TOBB UNIVERSITY OF ECONOMICS AND TECHNOLOGY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

INTEGRATING SOLAR-RELATED PASSIVE STRATEGIES IN THE INITIAL DESIGN PROCESS: A CUMULATIVE WORKFLOW PROPOSAL

MASTER THESIS

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Department of Architecture

Thesis Supervisor: Asst. Prof. Dr. Zelal ÇINAR

AUGUST 2024

DECLARATION OF THE THESIS

I hereby declare that all the information presented in this thesis has been obtained and presented in accordance with ethical conduct and academic rules. Proper citations have been provided for the sources referenced sources, and the references have been accurately stated. Furthermore, I confirm that this thesis has been prepared in compliance with the thesis writing guidelines of the TOBB ETU Graduate School of Natural and Applied Sciences.

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TEZ BİLDİRİMİ

Tez içindeki bütün bilgilerin etik davranış ve akademik kurallar çerçevesinde elde edilerek sunulduğunu, alıntı yapılan kaynaklara eksiksiz atıf yapıldığını, referansların tam olarak belirtildiğini ve ayrıca bu tezin TOBB ETÜ Fen Bilimleri Enstitüsü tez yazım kurallarına uygun olarak hazırlandığını bildiririm.

Sercan DENİZ

ABSTRACT

Master of Science

INTEGRATING SOLAR-RELATED PASSIVE STRATEGIES IN THE INITIAL DESIGN PROCESS: A CUMULATIVE WORKFLOW PROPOSAL

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Date: August 2024

In contemporary times, the effects of the global energy and climate crisis have increasingly underscored the importance of energy efficiency in architectural practices. Achieving energy efficiency in existing structures presents significant challenges, as the interventions that can be made are limited due to the building's pre-existing state. Consequently, making decisions regarding energy efficiency during the early design stages is more advantageous. However, this early design phase is inherently complex due to the abundance of alternatives, the variety of potential scenarios, and the limited data available. At this stage, increasing the climatic data available to architects contributes to the development of design proposals that align with these parameters, thereby enhancing the effectiveness of the design process. This thesis, therefore, aims to integrate climatic data into the early design process.

Solar-related energy-efficient design emerges as a significant consideration within the context of energy efficiency. Understanding the effects of the sun during the early stages of design greatly influences various design decisions, such as massing, plan layout, building envelope, and material selection. However, the implementation of these energy-efficient design methods also brings certain challenges. Therefore, it is crucial to establish a specific sequence and classification to use analysis methods and design strategies in energy-efficient design.

This study seeks to integrate energy-efficient strategies into the early design process in a consistent order that does not negatively affect the effectiveness of previous strategies. In this context, a cumulative process plan and workflow are proposed, beginning with massing studies and progressing towards more detailed design decisions. This workflow functions as a warning-suggestion algorithm, which divides the architectural design process into stages and aims to contribute to the design through strategy suggestions presented at the beginning of each stage. To observe the integration and advantages of this workflow, a case study was conducted in the city of İzmir, which poses challenging conditions in terms of solar exposure. The results of the case study indicate that this workflow has the potential to provide recommendations without slowing down the architectural project processes. The workflow evaluated the integration of 17 different strategies into the design, revealing that some strategies are compatible with each other, while others serve as alternatives. Applicability to projects at different stages is demonstrated by the fact that the workflow can continue even if certain recommendations are not used. In energy-efficient design, a cumulative approach made possible through a consistent sequence and elimination method is achievable with the workflow proposed in this study.

Keywords: Energy-efficiency, Insolation, Environmental data analysis, Initial design process, Performance-oriented, Workflow, Cumulative, Passive strategies, Solar-related.

ÖZET

Yüksek Lisans

GÜNEŞ BAĞLANTILI PASİF STRATEJİLERİN ERKEN TASARIM SÜRECİNE ENTEGRE EDİLMESİ: KÜMÜLATİF BİR İŞ AKIŞI ÖNERİSİ

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Günümüzde, küresel enerji ve iklim krizinin etkileri, mimari uygulamalarda enerji verimliliğinin önemini giderek daha fazla vurgulamaktadır. Mevcut yapıların enerji verimliliğini sağlamak, yapının mevcut durumundan kaynaklanan sınırlamalar nedeniyle önemli zorluklar barındırmaktadır. Bu nedenle, enerji verimliliği ile ilgili kararların erken tasarım aşamalarında alınması daha avantajlıdır. Ancak, bu erken tasarım aşaması, çok sayıda alternatifin bulunması, çeşitli olası senaryoların mevcudiyeti ve sınırlı veri nedeniyle doğası gereği karmaşıktır. Bu aşamada, mimarların kullanımına sunulan iklimsel verilerin artırılması, bu parametrelerle uyumlu tasarım önerilerinin geliştirilmesine katkı sağlayarak tasarım sürecinin etkinliğini artırmaktadır. Bu tez, bu doğrultuda iklimsel verilerin erken tasarım sürecine entegre edilmesini amaçlamaktadır.

Güneşle ilgili enerji verimli tasarım, enerji verimliliği bağlamında önemli bir husus olarak öne çıkmaktadır. Tasarımın erken aşamalarında güneşin etkilerinin anlaşılması, kütle formu, plan düzeni, yapı kabuğu ve malzeme seçimi gibi çeşitli tasarım kararlarını büyük ölçüde etkilemektedir. Ancak, bu enerji verimli tasarım yöntemlerinin uygulanması da belirli zorluklar getirmektedir. Bu nedenle, enerji verimli tasarımda analiz yöntemlerini ve tasarım stratejilerini kullanmada belirli bir sıra ve sınıflandırmanın oluşturulması kritik öneme sahiptir.

Bu çalışma, enerji verimli stratejilerin erken tasarım sürecine, önceki stratejilerin etkinliğini olumsuz etkilemeden tutarlı bir sırayla entegre edilmesini hedeflemektedir. Bu bağlamda, kütle çalışmaları ile başlayıp daha ayrıntılı tasarım kararlarına doğru ilerleyen kümülatif bir süreç planı ve iş akışı önerilmektedir. Bu iş akışı, mimari tasarım sürecini aşamalara ayıran ve her aşamanın başında sunulan strateji önerileriyle tasarıma katkı sağlamayı amaçlayan bir uyarı-öneri algoritması olarak işlev görmektedir. Bu iş akışının entegrasyonunu ve avantajlarını gözlemlemek amacıyla, güneş maruziyeti açısından zorlu koşullara sahip İzmir şehrinde bir vaka çalışması gerçekleştirilmiştir. Vaka çalışmasının sonuçları, bu iş akışının mimari proje süreçlerini yavaşlatmadan öneriler sunma potansiyeline sahip olduğunu göstermektedir. İş akışı, tasarıma 17 farklı stratejinin entegrasyonunu değerlendirmiş ve bazı stratejilerin birbiriyle uyumlu olduğunu, bazılarının ise alternatif olarak çalıştığını ortaya koymuştur. Farklı aşamalardaki projelere uygulanabilirlik, bazı öneriler kullanılmasa bile iş akışının devam edebilmesi gerçeğiyle gösterilmiştir. Enerji verimli tasarımda, tutarlı bir sıra ve eleme yöntemiyle mümkün kılınan kümülatif bir yaklaşım, bu çalışmada önerilen iş akışıyla elde edilebilir.

Anahtar Kelimeler: Enerji verimliliği, Güneşlenme, Çevresel veri analizi, Erken tasarım Süreci, Performans odaklı, İş akışı, Kümülatif, Pasif stratejiler, Güneş bağlantılı.

To those who work for a sustainable tomorrow

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AIA	: The American Institute of Architects
BEP	: Building Energy Performance Regulation (*Bina Enerji Performans Yönetmeliği*)
BIM	: Building Information Modelling
BREEM	: Building Research Establishment Environmental Assessment Method
CAD	: Computer-Aided Design
CASBEE	: Comprehensive Assessment System for Built Environment Efficiency
DGNB	: German Sustainable Building Council (*Deutsche Gesellschaft für Nachhaltiges Bauen*)
DSF	: Double-Skin Façade
GH	: Grasshopper
IISBE	: The International Initiative for a Sustainable Built Environment
ILD	: Internal-load-dominated
LEED	: Leadership Energy Environmental Design
Low-E	: Low-Emissivity
RCC	: Reinforced Cement Concrete
RSE	: Reverse Solar Envelope
SC	: Shading Coefficient
SHGC	: Solar Heat Gain Coefficient
SIEBB	: Sino-Italian Ecological and Energy Efficient Building
SLD	: Skin-Load-Dominated
WWR	: Window-Wall Ratio

GLOSSARY

Term	Definition
Active Strategies	: Systems and technologies that require external energy sources to regulate a building's environment and enhance energy efficiency.
Air Conditioning	: A system used to control the temperature, humidity, and air quality in an indoor space to provide comfort.
Annual Energy Requirements	: The total amount of energy a building needs to operate throughout a year, including heating, cooling, lighting.
Annual Glare	: Excessive brightness or reflection, often caused by large windows or reflective surfaces, which can lead to discomfort or reduced visibility.
Azimuth	: The angle between a specific point on the horizon and true north, used to determine the position of the sun.
Bio-Climatic Section	: A cross-sectional drawing showing the environmental strategies and climate controls used in a building's design.
Blueprint Documentation	: Detailed technical drawings used in construction, including plans, elevations, sections, and details.
Buffer Zone	: An area designed to separate or protect different land uses or environmental conditions.
Carbon Footprint	: The total greenhouse gases emitted by a person, organization, event, or product, are typically measured in terms of carbon dioxide equivalents.
Conductivity	: The property of a material that defines its ability to conduct heat, affecting insulation and thermal performance.
Cool Roofs	: Roofing materials designed to reflect more sunlight and absorb less heat, reducing the cooling needs of buildings.
Daylight Availability	: The extent to which natural light is accessible within a building, reducing the need for artificial lighting.
Daylight Intake	: The amount of natural light that enters a building

Deciduous Tree	: A type of tree that loses its leaves annually, used in landscaping to provide shade in summer and allow sunlight in winter.
Direct Gain	: A passive solar heating strategy where sunlight directly enters a building and is absorbed by materials that store and release heat.
Diurnal	: About daily cycles, especially changes in temperature, sunlight, and other environmental conditions.
Double Skin Façade	: A building façade with two layers, creating a cavity that enhances insulation, ventilation, and energy efficiency.
Emissivity	: A measure of a material's ability to emit absorbed infrared radiation, influencing its effectiveness in thermal insulation and solar control.
High Solar Reflectivity	: The ability of a material to reflect a significant portion of solar radiation, reducing heat gain.
Humid Climate	: A climate characterized by high moisture levels in the air.
Illumination	: The level of light falling on a surface, important for visual comfort and energy efficiency.
In-Glass Blinds	: Blinds integrated within the panes of a window, providing adjustable shading and privacy.
Indirect Gain	: A passive solar heating strategy where sunlight is absorbed and stored in materials that radiate heat into the living space.
Inherent Factors	: The intrinsic characteristics or conditions
Initiative of Designer	: The proactive role of the designer in making informed decisions that impact the functionality, aesthetics, and sustainability of a building project.
Insolation	: The amount of solar radiation received by a surface per unit area
Insolation Rate	: The rate at which solar energy is received on a given surface over a specific period.
Internal-Load-Dominated	: Buildings where internal heat sources (people, equipment, lighting) significantly affect the thermal load rather than external weather conditions.
Luminous	: Emitting or reflecting light

Low-E Glass : Glass with a low-emissivity coating that reduces heat transfer while allowing light to pass through, enhancing energy efficiency.

Non-Conductive : Materials that do not easily transmit heat or electricity, used in building design to minimize heat transfer and improve insulation.

Non-Renewable Primary Energy Consumption : The use of energy from sources that cannot be replenished on a human timescale, such as coal, oil, and natural gas.

Passive Strategies : Design approaches that use natural energy sources, like sunlight, wind, and thermal mass, to minimize energy consumption without mechanical systems.

Performance : The effectiveness of a building or system in achieving its intended function, often measured in terms of energy efficiency or user comfort.

Performance-Oriented : Design or approach that prioritizes achieving high levels of performance, particularly in energy efficiency and sustainability.

Radiant Heating/Cooling : A system that heats or cools a space by radiating heat from a surface or absorbing heat into a surface, typically through floors, walls, or ceilings.

Skylight : A window installed in a roof or ceiling to admit natural light, contributing to energy savings.

Solar Collection Envelope : The design boundary that maximizes the capture of solar energy for heating, lighting, and electricity generation

Solar Envelope : The hypothetical three-dimensional space that defines the maximum volume a building can occupy on a site without shading adjacent properties, considering solar access.

Solar Radiation : The electromagnetic energy emitted by the sun, which includes visible light, ultraviolet light, and infrared radiation.

Solar Rights Envelope : A design consideration ensuring that neighboring buildings or properties have access to sunlight, preventing new constructions from blocking solar exposure.

Subclimate Type : A classification of climate within a larger climatic zone, characterized by specific microclimatic conditions that influence building design.

Sunshades : Devices or architectural features designed to block or diffuse direct sunlight, reducing glare and heat gain.

Sunspaces : Rooms or areas designed with large windows or glazing to capture solar energy.

Thermal Efficiency : A measure of how well a system converts energy into useful work or heat, with higher thermal efficiency indicating less energy waste.

Thermal Emittance : The efficiency with which a material releases absorbed heat as thermal radiation, affecting its thermal performance.

Thermal Map : A visual representation showing the distribution of temperatures across different areas of a building or environment, used to analyze heat flow and efficiency.

Thermal Mass : Materials that absorb, store, and release heat, helping to moderate indoor temperatures by slowing the rate of heat transfer.

Thermal Storage : The process of retaining heat energy in a material or system for later use, enhancing energy efficiency in heating and cooling.

Thick Plan : A building layout characterized by deep interior spaces, which can affect natural lighting, ventilation, and energy efficiency.

Unwanted Heat Gain : Excessive heat entering a building due to poor insulation or uncontrolled solar exposure, leading to increased cooling needs and energy consumption.

Vegetated Roofs : Roof systems covered with plants and soil, providing insulation, reducing heat island effect, and enhancing stormwater management.

Volumetric Heat Capacity : The amount of heat required to raise the temperature of a unit volume of a material by one degree, influencing a material's thermal mass.

Workflow : The sequence of steps or processes involved in completing a task or project, in design and construction, ensuring efficiency and coordination.

1. INTRODUCTION

Incorporating solar energy into architectural designs has been a consideration for designers since ancient times until the present. Solar-related strategies are versatile, serving various functions such as space heating, water heating, natural lighting, and electricity generation. A major benefit of using a solar system is that it relies on the sun, a renewable and non-polluting energy source (Yılmaz, 2006).

From ancient times to the present day, solar strategies have been the subject of discussion in the architectural environment and have influenced the design processes. The suggestion of Socrates for the south-facing windows in the 4th century BC remains valid even in current passive design strategies (Dumont, 1993).

Design concepts related to the sun were also explored during the Roman Empire and arguments of Vitruvius (1914) on the solar systems are reflected in passive strategies seen in buildings such as the peristyle housing, which was designed by the Ancient Greeks and Romans, which consists of an arcade or colonnade framing the interior open spaces or gardens (Pollio, 1914). Similarly, in subsequent periods, such as in Colonial New England, examples of passive strategies can be observed. With the rise of epidemics in the early twentieth century, the link between sunlight and hygiene emerged as earlier buildings were perceived as unhealthy, leading to a revival in solar-oriented design (Erkan Bursa, 2022). Even the further acceptance of solar design by famous architects also contributed to the widespread adoption of such strategies. Afterward, in the modern era, the oil crisis of the early 1970s brought energy independence to the forefront and gained global importance. As a result, numerous conferences were organized to facilitate the exchange of information, providing architects with the opportunity to share data with colleagues in the field (Kimura, 1999). Solar-related design, which has been taken into consideration since the past, is an important issue discussed in today's architectural environment.

In parallel with the changing consumption habits and the needs created by past energy crises, the world of today faces a climate and energy crisis, underscoring the critical importance of mindful use of natural resources. The advantages of solar-integrated design present a significant opportunity in this context. It is essential that this issue be the subject of discussion in the architectural communities. It is necessary that this issue be made broadly applicable and, ideally, enacted into legislation. For this reason, numerous research teams and architectural firms have contributed to the literature with research and projects on this subject over the years. These teams continue to seek answers to how buildings can be constructed and utilized in energy-efficient approaches.

Designing a new building with energy efficiency in consideration is one approach; another approach involves the attempt to make existing buildings more energy efficient. This is also addressed through retrofitting, the process of replacing or repairing existing architectural elements to meet the needs of a building or structure rather than building from the beginning. This thesis investigated the role of energy efficiency strategies in the design process. Addressing energy efficiency in an existing building is more challenging because a limited approach can be achieved when many critical design decisions for energy efficiency are not made in the initial design phase. Incorporating climatic data earlier in the design process, which is one of the most challenging phases, can provide valuable information for later design phases. At the beginning of the design process, architects often have limited data on project location, site boundaries, program requirements, and the specific demands of their clients. Due to the difficulties associated with the early interpretation and utilization of climatic data and the need for prior knowledge, many designers tend to ignore this data in the initial design phase. This tendency explains why energy efficiency studies are often applied to optimize an already-completed design process rather than informing the early stages of design.

Within the given data, the architects start to design with their architectural understanding and produce the possible design scenarios. In fact, the energy efficiency issues can potentially provide data for the initial architectural design process. In the schematic design stage, the approximate mass of the building, plan layout, approximate openings, possible façade elements, and operational scheme are being studied. At this starting point, it is beneficial to increase the data that the architect receives from the environment and to be able to develop design proposals according to these parameters, which is considered in the context of the thesis. In architectural design, analyzing solar qualities through a developed design and reorganizing the design according to this analysis interrupts work fluency. However, if this data is included in the design process from the beginning, the fluency of the design process is maintained. Therefore, it is discussed in the thesis how climatic data can provide data for the initial design process and how these parameters give design suggestions. In this regard, this study indicates how the energy efficiency analysis based on environmental data affects the process of making schematic design decisions and discusses the contributions it can provide to the final production of the schematic design phase. It is posited that accurate analyses are performed and precise design strategies are developed, and energy-efficient solutions can be produced at a lower cost to the contractor than active strategies that need electrical support.

Buildings consume large amounts of energy and are prime candidates for energy-efficient design. One of the best approaches that can be used to reduce energy use is the energy-efficient design (Ward, 2004). It reduces the cost of energy production and consumption by polluting the environment less while preserving existing energy resources. Without proper energy analysis, building energy efficiency measures cannot be evaluated (Al-Homoud, 2001).

In the architectural design process, general protection from cold and heat, having enough daylight, and achieving thermal comfort are significant issues. Lighting, mechanical heating, and air-conditioning equipment are used when deemed necessary. Mechanical heating and air-conditioning requirements can be significantly reduced when the energy-efficient architectural design is provided (Chel & Kaustik, 2017).

The function of the building and how it will be operated after construction is not a factor that can be controlled particularly by the designer. Therefore, the selection of the physical elements of the building and their integration can be coordinated by the designer by considering the climatic data. There is a need for mechanical air conditioning and ventilation systems to control the indoor climate and an evaluation of the energy demand to operate them. Unstable energy prices can be reduced by reducing energy requirements through accurate analysis and design (Al-Homoud, 2001).

It is essential to discuss insolation and daylight situations over the surrounding structures and the sun. To achieve this, it is essential to understand the urban and site characteristics that influence the utilization of solar radiation and daylight. The initial step in integrating factors like insolation and natural lighting into a comprehensive planning framework involves setting planning and operational goals and developing evaluation criteria. A key objective is to ensure that sunlight and daylight are accessible both around and within buildings. Energy-efficient goals also protect neighboring buildings (Pereira et al., 2001).

There are many approaches and strategies for energy efficiency. These include the sun's position, wind effects, glazing, building mass, façade system, mechanisms of passive heating and cooling, shading, material selection, and the building orientation. Solar-related energy efficiency is one of the first issues to be discussed. It can influence many design decisions in the early design phase because the effects of the sun are a precise input from the beginning of the process. There are many architects and engineers who specialize in energy-efficient design processes and are actively working in the field or continuing their academic research. Because of the high learning load, many individuals who are interested in these subjects tend to concentrate and specialize in certain areas. This situation leads to the concentration of research in limited areas. Integrating energy efficiency strategies into architectural project processes requires designers to conduct extensive research to determine where and how to intervene. This complexity leads to a reduced prevalence of energy efficiency strategies. Consequently, there is a need to systematize and recategorize these strategies using simplified, easily learnable methods. Incorporating these strategies into the schematic design phase is foreseen to accelerate these processes.

It should be stated that some disadvantages might occur when using these energy-effective design strategies, for instance, some strategic design decisions override others and reduce efficiency. Energy-efficient design processes are generally stated to have an iterative nature; it is foreseen that the same analyses are used repeatedly as the design develops and changes (Gao et al., 2019). However, this may create complexity in the design process and require detailed prior knowledge. A design decision taken as a result of the analyses may change in the later stages of the design. However, initial analyses usually take data from elements unlikely to change during the project process, such as topography, position of surrounding buildings, and solar geometry. Therefore, even if the analyses and the optimum solution do not change, the design decision prioritized by the designer may change. Therefore, this study claims that having a specific organization between the analysis methods and design strategies used for energy-efficient design and designing according to this organization reduces the need for revision and increases energy efficiency due to the inherent structure of the strategies. If this organization is carried out according to the increasing level of architectural detail, there will be no need to revisit and discuss the interaction of the strategies. This is because a previous decision has a more significant impact on the building's mass, and the suitability of any newly added strategy will be evaluated based on that previous decision.

In this context, this study examines the passive strategies used for energy efficiency and proposes a workflow that integrates these strategies in the initial design phase. It aims to create a cumulative workflow for the project design process. This workflow is structured around the sequential application of solar-related strategies, classified within their own categories. A critical aspect of this approach is that these strategies provide warnings or recommendations before the beginning of the design process.

1.1. Aim of The Thesis

Integrating energy-efficient design strategies into the design process poses challenges. It is essential to address energy efficiency earlier in the architectural design process to avoid critical revisions later in the project. Energy efficiency is a broad topic and there are many different methods, analyses, and programs available. The abundance of these processes can make learning and implementing energy efficiency strategies challenging. Many architects and engineers have mastered these processes, actively working in the field or advancing their academic research. Those people interested in these subjects tend to focus on specific areas and specialize in these specific areas due to the amount of learning required. This causes a lot of research to remain in specific areas.

The practice of architecture is generally discussion-oriented. There is no output to discuss until the architect has drawn the first line. This thesis aims to identify when the use of energy-efficient strategies should be open for discussion.

When integrating strategies related to solar energy, there are challenges such as continuous review and retesting of decisions. Therefore, it is envisaged that strategies that can provide information before the design progresses are considered to reduce these revision processes. The thesis aims to create a workflow where solar-related strategies are suggested before the relevant stage of the design, and the decision to use these suggestions is left to the designer. The aim is to establish a cumulative workflow that incorporates passive energy-efficiency strategies into the design process from its early stages, utilizing a range of tools and data. Suggesting the strategy to the designer and allowing the designer to decide whether to implement it, while still being able to propose new strategies at later stages regardless of earlier decisions, offers an advantage in preserving the originality of the design.

1.2. Scope of the Thesis

There is a considerable amount of data on energy-efficient design. To make these data comprehensible, certain limitations and reorganization are required. Therefore, this research was required to be limited to certain topics.

The schematic design phase, where the most intensive revisions occur in the architectural design process (Wang et al., 2006). Therefore, it has been chosen as the most suitable stage for integrating effective design strategies. Control of the internal climate of a building (such as heating and ventilation) can be applied both actively and passively. In active control, energy expenditure depends on devices such as heaters, air conditioners, and fans, and central heating is required. The power and dimensions of the mechanical equipment significantly increase the carbon footprint of the building before it is built and during use (Silver, 2008). Therefore, minimizing these needs of the building with passive interventions is recommended to be preferred as it reduces the cost for the contractor and contributes to issues such as ecological sustainability and climate crisis. Energy efficiency strategies include both active and passive systems. In terms of energy efficiency, passive systems are more effective in the mass of a building compared to active systems. Therefore, it would be more consistent to focus on passive strategies in the initial design phase.

An important part of passive strategies in energy-efficient design consists of wind-based strategies and other non-solar strategies. In energy-efficient design, there are numerous data, and considering all of these data can lead to complex results. Thus, in this research, wind and other non-solar strategies were out of scope. Therefore, it would be more consistent to focus on passive strategies in the initial design phase.

Given the contemporary importance of rapid project generation, digital testing, and production are essential for architectural project processes (Al-Homoud, 2001). Therefore, strategies that can be tested digitally or decided analytically and transferred to a digital environment have been used.

Production and learning habits stemming from architects and designers anticipate a preference for graphical expression-based analyses (Odabaş, 2020). In addition to this classification, since the workflow to be created is intended to reduce revisions, analysis programs that can provide preliminary warnings and suggestions before the design is initiated and studies that can be used instantly were used.

Analog and computational data are used together to provide data diversity since there is a lot of data for solar-related energy-efficient design. One of the aims of the workflow presented in the thesis is to produce an approach that can be used in many architectural project designs apart from exceptional cases. The methods used may vary with each design. The designer should reconsider this approach for each design based on the context and available data.

1.3. Methodology

The challenges of integrating passive design strategies into the architectural design process are recognized and the relationship between these strategies is evaluated in this study. The thesis suggests that these strategies should be adapted to the rapid architectural project development process in practice and rather than the mostly used repetitive method, a cumulative workflow needs to be employed.

In this study, the approach for adapting passive design strategies to the initial architectural design process was followed as below:

- The schematic design phase, which is known for the intensive testing of alternatives and allowing revisions within the architectural project process, was selected among the architectural project phases.

- The schematic design process has been divided into four main stages, with the level of architectural detail increasing as the project progresses: Mass Settlement, Plan Layout, Building Shell Study, and Materials/Precautions.
- Strategies that can be integrated into these stages of the project process have been identified. When selecting these strategies, it is critical that they do not operate iteratively and can provide information and advice before the relevant phase of the design begins. These strategies are integrated in a sequence that reflects their impact on the building form, with increasing levels of architectural detail.
- To ensure the consistency of these strategies, examples where the relevant strategy is predominantly applied and has significant effects on the building form have been examined, along with the principles of operation and key considerations during decision-making.
- These strategies have been consolidated into a workflow, and to assess whether this workflow impedes the progress of the architectural project, a residential project in İzmir, a region that is known for its intense sunlight, has been discussed using this proposed workflow. In this case study, since most of the building stock is residential, the residential structure was studied. This case is an example and the workflow can be applied to buildings of different programs. Beyond addressing a specific building program type, this study concentrates in the workflow itself, providing information about which type of strategy should be discussed at which stage. It provides a guide to the designer. The workflow can be seen as a guide that provides solar-related energy-efficient alternatives to the designer.
- At the end of the relevant case study, the effectiveness of this workflow in facilitating the collaboration of these strategies and its contributions to the architectural design process had been discussed.

1.3.1. Thesis Flowchart

In the thesis, a flowchart (Figure 1.1) was developed to facilitate readability and effectively convey the principles of the study. In this study, the literature review on strategies(3. Solar-Related Performance-Oriented Cumulative Workflow) and the case study (4. A Case Study Of A Housing Project In Izmir/Bornova) were conducted in parallel. Through this dual approach, the proposed workflow was tested in a real project and regular feedback was obtained, allowing the workflow to be continuously reorganized. This process enabled a systematic evaluation of the applicability of the theoretical knowledge in a practical environment. The feedback from the implementation was primarily focused on the efficiency of the proposed workflow. If the integration of a strategy reduced the impact of a decision made at a previous stage or led to revisions, the position of this strategy within the overall workflow was re-evaluated, and necessary optimizations were made.

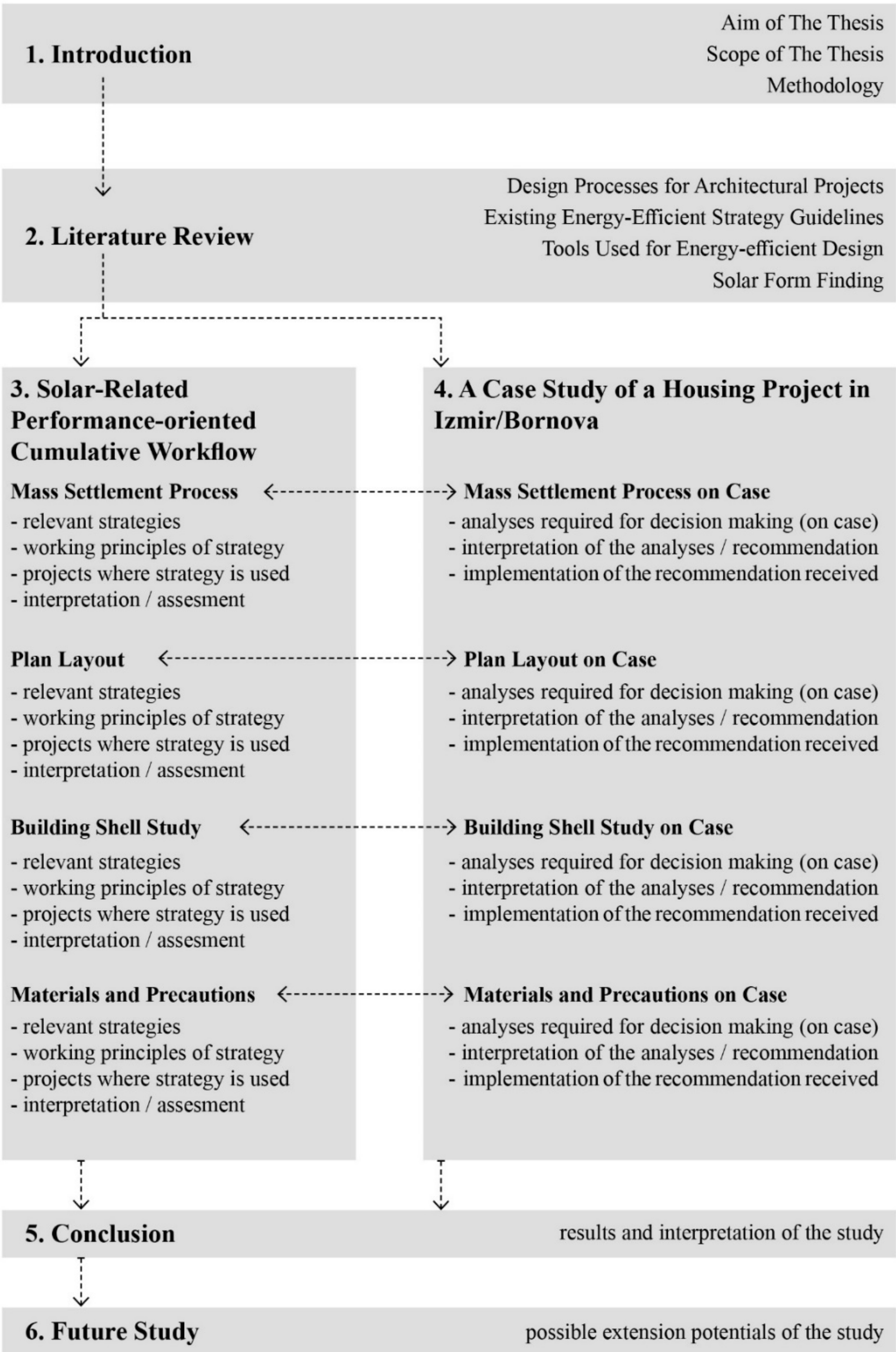


Figure 1.1: Thesis flowchart (produced by the Author)

2. INTEGRATION OF SOLAR-RELATED ENERGY EFFICIENCY INTO ARCHITECTURAL DESIGN (LITERATURE REVIEW)

In this chapter, the definition and the forms of progression for the architectural design processes were investigated. Possible ways for the integration of solar energy-efficient strategies into these projects were discussed. Then it is explained how the workflow proposed by the thesis differs from other sources in the literature and other workflows. Finally, example studies in the literature on solar form finding, which is an important part of the workflow, were given as the present examples.

2.1. Design Processes for Architectural Projects

Architectural design processes are diversifying according to the descriptions of the works and the agreement with the employers. In this research, the progression from the initial discussions with the employer regarding an architectural design on a site until the delivery of the final blueprint documents is defined as the architectural design process. Although it is possible to see variations according to the attitudes of the designers in the progress of the architectural project production, some definitions for the project processes can be made. Such definitions ease the processes for the architects during the initial agreements, determining job specifications, estimating the necessary workforce, and identifying the duration of regarded work.

Phases in the architectural design progress can be categorized as pre-design, schematic design, design development, construction documents, building permitting, construction administration, and post-design (Mahmoodi, 2001).

- Pre-design

At this stage, preliminary information about the project is gathered. It also includes scratching the first sketches.

- Schematic design

At this stage, decisions are taken for the properties such as the estimated building mass, approximate openings, potential facade elements, floor plan layout, and operational scheme.

- Design Development

In this stage, where the main decisions of the project are finalized, the architectural project and the projects of other disciplines are compared, and necessary revisions are made according to the needs (Mahmoodi, 2001).

Since this stage is the most intensive process of coordination with other disciplines, it is envisaged that any revision to be made would affect the projects of other disciplines. Therefore, revisions complicate the coordination and lower the motivation of the teams working in other disciplines.

- Construction Documents

At this stage, the details of the project and many decisions that have already been made are produced on the closest scale, and the drawing process is finalized (Mahmoodi, 2001). This stage is one of the most difficult processes to perform revisions because as the level of detail in the project increases, the number of drawings that need to be revised also increases.

- Building Permitting

The project and the last approximate cost table produced are harmonized in this phase of the project (Mahmoodi, 2001). The project is open to change in terms of information, but it is not a stage open to spatial revision.

- Construction Administration

This phase includes the work of managing and ensuring the oversight of construction and implementing alterations.

- Post-Design

Incorporating post-occupancy assessments, user manuals, and evaluative research (Mahmoodi, 2001).

While analyzing the phases of the architectural design process, the appropriateness of integrating solar energy-related energy efficiency strategies into these processes is discussed. The pre-design process usually occurs analogically and involves preliminary research and initial sketches. Therefore, including solar energy efficiency strategies in this phase depends on the prior knowledge and sensibility of the designer. Instead of personal knowledge, this research aims to find the stage in the architectural design process where solar energy efficiency strategies can be optimally integrated. Therefore, the pre-design process is very dependent on the designer's personal knowledge, sensitivities, and life perspective of the designer, it is less flexible in terms of integration.

Many decisions have to be made at the schematic design stage, which is one of the most challenging stages; otherwise, more intensive revision processes may occur in later phases. To make these decisions, the architectural project is going under revision.

Integrating solar-related energy efficiency strategies into the parameters that affect these revisions is envisaged to provide the designer with an important contribution of information about the project and reduce the possible revisions that may arise later. Therefore, schematic design is the most appropriate stage for integrating these strategies.

At the beginning of the Design Development phase, it is important to communicate the existence and use of these strategies to other engineering teams and to inform them of the compatibility of these strategies with the systems they may use. Based on this information, the engineering teams need to be guided and controlled during the remaining stages of the process. The process between the Schematic Design and Design Development phases is important in communicating the process to other teams. If there is a warning from engineering teams, the project may need to be revised before it is detailed.

In the continuing stages of the Design Development phase, the architectural and spatial revision process is completed, and the detail rate of the drawings increases. As spatial changes complicate the process, adding solar-related energy efficiency strategies would need to be finalized during the Schematic Design process. It would be more efficient for other processes to align with these strategies.

The phase of Construction Documents is usually a stage where more detailed information about the building is processed into the project. Spatial revisions can be challenging in this process. Adding energy efficiency strategies related to solar energy and integrating these strategies into the building can be completed earlier so that other phases can proceed with these strategies. Due to the amount of detailed information and drawings, building permitting processes may not be available for revision. In the case of revision, the workload is expected to be more intense than other processes.

