openings has been investigated with four scenarios to provide human comfort conditions. The CFD analysis showed that natural ventilation was the acceptable level for the human sensation as PMV between 0 and 3 in scenario 2. Therefore, it could be considered that there is no need for the cooling system for scenario 2 in summer times.

The model based predicted energy performance and its optimization gave an idea about how building input influences on energy use intensity. Further, the enlightened building input parameters in schematic design were utilized in detailed energy analysis to see actual building energy consumption. Also, it is important that the examination of high-performance building design whether to reach desired performance target and criteria [144]. In this context, the building energy class has been calculated based on the primary energy consumption of building in detailed design. The detailed energy analysis has been carried out via eQUEST©. The annually total energy consumption was 17865 kWh which was consisted of almost 25 % of electricity as 4399 kWh and 75 % of total gas consumption as 13467 kWh. Also, the energy requirement for space heating was the main contributor as 66 percentage of energy consumption. The building energy performance should be quantitatively obtained in order to investigate the building design quality within standard. For this reason, the reference building has been developed according to standard and compared the building and reference building as annual primary energy consumption. The detailed energy analysis put forward that the energy performance class of building was in A class.

7.4. Interoperability between Used Tools and Their Applications

The high-performance building design is a process that includes comprehensive, non-linear, iterative, and interactive actions. Further, this process needs an efficient association among multidisciplinary teams at the beginning of the design stages to obtain sustainable results [145]. The continuous analysis of sustainability throughout the design process restricts with the conventional design method owing to partial information [146]. Hence, there is an inadequate data for perform supreme judgement to get sustainable results [145]. Consequently, the collaboration and coordination between multidisciplinary design team and appropriate data to support design decisions is an inevitable situation. The BIM might be a proper platform in order to solve these issues. In the context of design stage, BIM supports the addition of multidisciplinary information, thus the sustainable preventions can be continuously combined during the design stage [146]. Also, BIM allows to make validation of design performance that allows to designers to evaluate their designs and choose the optimal option [147]. The prompt and correct comparison between various design possibilities can be acquired via BIM; therefore, the more effective, cost efficient, and sustainable solutions can be obtained [148]. During the examination of optimal building design alternative, the multi-disciplinary and multi-objective criteria had been considered. With the aimed optimize these criteria, several differ tools and their applications were utilized. The interoperability diagram between the used tools and their applications through the building design process is represented on Figure 7.1.

In the early design phases, the most common way of obtaining feedback about performance is related to manually remodeling or import and export for building geometry task [141]. According to Bazjanac, the manually iterable data for preparation of energy simulations which occurred with duplication of existence information had a deterioration of errors also the elimination of these errors from results had been difficult processes. The major percentage of effort had been for building geometry definitions. The cause of this was the recreation due to different aspects of structural, mechanical, electrical, further energy performance during the design of building geometry [149].

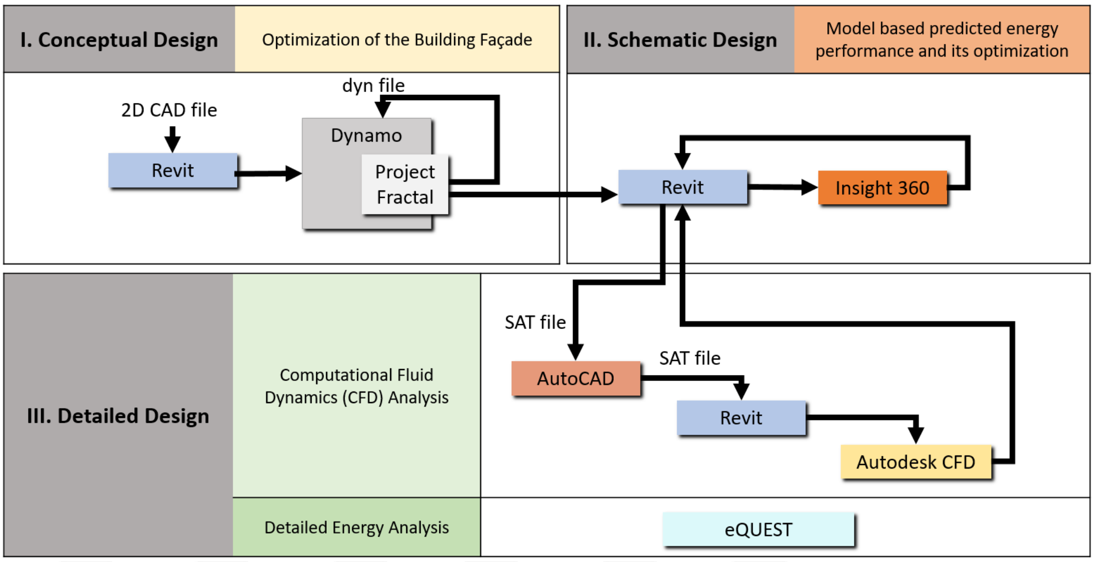


Figure 7.1 : The interoperability diagram between the used tools and their applications through the building design process.