The Construction Administration phase primarily focuses on oversight and regulation of the construction processes, involving the implementation of necessary revisions as required. It commonly represents one of the more demanding stages in project revision. The Post-Design process includes work that can be done after construction. So, it is not possible to integrate new design strategies, even though they contribute to further studies and projects.

This research concentrates on the Schematic design process, as it is considered to provide the most opportunity for integrating these strategies.

2.2. Existing Energy-Efficient Strategy Guidelines

The increasing global importance of energy efficiency has led to the establishment of standards in this field, including the development of various types of certificates. Some of these programs of the certificate are BREEM, LEED, DGNB, IISBE, GREENSTAR, and CASBEE. These evaluation systems are based on certificates issued due to tests initiated after building construction (Anbarcı et al., 2012). This regulation includes simple definitions for results and evaluation. Such evaluation systems have the potential to stimulate critical issues about energy-efficient aspects of design. Although performance evaluation systems are in use, the issue of performance has not yet become an integrated part of the design process, and this is only reflected in the application of the requirements of the regulation. These systems are limited in their recommendations for incorporating energy-efficient strategies into the project from the beginning of the design process.

In Turkiye, this issue is legislated by the Building Energy Performance Regulation (BEP) (Binalarda Enerji Performansı Yönetmeliği). Some workflows on energy-efficient design processes have also been proposed in Turkiye and can be reviewed in the BEP-TR Guidance Manual (Binalarda Enerji Performansı Yönetmeliği). This guide provides strategies for energy-efficient design and generates a Building Energy Performance Certificate through a digital system. Whilst these systems have the potential to provide information on energy-efficient strategies, due to the level of detail of the strategies they offer, they often refer to the later stages of architectural projects. Therefore, these processes should be considered as a guide that can be used for evaluation purposes rather than a guide that provides support to the design. The proposals presented in these processes point to the advanced stages of architectural design. An evaluation at the final stage of the project and revision of the project in case of a possible unfavorable situation in terms of energy-efficiency may be challenging because the project is now in its final stages.

Some resources on energy-efficient design strategies provide information on the justifications, working principles, and examples of their use. Such resources are close to the workflow due to their content sequencing and interconnected structure. These resources include the book of Mark DeKay (2014) ‘Sun, Wind, and Light: Architectural Design Strategies’, The ‘Architect's Guide to Building Performance’ published by AIA (American Institute of Architects) (AIA, 2023), and the ‘Energy Efficient Building Design Strategies guidebook‘ prepared within the scope of the ‘Technical Assistance Project for Increasing Energy Efficiency in Buildings’ in Turkiye (Ulukavak Harputlugil, 2013).

The book of DeKay (2014) is useful in understanding the interrelationships of strategies; it contributes to a holistic understanding of the subject by directing the reader to other related chapters while obtaining information about a strategy. It is an important contribution to the literature in terms of citing sample projects where the relevant strategy is used. While the categorization within the book is advantageous for understanding energy-efficient strategies, it is not intended to guide the designer in the integration of architectural projects. It is not the purpose of this study to give information about the order of implementation of the strategies.

Workflow processes that address architectural design processes and determine at which stages the issues related to energy efficiency are discussed and provide organization accordingly are included in the literature. It is possible to access various workflows related to architectural design processes on the website of the AIA, one of the important network organizations in the field of architecture (AIA, 2023). The ‘Architect's Guide to Building Performance’ is an important resource that emphasizes the role and importance of energy efficiency in the architectural design process. This guide defines the project phases in detail and provides information about the issues to be considered during these processes. It addresses critical issues in the design process by providing general headings and an approach that aims to be a warning to the designer. This study is a critical contribution to the literature in that it provides critical information and warnings for designers to receive general information and to see their place in the process. In the examples given in this study, a study is carried out, tested, and interpreted, then another alternative is studied and the intention is to find the most appropriate option among the alternatives. It is possible to see the iterative approach of energy-efficient design processes in this study. This approach will increase the amount of revisions in the project flow processes, as mentioned at the beginning of the thesis. In the workflow proposed in this thesis, instead of generating and testing an alternative, the designer can obtain the recommendations of the relevant phase before starting production.

The ‘Energy Efficient Building Design Strategies’ guide works together with the Building Energy Performance (BEP) regulation and addresses many energy-efficient strategies (Binalarda Enerji Performansı Yönetmeliği). However, there is no guidance for the designer and integration into the design process. In general, although these resources provide important contributions to the literature in terms of obtaining information about strategies, it can be difficult for designers to understand how to choose between these strategies and how to use them.

Furthermore, it does not guide the designer on the first line drawn or the first volume placed from the beginning, and the placement of potential strategies in parallel with the project flow becomes challenging. Unlike existing guidelines, this thesis aims to provide designers with a workflow that incorporates energy-efficient strategies from the very beginning of the design process. In the fast-paced project workflow of the present day, the main goal of this thesis is for designers to create a workflow without interrupting the process and requiring minimal revisions. It is also necessary to discuss the competence of programs and plug-ins that support energy-efficient design in this context.

2.3. Tools Used for Energy-efficient Design

Currently, tools for the application and simulation of solar energy-efficient design have increased and become easier to use. Numerous tools and types of analyses are available to identify critical points in insolation and analyze the consistency of form, façade, and plan layout.

The Grasshopper plugin for Rhino offers various plugins for this requirement such as LadyBug and HoneyBee (Roudsari & Pak, 2013). BIM(Building Information Modelling)-supported programs also provide analysis plugins for this purpose (Alhammad et al., 2024). Programs such as EnergyPlus and Climate Studio - Solemma, which can be integrated as plugins or run separately, also provide data about solar-related aspects (Solemma LLC). Within the scope of this thesis, the schematic design process of the architectural design progress is studied. Rhino software and its plug-ins

Grasshopper and Climate-Studio were preferred instead of Revit which requires a larger amount of input. Advantages such as the ability to produce graphical results and the simultaneous execution of model and analysis processes are the reasons for selection.

There are softwares that can make various suggestions before starting the design process, different from analysis programs that can proceed in parallel with the design. One such software is Climate Consultant. Climate Consultant can provide strategic recommendations on wind, insolation, and other environmental factors using data from the EPW file (Mwizerwa & Gupta, 2020). However, the ability of the Climate Consultant to provide recommendations at the building scale and later stages of the design process is limited. This thesis aims to provide energy-efficient design strategies at building scale and specific-to-project.

2.4. Solar Form Finding

An extensive review of the literature reveals the existence of studies that provide guidance on solar insolation prior to the initiation of the design process. One of the intentions is 'solar form finding', which considers the surrounding buildings and the buildings that will be designed. To reduce the mechanical and electrical needs of a building, it is necessary to utilize daylight for heating and lighting. Considering the solar geometry, the relationship of the mass of the building with the surrounding buildings is important for efficient solar insolation of a building. When analyzing the building's interaction of building with neighboring structures and topography, it is essential to ensure that the building's mass of building does not obstruct the solar gain needed by neighboring buildings, while also receiving adequate solar heat for its own mass.

Some methods can be used at the beginning of the project to make an optimized design in this regard. One of these is seen as the 'solar envelope' method. Capuleto and Shaviv (1997), in their study "Modeling the Design of Urban Fabric with Solar Rights Consideration", reference earlier research that aligns with their approach. For instance, Arumi developed a computerized model to assess the maximum height a building can achieve without infringing on the solar rights of nearby structures. Knowles (2003) proposed a method (Figure 2.1) to ensure each dwelling unit in a community has adequate solar access. DeKay (1992) conducted a comparative analysis of various building envelopes that facilitate daylight access. Expanding on Knowles' work, Schiller and Uen-Fang created a computer program to design solar envelopes specifically for flat-rectangular sites. Capuleto and Shaviv (1997) differentiated their approach by aiming to create a solar volume using the solar envelope method. In research titled 'A Compact Urban Block Design Method Based On 'Solar Envelope'', Jingjin Li (2020) discussed the use of solar envelopes on an urban scale and developed a corresponding method. Additionally, Francesco De Luca (2021) introduced the Reverse Solar Envelope method, a new technique for building design that integrates regulatory considerations and addresses the needs of tall buildings in densely built urban areas.

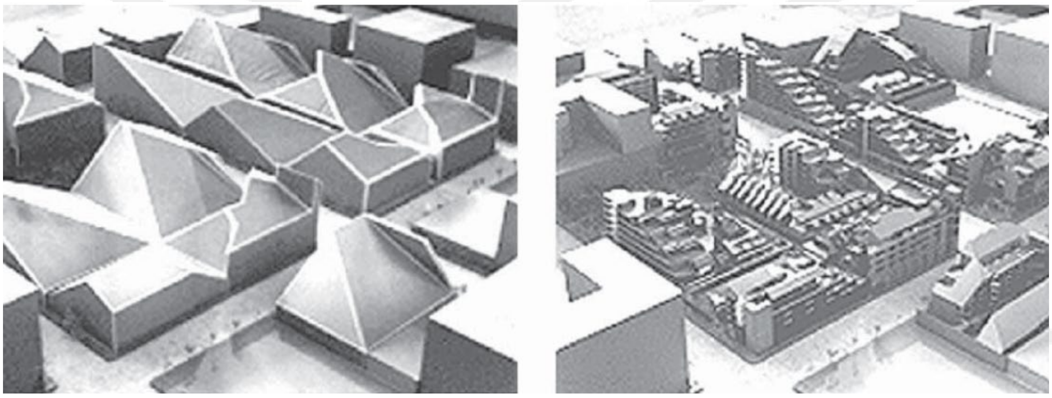


Figure 2.1: Typical housing project: viewed from the east, this test project illustrates multiple land parcels with housing over street-front shops; solar envelopes provide 6h of solar access above a 20 ft shadow fence at neighboring properties (left); all designs under the solar envelope provide at least 4h of solar access and cross-ventilation for each dwelling unit (right). (Knowles, 2003)

To understand the potentials of the solar envelope method, the Bunker Hill example of Jingjin Li (2020) at the urban scale, the study for high-rise buildings of Francesco de Luca: 'Solar Form Finding', and the SustArc model developed by Capeluto and Shaviv at the building scale were examined.

Figure 2.2: Site condition and initial solar envelope, The Bunker Hill Project (Li et al., 2020).

The Bunker Hill Project is a case study being trialed in Nanjing, China. Close to the east hill, 4 different parcel forms were selected, and the total land area is 95,000 square meters. Urban roads occupy the western and northern sides, with Dongshan Park positioned to the east. The 3 main focuses of this design are the maximum height is limited due to the existing hill; the building needs maximum floor area considering solar insolation and height. There is a need for insolation in the winter and shading in the summer in the Nanjing climate, which is cold in winter and hot in summer. Therefore, this study focused on designing the sun effect and building layout issues integrated way. Form and solar-related energy efficiency were compared over three models designed for the same site (Li et al., 2020).

Defined process of the case;

1. Workflow compilation: A workflow for generating a 'solar envelope' has been developed using Grasshopper (GH), encompassing five stages: climate information input, block boundary import, solar insolation time setting, solar envelope generation, and geometric parameter analysis. This study utilizes climate data for Nanjing sourced from the EnergyPlus official website, with solar insolation time set from 11 AM to 1 PM on the winter solstice (Li et al., 2020).

2. Application of solar envelope: The previously outlined workflow is applied to the site to establish the initial solar envelope. This involves setting up the sideline, generating the solar envelope, and performing a Boolean operation with the building control red line to define the maximum potential building volume within each block (Li et al., 2020).
3. Building layout inside the envelope: Three distinct block models are designed to fit within the generated envelope. Model 1 combines tower and slab buildings, Model 2 includes towers, slabs, and courtyards, and Model 3 incorporates towers and courtyards (Li et al., 2020).
4. Solar insolation simulation and geometry indicators calculation: Simulations are conducted to calculate the three-block models' solar insolation and geometric indicators of the three-block models. The solar insolation time includes total and average insolation at the summer and winter solstices. Total solar insolation time represents the total amount of solar energy received by the building surfaces, calculated using the Ladybug plug-in (Li et al., 2020).

The research findings are as follows,
In consideration of the findings of the analysis, the block sizes were examined by the solar envelope produced. This methodology, which is prevalent in China, strives to achieve equilibrium in the insolation rate of buildings at the urban settlement scale. A significant divergence is observed between the north-south orientations and the sun envelope. The maximum height permitted in the northern sector was determined to be 95 meters, while the maximum height allowed in the southern sector was established at 55 meters, as indicated by the solar envelope. Three distinct models were devised by modifying the architectural forms. Model 1 is composed primarily of towers and slabs. In accordance with the height restrictions imposed by the solar envelope, the northern area is occupied by tall towers. The estimated height of the towers is between 30 and 54 meters. In Model 2, an extension of the Model 1 approach is presented, incorporating inner courtyards and blocks with approximate heights of 9-27 meters. In Model 3, the configuration of the building blocks has been modified in accordance with the requirements of the solar envelope. The three models were then compared with regard to insolation (Li et al., 2020).

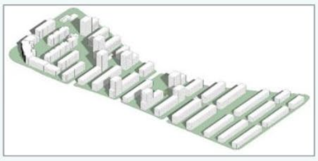
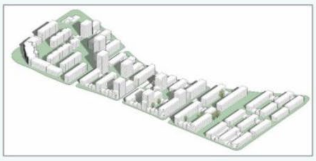
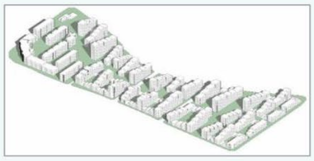
Type	Model 1	Model 2	Model 3
3D Model			
site area	94632m²	94632m²	94632m²
Floor area	150989m²	164189m²	201317m²
FAR	1.6	1.74	2.13
building coverage ratio	0.28	0.35	0.39
Average building height	19.7m	17.9m	19.2m
Open space ratio	0.45	0.37	0.29

Figure 2.3: Three 3D models and geometry indicators (Li et al., 2020).

Model 1 shows the lowest insolation rate compared to summertime, while model 3 shows the highest. However, when the average insolation conditions are examined, it is seen that model 3 has the lowest average insolation rate, with 1,99. The average insolation rate reflects the insolation quality more precisely than the highest insolation rate. Therefore, it can be said that Model 3 provides the best shading in summer, even though the sun exposure is limited in winter (Li et al., 2020).

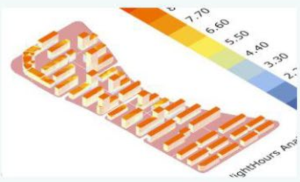
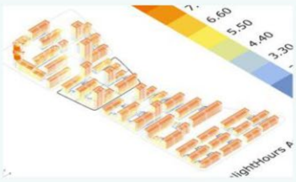
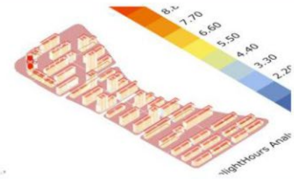
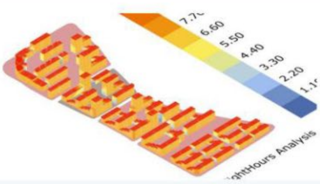
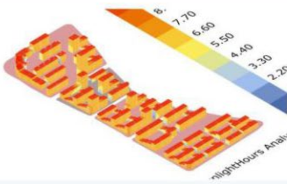
Type	Model 1	Model 2	Model 3
3D Model			
solar time in winter（hour*m2）	208246	215995	215413
Average solar time（hour/m2）	1.38	1.32	1.07
3D Model			
solar time in summer	334005	367096	401245
Average solar time	2.21	2.24	1.99

Figure 2.4: Simulation results of solar insolation time of three models (Li et al., 2020)

This design strategy facilitates the provision of height and overall volume limitations in large-scale areas. The planning that is implemented along primary roads can facilitate the creation of a general settlement volume. However, the information provided does not extend to planned side roads, except for the main road, at a more detailed scale. Consequently, alternative strategies may be required for more detailed planning. To achieve a more detailed volume limitation study, this method, when applied on a large scale, can be complemented with other strategies, such as the SustArc model on a lower scale.

When the model of the Sustarc is reviewed, the arrangement of a site plays a pivotal role in determining the efficiency of passive solar heating. Gaining heat from neighboring structures and experiencing a loss of solar illumination are inherent factors in urban environments, as noted by Littlefair (1998). In large cities, the dispersion of natural light within a building is significantly affected by tall buildings and close constructions. It can impede sunlight penetration, particularly during the winter months. Obstacle angles, as exemplified in Figure 2.5, illustrate this phenomenon. Consequently, there is a critical need for research into the impact of obstructions on solar radiation absorption.

In urban environments with high building density, the efficacy of conventional techniques for estimating the solar radiation obstructed by neighboring structures diminishes as the architectural density increases. Consequently, it is feasible to establish defined limits for the angles between the masses in buildings. When these angles exceed the predefined thresholds, occupants of the buildings in question experience a reduction in natural daylight, which in turn results in an increased dependence on artificial lighting (Pacheco et al., 2012).

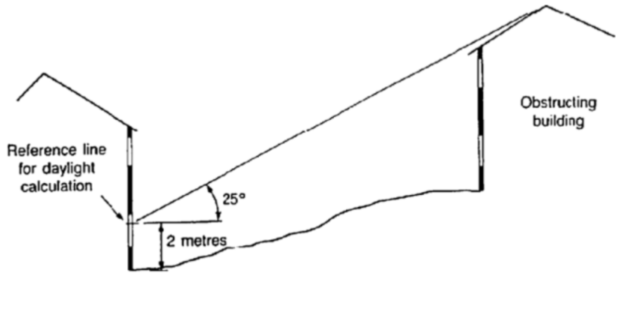


Figure 2.5: Section of a building showing an obstruction angle of 25◦ (Pacheco et al., 2012)

Ensuring access to passive solar exposure in buildings is a fundamental right that ought to be safeguarded by national laws or local urban planning regulations (Littlefair, 1998). The necessity of utilizing solar radiation during winter extends beyond the initial design phase of the building. It also extends to the planning of entire communities, encompassing pavements and open spaces. Consequently, each neighborhood is regarded as an integrated system, carefully planned to maximize sunlight exposure, thereby promoting energy efficiency and enhancing the well-being of its residents. (Pacheco et al., 2012).

Capeluto and Shaviv have proposed design guidelines that rely on the solar volume of the building, involving in their settlement and orientation, as shown in Figure 2.6 (Capeluto & Shaviv, 1997). These researchers use graphical representations to assess street width, overall building orientation, and building height intending to maximize urban density while optimizing solar exposure (Pacheco et al., 2012).

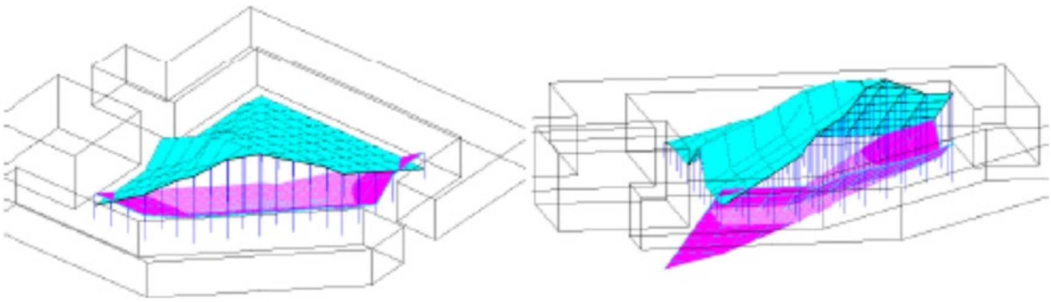


Figure 2.6: Solar volume as the conjunction of the solar rights envelope (upper plane) and solar collection envelope (lower plane) (Capeluto & Shaviv, 1997)

This model provides the most appropriate solution for the solar rights of the surrounding buildings and the structure to be designed. The model gives the designer an idea about insolation but leaves other parameters to the designer's interpretation and architectural knowledge. There are strategies that can be applied by interpreting the envelopes produced by this method.

The solar envelope method can be applied to Rhino Grasshopper(GH). It aims to optimize daylight use and give the maximum volume in which the designed building can be placed without blocking the sunlight of the surrounding buildings and allowing itself to receive enough sun exposure. When the script runs in Rhino GH, it gives users two envelopes: a 'solar collection envelope' and a 'solar rights envelope'.

The solar collection envelope provides a mesh about the minimum height required for our building to receive light according to the sunlight of the surrounding structures and topography. The purpose of the solar rights envelope is to give volumetric data on the maximum height at which the design can be placed, taking into account the solar rights of the surrounding buildings.

The space between these two envelopes is the most solar-efficient volume for both the designed building and the surrounding buildings (Capeluto & Shaviv, 1997).

This method may also not be effective in producing the optimal solution for high-rise buildings in adjacent or dense areas(see 5.1.1Limitation test of solar envelope method). In such cases, Francesco De Luca's study (2021), 'Reverse Solar Envelope,' which focuses on solar form finding in high-rise buildings, can be studied.

Francesco De Luca (2021) reviewed previous solar form-finding studies and developed an alternative method for high-rise buildings. Drawing from the pioneering work of Knowles (2003), existing methods employ the relative position of the sun and sunlight hours to generate solar envelopes. These methods treat the cut-off time as a constant input, enabling designers to specify particular hours or start and end times.

This research is based on the aforementioned workflows. The described method offers a different approach to designing solar envelopes by increasing building volume. It allows the form-finding process to include cutouts and cavities. By employing modular solid geometry to remove three-dimensional cells from the plot's volumetric space if they obstruct direct solar radiation to windows on adjacent facades (De Luca et al., 2021).

The method is called Reverse Solar Envelope (RSE). It advances the initial subtractive approach for generating solar envelopes by removing cells from a three-dimensional array through (De Luca et al., 2021):

1. The method enhances time selection and sequencing for solar rays, allowing for the development of larger envelopes and a broader range of shape variations.
2. The method accounts for core size and location to minimize the distance between the future building and buildable mass.

3. It facilitates the generation of floor contours and envelopes, which support preliminary environmental and energy performance assessments and helps select the optimal building form.
4. By incorporating an accelerated reverse ray casting process, the algorithm's robustness is enhanced, improving the organization of sun vectors and the analysis of different RSE forms (De Luca et al., 2021).

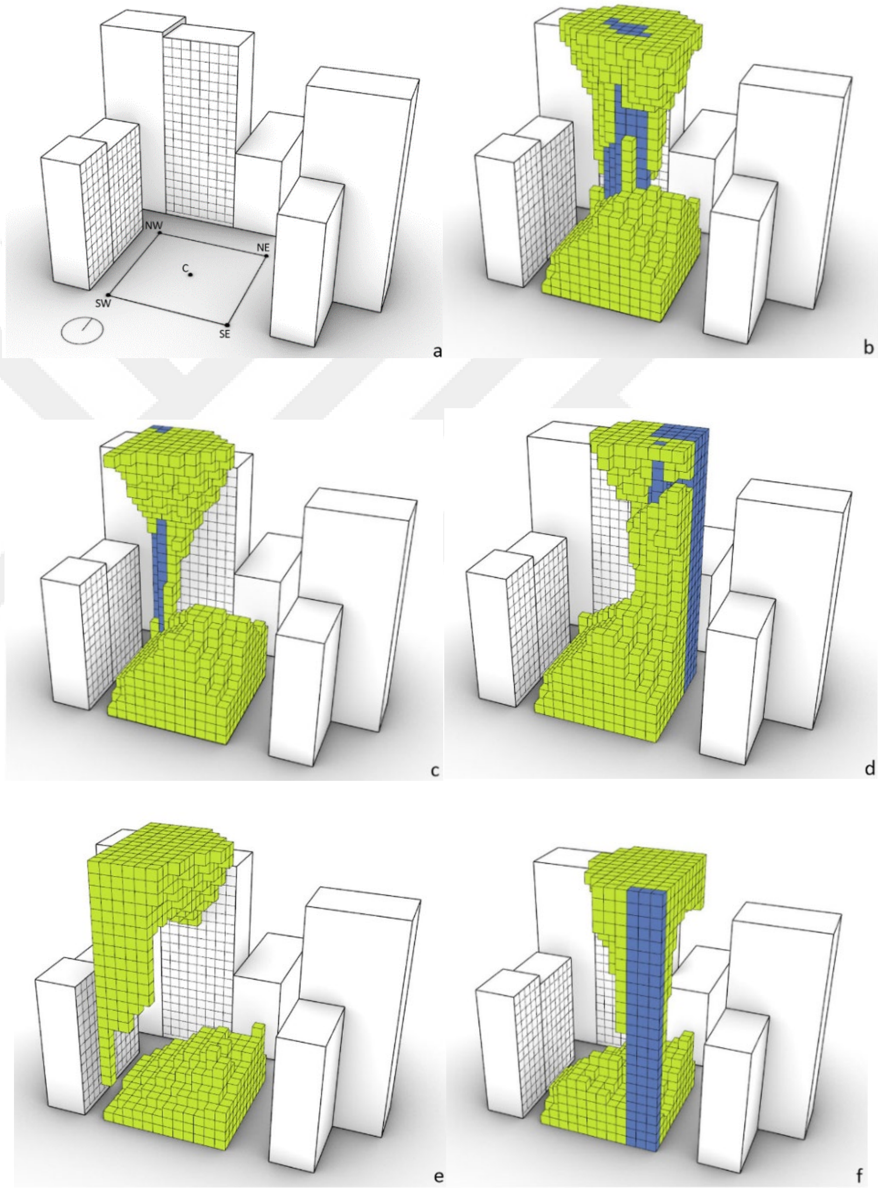


Figure 2.7: Façade subdivision, plot, and points for core location (a). RSE was generated using the plot center C (b), the North-West corner NW (c), the North-East corner NE (d), the South-West corner SW (e), and the South-East corner SE (f). The blue color cells are lo located in the same position on all the floors; they could be used as building cores if their quantity and layout allow that. (De Luca et al., 2021)

The solar form-finding method of De Luca(2021) can play a guiding role in designing high-rise buildings as it takes the solar envelope method to a 3D level and incorporates core structures as a realistic approach. This method is also applied through maximum volume. It is possible to incorporate an orientation study as a preliminary stage in this method. This method may be employed in the context of high-rise buildings, particularly in instances where the SustArc model is deemed inadequate, such as in densely developed areas or in situations where the objective is to design a taller structure in comparison to the surrounding built environment.

As evidenced by these case studies, the solar envelope, which was generated at the outset of the design process and serves as a reference point for other project data, proved instrumental in numerous mass settlement decisions prior to the formation of the design. As the design process advanced, the optimal insolation strategy became evident, as evidenced by the compatibility of the modifications made to the building forms, beyond those related to mass placement and height, with the initially mentioned solar envelope.

Therefore, it was found beneficial to utilize the solar envelope method during the initial design stages. Based on the solar envelope model, 3 different passive energy efficiency strategies can be decided. These are the direction of terracing, the location of the bioclimatic atrium, and the location of the cantilever systems.

2.5. Literature Review Assessment

As mentioned before, the literature on design processes related to solar energy is quite extensive. Therefore, it is challenging to understand and learn these processes. These studies can provide valuable information during the mass settlement process, but there is no study that has been carried forward from this stage for the next stages. Therefore, it is one of the aims of this thesis to provide preliminary information about the design process of a workflow that is used together rather than individually.

The results of the literature review indicated that the optimal stage for integrating passive design strategies is the schematic design stage. The present study differs from existing research in that it aims to integrate passive design strategies into the architectural design process. Furthermore, it addresses all stages of schematic design with a comprehensive approach, whereas previous studies have either presented strategies in the context of schematic design or have addressed only a limited number of stages. In the next part of the thesis, a workflow is developed graphically and a workflow process is presented by sequencing solar-related energy-saving passive strategies in a way that increases the level of architectural detail(Figure 3.1). The following section will present a detailed review of the general characteristics of the workflow, its contributions, and the principles of the strategies, with illustrative examples of their applications.

3. SOLAR-RELATED PERFORMANCE-ORIENTED CUMULATIVE WORKFLOW

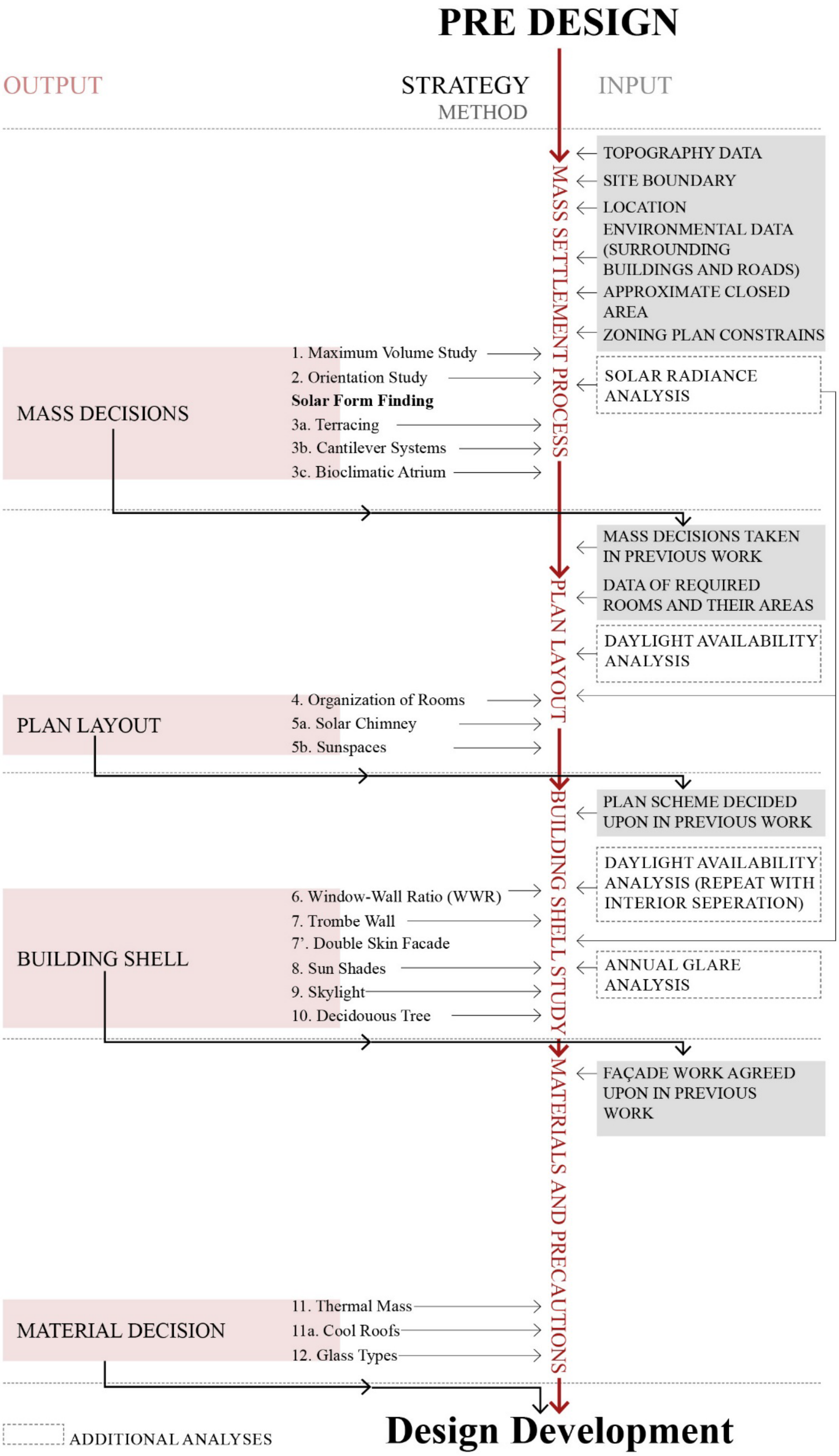


Figure 3.1 : Workflow integration into the design process, produced by the author.

Determining where and how to incorporate solar-related passive design strategies during the initial design phase presents a significant challenge for designers. Because analyzing the inclusion of some design decisions in the project is a significant labor force, the result obtained after this effort may affect a design decision beforehand. Therefore, this research seeks to answer which type of analysis needs to be applied in the initial design phase and which design decisions need to be taken accordingly.

For this purpose, it proposes to divide the initial design phase into parts according to the process and places possible design analyses and strategies into this workflow. The schematic design phase is divided into four stages, which are foreseen to be suitable for integrating solar-related energy efficiency strategies within the scope of this thesis. Although these processes can be interchanged according to the designer, a definition has been made from general to specific, from volume to detailed study.

The research proceeds through this process definition. These stages include mass settlement, plan layout, building shell study, and materials/precautions.

Mass Settlement Process: It is the stage where approximate mass settlement decisions of a design are made.

Plan Layout: The stage is where the necessary rooms are placed, and the operation scheme is decided.

Building Shell Study: This is the process in which questions such as where there should be openings or certain system integrations in the building mass and the solar qualities of the facades are found.

Materials and Precautions: At this stage, it is planned to determine the condition of the surfaces according to the solar radiation conditions of the building and to present the required recommendations, such as material selection according to thermal mass, reflectivity.

The workflow developed in this study aims to integrate seamlessly into the design process, provide graphical guidance, avoid a time-consuming research phase, and provide preliminary information about insolation before the design progresses. Therefore, analysis programs that require repeated testing are beyond the scope of this study; instead, tools and methods that can provide preliminary information before starting the relevant stage of the design are used. For this purpose, it proposes to divide the initial design phase into parts according to the process and places possible design analyses and strategies into this workflow.

In order to reduce the revision process while these processes are progressing, a process definition was made that progresses cumulatively by building on each other instead of going back and revising. As can be seen in Figure 3.1, the output of one phase is included as input to the next phase. This is envisaged to facilitate the integration of these passive energy and efficiency strategies into the project and reduce iterative processes requiring constant revision.

While designing this workflow process, a specific sequence was established to ensure the consistency of the design process. Although this sequencing may vary between offices and architects, it generally starts with massing and progresses to more detailed studies. Therefore, this workflow divides the schematic design process into parts. Furthermore, since the energy efficiency process can be more easily perceived and utilized in a cumulative progression, it is envisaged that decisions taken at these stages will be added. Accordingly, the output of one stage is planned to be used as input in the next stage.

The mass settlement process can be used to find a solar-efficient form, and the data required for this decision is often the first available data. Information about maximum volume, building orientation, and solar-form finding(terracing, cantilever, glass atrium) can be obtained at this stage.

The plan layout stage is the stage where the in-building programs are placed. Therefore, the analyses made before starting this process and the form obtained in the previous stage ensure that these program placements are more efficient regarding insolation and daylighting.

In the Building Shell Study phase, alongside the information from previous phases, relevant data can be gathered to assess and manage the solar conditions on the building's facade.

In the Materials and Precautions phase, the energy gains that can be achieved with the materials that can be used on the façade or flooring and the precautions that can be taken in cases where the designer cannot comply with the insolation recommendations obtained due to other parameters can be discussed.

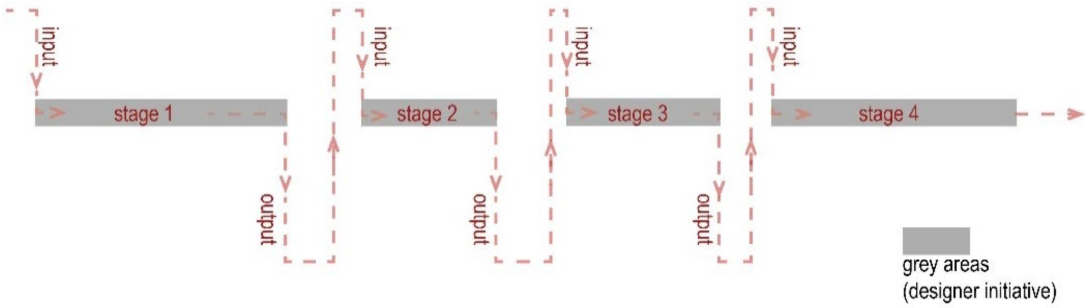


Figure 3.2: The position of the designer's initiative in the workflow process

One of the important advantages of this cumulative workflow process is that it prioritizes the designer's initiative. As can be seen in Figure 3.2, the use of the strategies acquired at the beginning of each phase is left to the designer's initiative. Even if the designer does not use any of these strategies, they have the opportunity to take the strategies for the next phase with the current study.

3.1. Mass Settlement Process

The massing process can be defined as determining the optimum volume that can be constructed following zoning rules, functions, and solar requirements. Although this stage has undergone historical transformations, it is one of the starting methods used for many years and is still frequently preferred by designers. Different tools and methods have been used throughout history in this process; the model is one of these tools.

Although the use of the model was not widespread during the Beaux-Arts period, Gaudi's use of the model as a design tool, and later the Bauhaus school and Le Corbusier's encouragement of the use of the model in design, made the model a powerful design tool in architecture. This stage refers to the use of the model, which was called the “massing model,” and plays an important role in making massing decisions (Mills, 2011).

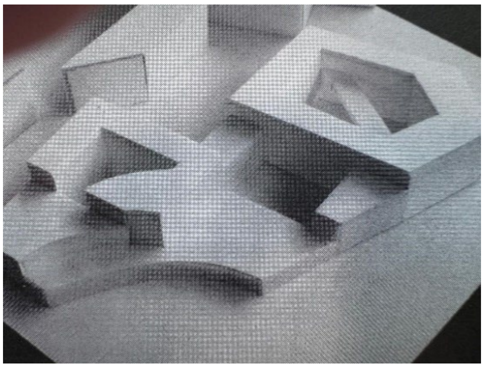


Figure 3.3: Massing model example (Mills, 2011)

Today, with the development of three-dimensional programs, the massing process has retained its purpose, but the tools and methods used have changed. The main purpose of this stage is to obtain a mass and develop the other stages of the design based on this mass.

The solar form is best identified during the mass settlement phase of the project. At this point, urban data, environmental relations, and the programs that are to be included in the design are important. Sun geometry can help designers make decisions in this process. It can help designers develop a massing proposal without preventing the right to sunlight needs of the surrounding buildings and protecting the sunlight rights of their buildings at the right rate.

To decide on a design's approximate mass settlement, architects need topography information, site boundary, location, data of surrounding buildings and roads, and approximate closed area information. These are mostly the first data provided in the project. Decisions on maximum volume, orientation, and solar form finding (terracing, cantilevering, and glass atrium) can be taken during the mass settlement process.

3.1.1. Maximum volume study

The focus at this stage is on generating a starting point for the design to move forward, where the employer's brief and the architect's communication with the employer are important. While the general tendency is to favor maximum enclosed space, the thin plan and east-west oriented plan can be used independently of such a constraint, which also supports daylight intake. In the case of maximum enclosed area, it is about determining the maximum volume within the limits of contemporary zoning laws, without taking into account energy efficiency considerations. It is known that zoning regulations are determined in relation to the surrounding buildings and roads and thus set limits for urban planning. This imposes constraints on the available space. Integrating this maximum volume into the 3D model ensures continuity throughout the process by ensuring that subsequent assessments are made against this volume. To complete this phase, certain data is needed at the start of the project, including topography, site boundaries, location, environmental data (surrounding buildings and roads), approximate closed area, and site constraints. The maximum volume can be used to provide a starting point for subsequent phases, enabling them to progress.

There are also processes where the maximum volume provided by law is not followed, depending on the communication between the designer and the employer at this stage. There may be areas that are not clearly defined by the zoning rules. The phase aims to produce a starting point for the workflow. When producing this starting point, some solar-related methods can be used if the designer does not work with maximum closed space. One of them is a thin plan, and the other is an east-west-oriented plan.

3.1.1.1. Example cases of thin plan and east-west oriented plan

The advantage of the thin plan is that it facilitates daylight intake in each room. An example of this type of construction can be seen in the Science and Technology Park in Germany, designed by Kiessel and partners. This building consists of offices located on the east-west axis and a corridor located on the north-south axis. It increases the daylight utilization rate by ensuring that all offices face these directions (DeKay & Brown, 2014).

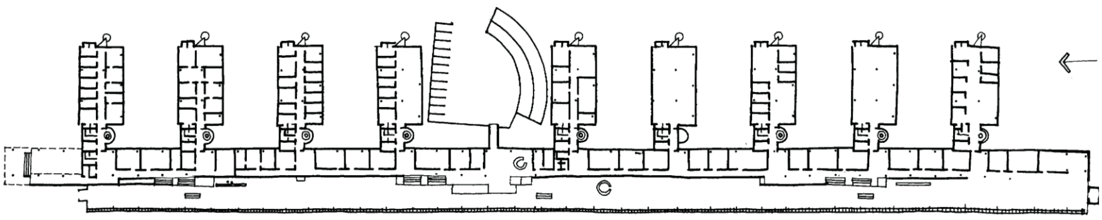


Figure 3.4: Science and Technology Park, Gelsenkirchen, Germany, Kiesel and Partners (DeKay & Brown, 2014)

Another basic layout strategy is the East-West orientated plan, in which the proportion of the south-facing façade is higher than that of the whole building to maximize solar heating with daylight intake. The Lloyd Lewis House in Illinois, designed by Frank Lloyd Wright, was built using this method. Rooms face south, and a circulation area that works like a buffer zone on the north façade. The narrow east and west facades prevent unwanted heat gain in summer (DeKay & Brown, 2014) .

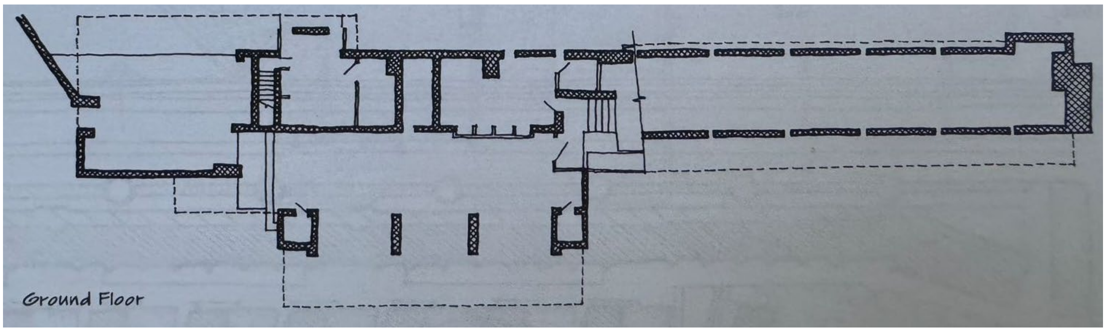


Figure 3.5: Lloyd Lewis House, Libertyville, Illinois, Frank Lloyd Wright (DeKay & Brown, 2014)

3.1.1.2. Interpretation / Assessment

The designer's determination of a mass considering this settlement pattern and the required indoor space will be the starting point for other design processes. In doing so, the need for maximum indoor space specific to the project supports decision-making on this issue. If there is a need or desire for maximum enclosed space, zoning laws can be followed. If there is no such constraint, an East-West orientated plan scheme or thin plan scheme can be used. At this stage, a basic mass can be created for the next stage, the Orientation study.

3.1.2. Orientation study

The rate of insolation a building receives is closely tied to its orientation. Therefore, this issue must be considered in the early design process. The amount of direct sunlight hitting the building's exterior is influenced by the azimuth of the wall, which is determined by the building's orientation angle (Mingfang, 2002).

The advantages of having an ideal building orientation include,

- Suitable for the early stages of project design, this strategy offers a cost-effective solution.
- It lessens the necessity for more intricate passive strategies.
- It minimizes energy consumption.
- It boosts natural daylight inside, reducing the need for artificial lighting and lowering the building's internal heat load.
- It enhances the effectiveness of other sophisticated passive techniques.
- It optimizes the performance of solar collectors.

In summer, controlling solar radiation and maximizing heat absorption in winter is best achieved with a southern orientation (Mingfang, 2002).

Typically, it is most advantageous if the longest sections of the walls face south (Mingfang, 2002). Nevertheless, orientation analysis can also consider optimizing factors such as building form, total solar exposure received, annual energy requirements, and ground plan area (Pacheco et al., 2012). While most literature on passive solar-related strategies recommends orienting buildings toward the south, Littlefair (2001) notes an emerging consensus favoring an orientation of 20-30° south as the most effective.

3.1.2.1. Example cases of Orientation Study (Ladybug)

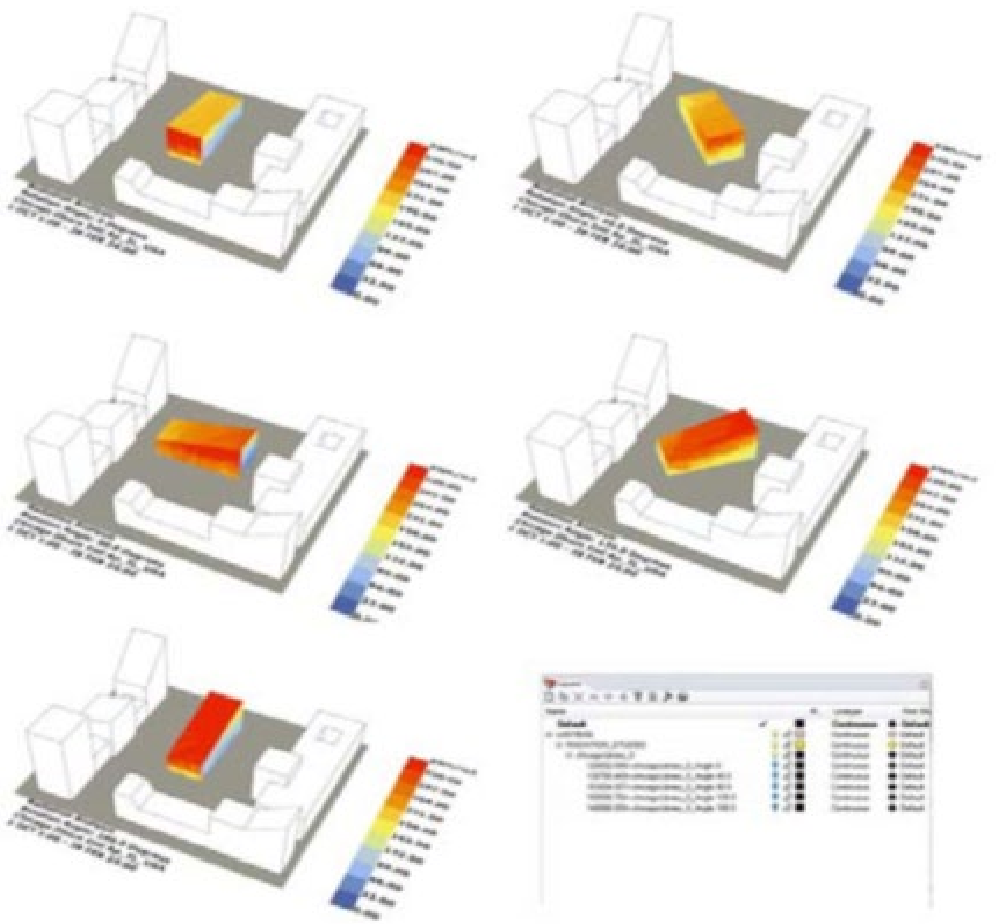


Figure 3.6 : Orientation study and the radiation results for each orientation angle (organized by layer), and the graph of the radiation values in the Grasshopper canvas (Roudsari & Pak, 2013).

Integrated into Ladybug's analysis components—such as radiation, sunlight hours, and view analysis—the orientation study enables users to explore how building orientation affects solar radiation and sun exposure. The script accounts for design form and context, allowing users to run the component for a user-defined period and adjust the range and segments of the angles. The results include the total radiation for each option, with a colored mesh visualizing the data for easy reference. In Figure 3.6, the study results for a sample building in Chicago are displayed. The analysis was conducted for orientations from 0 to 180 degrees, with increments of 45 degrees, to optimize solar radiation during Chicago's heating period. (Roudsari & Pak, 2013).

3.1.2.2. Interpretation / Assessment

According to the recognition in the literature, it is advantageous to have the long side of the building facing 20 degrees south. The radiation rate has the potential to give an idea about the location of the programs to be placed in the building, so it is important to make this analysis and design decision before the plan layout. This analysis can provide preliminary information about the future challenges in terms of solar radiation. One of the best-known ways to study and test orientation is Ladybug, a Rhino GH plugin.

3.1.3. Terracing

Solar envelope method of Sustarc (Figure 2.6) was used as the research constructed a building scale(see Solar Form Finding). The interpretation of this method and the volume of the building should be constrained accordingly. In areas with dense surrounding structures, it can be foreseen that the solar right envelope will go down in certain areas. In such cases, it is possible to respond according to the context. For example, if the solar rights envelope descends in the north direction, the example of terracing in the north, as Norman Foster did in the City Hall project, can be used here. This strategy can also support daylight availability. If there is a descent to the south, solar cells can be used by terracing to the south (because of high solar radiation), as was done in the SIEBB building. This would be an example of using active systems together with passive systems in the earlier design phase of the building rather than the usual case of integrating active systems later.

3.1.3.1. Example cases of terracing (City Hall building and SIEBB building)

City Hall is a project of great significance in the capital, symbolizing transparency in democratic processes and showcasing sustainable public infrastructure with minimal ecological impact. It is prominently located near the Thames, close to Tower Bridge. City Hall serves as the central administrative hub, housing an Assembly chamber, committee rooms, public amenities, and administrative offices across ten levels, spanning a total area of 12,000 square meters (Foster and Partners, 2023).

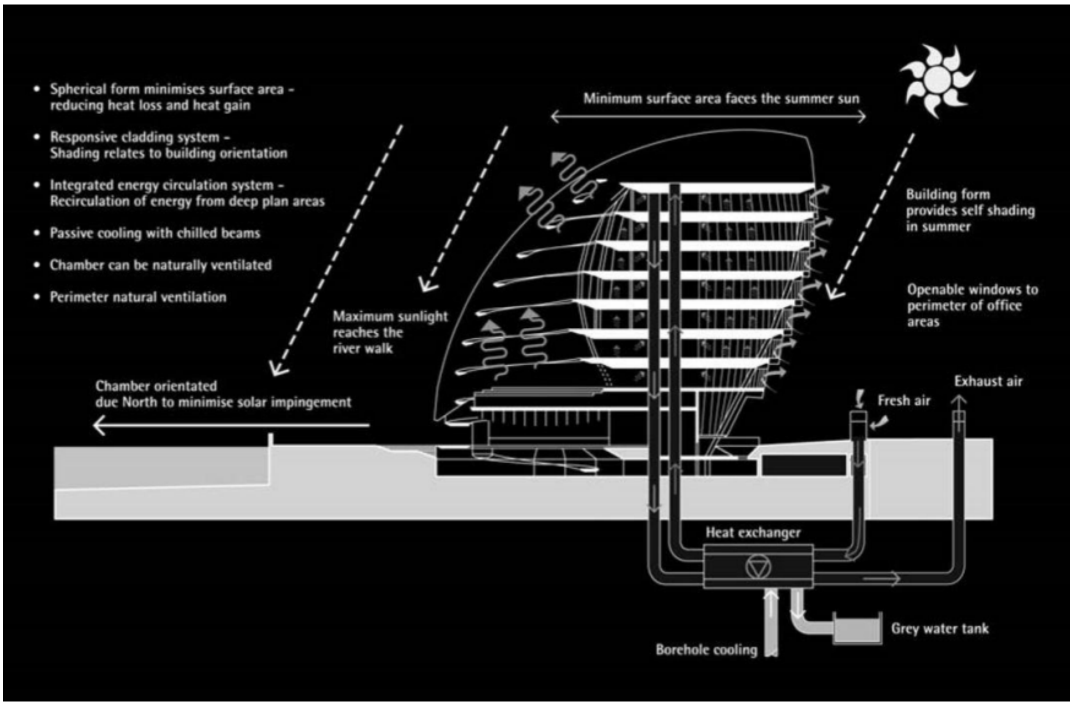


Figure 3.7: Bioclimatic Section of City Hall, Sir Norman Foster; Greater London Headquarters, London, England,2002 (Foster and Partners)

The form of the building, reminiscent of a geometrically modified sphere crafted using advanced computational models, prioritizes energy efficiency by minimizing direct exposure to sunlight. Comprehensive review of sunlight distribution culminated in a thermal map, which finds manifestation in the building's cladding. Utilizing various shading mechanisms, such as orienting the structure southward to provide natural shading for ventilated offices, substantially reduces energy consumption. These strategic measures obviate the need for chillers, and for the majority of the year, supplementary heating is unnecessary, ensuring a mere quarter of the energy consumption typical in conventionally air-conditioned office complexes (Foster and Partners, 2023)

When this building is analyzed, it can be seen that many passive and active energy efficiency strategies were used (Figure 3.7). The orientation and southward inclination of the building are among the most critical design decisions influencing its form. With this form, the slab array on the south provides shading in hot weather conditions in summer, while trying to maximize daylight on the north façade with low daylight exposure. This design demonstrates how building form can be influenced by incorporating energy-efficient decisions at the initial design stage.

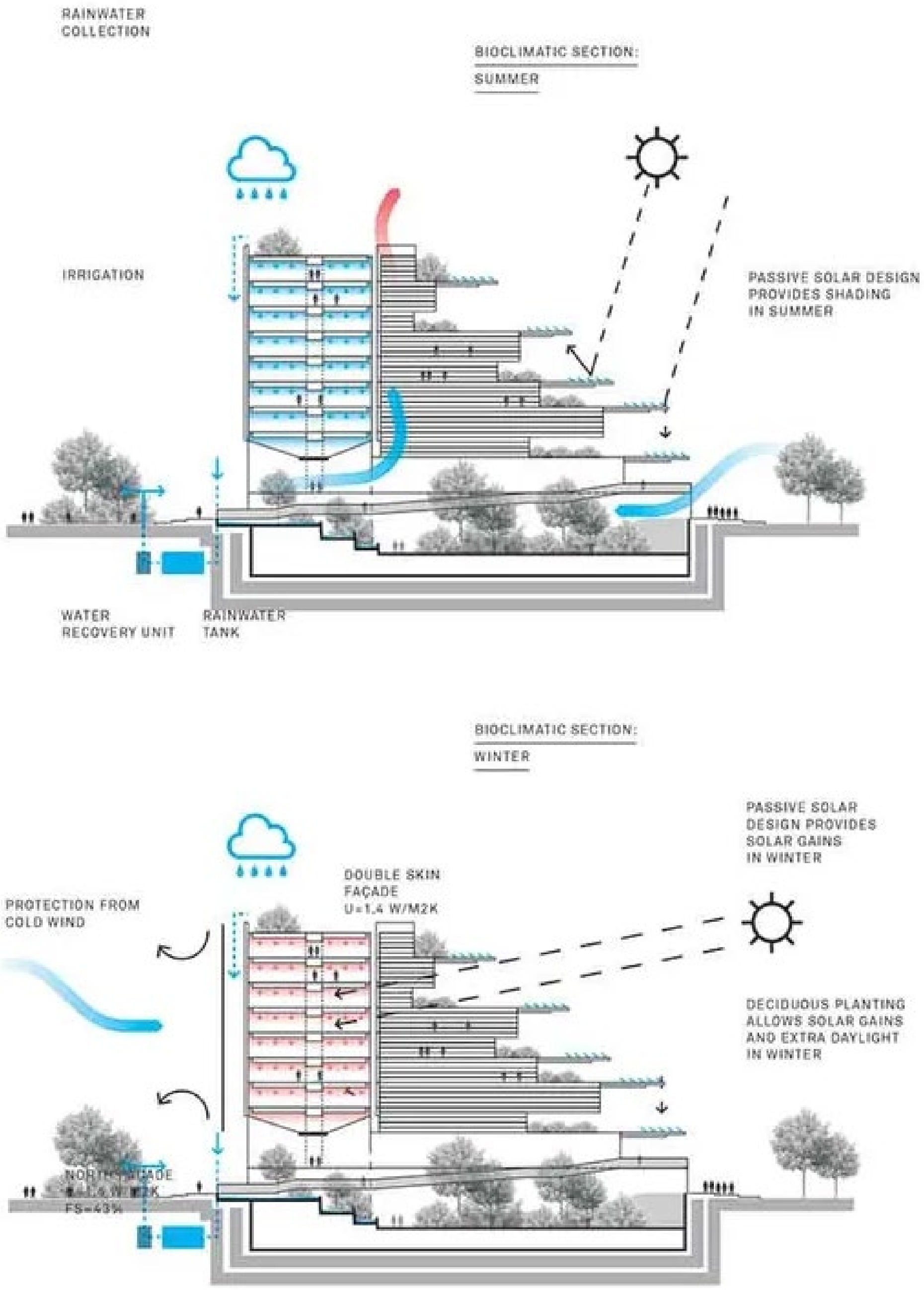


Figure 3.8: Bioclimatic sections OF SIEBB Building, Mario Cucinella Architects,

The Sino-Italy Environment&Energy Building (SIEEB) exemplifies smart, eco-friendly, and energy-efficient design within the sustainable building landscape. Spanning 20,000m², it houses a home office, labs, classrooms, and an Italian tech exhibition area. It serves as a model for reducing CO^2 emissions in Chinese construction and fostering bilateral cooperation in the environment and energy sectors. The integrated design process optimizes space, volume, and solar performance for energy gains and conservation. Technologies like solar shading, radiant heating/cooling, efficient lighting, and dynamic structures adapt to weather conditions. The shell's design, utilizing special materials and features, maximizes natural light, controls solar radiation, and integrates photovoltaic cells. Passive and active strategies complement each other to reduce energy needs. The building emphasizes the significance of early-stage energy efficiency tools in design for optimal environmental impact (Butera et al., 2005).

Upon examining this project, it's clear that various active and passive strategies were used. However, it's noticeable that the early analyses and passive design strategies supported the later addition of active strategies. For example, the decision to install solar panels on the terracing on the south side was taken as a result of these analyses and design strategies. Hence, it can be said that this building wasn't specifically optimized for energy efficiency after its design was finished but adjusted for energy efficiency during the schematic design phase.

3.1.3.2. Interpretation / Assessment

The terracing decision can be determined according to the building orientation. In the northern hemisphere, terracing on the north façade will provide an advantage in terms of daylight intake. If active system integration is initially determined in the project, terracing may be preferred to increase the surface area on the south facade, which is higher in terms of solar radiation. At this point, the decision depends on the designer's priorities. This workflow provides the designer with an additional decision-making option.

The solar rights envelope acts as a warning system about the solar rights of the surrounding buildings and provides information about the maximum height that can be reached without violating the solar rights of the surrounding buildings. In densely built-up areas, the solar rights envelope is likely to be lowered. Therefore, a terracing decision can be taken according to the direction in which the solar rights envelope descends. In this case, while the insolation advantage of the designed building is taken into consideration, the solar rights of the surrounding buildings are also taken into consideration. If there is a descent to the north, a similar approach to the City Hall project can be followed, and terracing to the north can be decided; if there is a descent to the south, a strategy similar to the SIEBB Building can be applied and the surface area can be increased by terracing to the south. This creates a favorable situation for the integration of active systems.

3.1.4. Cantilever systems

Cantilever systems can be used to control summer and winter sun intake. Norman Foster's cantilever system on the south side of the City Hall is an example in this regard. In summer, as the sun moves at a higher angle, the floors provide shading. This does not prevent the sun, which moves at a lower angle in winter, from heating the interior spaces (see Figure 3.7).

Another interpretation for cantilever systems can be made through the solar collection envelope. The solar collection envelope is the other critical envelope obtained with Sustarc's model (see Solar Form Finding) If there are places where this envelope does not touch the ground level and these places are on the outer edge, it can be predicted that the building designed in this region will have problems with daylight availability. Therefore, operating the upper floor with a cantilever system would be consistent in these regions by leaving a gap on the ground floor. To interpret and use this envelope, see *Mass Settlement Study on* Case.

3.1.5. Location of glass- bioclimatic atrium

In buildings with insufficient side lighting due to thickness, natural light can be introduced through unglazed courtyards or glazed atriums. These atriums illuminate adjacent rooms, support plant growth, and several activities in buffer spaces, and offer added advantages. By reducing conductive heat loss and gain, these systems enhance thermal efficiency. They also facilitate solar heat gain in winter and function as passive chimney ventilation systems (DeKay & Brown, 2014).

3.1.5.1. Example cases of glass-bioclimatic atrium (Public Housing in Platja D’En Bossa and Reitestrasse Building)

Located in the scenic city of Ibiza, Spain, this modern architectural structure was completed in 2022 by the firm 08014 Arquitectura. Spanning 2,596 square meters, the building was designed under the leadership of principal architects Adrià Guardiet and Sandra Torres. The project prioritized sustainability, utilizing the expertise of Societat Orgànica to ensure an environmentally friendly approach (08014 arquitectura).

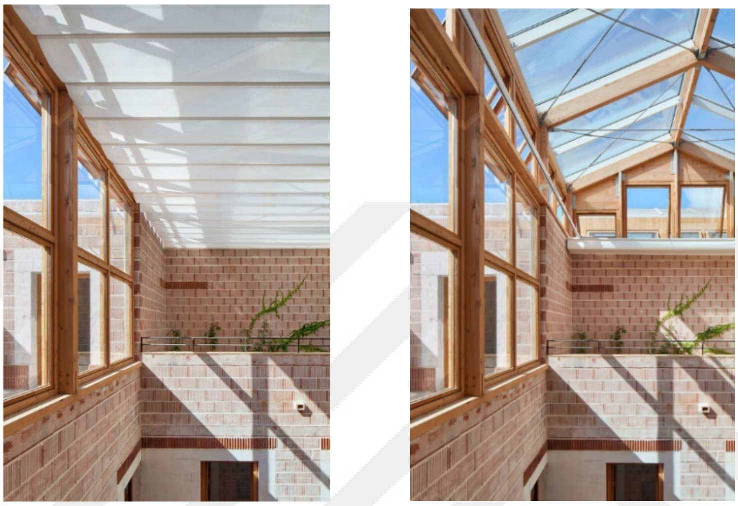


Figure 3.9: Glass Atrium of Public Housing in Platja D’En Bossa / Arcdaily

Drawing from architectural traditions rooted in warm climates, including influences from classical domus, Islamic house design, and the island's native architectural heritage, the building's placement strategy revolves around achieving a sense of independence from its immediate surroundings. This is achieved by defining a self-contained, four-story volume that optimizes plot occupancy and buildability. The structural stability of the building is maintained by carrier walls, which form a network of spaces with nearly square proportions, ensuring a harmonious integration of the structural framework and spatial design. The arrangement features two concentric zones: the outer zone accommodates bedrooms, bathrooms, and living rooms while the inner zone comprises the four courtyards and kitchens. These elements encircle the building's gravitational center, which contains the stairwell, facilitating access to eight residences per floor, with a distribution of four one-bedroom and four two-bedroom units.

The eight residences thoughtfully interact with the central courtyards, forming pairs intimately connecting with the luminous, verdant, and bioclimatic environment through dual facades. This arrangement enriches the residents' living experience by integrating the courtyards as more than just spaces to traverse but as versatile areas with abundant natural light and generous dimensions. Such architectural design transcends its utilitarian purpose. The project adheres to rigorous sustainability and energy efficiency standards, surpassing current regulations.

Implementing passive design strategies, the project initially reduces non-renewable primary energy consumption to just 10.7 kW/m^2/year. These strategies include a building envelope with high thermal inertia, thermoclay walls filled with, a roofing system over the courtyards with glazed enclosures and adjustable sunshades, cross-ventilation throughout all rooms, and excavation soil. The courtyards are transformed into bioclimatic atriums by these innovations, functioning as heat reservoirs in winter and providing shading during the intense summer heat. This approach enhances comfort inside the homes, eliminates the need for central heating systems, and lowers energy expenses, benefiting especially those in low-income households (08014 arquitectura).

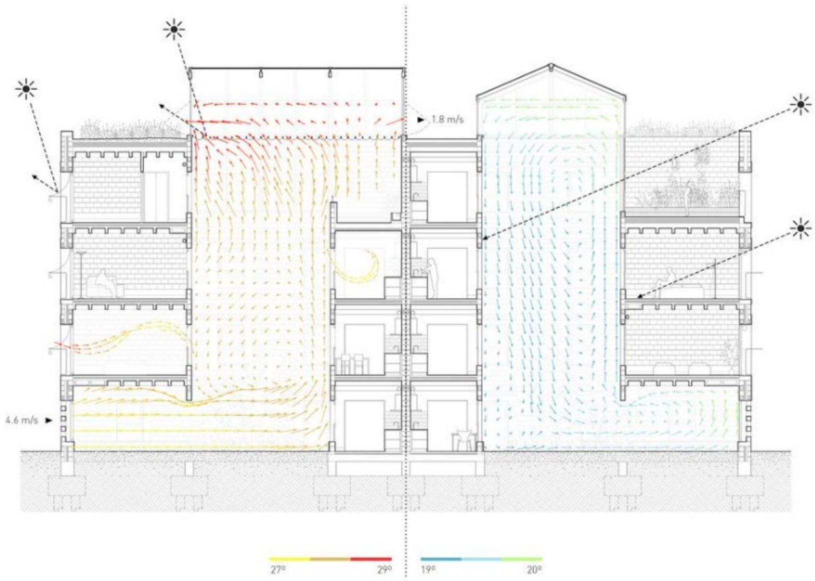


Figure 3.10: Bioclimatic Section of Public Housing in Platja D’En Bossa / Arcdaily

Moreover, the environmental impact is further mitigated by constraining CO^2 emissions associated with construction materials and systems, reducing them to a mere 438.91 $kgCO^2/m^2$. Compared to a building with identical specifications constructed using conventional methods, this approach leads to an approximate 30% reduction.

Sustainable materials, including ceramics fired in biomass kilns, timber beams, atrium structures, dried seagrass for roof insulation, carpentry, and recycled cotton for facade insulation, contribute to achieving this objective. This method aligns with local architectural construction traditions (08014 arquitectura).

Finally, incorporating extensive greenery across courtyards, urban spaces, roofs, and planters is instrumental in mitigating the heat island effect and enhancing the overall living environment. The selection of plant species with low water demands and the responsible use of rainwater harvested from the roof, stored in an underground cistern adjacent to the building, ensures sustainable vegetation growth in Ibiza's arid climate (08014 arquitectura).

In conclusion, this architectural project integrates modern living with a bioclimatic approach, demonstrating a strong commitment to sustainability and energy efficiency through various passive design strategies. Essential components of the design involve a high thermal mass envelope featuring thermoclay walls, a cutting-edge roofing system with glazed enclosures over the courtyards, and adjustable sunshades, which convert the courtyards into bioclimatic atriums. These strategies minimize energy consumption and significantly reduce carbon emissions associated with construction materials. By embracing local architectural traditions and implementing responsible water management, this project exemplifies environmentally conscious urban development, creating a more habitable and eco-friendly space in Ibiza.

Another example is the Reitestrasse Building in Bern, Switzerland. Designed by the Bureau d'Architecture, this building is a project in which the glass atrium is an important design element. The Reiterstrasse Building uses a combination of top-lit circulation spaces and regularly spaced lighted courtyards to provide daylight to all occupied rooms. While peripheral rooms are traditionally illuminated by side lighting, the plan of the two-story building is quite thick, so light from the side cannot penetrate the corridor. The addition of unlit lighted courtyards ensures that interior rooms have windows on at least one side. Many rooms have skylights as a second source of light from the corridor.

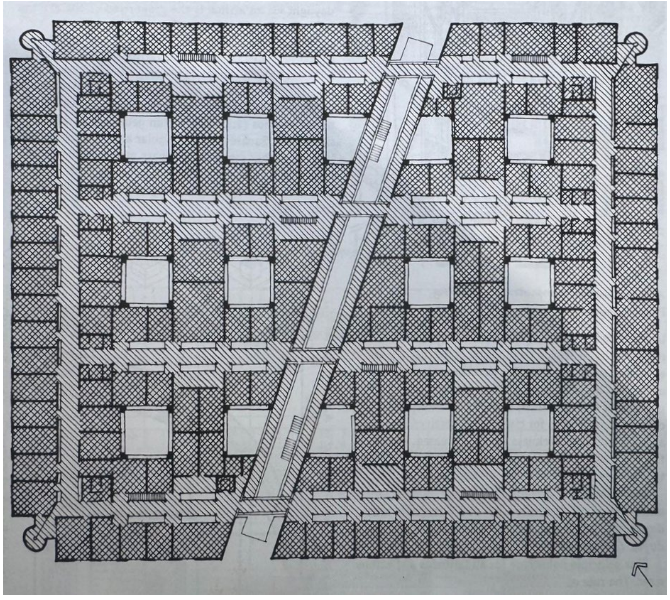


Figure 3.11: Second Floor Plan, Reitestrasse Building, Bern, Switzerland, Bureau d'architecture (DeKay & Brown, 2014)

The main corridor essentially functions as a two-story linear atrium with second-floor circulation on either side of the floor opening of the second-floor circulation path. The secondary corridors have floor openings on either side of the circulation space to allow light from above to enter from the lower floor. Internal clerestory windows facing the corridor project outward from the wall and are angled toward the daylight source (DeKay & Brown, 2014).

3.1.5.2.Interpretation / Assessment

If the project has a thick plan, the use of an atrium can be preferred. This strategy contributes to energy saving by offering the advantages of daylighting and natural ventilation, as in the case of Public Housing in Platja d'en Bossa, designed by 08014 Arquitectura and Reiterstrasse Building in Bern, Switzerland, by Bureau D'architecture. This workflow recommends the use of atrium in buildings with a thick plan. In addition to having a thick plan, where the solar rights envelope begins to descend, the building may need to be made transparent or subtracted, which may influence the location of the atrium. (see Solar Form Finding). In this case, the use of a glass atrium at this point makes the building transparent and doesn't block the solar rights of the neighboring buildings. This decision is taken before proceeding with the plan layout. Determining the approximate location of the atrium is a critical consideration that can affect the program arrangement during the plan layout phase. The location of the atrium can be evaluated as a potential for the entrance of the building, circulation areas, and public spaces. It offers flexibility that can serve different programs in buildings of various qualities. At this point, the decision is left to the designer's initiative.

3.2. Plan Layout

In architecture, the plan layout refers to the arrangement of the interior separations, and this arrangement significantly impacts the energy efficiency of buildings. The plan layout was designed by considering the insolation factor to ensure maximum utilization of light and heat. This approach offers benefits in terms of both economic and environmental sustainability by reducing the energy consumption of buildings. While deciding on the layout of the rooms, considering insolation contributes to energy efficiency, and some passive strategies that affect the space-mass relationship can also be made through this interpretation. In this way, energy efficiency is increased in the operational process and the carbon footprint of the building is reduced, thus complying with the principles of sustainable architecture.

In the mass settlement process, obtaining data about the overall mass is possible after the maximum volume, orientation, and solar form finding studies are applied sequentially. Since these processes are based on the maximum volume that can be settled and the result of some analyses gives us information about the plan layout, the plan study can be continued based on this situation obtained from the previous stages. Before the plan layout study, some analyses can provide information about the layout of the programs. For example, the room's daylight availability, sun exposure, or illumination status affect the designer's choice for placing the rooms. Placing a room with a higher daylight requirement on the outer edge with a high daylight potential reduces electricity and lighting requirements.

Many analysis programs can be used in the plan layout process. Climate Studio, which can be added as a plugin to the Rhino program, was used in this research. Because it allows for a wide range of analyses. Simulation workflows aid designers and consultants in optimizing buildings for energy efficiency, daylight access, electric lighting performance, visual and thermal comfort, and other occupant health measures (Solemma LLC). The reasons for preference are that it provides fast and accurate results, is easy to use, is designed according to the real world, has realistic materials, can perform analyses such as climate analysis and sun path shadow study, and makes much environmental information easy to read. Additionally, it is crucial that the system facilitates preliminary analysis, aligning with the research's objective. It can generate numerous analyses and present results graphically, which is anticipated to simplify decision-making during the initial design stages.

At the plan layout stage, it is important to consider several factors. Arranging the layout of interior spaces in line with these considerations is of great importance for both energy efficiency and thermal comfort. There are some advantages obtained in the massing process. For example, studies on the orientation of the building strengthen the strategies planned to be added(see 3.1.2 Orientation study). The solar form finding study ensures that the sunlight coming to the surrounding buildings is not blocked and maximizes the amount of sunlight received for our building. At the same time, various strategies that affect the plan layout were identified, and boundary definitions were made to start the plan layout. These strategies include the location of the bioclimatic atrium, terracing, and areas that need cantilevering.

Before the building plan is created, information about the insolation of the plan layout can be obtained. The slabs create shading. Before the interior arrangement of the building is made, a preliminary assessment can be made according to the shading created by these slabs. Also, knowing the strategies designed according to the conventional sun direction before the planning scheme is decided can accelerate the design process.

These methods are examined under the titles of room organization, solar chimneys, and sunspaces. With these methods, information can be accessed before the study starts (which is one of the important limitations of the research). There is no need for an existing plan diagram to determine the possible location of these methods.

3.2.1. Organization of rooms

Some parameters need to be considered in locating the rooms, including daylight availability and sun exposure. Buildings have a variety of activities with different visual tasks and, accordingly, have different lighting requirements. The areas closest to the façade of the building have the greatest daylighting opportunity at the highest illumination values. If activities are zoned so that those that need light are located close to openings on the exterior façade and those that do not are located on the interior, the amount of relatively expensive façade and glass openings can be reduced due to a smaller façade-to-volume ratio. This arrangement also reduces the use of electric lighting and, thus, unwanted heat gain (DeKay & Brown, 2014).

Mount Angel Library designed by Alvar Aalto and the Auditorium Building in Chicago, Illinois which was designed by Adler and Sullivan are important examples of literature for this situation.

3.2.1.1.Example cases of organization of rooms (Library, Mount Angel Abbey and Auditorium Building, Chicago)

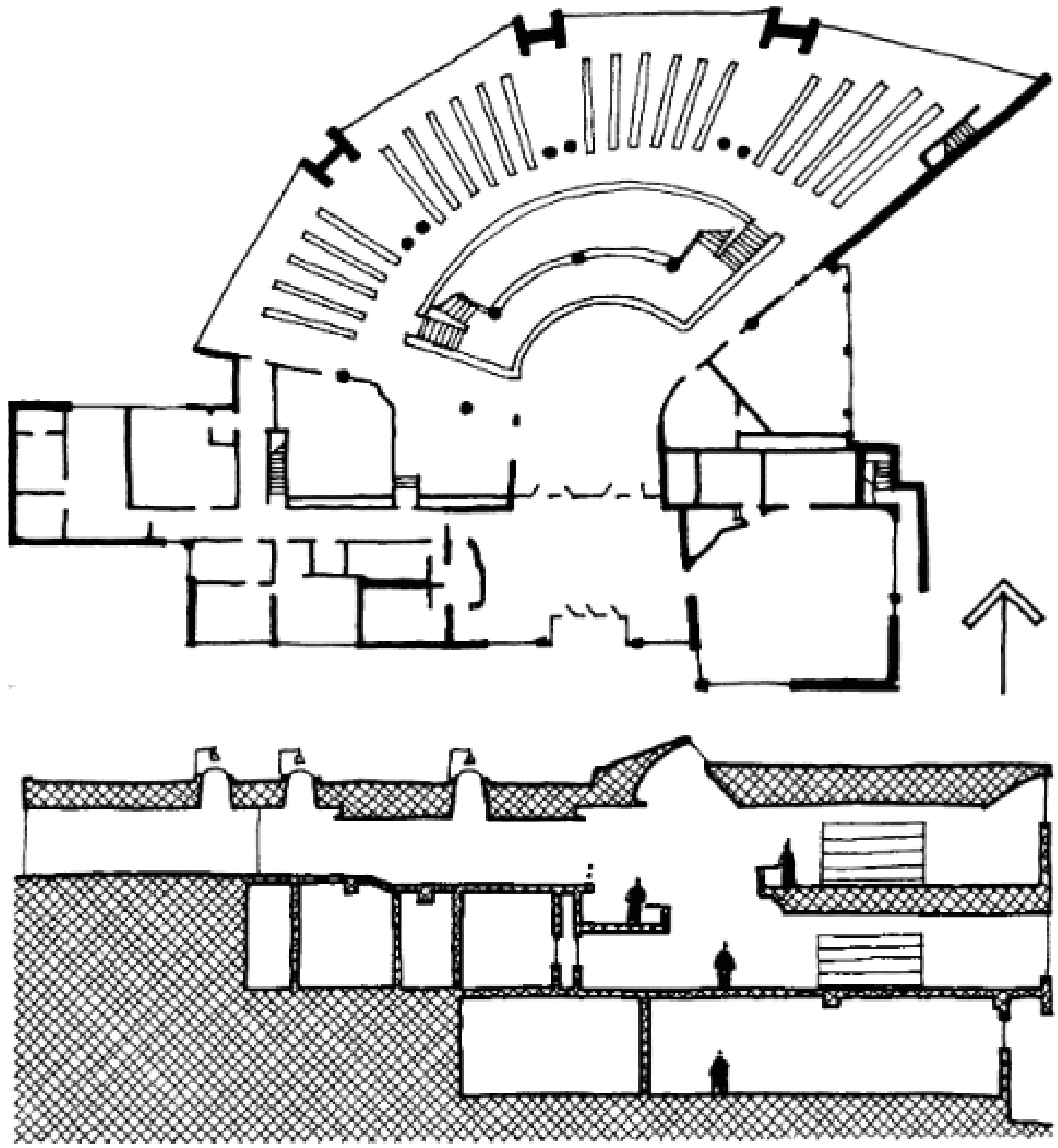


Figure 3.12: Library, Mount Angel Abbey, Oregon, Alvar Aalto (DeKay & Brown, 2014)

The Mount Angel Library in Oregon, originally designed by Alvar Aalto, separates activities into two main categories

- Reading areas that need high illumination levels and reading areas are situated by the façade openings and under the central skylight.
- Book storage areas that require lower lighting. Whereas book storage is positioned between these areas, away from the main light sources (DeKay & Brown, 2014).

Adler and Sullivan adopted a similar strategy for the Auditorium Building in Chicago, Illinois. Designers placed the offices, which need light, on the exterior of the building, while the auditorium, which needs light control, is located in the darker central part of the building (DeKay & Brown, 2014).

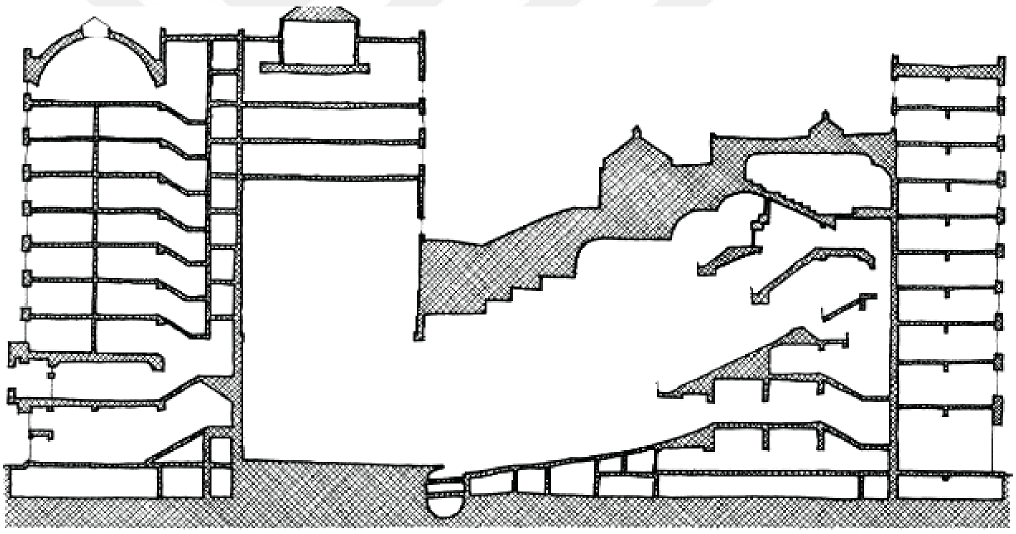


Figure 3.13: Auditorium Building, Chicago, Illinois, Adler and Sullivan (DeKay & Brown, 2014)

3.2.1.2.Interpretation / Assessment

Before proceeding to the plan layout stage, information about the mass was obtained from the previous mass settlement stage. When it has a mass placement interpreted in line with the strategies proposed in the previous stage, evaluations about energy-efficient strategies can be made on the plan layout. If a simple 3D modeling is made for the mass created, the areas that do not receive daylight in the building can be identified through the shading created by the slabs.

In this direction, according to the needs program of the building, placing the rooms that need the least daylight in these shaded areas and placing the rooms that need daylight in brighter areas will reduce the amount of energy to be spent for lighting. This situation may be suitable for spaces such as wet areas and storage areas in residential projects, but it can also be applied in buildings with different programs, for example for areas where the lighting should be controlled, such as in the example projects.

3.2.2. Solar chimney

The main principle of the solar chimney strategy is that warm air rises. Building designs from the past have utilized this principle to incorporate chimneys or elevated spaces that facilitate air circulation. The warm air rising from these areas creates an airflow and draws cooler air out of the lower sections of the building. This process is called the chimney effect. This phenomenon clarifies why open-fronted fireplaces can make buildings colder: the upward flow of air through the chimney necessitates outside air intake into the room. Warm air from the fireplace is sent up and out through the chimney, while cooler outside air is drawn into the room. Apart from just in front of the fireplace, the only heated place is the chimney. The technique commonly known as a "solar chimney" can be intentionally employed in warmer weather to naturally cool and ventilate spaces. An elevated space with a ventilated top can create this effect by enabling warm air to flow upwards and escape as it heats. Enhancing this effect involves using sunlight to warm the chimney and the air within it, which accelerates the rise of the air. Absorbing solar radiation more effectively, the chimney should be oriented south and have a dark surface for maximum impact (Bergman, 2012).

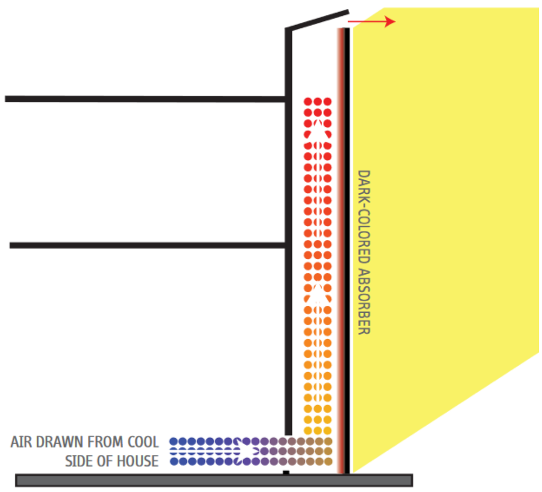


Figure 3.14: Illustration of a solar chimney (Bergman, 2012)

Some examples in literature use solar chimneys as design elements. Sidwell Friends School is one important example.

3.2.2.1. Example cases of solar chimney (Sidwell Friends School)

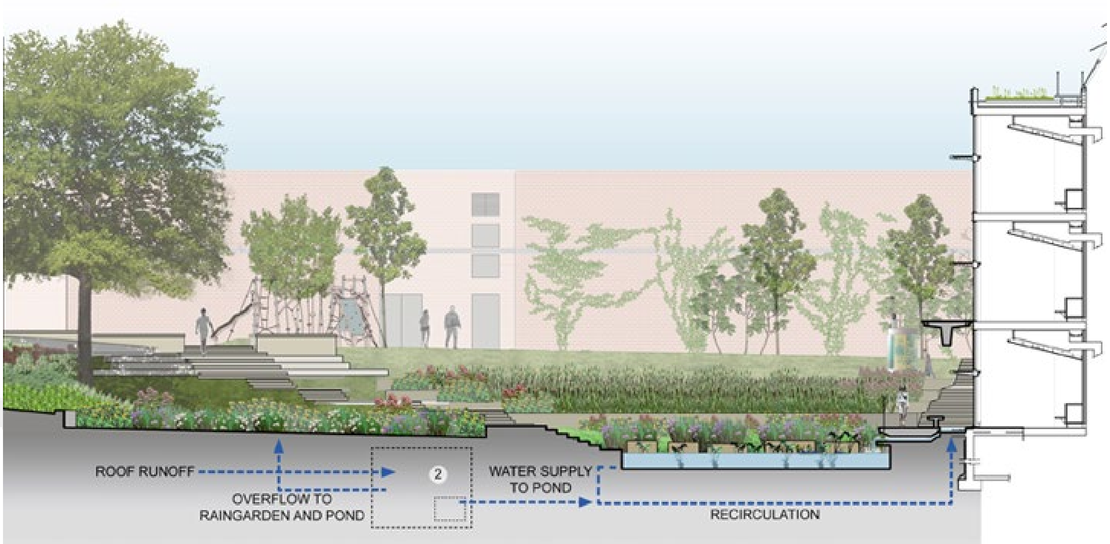


Figure 3.15: The constructed wetland shown in this rendering features more than 80 native species. - Photo Credit: Andropogon Associates (The American Institute of Architects)

Kieran Timberlake's design of solar chimneys at Sidwell Friends School in Washington, DC, serves classrooms. Equipped with south-facing glazing to act as greenhouses, these chimneys also offer an educational experience. Reflecting the didactic "visible green" concept in sustainable design, the architects added a weather vane and wind chime at the entrances of the chimneys.

Figure 3.16: Solar Chimneys of Sidwell Friends School (Barns, 2008)

3.2.2.2. Interpretation / Assessment

The position of the solar chimney can be defined according to the sun exposure based on solar radiation analysis. The advantage of studying the location of the solar chimney at the plan layout stage is to be aware of whether it coincides with rooms with high usage rates and to make the decision accordingly.

3.2.3. Sunspaces

The purpose of the sunspace is to provide heat to the rest of the building, it experiences large day-night temperature fluctuations and, therefore, may not always be comfortable. It can be very hot during sunny periods and very cold at night. It is generally assumed that the temperature of the sunspace can go up to 35°C and down to 7°C. More thermal mass reduces temperature fluctuations in the sunroom and stores more of the collected heat. Unlike direct gain and Trombe wall systems, a sunspace adds room to the building. The sunspace can be adjacent to the main space, share one common wall, or be enclosed by the building and share three common walls. Enclosed sunrooms are more efficient than adjacent sunrooms as they only lose heat through one open wall. Heat is typically delivered to the main space through a stationary thermal storage wall and by convection through its open areas. Another approach involves insulating the wall and positioning the thermal mass in the sunroom, where heat transfer can be facilitated by convection loops or a fan. To provide adequate thermal storage, sunspaces with insulated common walls often need additional mass, such as water or a bed of stones under the sunroom floor. Insulated stone walls outside adjacent sunrooms improve thermal comfort and performance compared to glazed walls, which have a low R-value and collect little heat in winter. As with all passive solar approaches, sunrooms require good shading and ventilation to avoid unwanted heat gain in summer (DeKay & Brown, 2014).

3.2.3.1. Example cases of sunspaces (Solarhaus)

The IBUS Institute for Building, Environmental, and Solar Research uses one- and two-story semi-enclosed sunspace areas for floors 3-6. Movable sliding insulation panels insulate them at night. Attached are solar areas with blown polystyrene-lead night insulation between layers of glass heat split-level units in the attic. North-facing bedrooms are half a floor lower to encourage better sun and light penetration from the south.

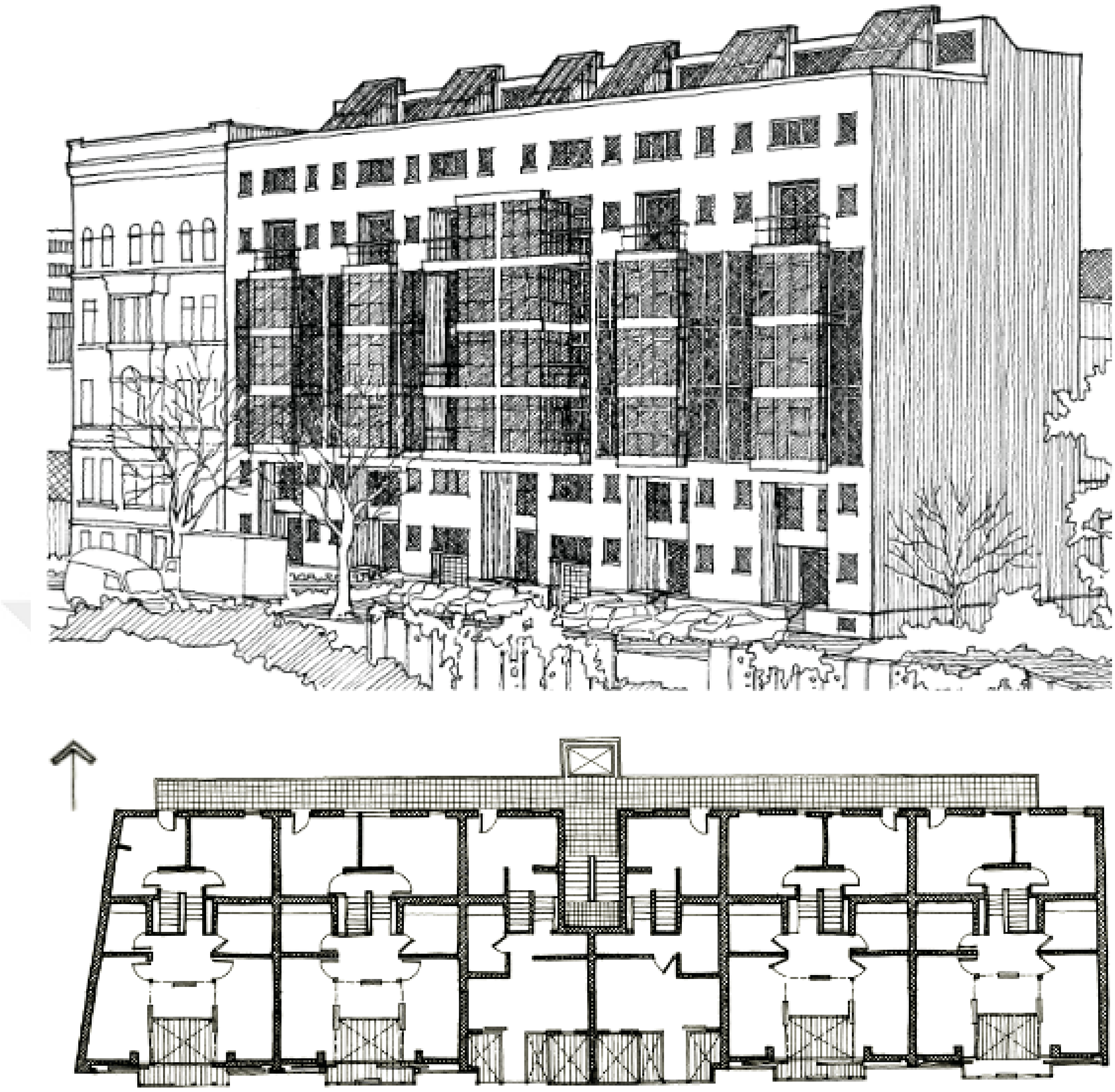


Figure 3.17: South Facade, Solarhaus, Lützowstrasse, Berlin,Germany, IBUS (DeKay & Brown, 2014)

3.2.3.2.Interpretation / Assessment

Sunspace differs from solar chimneys or the strategies applied as a surface intervention because it adds rooms to the building. Therefore, it should be discussed at the plan layout stage. The advantage of positioning this strategy at the plan layout stage is that it can be discussed and decided at this stage whether the room to be added is a useful space or not.

Instead of working for a single room like solar chimneys, sunspaces can serve about three rooms. This type of placement is generally advantageous on facades with high solar radiation. It can be decided with solar radiation analysis.

3.3. Building Shell Study

The building envelope is the element that separates the indoor and outdoor environments of a building. It is the main factor that determines and controls the quality of the indoor conditions and functions independently of the unstable outdoor conditions. This important part comprises various components such as walls, window systems, roofs, foundations, thermal insulation, external shading devices, etc. Improvements to building envelopes and their effects on energy use in buildings have been extensively studied by researchers worldwide (Sadineni et al., 2011).

For instance, Hong Kong's hot and humid climate provides an example of how implementing passive energy efficiency strategies in high-rise apartments resulted in a 31.4% reduction in energy use and a 36.8% decrease in peak load compared to the baseline scenario (Cheung et al., 2005).

The building envelope is a topic of frequent study today, and the fact that designing only the building envelope accurately can contribute up to 30 percent to energy savings, as in the case of Hong Kong, makes it a critical aspect (Aydın & Mıhlayanlar, 2020). Within this study's scope, the way design strategies are integrated should be examined based on the analyses to be made before the building shell is started to be designed.

Completing the plan layout is advantageous when making decisions about the building envelope. Interior partitions help determine which room requires how much light and how much daylight it receives. In addition, including the shading situation created by the interior partitions in the system will give a more consistent result. This stage, which comes after the plan layout, ensures that the project progresses cumulatively and with less need for revision.

3.3.1. Window-wall ratio (WWR)

Efficient Window-Wall Ratio (WWR) design can significantly contribute to energy savings. Total energy consumption over a year, encompassing cooling, heating, and lighting, is used to determine the optimal Window-Wall Ratio (WWR). The Koppen-Geiger climate classification is useful for finding the appropriate WWR for the context. This classification is based on climate types, and decision-making can be based on this classification (Goia, 2016). The Koppen-Geiger climate classification system can be seen Table 1. It would be advantageous to use this classification to identify the climatic characteristics of the context.

Table 3.1: Köppen–Geiger (KG) climate classification system. (Andrade, Fonseca, Santos, Bois, & Jones, 2024)

Climate Type	Description
A Tropical	Af Tropical rainforest
	Am Tropical monsoon
	Aw Tropical savanna with dry winter
	As Tropical savanna with a dry summer
B Dry	BWh Arid hot (Desert)
	BWk Arid cold (Desert)
	BSh Semi-arid hot (Steppe)
	BSk Semi-arid cold (Steppe)
C Temperate	Cfa Humid subtropical
	Cfb Temperate oceanic
	Cfc Subpolar oceanic
	Cwa Monsoon-influenced humid subtropical
	Cwb Subtropical highland climate or monsoon-influenced temperate oceanic
	Cwc Cold subtropical highland climate or monsoon-influenced subpolar oceanic climate
	Csa Hot-summer Mediterranean climate
	Csb Warm-summer Mediterranean climate
	Csc Cold-summer Mediterranean climate
D Continental	Dfa Hot-summer humid continental
	Dfb Warm-summer humid continental climate
	Dfc Subarctic climate
	Dfd Extremely cold subarctic
	Dwa Monsoon-influenced hot-summer humid continental
	Dwb Monsoon-influenced warm-summer humid continental
	Dwc Monsoon-influenced subarctic climate
	Dwd Monsoon-influenced extremely cold subarctic
	Dsa Mediterranean-influenced hot-summer humid continental
	Dsb Mediterranean-influenced warm-summer humid continental climate
	Dsc Mediterranean-influenced subarctic climate
	Dsd Mediterranean-influenced extremely cold subarctic climate
E Polar	ET Tundra
	EF Icecap

The Koppen-Geiger classification for subclimate detection is used for different purposes in Turkey and has been classified and mapped (Figure 3.18). This information is useful to consistently study WWR in an architectural design.

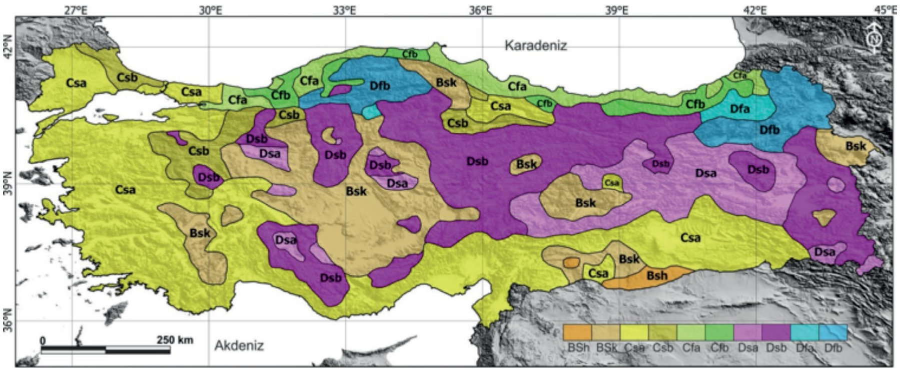


Figure 3.18: Köppen-Geiger subclimate types of Turkey (Öztürk et al., 2017)

3.3.1.1. Interpretation / Assessment

The window wall ratio decision is an issue that can be decided according to the sub-climate classification. While making this decision, studies that discuss this ratio according to sub-climate classifications in the literature and obtain accurate results can be examined. Firstly, it will be consistent to find the region studied and then to adapt the ratios used in the studies carried out in similar climate zones.

One of the sources to look at when designing in these climate types is Francesco Goia's (2016) 'Search for the optimal window-wall ratio in office buildings in different European climates and the implications on total energy saving potential.' This study focuses on finding the optimal WWR for European cities with different climate types. Another critical study studied by Sayadi, Hayati, and Salmanzadeh (Sayadi et al., 2021) is 'Optimization of Window- Wall Ratio for Buildings Located in Different Climates: An IDA-Indoor Climate and Energy Simulation Study.' The design can be improved with the WWR ratios obtained from these studies. WWR suitable for different climate types can be found on the basis of other studies in this field.

3.3.2. Double skin façade (DSF)

A double-skin facade (DSF) is one of the optimal solutions when managing indoor and outdoor spaces. Due to its design flexibility and contribution to energy savings, it attracts more attention than the standard typical glazed curtain wall. The energy savings from this design decision directly depend on the design and the climate in which it is placed DSF influences multiple features of the building design phase. For example, the operational phase is influenced by thermal features, daylighting, and acoustic qualifications. In addition, building safety, fire propagation maintenance, and glazing thermal refraction must be considered (Shameri et al., 2011). Solar qualities and possible location prediction were studied within this research's scope.

A double-skin facade consists of two layers, usually made of glass, with air circulating in the space between them (Souza, 2024). This air gap can be ventilated naturally or mechanically. It can solve the overheating problem in summer and contribute to energy efficiency by preventing heat loss in winter (Safer et al., 2005).

There are classifications for double-skin facades. These are mostly based on geometric features. Since passive strategies were examined in this research, the classification based on the working method was examined.

There are 3 different types of double-skin glass facades working with ventilation systems (Yazdizad et al., 2014):

- Natural Ventilation (Figure 3.19)

It works on the principle of heated air rising. Users can also access the airflow, which contributes to energy savings.

- Mechanical Ventilation (Figure 3.19)

In this system, a mechanical ventilation system is needed to provide airflow.

- Hybrid Ventilation

It is a situation where two systems work together. It should be used when there is no natural ventilation. Otherwise, it doesn't work properly (Yazdizad et al., 2014).

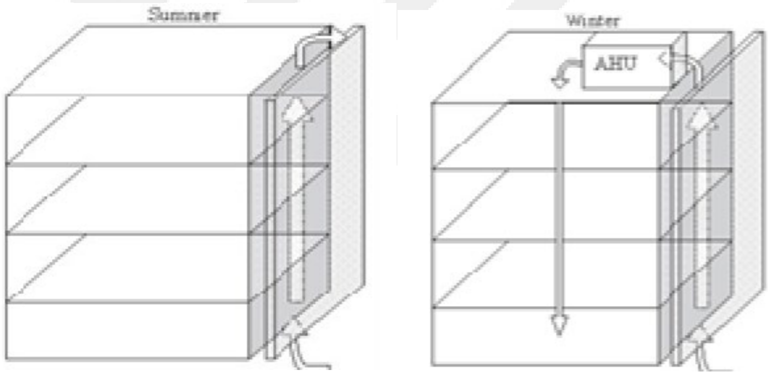


Figure 3.19: Natural ventilation system(left), Mechanical ventilation system(right) (Yazdizad et al., 2014)

Within this classification, the scope of this research included natural ventilation.

There have been studies to find the right location for the double-skin facade. In an example case studied by Kim, Alzoubi, and Ihm, to investigate the contributions of the double-skin envelope, a double-skin facade was created on the east-facing and west-facing facades of a real 3-story building and supported their research with measurements of both in a computer environment and in the field. As learned from this experiment, while the west facade contributes to energy efficiency, the east facade is not recommended due to low solar radiance (Kim et al., 2009).

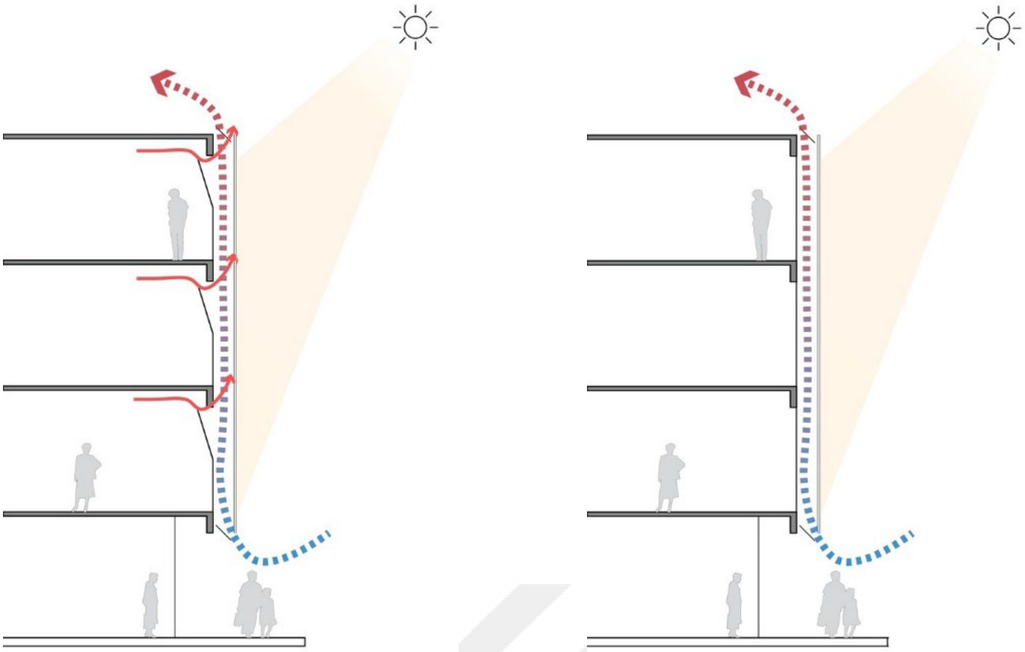


Figure 3.20: The basic principle of DSF's contribution to natural ventilation (Souza, 2024)

3.3.2.1. Example cases of double-skin façade (Phil and Penny Knight Campus and 30 St Mary Axe Tower)

The literature provides examples of the effective use of a DSF, which forms the main decisions of the project. In the Phil and Penny Knight Campus for Accelerating Scientific Impact project designed by Ennead Architects and Bora Architects, a double-skin facade was used on the laboratory's and offices' facades to reduce glare and heat gain. This structural strategy allows natural light to enter the laboratories while filtering the light. It also supports natural ventilation (Ennead Architects and Bora Architects, 2020).

Figure 3.21: Phil and Penny Knight Campus for Accelerating Scientific Impact/ Ennead Architects+Bora Architects (Ennead Architects and Bora Architects, 2020)

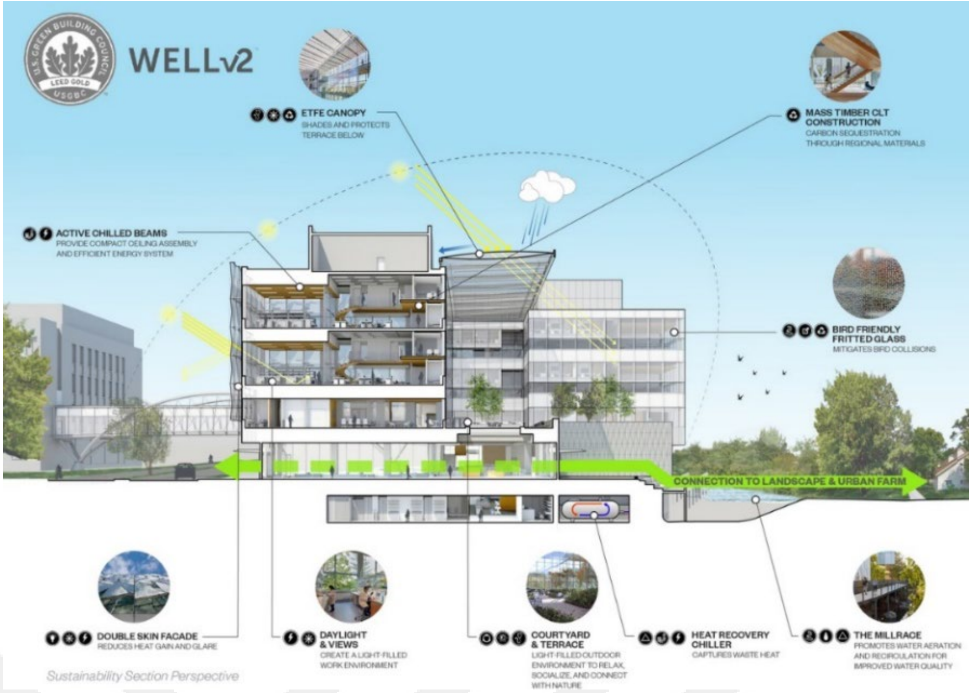


Figure 3.22: Bioclimatic section of Phil and Penny Knight Campus for Accelerating Scientific Impact (Ennead Architects and Bora Architects, 2020)

Another example of this passive strategy is the 30 St. Mary Axe Tower, designed by Foster and his partners. This tower extensively integrated environmental considerations into its design, featuring an aerodynamic shape that enhances daylighting and natural ventilation, thereby reducing the building's energy consumption. The double-skin facade supports natural ventilation inside the building. When these strategies and objectives are analyzed, their effect on the building form is directly observable.

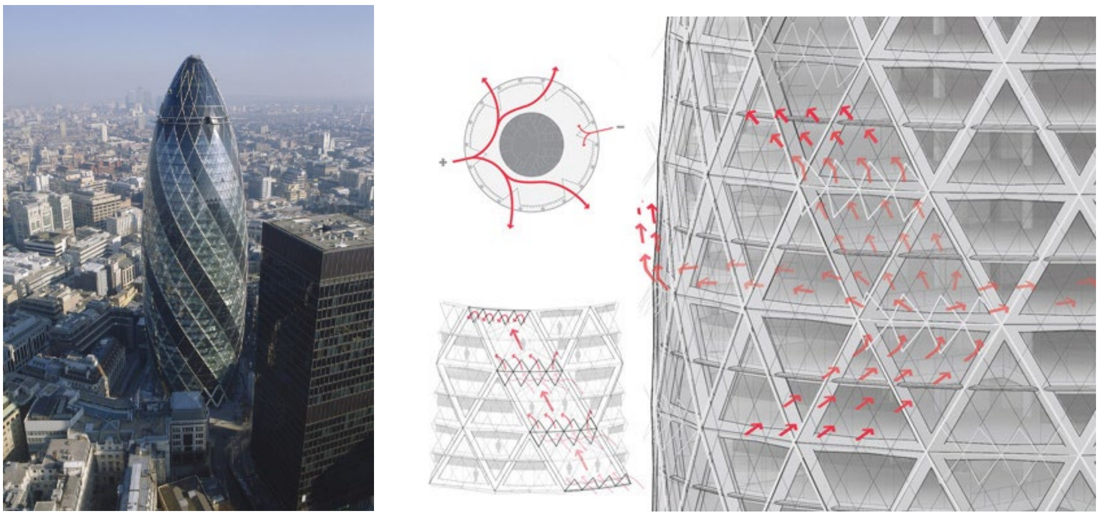


Figure 3.23: 30 St Mary Axe Tower and ventilation principle of double skin glass facade / Foster + Partners (Massey, 2013)

3.3.2.2. Interpretation / Assessment

Double-skin façades (DSF) are generally used in applications involving double-layered glass façades. If the amount of glass facade elements is low, the use of DSF will not be appropriate. This is why the decision to implement a double-skin façade typically follows the consideration of the window-wall ratio (WWR). It is advantageous to propose the use of a DSF only after discussing the WWR of the façade and depending on the outcome of that discussion, as well as the preferences of the designer.

Although such comments can be made on a project-specific basis, for a double-skin facade to work consistently, the sun exposure of the facade where it is used must be consistently high. In principle, the double skin facade contributes to ventilation and filtered natural light intake by reducing glare and adding an extra layer. This has the potential to vary depending on the context of the design. Therefore, some analysis is required to determine the location of the double-skin facade. This decision can be made by discussing the solar radiance and annual glare data.

3.3.3. Trombe wall

In southern France, engineers Felix Trombe and Jacques Michel devised a concept that still bears their names today. Placing a glass facade in a large south-oriented wall, solar heat could be absorbed into the wall's mass. Because the glass and air buffer prevented the heat from escaping, heat was delayed in penetrating the wall and radiating into the room behind it. This delay allowed the heat to be released at night, supplementing solar gains during daylight hours (Hastings)

The Trombe wall system transfers heat to the air trapped between the wall and the glass, and the system works as an indirect gain system based on the greenhouse principle. The heated air rises through the upper ventilation hole and heats the room by convection. Meanwhile, cooler air enters through the lower vent, is heated by the sun, and then rises (Sharma & Gupta, 2012).

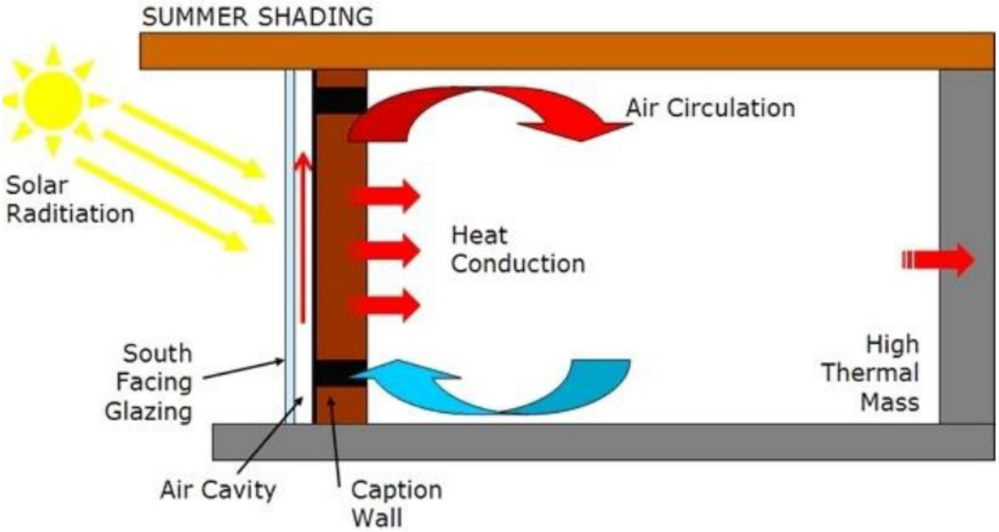


Figure 3.24: Basic principle for Trombe wall (Solaripedia, 2010)

When the Trombe wall system is compared with direct gain:

- Trombe wall collecting does not provide as high a gain as direct gain when analyzed in terms of solar heat.
- According to the simple scheme of the Trombe wall, it does not need any ducts, controllers, or fans.
- At night, it loses less heat than the direct gain window.
- Acoustic purposes can also be used for acoustic purposes compared to the direct window.
- Trombe walls can be advantageous or disadvantageous according to light-proof design.
- Retrofitting for an existing building is easier than the direct gain window (Sharma & Gupta, 2012).

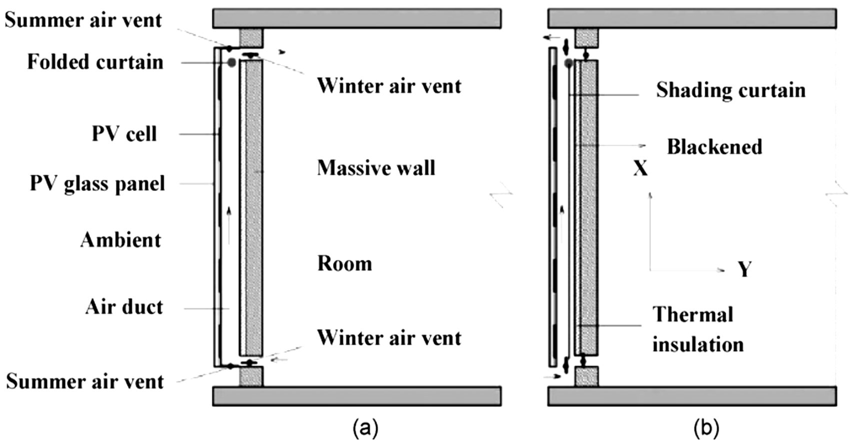


Figure 3.25: Trombe wall for (a) winter heating and (b) summer cooling (Sharma & Gupta, 2012)

The Trombe wall works differently in summer and winter due to the change in heating and cooling needs. During the summer, the Trombe wall is kept in the shade, preventing it from receiving direct sunlight. Its unique heat-absorbing properties allow it to stay cool when covered, which in turn helps to keep the surrounding area cooler. The materials used in Trombe walls are designed to gradually store and transfer heat. The upper shaded area blocks the summer sun from reaching the wall. Objects placed within the thermal mass can act as heat batteries.

When sunlight hits the Trombe wall in winter, it stores heat and transfers it indoors to warm the house. The thermal mass gradually absorbs the sun's energy, increasing its temperature and slowly releasing the stored heat over time. When temperatures fall at night, especially in winter, the thermal mass gradually releases the stored heat energy, keeping the building warm for a longer period after sunset. Once all the heat is released, the structure is ready to gain more heat the following day (Sharma & Gupta, 2012).

The material properties of the glass used are also important. The glass panel is usually placed 2-5 cm from the primary wall surface. One of two types of glass is typically used in these panels:
Insulated glass (double glazing): The gap between the glass panel and the wall contains air, which acts as a thermal insulator and thus retains more heat indoors. Low-emissivity glass (Low-E glass): Coated with a low-emissivity layer, this type of glass absorbs heat but transmits very little. Combining both types of glass is a common method to further improve thermal performance (Arch2O).

3.3.3.1. Example case of trombe wall (National Renewable Energy Laboratory of the Zion National Park Visitor Centre)

The literature provides examples of the Trombe wall system being actively used. One such building is the National Renewable Energy Laboratory of the Zion National Park Visitor Centre, an award-winning example of sustainable design. Many energy-efficient design strategies have been used in this building, and the Trombe wall is a critical strategy that guides the design (Torcellini et al., 2005).

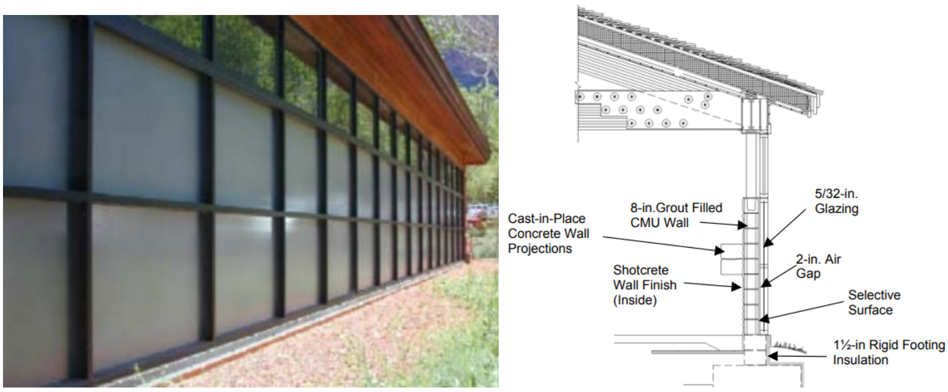


Figure 3.26: Photograph of Trombe wall showing patterned glass over the Trombe wall, row of daylighting glass, and overhang to shade wall during the summer (left) / Cross-section of Trombe Wall(right) (Torcellini et al., 2005)

The Trombe wall plays a crucial role in space heating by capturing and retaining solar radiation within its masonry. As temperatures decline during the day, this stored heat is gradually emitted back into the building. External glazing and a black selective coating are employed to reduce heat loss to the outside. During winter, the interior surface temperature of the Trombe wall can surpass 100°F (37.8°C). This heated surface offers radiant comfort to occupants. During times when solar gain is insufficient, and the Trombe wall alone cannot fulfill the heating needs, electric radiant ceiling panels supplement the warmth (Balcomb et al., 1998).

To optimize heat transfer to the interior space, the Zion Trombe wall features an interior surface designed for maximum efficiency. Materials like drywall, which create non-conductive air gaps between the concrete wall and the interior surface, can diminish the heat provided by Trombe walls. Consequently, it is important for the Trombe wall to be constructed with materials that possess high thermal mass (Balcomb et al., 1998).

3.3.3.2.Interpretation / Assessment

When determining the position of a Trombe wall, it is crucial to select a façade that receives high solar radiation to ensure the system functions effectively. The decision regarding the Trombe wall's placement follows the determination of the window-to-wall ratio (WWR) because this design strategy requires a solid wall with a high thermal mass. Discussing the WWR of the façade first, and selecting a façade with a large solid wall surface that receives high solar radiation, will create a suitable area for the use of a Trombe wall.

3.3.4. Skylight

Skylights simply refer to windows that open on the roof. This strategy should be considered when discussing the façade of the building. It can be used in areas with low daylight availability and supports ventilation.

Some advantages of using skylights are as follows:

- With an appropriate skylight design, the kitchen can receive daylight without wall loss. It can also support natural ventilation in the room where food is cooked.
- It can prevent mold-like formations by providing natural light to wet areas.
- It can support increasing the bedroom wall ratio to block unwanted light (outside light at night and direct daylight from the east facade in the early hours of the day).
- It can provide support for the ventilation of common areas.

If the building envelope is designed with these advantages in consideration, many undesirable, uncomfortable situations can be avoided, and the comfort rate can be increased with skylights.

There are some advantages and some disadvantages when looking at the orientation of skylights; these are as follows:

- North-oriented skylights produce a stable but cooler glare.
- Skylights positioned towards the east enhance daylight and solar heat intake throughout the day.
- Skylights facing west are optimal for capturing daylight and heat gain during the late afternoon.
- Skylights oriented to the south provide the best heat gain during winter but can lead to excessive heat gain in the summer (Giroux Glass).

When designing according to such methods, achieving a consistent result for winter is possible. However, it is possible to get unwanted heat gain in summer. There are several ways to avoid this situation. These are:

- The area where the skylight is can be surrounded by trees.
- Add a movable window shade (Sunsquare, 2017).

The roof does not need to be sloped for skylight use. There are also skylight systems(Figure 3.27) that allow different uses (Demers & Potvin, 2013).

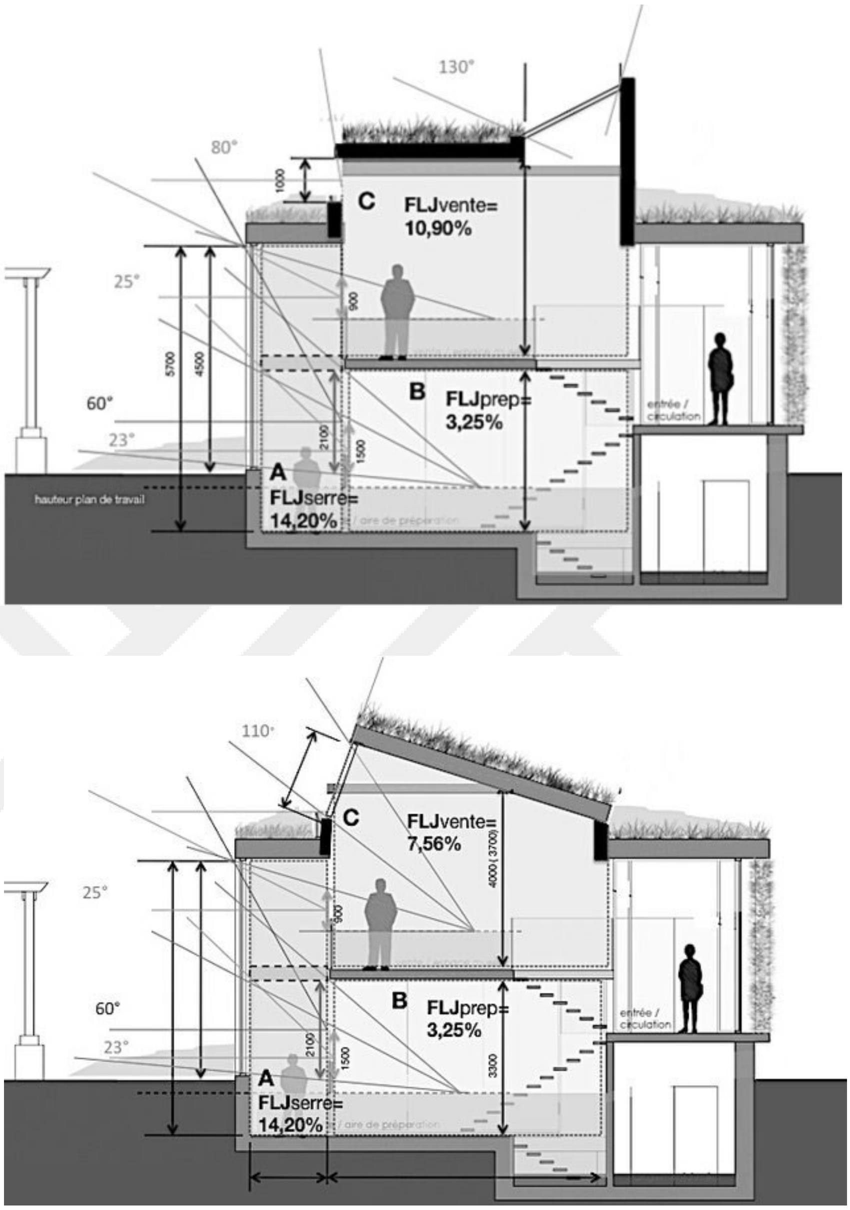


Figure 3.27: Skylight alternatives (Demers & Potvin, 2013)

3.3.4.1.Example case of skylight (California Academy of Sciences)

The advantages of skylights can guide the design. The literature provides examples of skylights and their advantages being used as critical design elements. One such example is the California Academy of Sciences building, designed by Renzo Piano Building Workshop and Stantec Architecture. This university building was designed in 2008 to accommodate many programs (Renzo Piano Building Workshop, Stantec Architecture, 2008).

Figure 3.28: California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture (Renzo Piano Building Workshop, Stantec Architecture, 2008).

A dominant skylight system meets the need for daylight because of the large closed areas inside, which are defined as planetariums and rainforests(where plants are supposed to be used and daylighting is necessary). These skylights also work as a ventilation system.

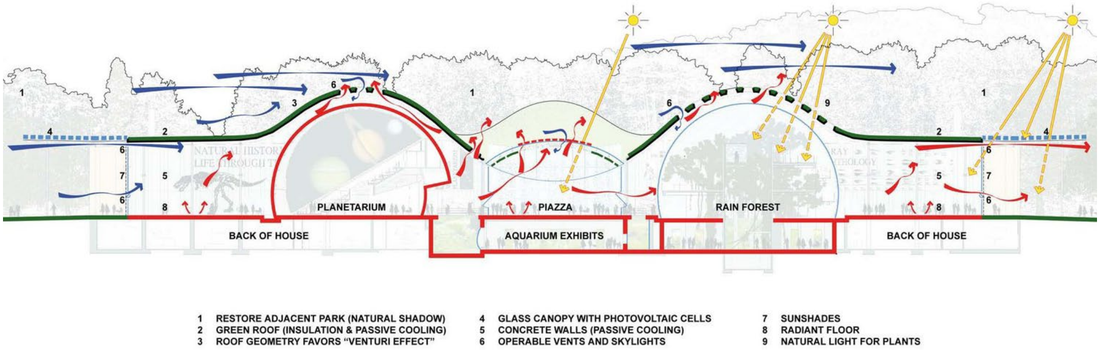


Figure 3.29: Bioclimatic Section of California Academy of Sciences (Renzo Piano Building Workshop, Stantec Architecture, 2008).

3.3.4.2.Interpretation / Assessment

When making decisions about skylights, the design requirements should be reviewed thoroughly. Generally, it is consistent to place skylights in areas of the building that do not receive sufficient daylight. A thick building plan will increase the proportion of dark areas. Conducting a daylight availability analysis can help identify these dark areas, guiding the decision-making process. Additionally, skylights can be used to enhance daylight intake in buildings with special programs, as seen in the mentioned example.

3.3.5. Sunshades

Exterior solar shading effectively minimizes cooling and mechanical heating needs, thereby achieving thermal comfort with lower energy consumption. Additionally, choosing the right size and type of glazing can help prevent excessive heat gain from solar radiation.

Although sun shading devices used indoors also contribute to energy-efficient design, since they are indoors, they can heat up and radiate heat into the room. The design of exterior shading devices is primarily influenced by the orientation of openings and the amount of solar radiation they receive.

The orientation of structures is influenced by seasonal variations in the solar path and incoming solar radiation. During winter, in the northern hemisphere, the sun travels at a lower angle and is positioned slightly south of both east and west. During summer, the sun follows a higher path, positioned north of west, and east. Therefore, it is advantageous to design horizontal sunshades for south-facing openings to block the high-angle summer sun while still permitting the low-angle winter sun to provide heat gain. The openings on the north façades only need shading to prevent the entry of high-angle sun in summer.

Solar radiation to openings on the eastern and western facades is not much affected by seasonal changes in the solar path. Compared to north and south facades, which experience more variation, these facades receive a more uniform level of solar radiation throughout the year (Net Zero Energy Building).

There are some recommendations on the use of sunshades:

- South-facing windows can be shaded efficiently using horizontal eaves. These eaves are designed to block the sun during the summer while permitting sunlight in during the winter. Installing fixed horizontal eaves on south-facing windows can notably reduce cooling requirements, with a 1-meter projection being particularly effective.
- The east and west facades must be limited in windows as much as possible (minimizing the window area), as shading them is more difficult. Landscaping should be considered for shading the eastern and western facades.

- A roof extension can provide shade to the entire north and south walls, effectively blocking the midday sun.
- Generally, there is no shading requirement on the north façade. Only vertical shades or interior roller blinds can be used to block the low-angle sun in the summer afternoon.

To effectively configure solar shading devices, it is critical to account for the wall's orientation and the building's geographical location. These factors determine the timing and angle of solar radiation daily and throughout the year (Net Zero Energy Building).

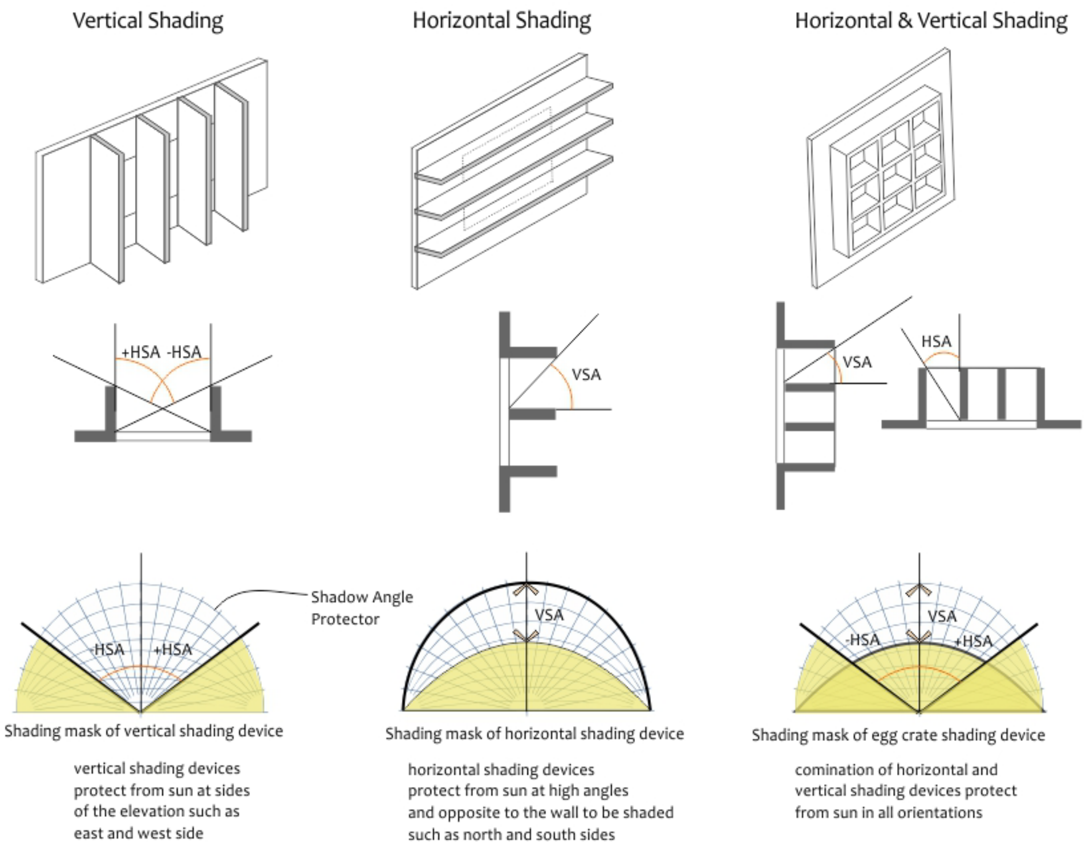


Figure 3.30: Sunshades recommendations according to directions (Net Zero Energy Building)

3.3.5.1. Example case of sunshades (Edith Green-Wendell Wyatt Federal Building)

There are important projects in the literature where sunshades have influenced design decisions intensively. One of them is The Edith Green-Wendell Wyatt (EGWW) Federal Building. The energy-efficient design of the building hinged on converting the existing uninsulated façade into a high-performance curtain wall. The wall features various shading devices customized for each surface: "canes" extending 18 stories high on the northwest façade and built-in sunshades with lighting reflectors on the southeast and southwest façades. These shading solutions effectively enhance the cooling system and hydronic radiant heating, which is the project's primary measure for energy conservation (SERA Architects).

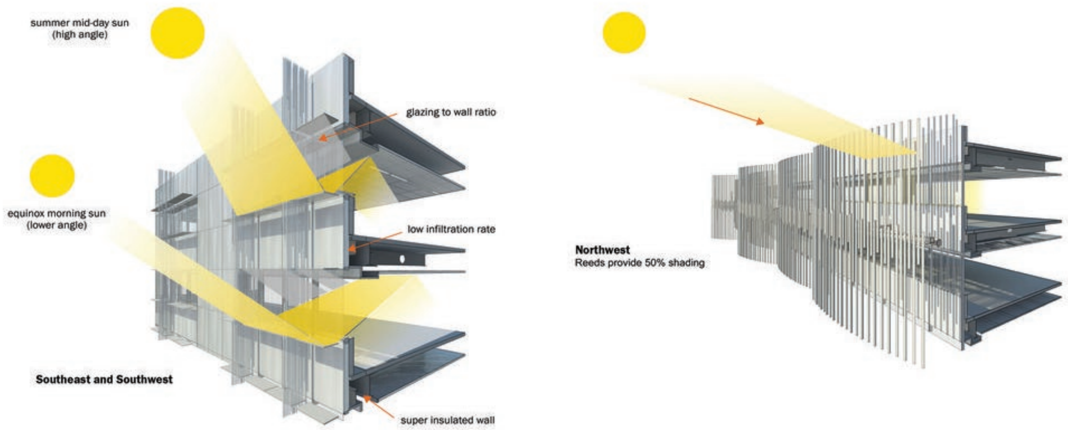


Figure 3.31: Sun Shade System of The Edith Green-Wendell Wyatt (EGWW) Federal Building (SERA Architects)

To determine the optimal shading and daylighting strategy, a parametric analysis was performed. This involved evaluating peak cooling loads across different orientations. The analysis included simulations of three glazing percentages (40%, 50%, and 57%), both with and without shading, to assess their effects on a typical space. Following determining which façades required shading (south, east, and west) and which did not (north), the focus shifted to calculating the appropriate duration for shading each façade. Shading devices were varied in depth and spacing by the designers to meet both performance and design objectives. At the top of the building, a large beam offers extra shading for the 18th floor's upper section, supports photovoltaic panels positioned at an optimal angle, and includes space for water collection (SERA Architects).

3.3.5.2. Interpretation / Assessment

The organization of sunshades can be determined based on the orientation of the building. One important consideration in this decision-making process is the relationship with surrounding structures. If the surrounding buildings already provide sufficient shading, additional sunshade design may be unnecessary and costly. According to the literature, in the Northern Hemisphere, it is generally recommended to use horizontal sunshades on the north and south façades, and vertical sunshades on the east and west façades.

3.3.6. Decidouous tree

One of the most valuable landscaping tools is trees, which can passively increase the comfort of the interior. They provide good shading and serve as an insulating wind barrier. During the long days of summer, most heat accumulates on the east and west walls. This is why tree shading should be maximized on these sides of the house (Meerow & Black). Deciduous trees strategically placed to the east and west in low-rise buildings reduce summer overheating while allowing the desired winter solar gain (Net Zero Energy Building).

The southern walls also benefit from tree shade. Since the orientation of the earth changes, south facades, comparatively free from direct radiation in June, can allow significant heat load increases until August. The most direct way for sunlight to enter homes is through windows. Shading devices such as trees (or awnings) should be positioned to shade windows throughout the day (Meerow & Black).

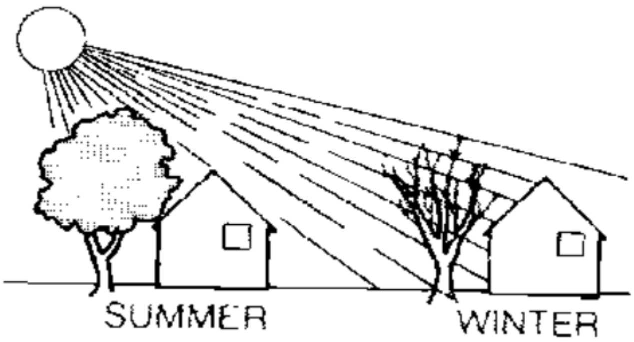


Figure 3.32: Summer shading and winter sun-warming deciduous trees (Meerow & Black).

3.3.6.1. Interpretation / Assessment

Placing deciduous trees on the south, west, and east façades can provide shading during the summer while allowing sunlight in during the winter. When making this decision, the relationship with the surrounding environment is important. These trees have the ability to provide privacy apart from the ability to insolation, it can be used as an advantage by the designer.

3.4. Materials and Precautions

The strategies mentioned previously affect the form and mass relations of the building. Some material selection decisions can be taken to support these strategies. In addition, only one material decision can also support energy efficiency. Material decisions should be discussed to support the passive energy efficiency strategies used in the building and contribute to its overall energy saving. Since this stage is focused on material selection in the architectural project, it can contribute to energy saving without changing the building form. Since the decisions to be taken are related to the material, it is foreseen that there will be no need for revision in the form of the building. At the end of this stage, the schematic design has the potential to provide data on energy-efficient design strategies for the following stages.

In the previous stages, many form-related decisions have been taken. Before the material decision stage, the design should be interpreted through certain solar-oriented analyses. For example, illuminance, solar radiation, and annual glare analyses can be made, and material decisions can be determined. In addition, the materials required for the correct operation of the passive energy efficient strategies used in the design until this final stage should be discussed at this stage. The energy-saving contribution that only the material selection can create and the strategies that can be applied in this regard should be discussed at this stage. The strategies to be discussed at this stage are thermal mass, cool roofs, and window glass types.

3.4.1. Thermal mass

Thermal mass refers to a material's capacity to absorb, store, and release heat energy. It helps regulate temperature fluctuations by capturing heat when temperatures increase and gradually releasing it as they decrease, thus stabilizing both internal and external climate (Designing Buildings Ltd., 2022). In this study, the thermal mass decision is considered at the scope of wall cladding, floor covering and roof covering.

Since thermal mass is a material-based discussion, solar qualities can be evaluated through different aspects of the building. It is necessary to discuss the thermal mass features of the materials both on the façade and the floor and roof coverings. Some passive energy-efficient design strategies are based on the thermal mass features of materials (such as Trombe walls, and sunspaces). If such decisions are made in the design, they should be supported by material selection.

The heat storage feature of the thermal mass has 2 different effects on the building. One is to balance the daytime and end-of-day temperatures. The other is to delay the moment when the heating is the highest. One of the most important contributions is to organize the thermal energy flow in the building. Thanks to this organization's ability, the building's heating needs can be reduced (Walsh et al., 2006).

Material selection is very important for thermal mass decisions. For this material to work properly, it is crucial that it can store a high amount of heat as well as release heat efficiently. Volumetric heat capacity quantifies the amount of heat a material can store. Materials with high volumetric heat capacity include metal, water, marble, and stone. In the diurnal thermal cycle, the loading and unloading of the metal is generally defined as conductivity. For example, a material such as metal can heat up quickly and dissipate this heat very quickly, so metal is a material with high conductivity. Materials with low conductivity, like wood, are capable of retaining heat over extended periods but are less effective at storing and releasing it within the daily thermal cycle (Walsh et al., 2006).

Table 3.2: Volumetric heat capacity of different materials. (Walsh et al., 2006)

Material	**Volumetric Heat Capacity ($kJ/m^3 \cdot K$)**
Air	1
Mineral insulation materials	90
Plastic insulation Materials	100
Wood	187
Brick	1360
Rammed Earth	1673
Sandstone	1800
Concrete	1940
Glass	2184
Marble	2376
Water	4180

The accurate application of thermal mass generally depends on passive solar heating, which is generally dependent on the form and materials of the building. In new buildings, passive solar heating can reduce heating demand by around 20%. A suitable passive solar heating can generally be achieved with appropriate solar heat collection and appropriate heat storage (Walsh et al., 2006).

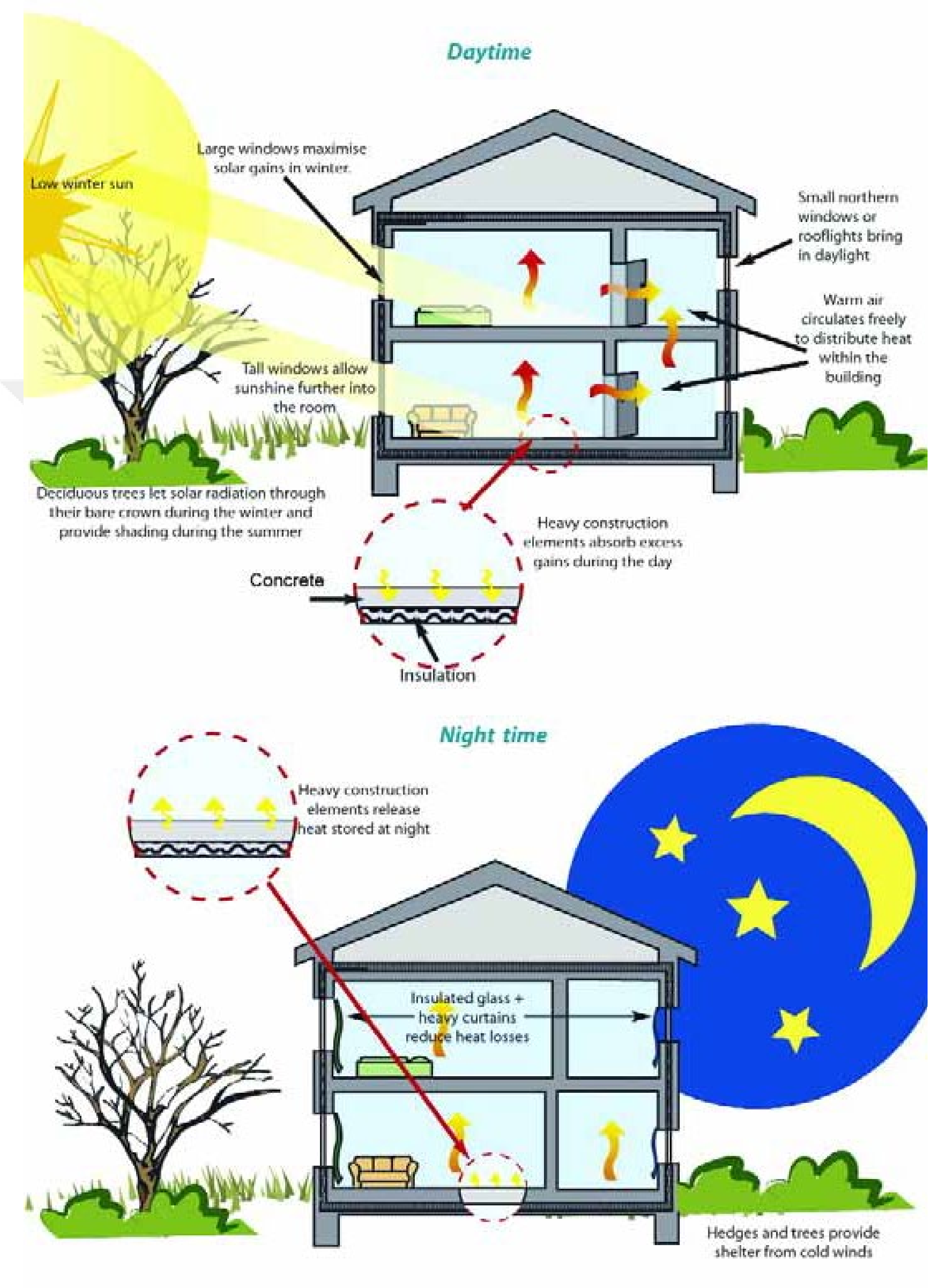


Figure 3.33: Diagrams illustrating how sunshine brings useful winter heating in a solar house. (Walsh et al., 2006)

There are some ways to integrate thermal mass into the building. It should be considered in areas such as the building shell, floor and ceiling slabs, and internal separations. Some applications are related to thermal mass in the building shell (Walsh et al., 2006).

- The usage of thermal mass in rooms with high sunlight.
- While exposing the mass to direct sunlight is 30% more effective than keeping it in the shade, it is also important to distribute the mass across as much of the room as possible.
- Materials with high density, such as masonry, offer the greatest thermal mass.
- For optimal thermal mass, the initial 100 mm of a high-density wall (2,000–2,500 kg/m^3) provides the most effective results. Additional layers of thickness decrease performance benefits.
- Internal insulation reduces the thermal mass effect. Externally insulated walls can still produce a thermal mass effect (Walsh et al., 2006).

The floor covering has the opportunity to be used as thermal mass:

- Since the floor covering is the area that receives the most solar radiation during the year, it is appropriate to use it as thermal mass.
- Applications such as raised flooring or carpeting prevent this situation. If a thermal mass effect is desired, prevention like carpeting and raised flooring should be avoided.
- Ceramic, natural stone materials or tiled also provide a thermal connects sunlight with the indoors, although polished concrete remains the most effective choice (Walsh et al., 2006).

3.4.1.1. Example case of thermal mass (Hockerton Housing Project)

There are examples in the literature that have made the thermal mass discussion effective and obtained efficient results.

When the example of the Elizabeth Fry Building, needed by the University of East Anglia and designed by John Miller and Partners, is analyzed, the thermal mass discussion does not have to be solar-related. Thanks to thermal mass, significant savings can be made in a well-insulated building with innovative systems (Walsh et al., 2006).

Solar-related examples are also found in the literature. One of them is the Hockerton Housing Project building designed by Brenda and Robert Vale. The thermal mass technique of this building is based on passive solar gain. Without the risk of overheating, highly insulated buildings can adopt a passive heat collection strategy, thanks to the crucial role of concrete slab formation. By insulating the slabs on the exterior while keeping them exposed on the interior, the building can fully utilize its heat potential. This setup not only facilitates heat gain across seasons but also significantly reduces the need for active indoor heating throughout the year. The conservatory, south-facing, functions as a major solar collector. Opening the three-meter-high intermediate windows can transfer heat from the conservatory to the interior rooms. The internal structure captures the free solar thermal energy accumulated throughout the day. At night, when the air temperature drops below that of the concrete surfaces, this stored energy is released back into the indoor environment. Internal walls are especially effective in this process because they are oriented to receive direct solar radiation in the morning and evening. Moreover, each wall features two surfaces that facilitate both the absorption and release of thermal energy (Walsh et al., 2006).

Figure 3.34: 1) The south-facing conservatory acts as a large suntrap. 2) The slab construction is left exposed internally in this room, allowing the walls and ceilings to contribute thermal mass. The tiled floor provides Additional thermal mass, which creates a thermal link to the ground floor slab. 3) Exterior view of Hockerton Housing Development (Walsh et al., 2006)

3.4.1.2.Interpretation / Assessment

When discussing thermal mass strategies, several key factors must be considered. First, choosing façades with high exposure to solar radiation is essential for optimizing heat absorption and retention. For these sun-exposed areas, it is beneficial to select flooring and cladding materials with high thermal mass, as these materials can absorb heat during the day and release it gradually throughout the evening, thus enhancing the overall thermal comfort within the building. Moreover, incorporating thermal mass effectively supports other passive solar strategies, such as sunspaces and Trombe walls. These systems rely on walls with substantial thermal mass to store and regulate heat efficiently. Ensuring that walls in these systems are constructed from materials with high thermal mass is vital for their accurate performance. Therefore, providing information about material selection and placement is crucial during the design process to maximize the effectiveness of thermal mass strategies.

3.4.2. Cool roofs

Cool roof is a solar-related passive strategy that works with the choice of roof material. The climate type should be considered when deciding on a cool roof. While it reduces the need for cooling in hot climates, it can prevent the heat gain that is necessary in cold climates. The roof material should be selected to ensure that it has features that prevent mold and algae formation. If appropriate design criteria are not used, condensation may occur, which is one of the aspects that should be considered in cold climates. It is generally considered a low-budget, energy-efficient design strategy. Examples of materials suitable for cool roofing include broken white glazed tiles, bitumen modified with plastic and reinforced layers, elastomeric cool roofing on RCC roofs, and broken tile mosaics. Slate and tile products in a wide range of colors with high solar reflectivity reflect sunlight and provide additional energy savings thanks to their thermal mass. Concrete and clay tiles, available in white, can increase solar reflectivity by up to 70 percent. Some additional measures can be taken to prevent the transfer of solar heat (roof insulation, vegetated roofs, solar panels) (Net Zero Energy Buildings).

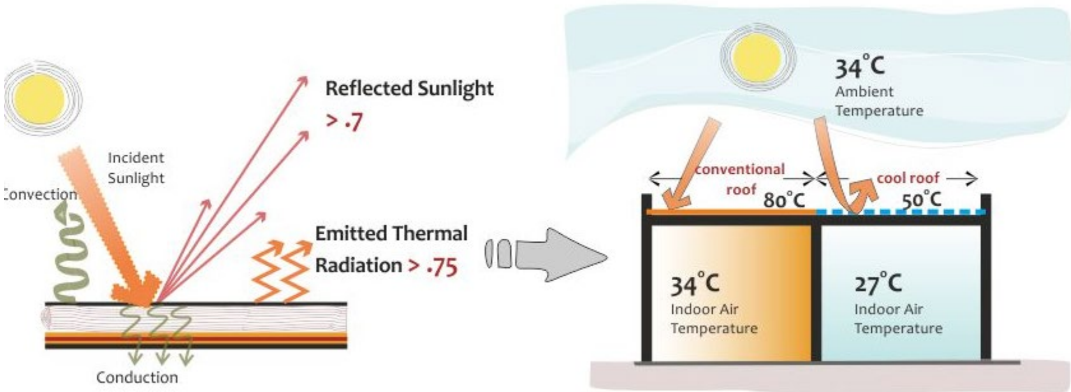


Figure 3.35: Cool Roof Properties and Performance (Net Zero Energy Buildings)

Air temperature indoors can be maintained 6-8°C cooler than the outside environment due to the high solar reflectivity and thermal emittance of cool roofs. Roofs with highly reflective and light color tones are now a key component of building energy efficiency strategies. These cool roofs reduce energy costs by reducing air conditioning requirements, improving thermal comfort indoors, and lowering roof surface temperatures. Traditional dark-colored roofs can reach temperatures of 66ºC (150ºF) or higher during the summer months, while cool roofs can remain 28ºC (50ºF) lower in these conditions (Net Zero Energy Buildings).

According to research, cool roofs make a significant contribution in terms of energy and cost efficiency in hot and warm climates. By reducing energy consumption in a single-story building by 15%, cool roofs also lower the reliance on fossil fuels and decrease carbon emissions. At the same time, this system, which cools the atmosphere, also has the ability to delay global warming. It also increases the comfort level in a structure without a cooling system (Net Zero Energy Buildings).

3.4.2.1. Interpretation / Assessment

The decision to implement a cool roof strategy can be based on the climate type of the location. This strategy can be particularly effective if the building is located in a hot climate where the cooling demand exceeds the heating demand. The reason for positioning this strategy towards the end of the schematic design process is that decisions on the form and shape of the building are often made at earlier stages. The cool roof strategy involves primarily selecting appropriate roofing materials rather than changing the overall form of the building. It is therefore a material-specific strategy that does not require revisions to the shape of the building.

3.4.3. Window and glass types

After the window and opening placement decisions are made, the necessary analyses should be made again, and the properties of these materials should be re-evaluated.

There are three types of energy flow through windows. One aspect involves conductive and radiative heat flowing through the window installation. Another is the gain of solar radiant heat. Additionally, there are gains and losses due to infiltration from air leakage (DeKay & Brown, 2014).

The U-value controls heat conduction, representing how quickly heat moves through the window material. A lower U-value (or higher R-value) signifies improved insulation. Compared to most building materials, glass has relatively poor heat resistance. In buildings with significant skin loads, windows can heavily influence the heating or cooling requirements. Thus, as the temperature difference between the inside and outside increases, it is generally advisable to lower the U-values of windows (DeKay & Brown, 2014).

Windows also absorb solar heat, which can be beneficial or burdensome depending on the building's heating or cooling needs at a given time. A window's solar heat gain coefficient (SHGC) and shading coefficient (SC) reflect its ability to transmit solar heat gain. SHGC is the fraction of incoming radiation transmitted by the glass or window. SC is the proportion of heat transmitted by the glass compared to transparent single glazing. SC ≈ 1.15 x SHGC (DeKay & Brown, 2014).

The Generalized Recommendations for Glazing + Window Selection Table (Figure 3.36) can give useful ideas for determining recommendations according to climate zone, glazing orientation, and whether the building is Internal-load-dominated (ILD) or skin-load-dominated (SLD).

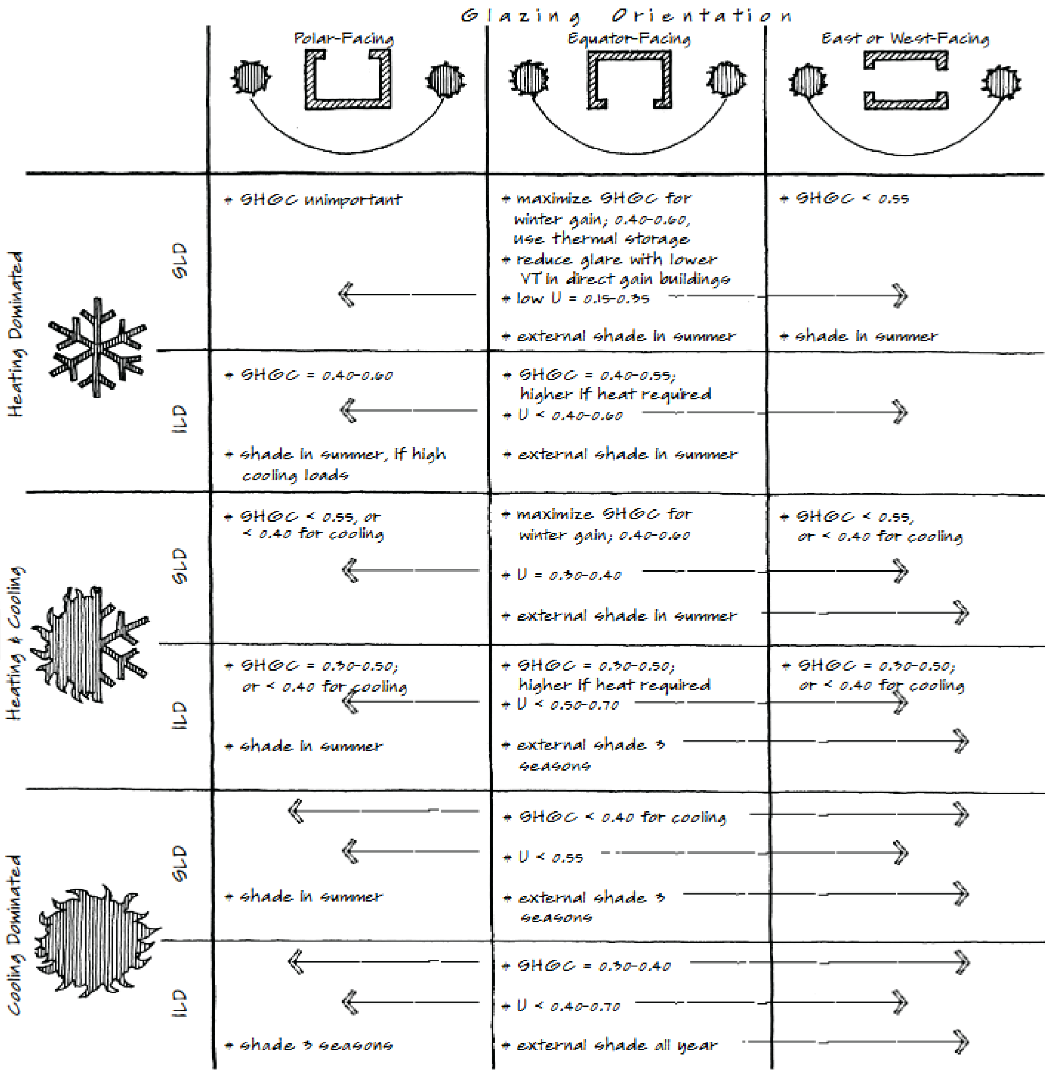


Figure 3.36: Generalized Recommendations for Glazing + Window Selection (DeKay & Brown, 2014)

In passive solar-heated buildings, choose a high SHGC (0.40-0.60) on south-orientated (north in the southern hemisphere) windows to collect as much heat as possible. Equatorially orientated windows can also have high SHGCs in ILD buildings, but the potential for overheating should be controlled by appropriate window sizing or thermal storage. Shade these windows with exterior shades in summer. In SLD buildings, select SHGCs lower than equatorial orientation windows for east and west windows that do not provide significant gain in winter and are difficult to shade in summer. If unshaded with a full sky view, Pole-orientated windows can provide significant heat gain in summer because all light, including diffuse skylight, carries heat. Use low SHGC for pole orientations in buildings with significant cooling loads. ILD buildings, especially in hot climates that require cooling most of the year, can use low SHGC for all orientations (DeKay & Brown, 2014).

3.4.3.1. Interpretation / Assessment

The selection of window glass type can be determined based on the climate type, building orientation, and heating methods of the structure. It is advantageous to utilize the recommendations provided in the "Generalized Recommendations for Glazing + Window Selection" table, as they offer tailored guidance for optimizing window performance according to these factors. By aligning the glass type with the specific climatic conditions and the building's orientation, designers can enhance energy efficiency and thermal comfort, ensuring that the glazing contributes effectively to the overall performance of the building.

While discussing the light transmittance of glasses, the issue of glare should also be discussed. It is an important strategy that affects the visual comfort of the user. As a consequence of the annual glare analysis, the glass in the glare façades can be selected to implement measures against this issue. In general, methods such as reflection and blackening are used for glass. When this strategy is added, it can affect heat gain and daylight availability. This situation depends on the designer's initiative.

4. A CASE STUDY OF A HOUSING PROJECT IN IZMIR/BORNOVA

To understand whether the proposed workflow minimizes the need for revisions when integrating energy-efficient strategies into the design process, a project case study was designed in which these strategies were integrated in the order mentioned earlier. The feasibility of the proposed strategies was tested, and their practical implications in architectural contexts were examined. Located in Bornova, Izmir, this area of 1750 m², which is allocated for housing in the zoning plan, was studied. A public house study was made by combining 4 residential parcels. This case study was produced to see the physical equivalents of the mentioned processes at the project scale. The stages as mentioned earlier have been studied here within the framework of environmental data and zoning limits. This study was conducted in Izmir region as it represents one of the most extreme cases in terms of sun exposure among the climatic zones in Turkey. Furthermore, the decision to study residential buildings is motivated by the fact that a significant proportion of the global building stock consists of residential buildings. It was chosen due to the availability of data and defined zoning plans.

Figure 4.1: Case study area marking (produced by author)

4.1. Mass Settlement Study on Case

The mass settlement process was performed on the defined case study. In this study, the considerations for creating a mass model and the strategies to be included were incorporated in the correct order according to the defined workflow. As a result, a mass model was developed by integrating passive strategies into the design during the schematic design process without compromising their effectiveness. The subsequent stage, the plan layout process, was then carried out based on the mass model established in this stage.

To start the workflow, a volume needs to be produced and interpreted. This volume can be produced by solar-related strategies or by using the maximum volume limited by law (see Maximum volume study), which is a commonly used method independent of insolation. This case focuses on determining the maximum volume permitted in architectural projects, independent of energy efficiency considerations, assuming that the employer wants to use the maximum space. It is a process that is driven by compliance with zoning regulations that set the limits of urban development based on factors such as surrounding utilities and roads. Incorporating the maximum volume determination into the architectural model provides a starting point for the design process and a reference for future assessments. This is achieved by graphically producing the maximum volume in a 3D digital environment and facilitating its use in subsequent phases of the project.
Initial data required for this stage includes:

- Topography
- site boundaries
- location
- environmental information
- approximate enclosed area
- site constraints by law

The identified site in Izmir/Bornova is in a residence zone and subject to a 5-meter setback from surrounding roads and a 3-meter setback from neighboring parcels. The site also has permission for the construction of a two-story building. After the maximum volume is obtained, it is considered as a starting point for the other stages.

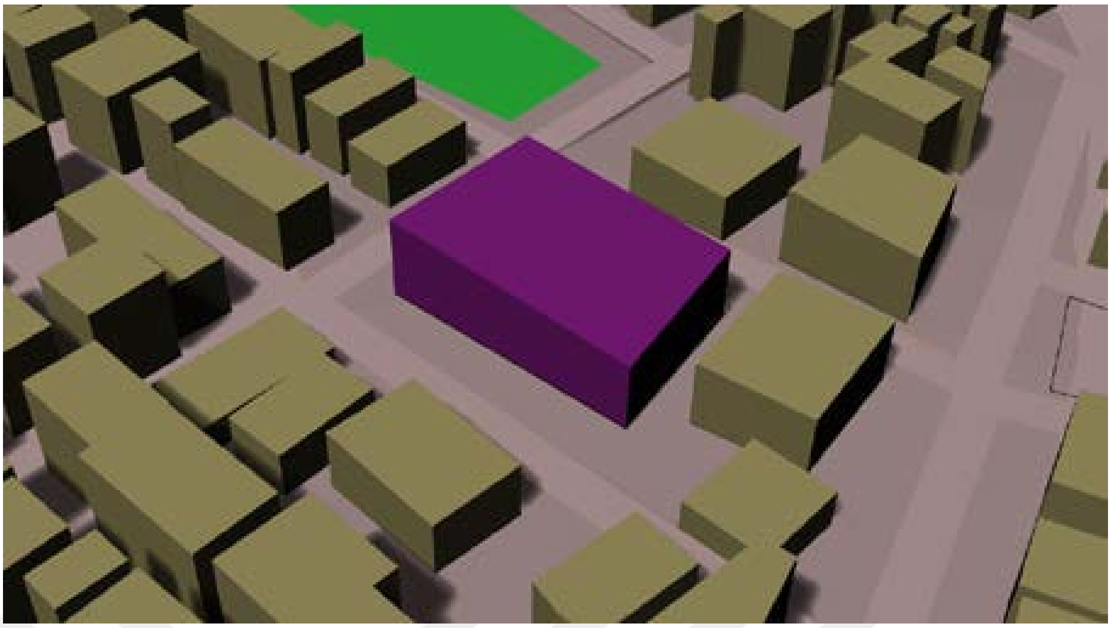


Figure 4.2: Output of Maximum Volume Study (produced by author)

The orientation of the building was evaluated after the maximum volume study. It is tested whether the orientation of the placed mass yields positive results in terms of solar exposure, and adjustments are made accordingly. Through the orientation study, orientation with respect to the sun enables the final model to play a supporting role in developing other energy efficiency strategies. In addition, the added scenario allows to recognize critical and overheated facades through the obtained signs.

The required input for this stage is the box model obtained in the previous stage and the related EPW file. The Rhino Grasshopper plugin was used to get the necessary solar exposure analysis. The process is as follows:

- Writing the relevant GH script.
- Connect the built model and the related script to the EPW file.

After the necessary processes are completed, the script assigns colors to the surfaces of the object. This script marks facades that are overexposed to the sun and where there may be problems with insolation.

There is a color scale from red to blue. A strategy supported by the research was the suggestion that the long side of the building facing 20 degrees to the south provides optimum insolation and supports passive strategies. (see Orientation study)

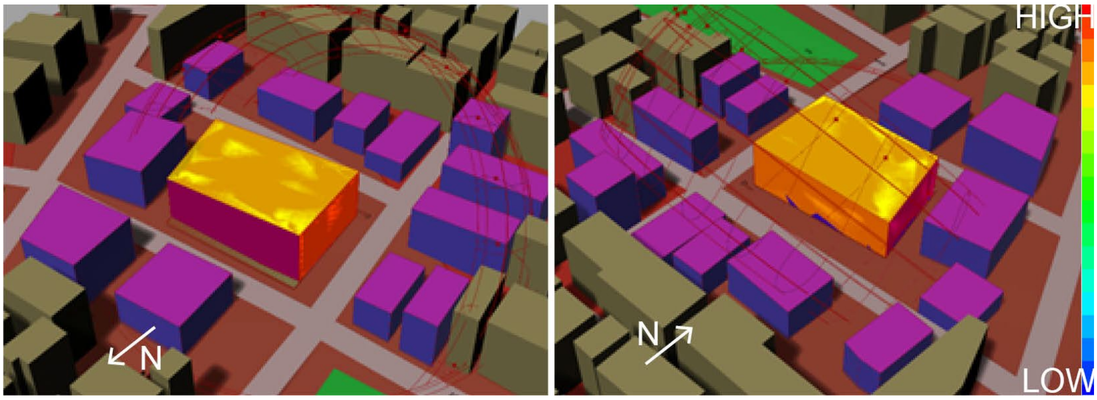


Figure 4.3: Output of Solar Radiation Analysis / Rhino GH / Red marks areas with high solar radiation, and blue marks areas with low solar radiation (produced by author)

As a result of this recommendation, the building is rotated 20 degrees to the south. To prevent area loss, the maximum volume was divided into 2 pieces. When the script is run, the red color of the south and west facades gives preliminary information about the high solar radiation on these facades and the necessary precautions to be taken or the potential to be used. This 3D model was used in the next stage, solar form finding.

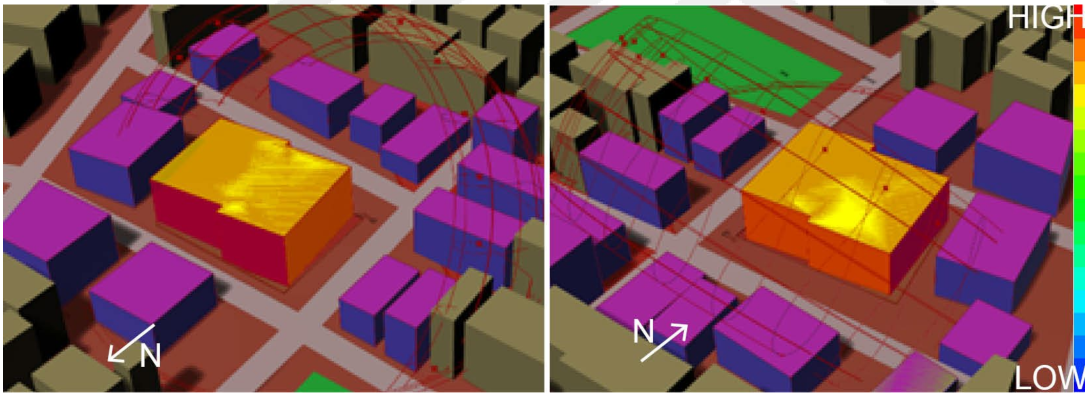


Figure 4.4: Intervention According to Solar Radiance analysis and Recommendation / Rhino GH (produced by author)

Solar form finding study is designed to ensure that the building to be designed receives enough daylight and doesn't prevent the solar rights of the surrounding structures and to take critical measures before proceeding to the other stages. This stage, which proposes a volume, is based on Sustarc's model (see Solar Form Finding).

Inputs needed for this stage:

- volumes of surrounding structures,
- project site,
- maximum height,
- location.

The process for using this method is as follows;

- Writing the relevant GH script (With data on the building limit and maximum height according to the zoning plan for the land)
- Connect the built model and the related script with the EPW file (Which can be obtained easily online).

After completing the necessary processes, the script produces two different surfaces. The volume between these two envelopes forms the most efficient volume for sufficient insolation of the building to be designed and to protect the solar rights of surrounding buildings. One of the two envelopes produced is the solar rights envelope, and the other is the solar collection envelope (see Solar Form Finding).

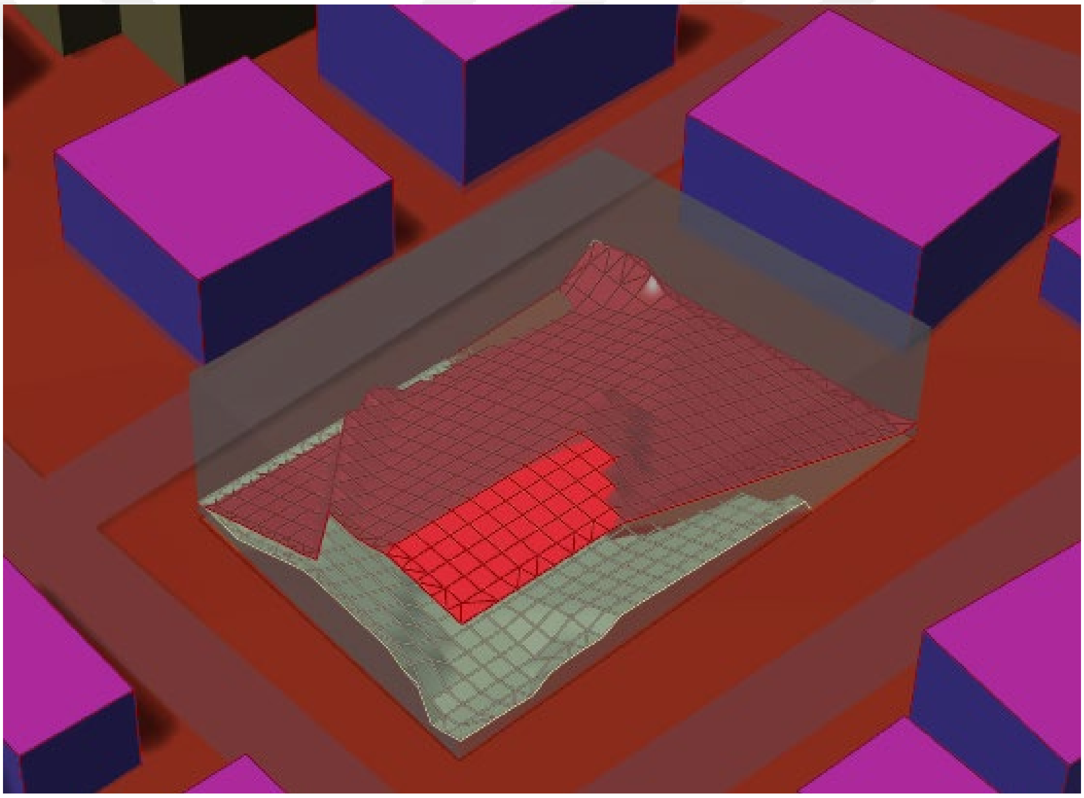


Figure 4.5: Output of Solar Envelope Method (Red envelope: Solar rights envelope / Green envelope: Solar collection envelope) / Rhino GH (produced by author)

The solar envelope study provides the most appropriate form for the building mass, and by interpreting the form created by the method, some energy-efficient design strategies can be interpreted. Therefore, it is important to interpret this form and design interventions accordingly before proceeding to further stages. Otherwise, as the design progresses and different design parameters are included, subsequent interventions increase the workload and project duration.

4.1.1. Analysis of the mass settlement study

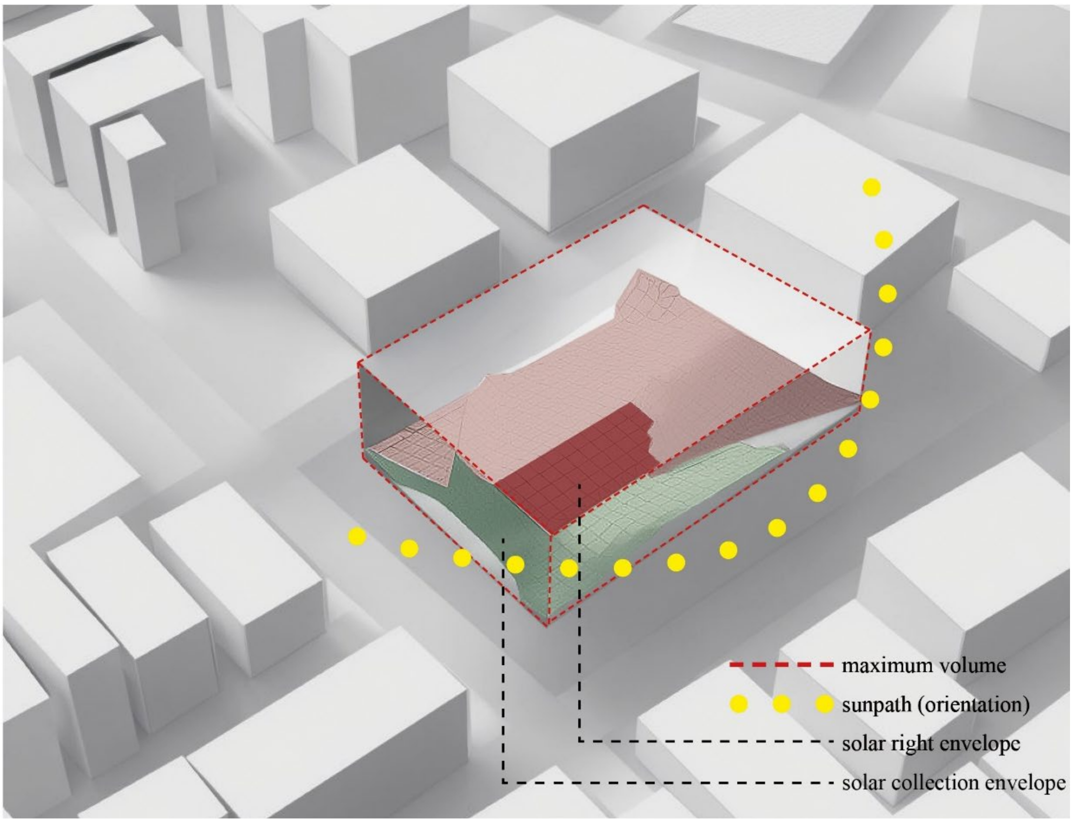


Figure 4.6: Analysis obtained during the mass settlement process (produced by author)

The analyses made during the mass settlement process are shown in Figure 4.6. The design is a dynamic process and different parameters are involved in the process in each project. The designer does not have to use all of these methods to follow this workflow. However, if the recommendations made as a result of these analyses are not complied with, the designer has the opportunity to see the points ignored and take the necessary precautions at other stages. According to the analyses:

- It has been observed that the solar collection envelope is elevated above ground level on both the west and south façades, with a more significant elevation on the west façade. This indicates a potential problem with daylight intake in these areas and demonstrates that natural light intake may be insufficient. The solar rights envelope is seen to descend towards the north, which implies that if the maximum volume is built on the northern side, the designed structure might obstruct the solar rights of neighboring buildings.

- The solar radiation analysis indicates that the building's orientation, with its longer side facing south, is advantageous in terms of solar gain. In addition, the literature shows that it would be even more advantageous to orientate the building approximately 20 degrees to the south.

4.1.2. Recommendations of the mass settlement study

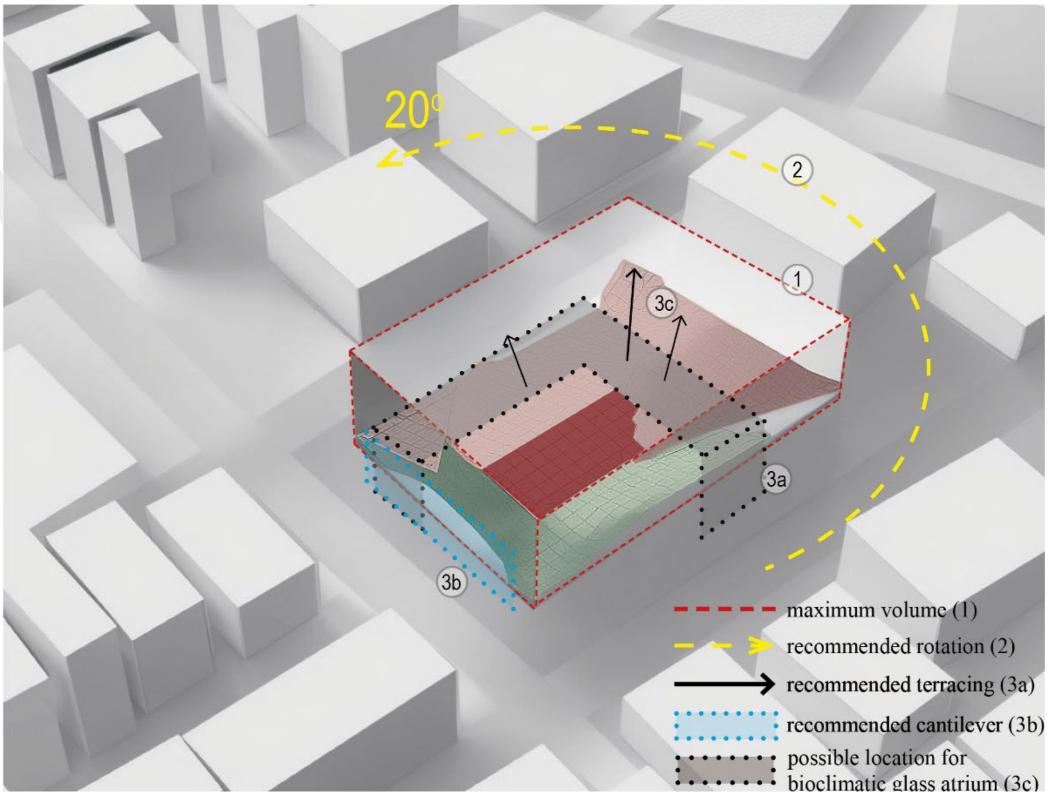


Figure 4.7: Recommendations of mass settlement process(produced by author)

The suggestions received at this stage are as follows:

- In case 1, The maximum volume that can be produced according to the zoning restrictions, assuming that the employer wants a maximum closed area. Thin plan and east-west oriented plan schemes can also be used.
- In case 2, 20 degrees to the south makes the building's solar radiation more consistent and supports other passive strategies.
- In case 3a, to protect the solar rights of the surrounding buildings in the direction where the solar rights envelope is lowered, it is recommended to reduce the structure or terracing. At the same time, the daylight intake of the

facade can be increased by terracing to the north independently from the surrounding buildings.

- In case 3b, the fact that the solar collection envelope is above ground level means that this area can’t receive daylight; therefore, cantilever systems can be considered. Cantilever systems can be preferred due to the shading it will provide in summer due to the high sun angle on the south facade after examining the situation with the surrounding buildings.
- In case 3c, the solar rights envelope is lowered; therefore, the structure is suggested to be transparent. Therefore, it can be determined that it is a suitable location for a glass bioclimatic atrium.

4.1.3. Result of the mass settlement study

A minimum revision is envisaged when these interventions are made in the order in Figure 4.7. There is no specific order for suggestions with the same number but different letters (such as 3a, 3b)

5 different design decisions were taken following this workflow:

- Case 1 in Figure 4.7 results from the first stage, maximum volume. The design was started with maximum volume, assuming that the client prefers maximum closed space.
- Case 2 was rotated 20 degrees to the south, following the orientation study's suggestion. The building is also divided into 2 sections to avoid loss of space.
- Case 3a is taken from the solar form finding study. It can give an idea of the direction of the building's terracing. In this building, the solar rights envelope shows a descent in the Northeast direction. This descent shows that if the building is designed at maximum volume, it blocks the solar rights of the surrounding buildings. Therefore, the building needs to be reduced or made transparent in this direction.

  Terracing the building can have significant effects in terms of solar radiation. Such interventions have been studied in many buildings. There are two different examples of terracing previously mentioned (see Terracing). The solar rights envelope can be used to decide which case to apply. When the solar rights envelope is lowered on the north façade, the northern slabs can be terraced, as Norman Foster and partners did in his City Hall project. In this case, a terracing method was used in the north direction, as in the City Hall project described under Terracing and the building height was reduced by 1 meter in this direction. The north façade of the eastern mass is proposed as a transparent construction to protect the solar rights of the surrounding buildings in the solar envelope analysis. This was envisioned as a balcony without a covering. The terracing strategy can also be discussed independently of the surrounding buildings; in this case, it is discussed in terms of the solar rights envelope.

- In case number 3b, the fact that the solar collection envelope is above ground level on the west façade indicates that the designed building cannot receive light at this point due to the surrounding buildings. Here, a cantilever system is proposed to receive daylight at this point of the building.
- Case 3c in Figure 4.7 is the decision to make the building transparent when the solar rights envelope descends. The lowering of the solar envelope can inform the designer of a bioclimatic atrium. If it is an appropriate point for the whole building, a glass atrium can be decided, which can also be used for the entrance and circulation. This atrium, working in combination with other energy-efficient systems, can be useful at a later stage. The Public Housing in Platja D'En Bossa / 08014 Arquitectura project (see 4.1.3.3. Location of Glass-Bioclimatic Atrium) can be used as an example for a transparent atrium, and a similar intervention can be made. When the solar rights envelope starts to descend, the glass atrium was preferred on the north-south axis as it coincides with a suitable point for the building entrance.

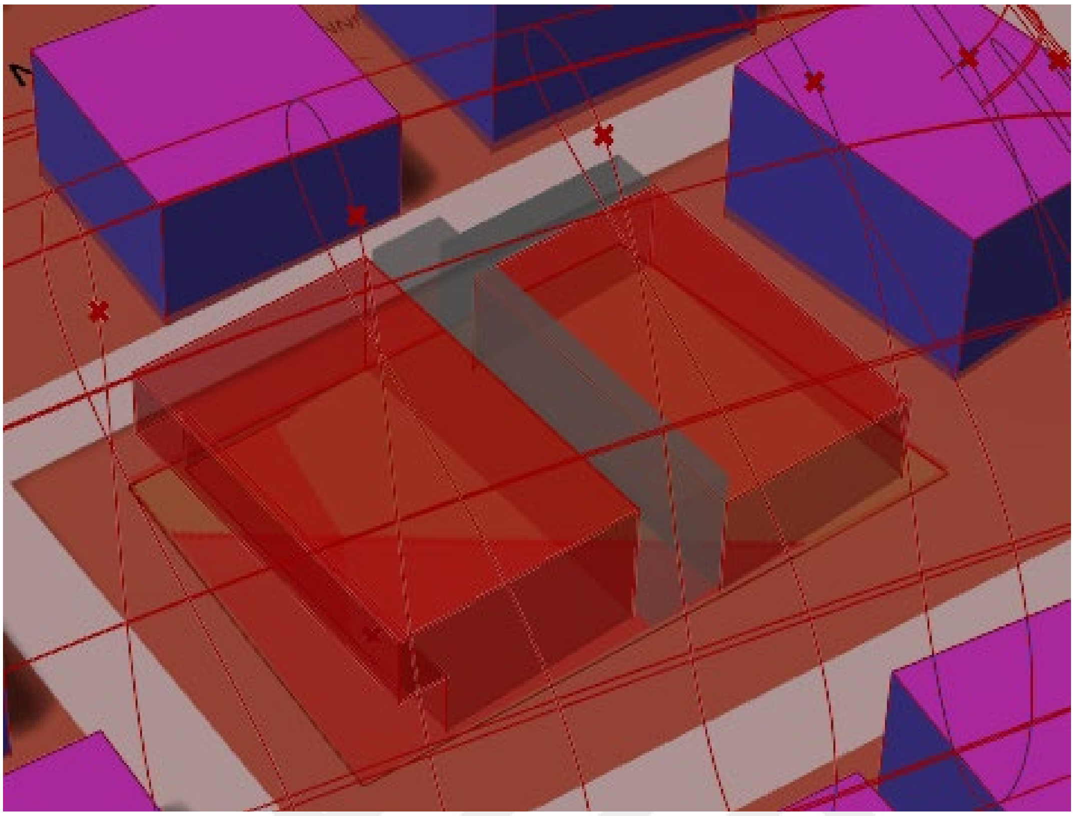


Figure 4.8: Output of the mass settlement process according to the suggestions received from the workflow (produced by the author.)

To increase the design's detail and make the analysis on the mass model obtained from the previous stage, the floors, and the facade were modeled with basic material definitions as much as possible.

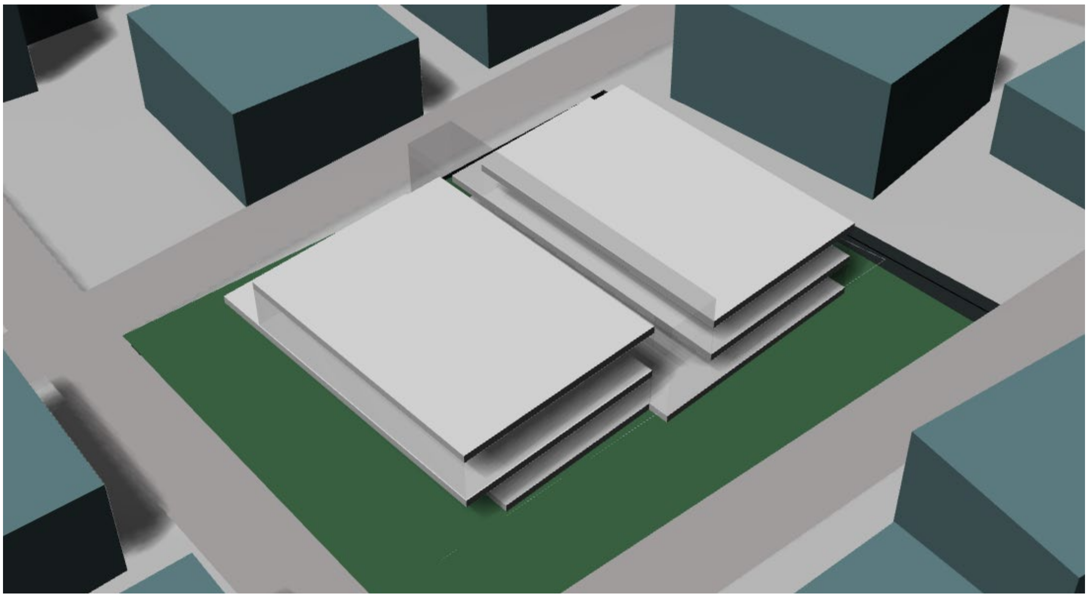


Figure 4.9: Detailed mass study after mass settlement process (produced by author)

4.2. Plan Layout on Case

After the mass settlement process, a consistent and effective mass model for insolation has been obtained. In the continuation of this process, analyses and inferences can be made for the interior organization of this mass before the first line is drawn in the plan layout stage. These analyses can provide the designer with data about the layout of the rooms. At the same time, the plan layout is being formed and can also provide insights into possible passive energy efficiency strategies that can be integrated.

4.2.1. Analysis of the plan layout phase

This 3D model's contribution is that it allows analysis programs to run through the slabs' shading. The plan layout process is based on the boundaries created by this model, the analyses that can be done on it, and their interpretation.

Climate studio analysis program was used to take these analyses. One of the reasons for this is that it can work consistently with the rhino program, where we can also use the grasshopper which was used in the previous stages. The analysis to be used in the following processes can be taken from this program. These analyses can be done in many different programs (Revit, Sketchup, and some companies' applications such as Velux). Within the scope of this thesis, the efficiency of the workflow, which is a decision stage independent of where these analyses are performed, is discussed.

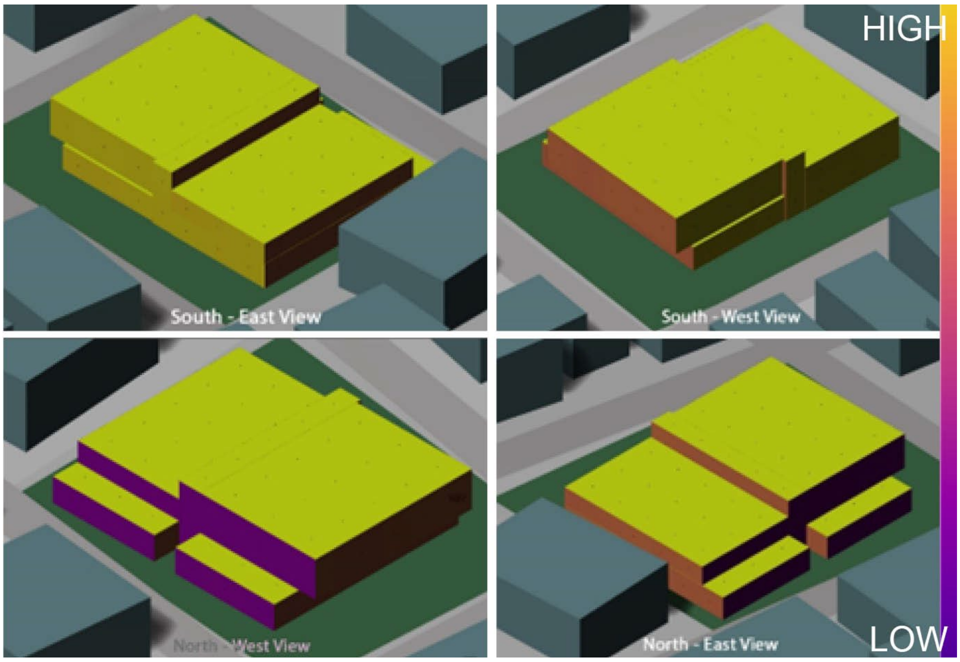


Figure 4.10: Solar Radiation Analysis Climate Studio(Created by author)

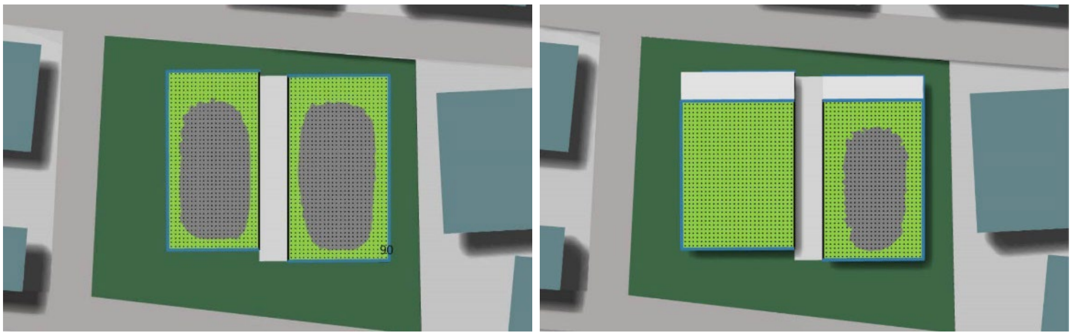


Figure 4.11: Daylight availability analysis (Ground floor: left – First floor: right / Green areas are daylight available) / Climate Studio(produced by author)

The inferences made from the related analyses are as follows:

- According to solar radiation analysis(Figure 4.10), the south façade is the façade exposed to the highest solar radiation, while the western façade has the second highest solar radiation, followed by the east façade. The north facade has the lowest solar radiation.
- According to the daylight availability analysis(Figure 4.11), areas without daylight were analyzed. Except for the area on the west side of the first floor, it can be understood by this analysis that the areas in the middle of the blocks in general are daylight unavailable.

4.2.2. Recommendation of the plan layout phase

Before proceeding to the plan layout phase, one of the analyses that can be done on the model obtained is to examine the daylight availability status (Figure 4.11). Before starting the design, the ground trace obtained from the previous phase and the location of the atrium were transferred to CAD. The areas with the lowest daylight availability and possible sunspace and solar chimney locations were marked on this trace, and the plan scheme work was continued with these recommendations.

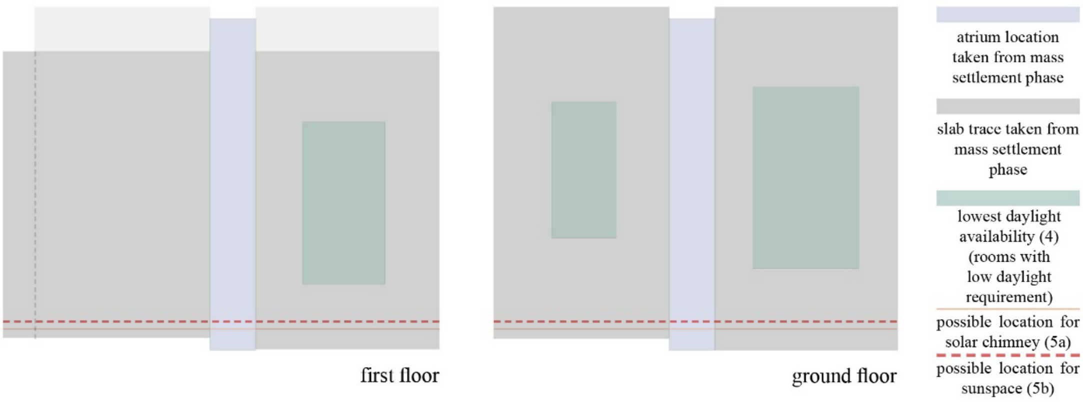


Figure 4.12: Recommendations from the analysis and research on the plan layout process (produced by the author)

- In case 4, rooms, where artificial lighting is preferred, can be placed in the area that benefits the lowest amount of daylight due to this analysis.
- According to 5a and 5b, decisions about sunspaces or solar chimneys can be used depending on the orientation but affect the plan layout and are difficult to add later. The fact that this information is obtained before studying the plan layout is an advantage when designing floor plans.

4.2.3. Result of the plan layout phase

According to these recommendations, 3 different design strategies can be decided.

- In case 4 (Figure 4.12), the places with the lowest daylight availability, toilets, bathrooms, and storage areas, where artificial lighting is generally preferred, are placed in the center of the blocks instead of the usual corners. In this case, a corridor facing the atrium at the back with daylight access is obtained, while daylight access is provided to the rooms with higher usage.
- In cases 5 and 5a, because of the suggestion of the solar chimney and sunspace, sunspace and solar chimney that can affect 2 rooms were installed according to the suitability of the plan layout.

The plan layout was produced following these recommendations.

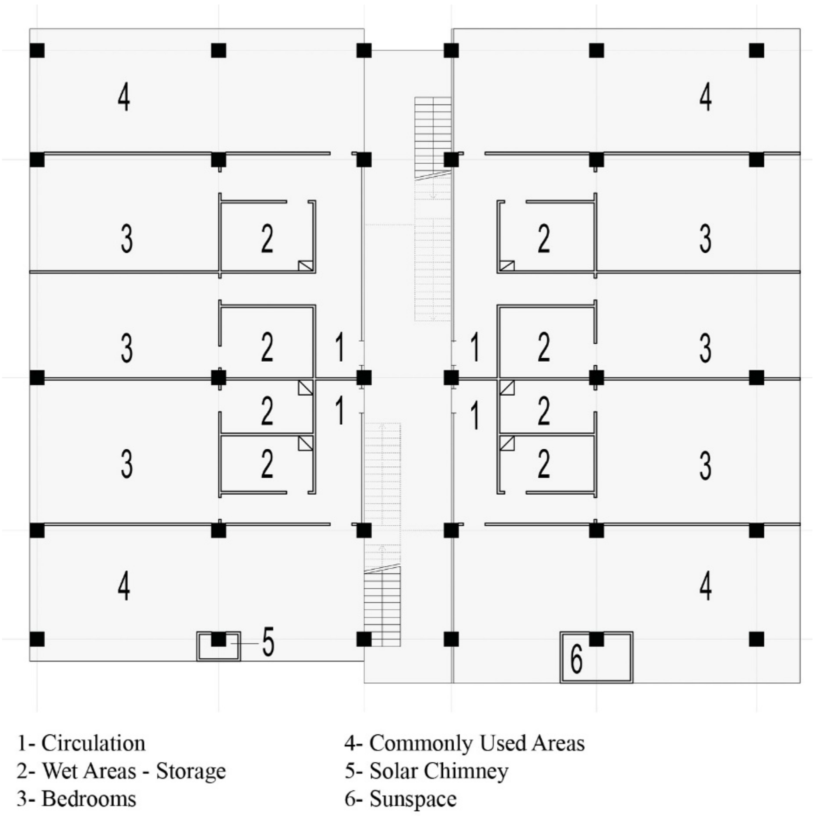


Figure 4.13: Ground floor plan designed according to the recommendations

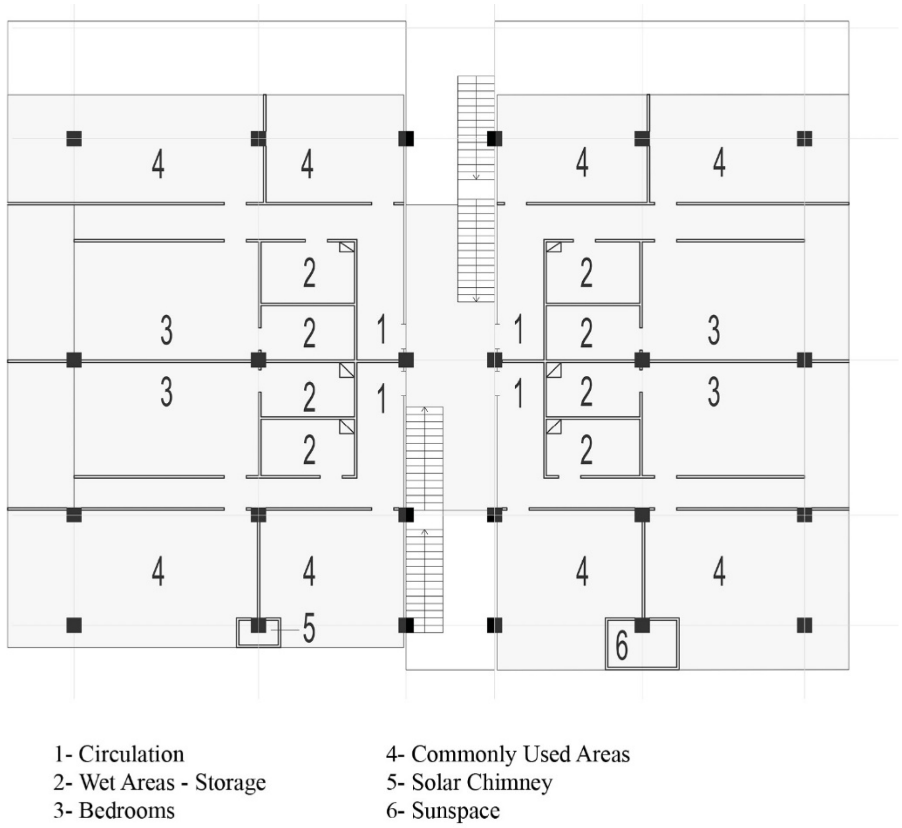


Figure 4.14: First-floor plan designed according to the recommendations

To ensure that this plan layout can be analyzed to contribute to the other phases, the interior partition walls were modeled and re-analyzed in 3D. (Figure 4.15)

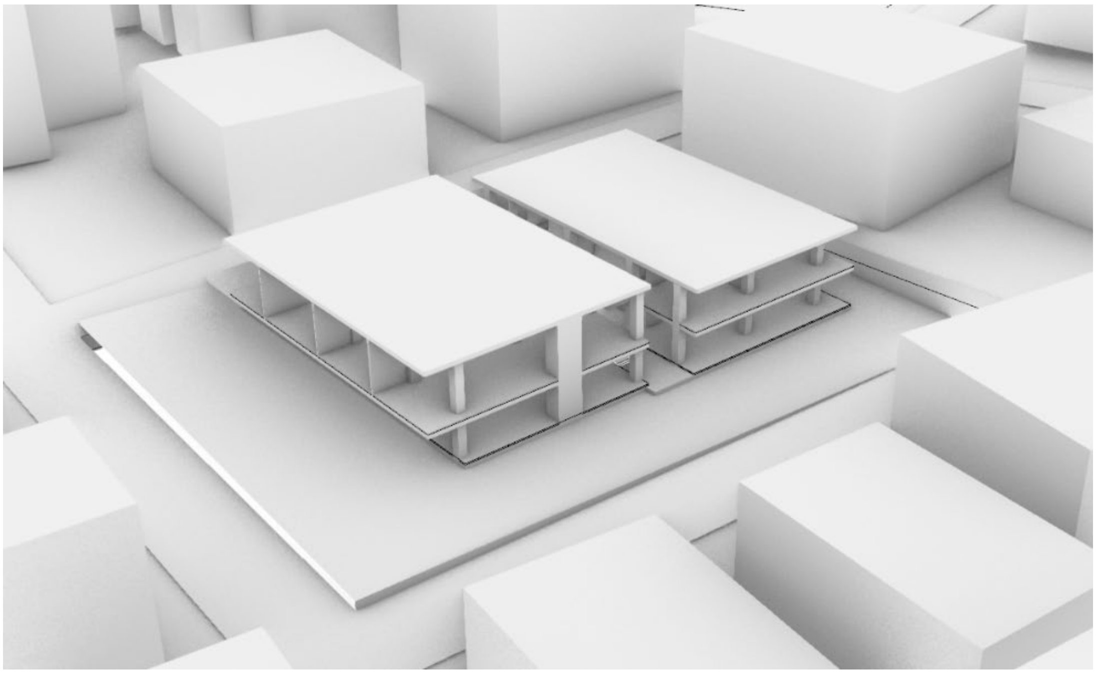


Figure 4.15: The Output of Plan Layout Phase (produced by author)

Performing these analyses and identifying possible strategies before starting the plan layout provides advantages for energy-efficient design without interrupting the architectural design process.

When the contribution of the previous phase to this phase was discussed, a consistent slab trace was obtained concerning the sun's effects. The decision to create an atrium in the previous phase resulted in a corridor with a high daylight intake during the day instead of a dark corridor (which would require artificial lighting).

4.3. Building Shell Study on Case

While discussing the building envelope, the data taken from the plan layout section was continued. After examining the plan layout, there are analyses that can be discussed when making building shell decisions. Such as daylight availability, annual glare, and solar radiation. With these analyses and the decisions that can be made manually (see Building Shell Study), some suggestions were obtained. Daylight availability, annual glare, and solar radiation analyses were carried out in the Climate Studio. As a result of these analyses, important recommendations were obtained.

4.3.1. Analysis of building shell phase

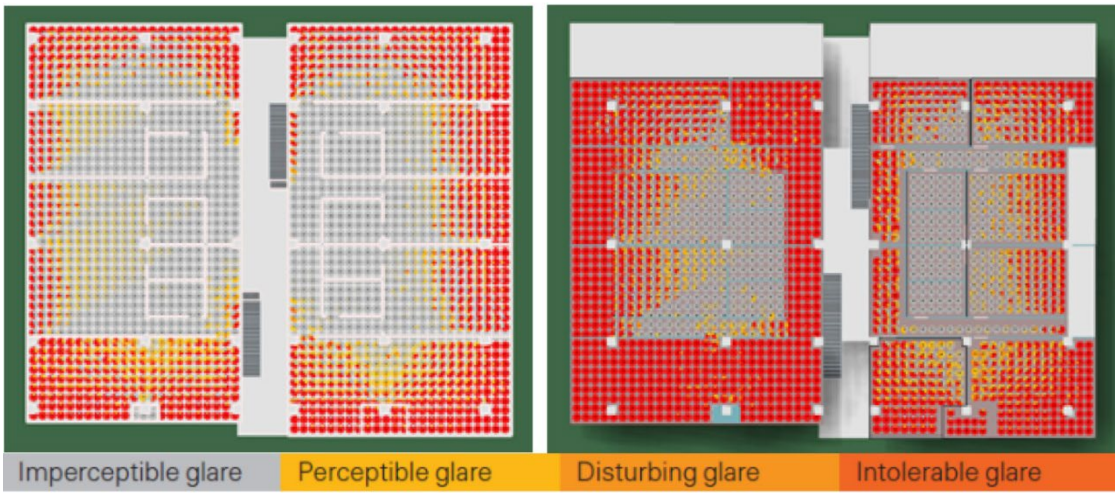


Figure 4.16: Annual Glare analysis with current model, Climate Studio,((ground floor: left first floor: right)(Created by author)

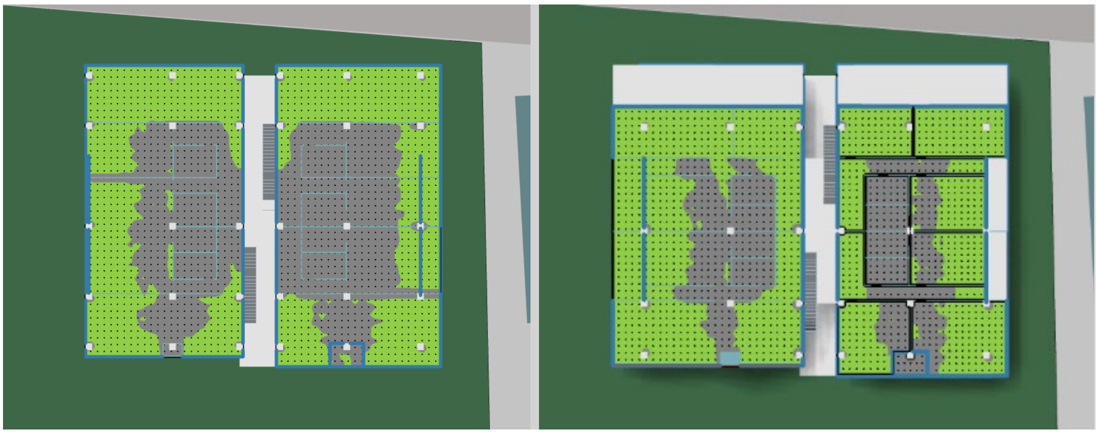


Figure 4.17: Daylight availability analysis of output of plan layout phase / Climate studio (ground floor: left first floor: right/ Green areas are daylight available) (Created by Author)

The inferences made from the related analyses are as follows:

- According to the annual glare analysis, the annual glare rate is high on the west and south facades, especially on the first floor. According to this analysis, measures should be taken to reduce the annual glare on this façade.
- As can be seen from the daylight availability analysis, the rooms with more use are advantageous in terms of daylight availability, except for toilets and bathrooms, where artificial lighting is preferred.

In a design requiring such a thick plan, the atrium decision taken in the previous stage enabled daylight in the interior. Otherwise, artificial lighting would have been needed in these areas. At this stage, interventions can be made for the points where daylight does not reach.

4.3.2. Recommendations for building shell phase

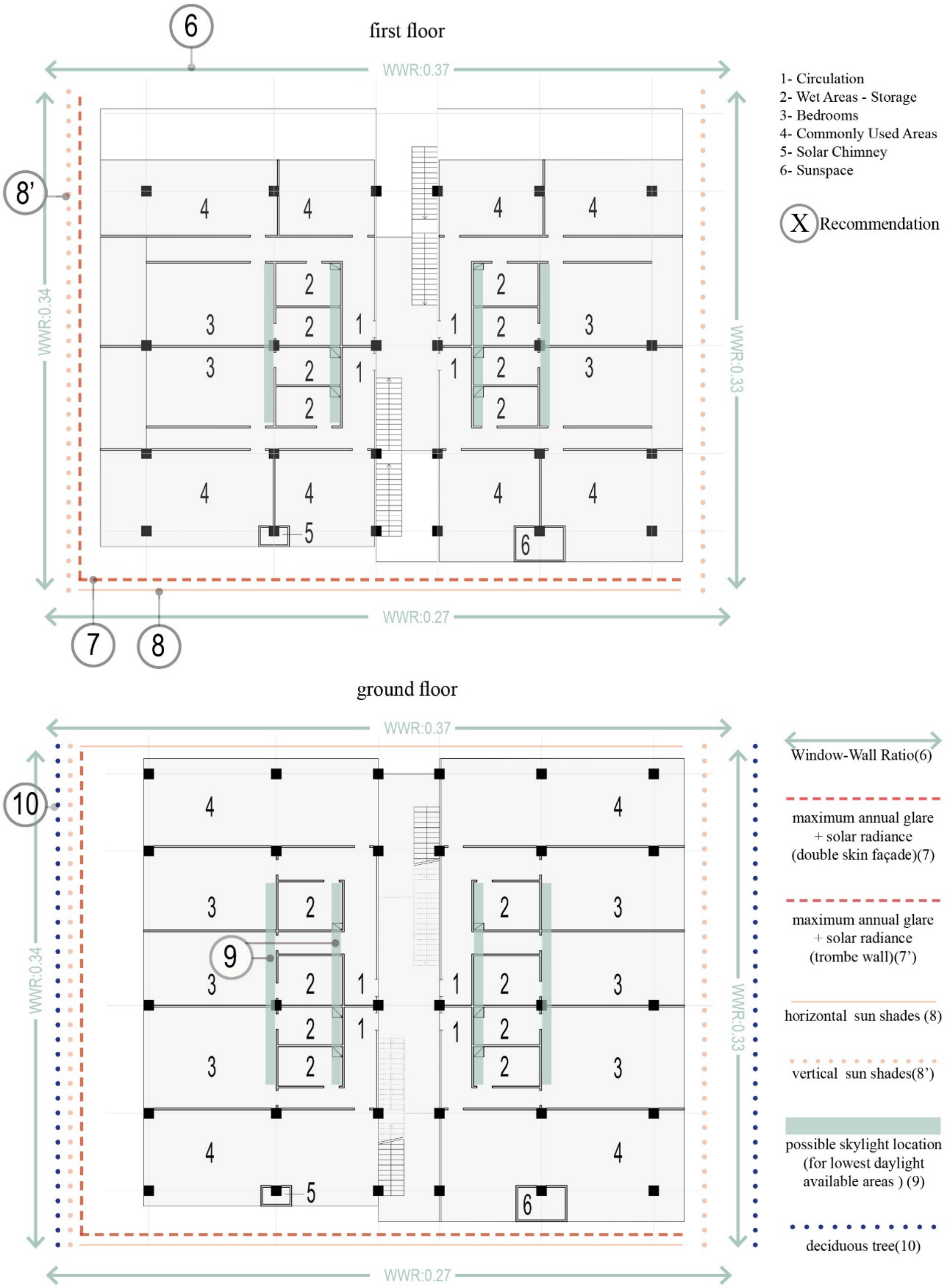


Figure 4.18: Recommendations from the analysis and research on the building shell process (produced by the author)

The strategies provided by the workflow are as follows

- According to case 6, when discussing WWR, the rates given in academic research can be used according to the determination of the subclimate from the Koppen-Geiger climate classification.
- In cases 7 and 7', some strategies can be recommended according to sun exposure and annual glare. The Double-skin façade has a glare reduction feature and works on a façade with high solar exposure. It can be recommended on the west and south facades. If there is a higher proportion of solid surface on the façade, a Trombe wall can be proposed as an alternative, which can be used on façades with high solar radiation.
- Sunshade suggestions (8 and 8') can be given according to direct directions. Vertical is recommended for east and west, horizontal for south and north. In this building, the solar radiation of the north façade was low, so it is not recommended.
- Skylight (no 9) can be recommended in parts of the building where daylight is unavailable.
- Deciduous trees can also be recommended on the east and west facades.

4.3.3. Result of building shell phase

When the recommendations are evaluated, 6 different recommendations have been taken at this stage.

- In case number 6, the Window-Wall Ratio (WWR) is discussed. This decision can be taken according to the Koppen Geiger subclimate system classification. When the studies cited in WWR are analyzed (see Window-wall ratio (WWR)), the Window-Wall Ratio (WWR) in Athens (CSA), which has the same subclimate type as Izmir, is proposed. The ratios suggested for the CSA type sublimate are applied.
- Case numbers 7 and 7', the possible points where double skin façade or Trombe wall application is possible, have been identified. Sun exposure is necessary for the double skin facade to work properly, and double skin has glare-reduction features (see Double skin façade). The west and south facades with maximum annual glare (Figure 4.16) and solar radiation (see Figure 4.10) are the most suitable facades for the double-skin façade. However, since the solid

wall ratio is higher than glass wall, the other alternative, the Trombe wall system, which can be decided according to solar radiation, was used.

- In case number 8, solar shading is not required in the north. Horizontal sunshades on the south façade and vertical sunshades on the east and west façades are recommended. (see Sunshades)
- In case number 9, skylights are used for daylight availability in wet areas and deep rooms where daylight does not reach. Daylight reaching wet areas prevents the formation of mold and algae. (see Skylight)
- Case no. 10 suggests planting deciduous trees in front of the building on the west and east facades where the designer does not prefer to use sun shading or where sun shading is not feasible according to the project. This situation can also be used according to the requirements independent of the sunshades or according to the architect's design approach. Deciduous trees were used on the west façade as the designer did not prefer to use a sunshade. (see Decidouous tree)

When the contribution of the previous phase to this phase is discussed, this consistency is the reason why the strategy, such as the trombe wall, coincides with the high-use rooms in the plan (strategy 4 and 7). The most frequently used rooms in the house could benefit from the trombe wall.

As an advantage of using this sequence, the necessity of double skin was discussed with the WWR decision. The Trombe wall was used because it was not needed due to the excess solid surface. Double skin façade is not used.

Since the sunshade decision was taken after the Trombe wall, the sunshades can be an integrated construction of the Trombe wall.

Because the sun shade decision was discussed before the deciduous tree decision, deciduous trees were used in the east, where sun shade would not be preferred. This provided an alternative for the solution.

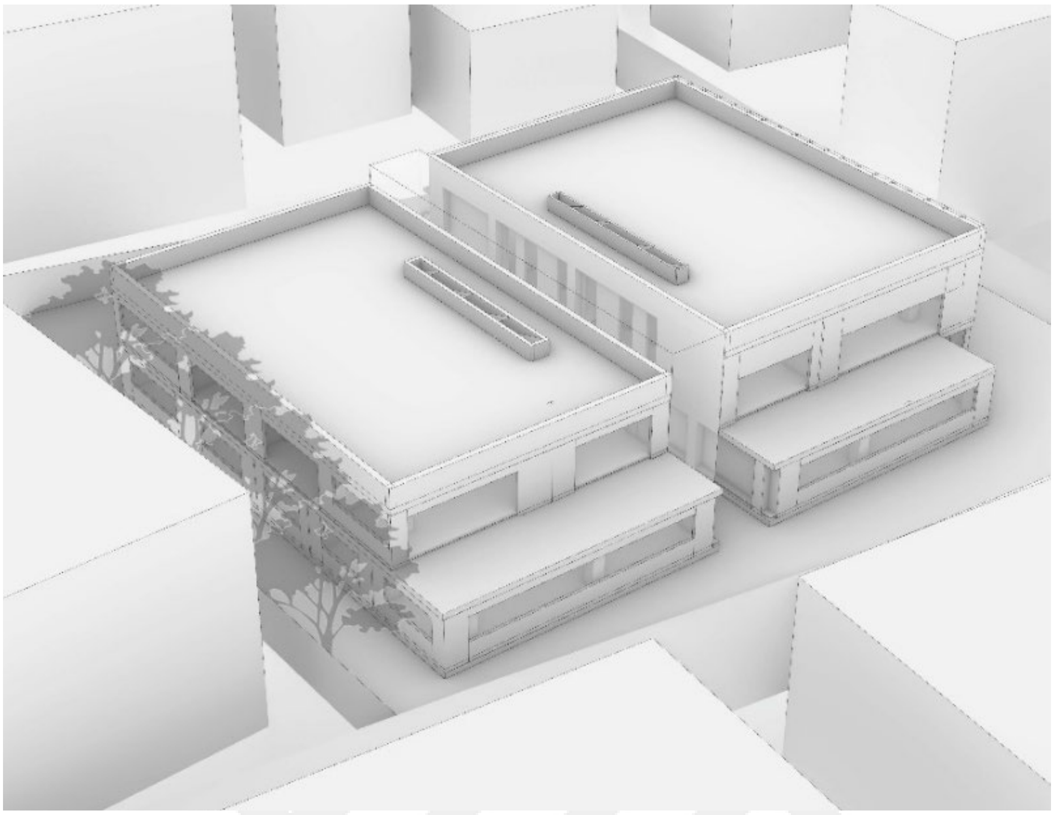


Figure 4.19: The Output of Building Shell Phase, view from the north-east (produced by author)

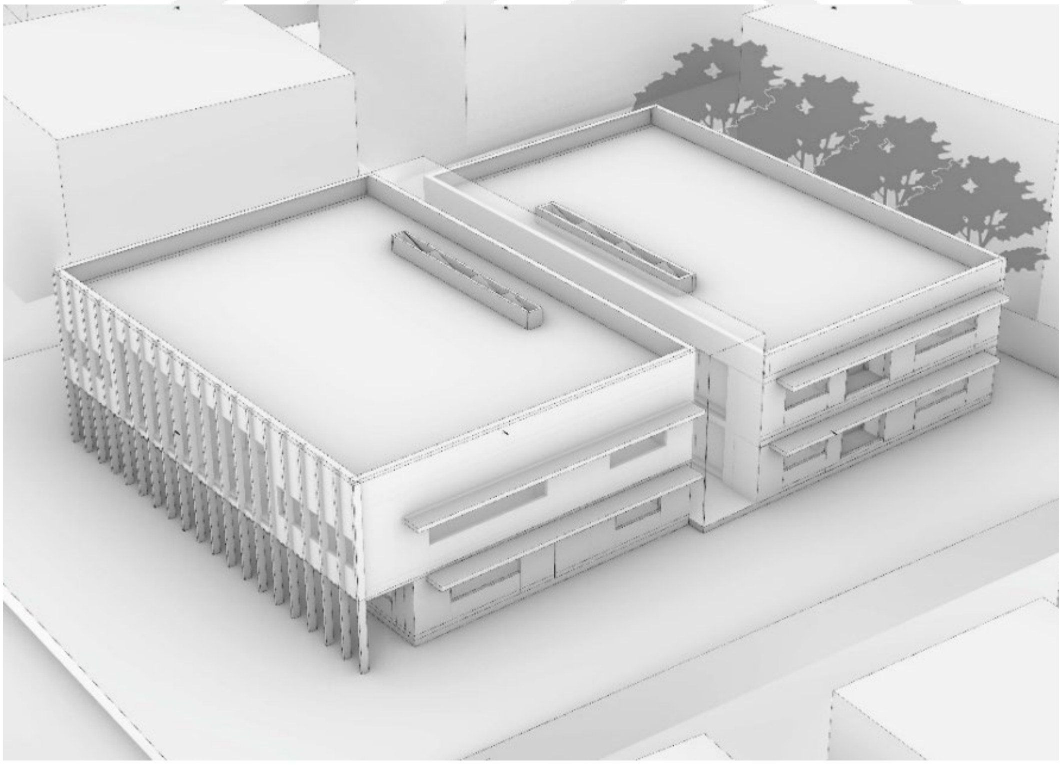


Figure 4.20: The Output of Building Shell Phase, view from the south-west (produced by author)

4.4. Materials and Precautions on Case

Many design decisions have been made until this stage, which is the last stage of the schematic design process. After this stage, the project continued with a stage where detailed drawings can be drawn. At this stage, it is necessary to discuss the material to ensure that the strategies used so far work consistently. There are also strategies that can only be achieved by selecting the characteristics of the material and this is the most appropriate stage for their use. This stage generally provides information about the critical properties of the material and the locations where it will be used.

4.4.1. Analysis of materials and precautions phase

The project is detailed after the building shell phase. For this phase, an analysis series was run again with the output of the building shell phase.

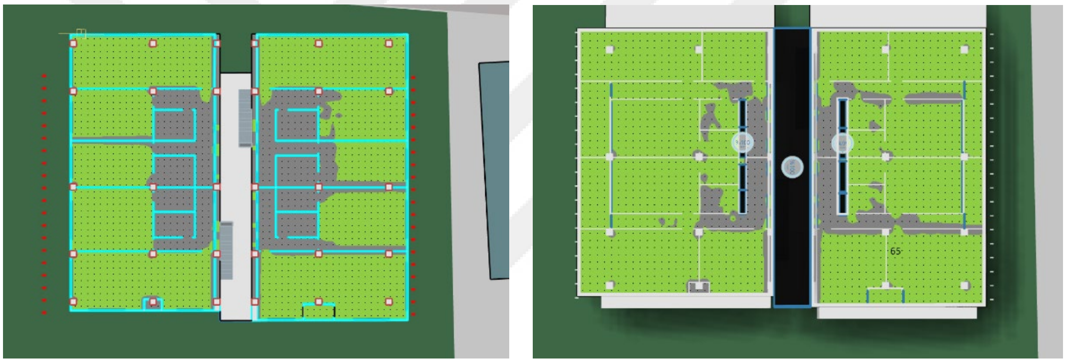


Figure 4.21: Daylight availability analysis of output of building shell phase / Climate studio (ground floor: left/first floor: right / Green areas are daylight available) (produced by Author)

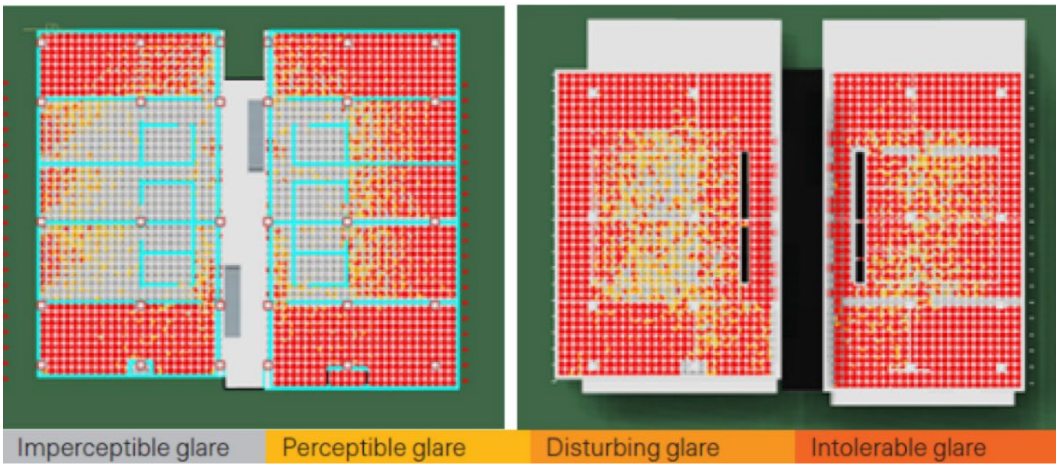


Figure 4.22: Annual Glare analysis of output of building shell phase / Climate studio (ground floor: left first floor: right) (produced by Author)

As a result of the analyses,

- According to the daylight availability analysis, it can be seen that many areas are daylight accessible as a result of the skylights added to the first floor of the building.
- As a result of the annual glare analysis, it is seen that the rooms with exterior facades of the building are disadvantaged in terms of glare. Especially on the first floor, this situation can be observed as dominant.

4.4.2. Recommendation of materials and precautions phase

To discuss some of the strategies used consistently, there are materials that need to be selected according to some characteristics.

- It is recommended that the sun-exposed surface of the solar chimney should be dark in color. (see Solar chimney)
- For Sunspaces to work consistently, the thermal mass of the part exposed to the sun must be high. This ensures that the heat is delayed and transferred to the rooms. (see Sunspaces)
- For the Trombe wall system to work consistently, no insulation should be applied to the face of the Trombe wall indoors. For the heat conduction of the trombe wall to be consistent and for daily needs, it should be produced with a material with high thermal mass. There are two suggestions for glass type. The first is insulated glass, and the other is low-E glass. Insulated glass (double glazing) utilizes the air gap between the glass panel and the wall as a thermal insulator, effectively retaining more heat indoors. In contrast, low-emissivity glass (Low-E glass), which is coated with a low-emissivity layer, absorbs heat while transmitting very little of it. The combination of these two is also favored. (see Trombe wall)

- Skylight can provide unwanted heat gain in summer. For this, adding a movable window shade or using in-glass blinds would be consistent.
- The bioclimatic atrium provides advantages in terms of insolation in winter because of its glass surfaces. In summer it is recommended to integrate a shading device to minimize unwanted heat gain.

Apart from these types of material interventions that support the currently used strategies, some strategies can only be done on a material or equipment scale.

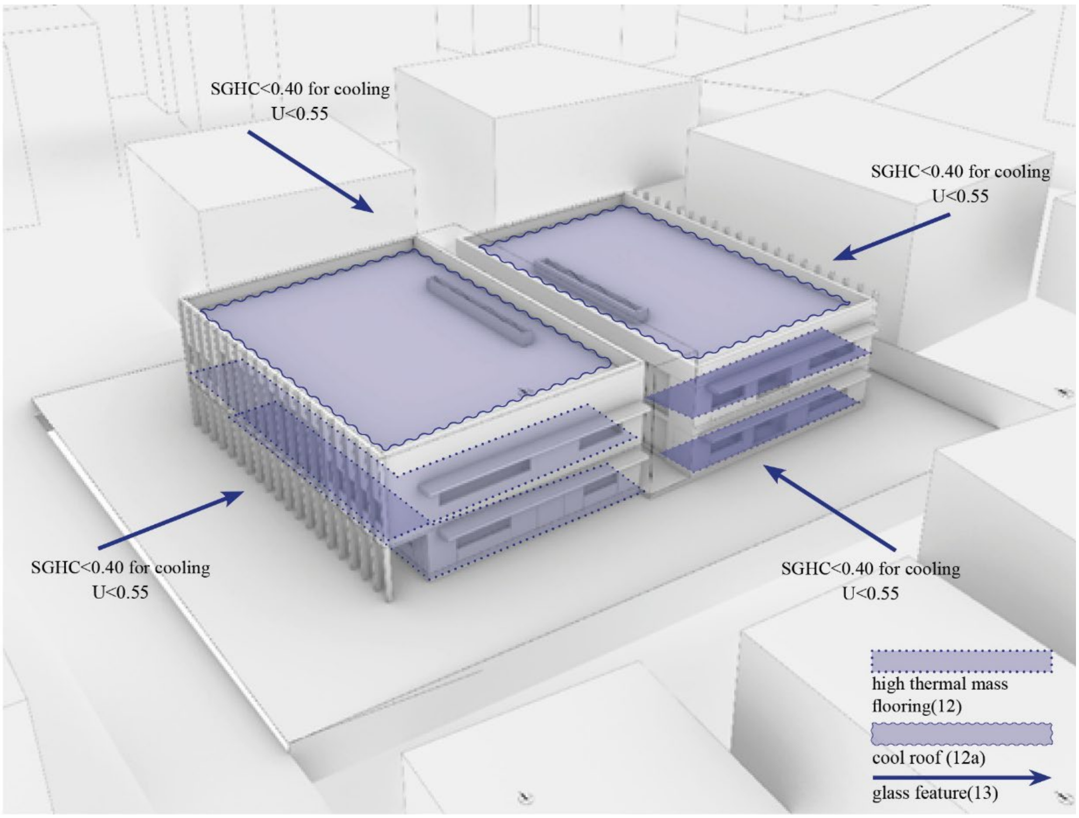


Figure 4.23: Recommendations from the analysis and research on the Material and Precautions process (produced by the author)

Firstly, when the recommendations are evaluated, design decisions that support the previous strategies have been taken. At this stage, 3 different recommendations can be taken apart from the material decisions that support the previous strategies.

- In case number 12, to reduce the building's heating requirement in winter, a material with high thermal mass properties was selected for the floors in the rooms with high solar exposure. This is an advantageous strategy for the winter period as the sunshades reduce the unwanted heat gain in summer.
- In case 12a, a cool roof, which is recommended for hot climate-type buildings, is used. This feature can be provided with material.

- In case 13, window and glass types can be selected according to the climate of the building location and the orientation of the window. Critical features are taken in Figure 3.36: Generalized Recommendations for Glazing + Window Selection. Since it is a skin-loaded building in the cooling-dominated climate type, according to the recommendation, glass types with SHGC less than 0.40 and U value less than 0.40-0.70 are used in both polar-faced and equator-faced facades and east-west facing facades. (see Window and glass types)

4.4.3. Result of materials and precautions phase

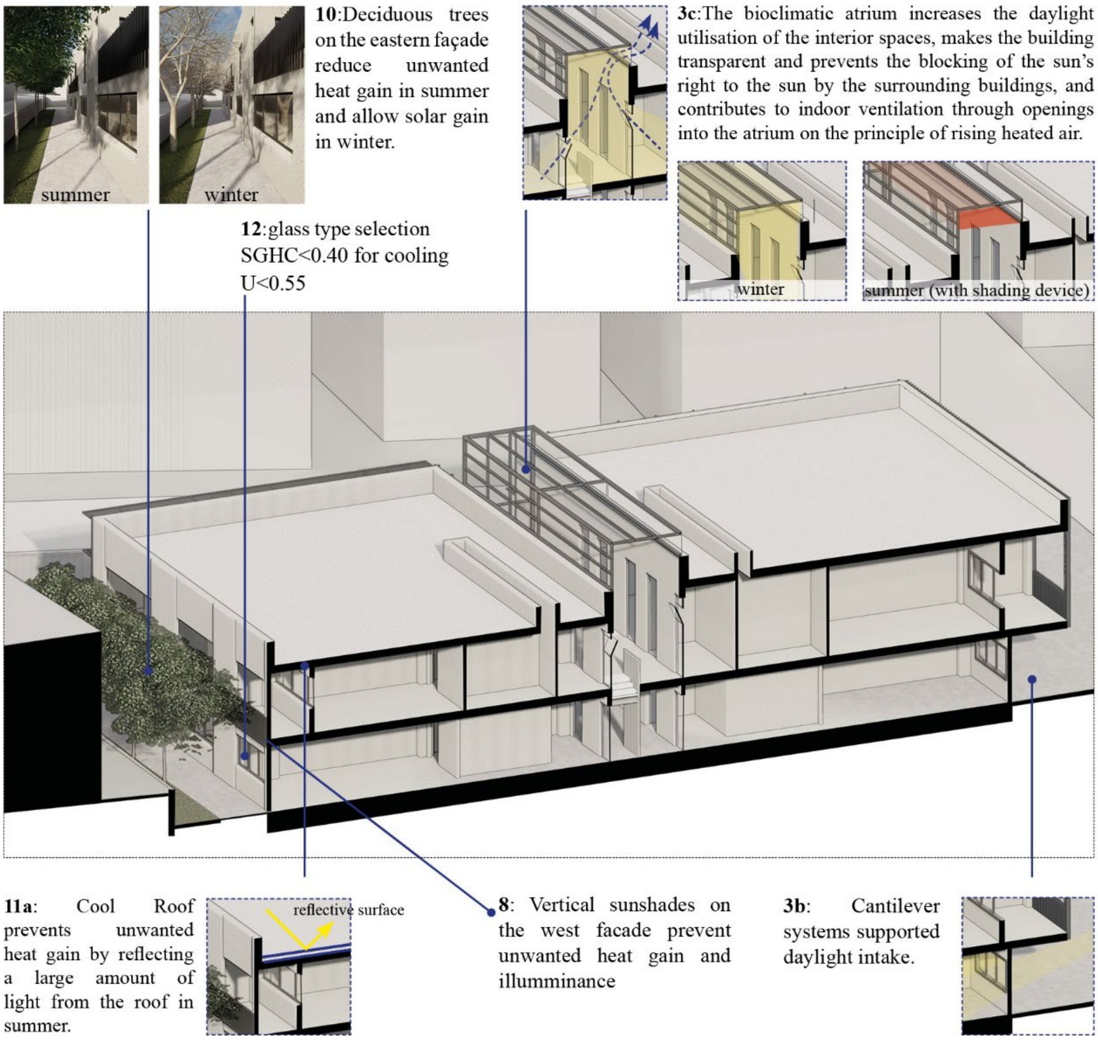


Figure 4.24: Bioclimatic Section of Case Project

In the project, the schematic design phase was finalized by adding the recommendations taken in this phase to the model formed by the decisions taken in the building shell phase. About 17 energy-efficient passive strategies were discussed in the project, and most of them were applied. Through the organization, the appropriateness of the discussed strategies or whether they would reduce the effectiveness of another strategy in case of addition was predicted. This cumulative approach ensured that each added system supported rather than prevented each other. It can be seen from Figure 4.25 that some strategies work together.

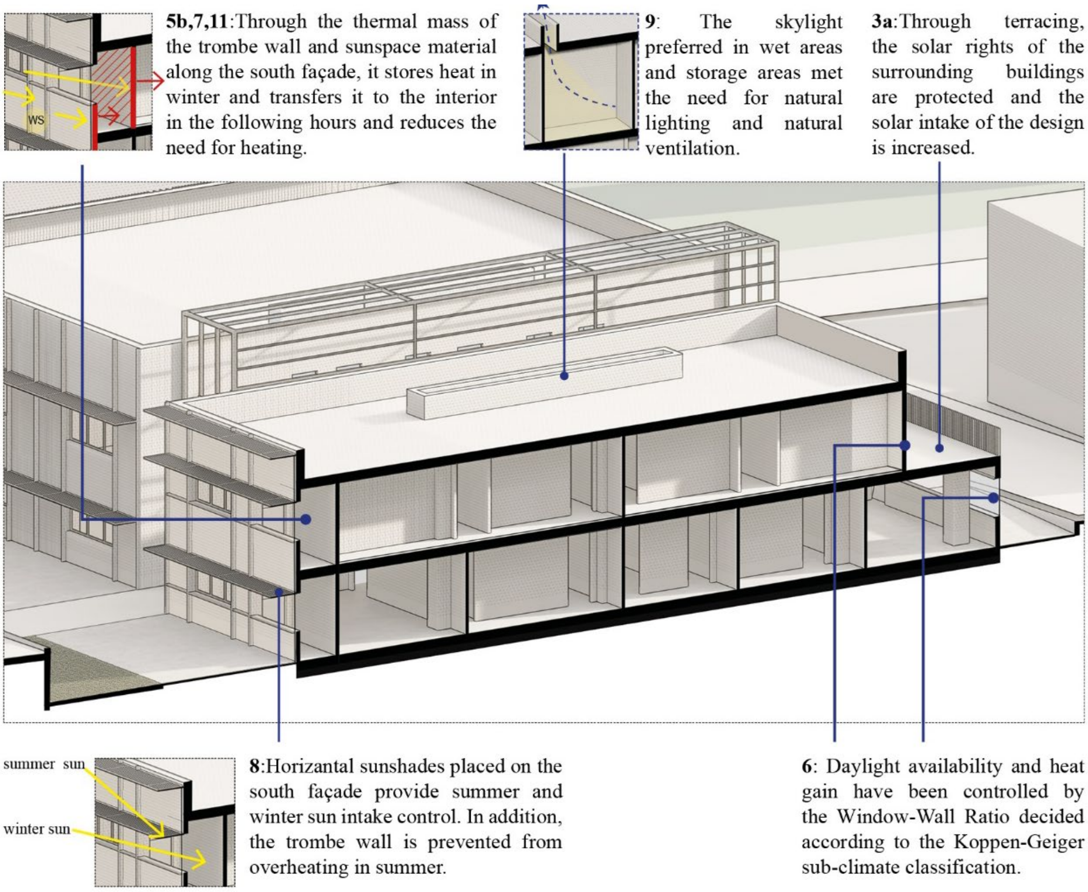


Figure 4.25: Bioclimatic Section of Case Project

5. CONCLUSION

Due to the current climate crisis, integrating energy-efficient strategies into the architectural project process is critical in contemporary architectural practice. Incorporating such strategies at the beginning of the project offers a wider scope for implementing passive energy efficiency strategies. Therefore, retrofitting existing buildings with these strategies involves higher costs and complexities. This emphasizes the importance of integrating energy efficiency strategies at the very beginning of the design phase, making this approach more integrated and effective.

This study is a pilot study designed to use and disseminate passive energy efficiency strategies. Although many energy efficiency strategies are available, the implementation processes of these strategies are not perceived as defined by many architects and architect candidates. This study aims to address this lack of guide and present an approach to facilitate the transfer of passive energy efficiency strategies that can be used without the need to perform mathematical calculations into the architectural project process with a simplified workflow. The schematic design process is specially designed to not interfere with the usual flow of architectural project processes.

Integrating passive energy efficiency strategies into the typical flow of architectural project processes aims to provide opportunities for designers by expanding parameters and adding inputs at the beginning of projects rather than imposing constraints. Existing buildings and academic research using these strategies have been reviewed and included in this thesis to accomplish this aim. With the approach provided in this research, it was possible to discuss the integration of many energy-efficient design strategies into the project. These strategies are presented by cases and examples used in practice. When the strategies provided by this workflow are applied to the project process, a case was studied to discuss the effect of the mentioned strategies on each other(see A Case Study Of A Housing Project In Izmir/Bornova).

Dividing the architectural project process into four different discussion processes allowed for the strategies to be discussed at an accurate time. In this way, revisions and constraints imposed on the project by early discussed strategies were prevented. Discussing about 17 energy-efficient design strategies in these four processes is possible. These strategies are listed in Decision-Making Framework in the Workflow Process (produced by Author)(Table 3).

Different analyses with different inputs can obtain these energy-efficient design decisions, and in some situations, they can be alternatives to each other.

When this table is analyzed,
There is no specific ranking between strategies with the same number (such as 3a and 3b).
Strategies such as ‘8 and 8’ are alternatives to each other.
Mass settlement is the first stage, and the strategies involved are as follows:

- No. 1 The maximum volume study is about placing a volume that creates a starting point for the project. This may vary depending on whether the employer wants maximum confined space or other negotiations. If there is a purpose, such as maximum closed area, the maximum volume that can be created according to the law can give a starting point. If there is no such purpose, a thin plan or east-west-oriented plan scheme can be used. The case study (see 4.1 Mass Settlement Study on Case) assumed that the employer wanted a maximum closed area.
- Strategy number 2 focuses on reconsidering the orientation of the building. The decision can be made according to the sun's path and solar radiation. According to the research, the most advantageous solution is to have the long side of the building facing 20 degrees to the south. The orientation of the case study is 20 degrees to the south (see 4.1 Mass Settlement Study on Case).
- Strategy 3a is used to decide the direction of the terracing of the building. This strategy can be based on the structure's daylight utilization or the solar rights of the surrounding structures. The process should be determined by which parameter is taken into account. Once the parameters have been decided upon, the process in the table can be followed. In the case (see 4.1 Mass Settlement Study on Case), the orientation parameter with respect to the surrounding buildings is taken into account, and a terracing is made towards the north.
- Number 3b strategy determines the points where a cantilever is required. This analysis can be done through the solar collection envelope. This decision can be made based on whether the point where the solar collection envelope is

above ground level has a poor solar collection. At the same time, the cantilever decision can be taken manually to protect from the summer sun on the south façade. In the case study (see 4.1 Mass Settlement Study on Case), the relevant intervention was made on the west façade to increase the sunlight intake(not on the long south façade to prevent loss of space).

- The Strategy 3c gives information about the location of the glass-bioclimatic atrium. Its purpose is to provide daylight and natural ventilation to the interior spaces. When used in a building, it can make part of the building transparent due to the large amount of glass surfaces, which is a method that can be used while protecting the solar rights of the surrounding buildings. This can be decided through the solar rights envelope. This strategy can be preferred in thick-plan buildings where daylight is needed. In the case study (see 4.1 Mass Settlement Study on Case), a decision was made according to the surrounding buildings, and a bioclimatic-glass atrium was proposed on the north-south axis, which can also work as an entrance.

The plan layout phase is the second phase, and the related strategies are as follows:

- Strategy 4 concerns the organization of the rooms. This can be discussed in terms of the shading created by the slabs, and in this case, it is possible to find areas that do not receive daylight and place wet rooms and storage areas in these areas, where artificial lighting is generally preferred. The case study (see Plan Layout on Case) placed wet areas and storage in these dark areas. The atrium decision taken in the previous phase (strategy 3c) and the analysis made before this phase allowed the design of a corridor with high daylight intake. It reduced the need for artificial lighting.
- Strategy 5a can give information about the location of the solar chimney. It can be placed on the façade with high solar radiation. The relevant strategy is applied in the case (see Plan Layout on Case).
- 5b sunspace strategy can give information about the location of sunspaces. It is recommended to place it on the facade most exposed to the sun. The relevant strategy is applied in the case (see Plan Layout on Case).

The building shell phase is the third phase, and the related strategies are as follows.

- Strategy number 6 is when the Window-Wall Ratio (WWR) is adjusted. Studies are made according to the Koppen-Geiger subclimate classification system, and decisions can be made on these. This decision was made as a subclimate type of CSA (see Building Shell Study on Case).
- The trombe wall strategy is number 7 in the table. It gives information about the location of the Trombe wall. A wall with high solar exposure is preferred. This decision can be made using solar radiation analysis. A Trombe wall is recommended if the proportion of solid walls on the facade is higher. In this case (see Building Shell Study on Case), the eastern part of the south façade works as a trombe wall. The glazing element used for the Trombe wall on this façade is in a position to support the sunspace. On the other side of the façade, the Trombe wall is not preferred.
- Strategy number 7' is used to determine the location of the DSF. It is recommended to be used if the glass façade ratio is higher than the solid façade according to WWR or if the glass façade ratio is preferred higher regardless of the WWR decision. In this case, it was not used. Because the ratio of solid façade is higher.
- Strategy 8 is about the form and position of the sunshades. This decision can be taken in several ways. Horizontal sunshades are recommended to operate the Trombe wall accurately, which is intended to prevent unwanted heat gain from the Trombe wall in summer. Sunshades can be used both as carriers in the double-skin facade and as integrated into the same facade system. Alternatively, horizontal use in the south and vertical use in the west and east in the northern hemisphere can be proposed independent of these two systems. This strategy has been applied in this case. (see Building Shell Study on Case)
- Strategy number 9 is related to skylight placement. It is recommended in locations that are dark in daylight availability analysis. It is recommended to be used for natural ventilation and lighting in rooms such as toilets and bathrooms, preventing mold and algae formation. In the case study, the skylight was used on the upper slab of the first floor
- Strategy number 10, deciduous trees, can be used as a precaution against sunlight exposure. It can be decided according to the location. If there is a need for additional privacy, the designer can prefer this strategy. In Case (see 4.3

Building Shell Study on Case), it was applied on the east façade to control the summer and winter sun and draw a visual boundary between the neighboring buildings.

The materials and precautions stage is the last stage of the schematic design process. Before proceeding to this stage, the strategies that concern the material properties and, in some cases, strategies should be revisited, and the necessary materials and precautions should be decided, for example, Trombe wall, DSF, or skylight.

- Strategy number 11 is the stage where the thermal mass of materials used in places such as flooring and walls is discussed. It can be decided based on solar radiation.
- Stage 11a is the cool roof strategy. It can be decided according to the climate type used in the case. This strategy was used in the case study because Izmir has a hot climate. (see Materials and Precautions on Case)
- Strategy number 12 is window and glass types. It can be decided according to climate type and directions. In the case study, the information given in Figure 3.36: Generalized Recommendations for Glazing + Window Selection (DeKay & Brown, 2014)table for the relevant climate type, Cooling dominated, building type, and Skin loaded building type were used strategically. Since the interventions that can be made for annual glare can reduce heat gain and daylight, the relevant intervention has not been made in the case study (see Window and glass types).

As can be seen from Table 3, the decision to use many energy-efficient strategies can contribute to the design by supporting each other when taken in the correct order. Being involved in this workflow process at any design stage is possible. For example, in a building whose structural elements are constructed, these strategies can be integrated at the plan layout stage, or in a structure whose internal partitions have already been built, the energy-efficient workflow can be integrated at the building shell stage. It is also possible to participate in the materials/ precautions phase of a building whose façade decisions have been largely completed.

As a result, passive energy efficiency strategies which are integrated early in the architectural design process can be discussed without slowing down the design process when discussed in the right sequence and cumulatively. This table is not a definitive conclusion or a method that must be followed, but it can be used by integrating different strategies or by reducing the aforementioned strategies. This workflow is an approach to understanding energy-efficient design and utilizing these strategies without getting lost in the abundance of data.

Table 5.1: Decision-Making Framework in the Workflow Process (produced by Author)

	Schematic Design Phase	Aim	Input	Interpretation / Assesment	Related Condition	Example / Case
	Mass Settlement Process					
1	Maximum Volume Study	To have a starting point	Topography Site boundaries, Location, Environmental data (surrounding buildings and roads), Approximate closed area, Site constraints	Maximum volume stated by law	If the employer requests a maximum closed area,	
		Maximizing Daylight		Thin plan or East-West oriented plan can be used.	If the employer is not concerned about maximum closed space,	Lloyd Lewis House, Libertyville, Illinois, Frank Lloyd Wright Science and Technology park, Gelsenkirchen, Germany, Kiesel and Partners
2	Orientation Study	Finding appropriate solar orientation	Solar radiation analysis	It is recommended that the long side of the building faces 20 degrees south	If it is possible according to project site,	
3a	Terracing	To have daylight without preventing solar rights of surrounding buildings	Solar envelope analysis	Decision can be taken according to the direction of descent of the solar rights envelope.	If there is a descent solar rights envelope,	*In case of northwards descent: of City Hall, Sir Norman Foster; Greater London Headquarters, London, England,2002 *In case of southwards descent: SIEBB Building, Mario Cucinella Architects
		To control heat gain and daylighing	Sunpath / Orientation	Can be done unrelated to surrounding buildings to create shade according to direction		the above 2 examples can also be used according to the designer's interpretation
3b	Cantilever Systems	To have daylight every facade	Solar envelope analysis	can be used where the solar collection envelope is higher than ground level	If part of the solar collection envelope above ground level,	
		To control heat gain and daylighing	Sunpath / Orientation	This can be done unrelated to the surrounding buildings to control heat gain on a specific facade		City Hall, Sir Norman Foster; Greater London Headquarters, London, England,2002
3c	Location of Glass- Bioclimatic Atrium	Daylight and natural ventilation indoors	Detection of daylight unavailable places in the interior	Can be done unrelated to surrounding buildings to take light interior rooms	If project have thick plan,	Reiterstrasse Building,in Bern, Switzerland by Bureau D'architecture
			Solar envelope analysis	The line in the solar rights envelope where the descent begins.		Public Housing in Platja D'En Bossa,08014 arquitectura
	Plan Layout					
4	Organization of Rooms	Use daylight effectively in rooms	Daylight availability analysis	Areas with the lowest daylight suitable for toilets and storage	If there are areas in the building that will be advantageous to receive light or if there are areas that need to be protected from light	Library,Mount Angel Abbey, Oregon, Alvar Aalto Auditorium Building, Chicago, Illinois, Adler and Sullivan
5a	Solar Chimney	Solar related ventilation	Solar exposure analysis	The most sun-exposed wall is suitable for solar chimney (mostly South façade for Northern hemisphere)	If the usage rate of the rooms is high.	Sidwell Friends School
5b	Sunspaces	Heat gain during winter	Solar exposure analysis	The most sun-exposed wall is suitable for sunspace (mostly South façade for Northern hemisphere)	If the usage rate of the rooms is high.	Solarhaus, Lützowstrasse, Berlin,Germany, Ibus
	Building Shell Study					
6	Window-Wall Ratio (WWR)	Optimize daylighting and heat gain	Koppen Geiger classification sub-climate type detection and related research	Ratios can be obtained according to subclimate		
7	Trombe wall	Reducing the need for heating in winter	Solar radiance analysis	Recommended for use on facades with high solar radiation.	If, according to WWR, there are more solid surfaces than glass surfaces If solid wall is preferred instead of following WWR	National Renewable Energy Laboratory of the Zion National Park Visitor Centre
7'	Double Skin Facade	Ventilation Glare reduction Heat gain control	Solar radiance analysis annual glare analysis	It is recommended for use on facades with high solar radiation and annual glare.	If, according to WWR, there are more glass surfaces than solid surfaces If WWR is not followed because glass facade is requested/preferred	Phil and Penny Knight Campus for Accelerating Scientific Impact/Ennead Architects+Bora Architects
8	Sun Shades	Optimising the heat gain by controlling daylight into the interior space	Trombe wall location	The Trombe wall must work together with the sunshade to prevent the storage of unwanted heat during the summer months.	If Trombe wall was used	The Edith Green-Wendell Wyatt (EGWW) Federal Building
			DSF location	Can be constructed as a carrier system together with DSF	If DSF was used	
			Orientation	Can be decide according to directions	If both cases are not used	
9	Skylight	To get daylight to areas that has low daylight availability	Daylight Availability Analysis	It prevents mould formation in wet areas and is therefore recommended.	Orientation should be chosen according to the need.	California Academy of Sciences
10	Decidouous Tree	Optimising the heat gain by controlling daylight into the interior space	Orientation	Can be decide according to directions	If the sunshade is not placed where it should be by design If there is a need for additional privacy	
	Materials and Precautions					
11	Thermal mass	To reduce the need for heating in the winter months	Solar Radiance	Flooring that coincides with facades with high solar radiance		Hockerton Housing Project building
		Ensure the effective operation of previous strategies	Material properties required by the strategies used	can be used in walls where thermal mass is effective such as sunspace, Trombe wall	If strategies requiring thermal mass were used	
11a	Cool roofs	Prevent unwanted heat gain	Climate type	can be used if the building is located in a climate type with high temperatures	If the need for cooling is more than heating according to the climate	
12	Window and glass types	Prevent unwanted heat gain	Climate type and orientation of facade	Glazing on facades with glare can be selected to prevent this situation.	If there are surfaces with excessive glare according to annual glare analysis	
		Prevent Glare	Annual Glare analysis			
		Ensure the effective operation of previous strategies	material properties required by the strategies used	Glass type should be reconsidered in strategies such as trombe wall, DSF.	If strategies requiring special glass types are used.	

General information about the table:
1) Regarding strategies with the same number. There is no recommended order, it is left to the designer (e.g. 3a,3b).
2) Strategies like numbered 7 and 7' are alternatives to each other. They depend on the decisions taken in the previous stages.

5.1. Research Limitations

Some challenges were experienced while conducting this research and some issues were consciously left out of the scope. Potential challenging situations for people who want to work in this field are mentioned below. Then, the limitations of the solar envelope technique, which is one of the techniques used, are presented.

The room's purpose is important when making decisions such as window placement. Still, the design that can be made according to the interior organization of this room is outside the scope.

Another limitation of this research is that many passive strategies can be used in the energy-efficient design process. Some of these strategies require regular revision and iterative work. As mentioned at the beginning of the study, strategies that require regular revising were not used. These strategies and methods contribute to energy-efficient design, and design can be improved in this way. The reason for not including them in this study is that they cause a delay and revision in the project process due to their iterative nature.

These strategies can be implemented through a calculational study and the consistency of these decisions can be proved by such methods. However, this requires intensive preliminary work and learning difficulties. For this reason, the computational approach was excluded from the scope of this research, and graphic-based programs were preferred as a more consistent learning method for designers. In the proposed workflow, the contribution of energy-efficient strategies to the efficiency of the design process when integrated in a specific order is discussed. It is posited that, inevitably, these strategies will increase the energy efficiency of the design, therefore no comparative calculation is made.

Another limitation of this study is that the proposed workflow is primarily based on reinforced concrete structures, due to the prevalence of reinforced concrete in contemporary building technology. If the study were to focus on other construction techniques, many of the decisions within the workflow would still be applicable; however, some modifications to the workflow might be necessary to accommodate the specific characteristics of different construction methods.

5.1.1. Limitation test of solar envelope method

This test aims to analyze the information it provides when the difference between the heights of the surrounding structures and the designed building varies. First, it examines the case where the building to be designed is higher than the surrounding structures, then the case where it has a similar height to the surrounding structures, and finally, the case where it is planned to design a building with a lower height than the surrounding structures.

When the designed building is higher than the surrounding buildings,

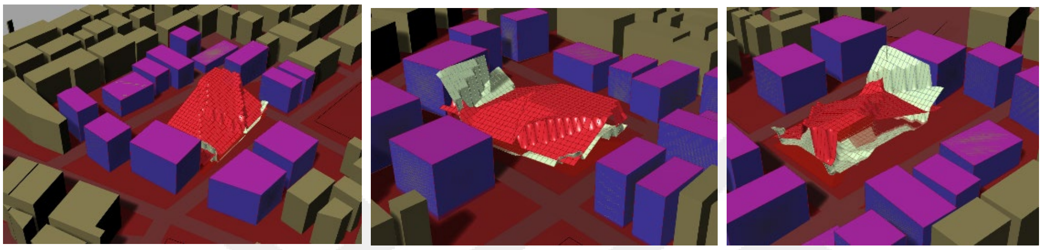


Figure 5.1: The result when the solar envelope method is run with the condition (Green Envelope: Solar Collection envelope / Red Envelope: Solar rights envelope)(produced by author)

For this test, the maximum height parameter used in the script was increased to 80 meters. The solar envelope method does not offer recommendations above a certain height. The solar envelope method restricts design proposals above a certain height because the upper envelope represents the maximum height that can be achieved without infringing on the solar rights of surrounding buildings. Therefore, there is an upper limit. However, carrying out this analysis creates awareness of the situation and makes the designer aware that the surrounding buildings' solar rights are blocked above a certain height.

When analyzed through this example, it is unlikely to find a form in high-rise buildings according to the surrounding structures. However, sometimes architects may be faced with such a problem. In such a case, an approach can be taken through Francesco De Luca's 'Solar Form Finding', which offers a consistent solution by considering the insolation needs of the surrounding structures and the designed building (see Solar Form Finding). Figure 5.2 shows the results when the designed building has a similar height to the surrounding buildings.

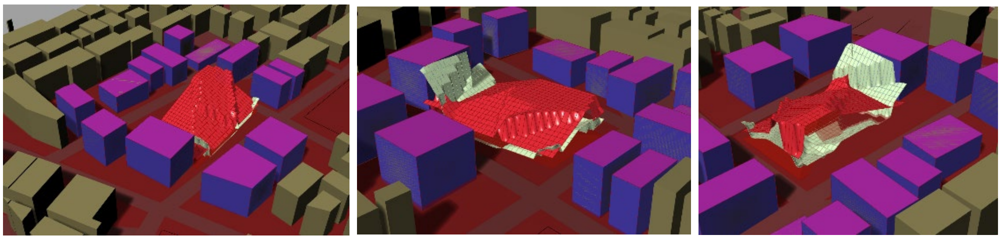


Figure 5.2: The result when the solar envelope method is run with the condition (Green Envelope: Solar Collection envelope / Red Envelope: Solar rights envelope)(produced by author)

The maximum height parameter used in the script for this test was entered as 10 meters by the standard in the context limited by the height of 2 floors. The building to be designed is desired to be 10 meters high, the volume produced by these envelopes is compatible with the desired building volume. Therefore, when the conditions were provided in this way, it gave a consistent and useful result. Figure 5.3 shows the results when the designed building has less height than the surrounding structures.