The interoperability between different building simulation tools eliminates these copied data requirements. The building geometry was transferred via data exchange via 2D or 3D. There was no losing data or extra time and effort for manually copy data with the utilized data exchange formats for building geometry, which would be DWG and SAT in this study. Beside data exchange file, the used tools were directly linked, for instance Dynamo directly linked Revit via Revit Application Programming Interface (API), thus the model information could be easily extracted, read, and wrote.

8. CONCLUSION

In this research, the goal is to provide a methodology for optimizing the building performance with a holistic approach through the decision making process. The multi-objective building performance optimization by integrating design, indoor air quality, thermal comfort, and energy consumption is conducted within various design alternatives. BIM based optimization methodology is evolved and applied on a two story hypothetical building by identifying the activities in each design stage. The aim of each design stage of the process is summarized below.

- In the conceptual design stage, the primary aim was the optimization of building envelope related to windows size and window wall ratio.
- In the schematic design stage, the desired goal was to optimize building energy performance via model based predicted energy performance and its optimization corresponding with energy use intensity.
- In the detailed design stage aim was the investigation of design quality with standards and criteria related to human comfort, indoor air quality, and building energy class based on energy consumption. In this context, the computational fluid dynamics (CFD) analysis structured to analyze the indoor air quality and thermal comfort conditions. The detailed energy analysis was conducted to examine more clearly on energy usage.

The striking feature of this study is building energy performance with a holistic approach evaluated in a case study. The building energy performance optimization is comprehended of building envelope, indoor air quality, human comfort, and energy consumption in this study. Moreover, building energy performance has been revealed with quantitative outcomes. The case study has been examined from hypothetical building to final design through the building design stages. Each stage has own considerations and outcomes. Also, the evaluation of building design is depended on each design stages by BIM platform. Hence, each design stages are related to each other. The importance of this implemented BIM based energy performance optimization methodology is listed.

- The building has been considered as a whole with multidisciplinary and multi-objective design in the context of building performance optimization in all design stages. The BIM-based performance optimization of the building had been implemented on early design stage in order to evaluate more design alternatives and making decision of optimal one. The optimization of the building design with its physical, thermal and indoor comfort conditions, as well energy consumption as a whole has been realized by utilizing the 3D design, CFD model, and energy model within the BIM platform.
- The different tools and their applications have been used to achieve the desired performance. The interoperability with the BIM approach has been aimed to emphasize in between the used programs during this study. 3D building model which has specifications about the building's physical condition, CFD model which has specifications about indoor comfort conditions, and energy analysis model are integrated via BIM platform during the design stage. Thus, the complication of different software integration could be eliminated by BIM-based proposed methodology.
- The multidisciplinary approach can be utilized through the BIM platform. The building envelope design with passive techniques and aesthetic concerns can be evolved and optimized in the proposed methodology from an architectural point of view. Further, the CFD approach is applied with the integration of BIM platform. Thus, the design team during the design process could link building envelope, indoor air quality, human thermal comfort as well as a projection of the HVAC system. With the consideration of outcomes of CFD analysis, the suitable cooling, and ventilation system can be integrated into the building during the design stage. In respect of architects and engineers, the multidisciplinary building design process is handled with the BIM platform.

This research aims to provide a building model that includes detailed information that is developed based on the interactive analysis of building envelope, energy performance, and natural air distribution inside of the building. Therefore, the building location, orientation, building shape, functionality beside the pysical conditions such as applied materials, and building systems including renewable and mechanical systems are designed based on those analyses. It is recommended that all these evaluation shold be done during conceptual design stage with the participation of all involved disciplines.

In further work,

- Those models could be developed in detail by each involved disciplines, thus overall capacities such as energy consumption and comfort condition could be developed comprehensively.
- The detailed analysis likewise could be done with each discipline by means of the mechanical system, electrical system, architecture and so forth.
- The proposed methodology could be further improved by integrating other analysis methods such as sensitivity analysis that could be correlated with measured data to do calibration or prediction for energy performance analysis.
- The proposed methodology could also be further developed for big scale buildings that have complex physical or functional characteristics.

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PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS: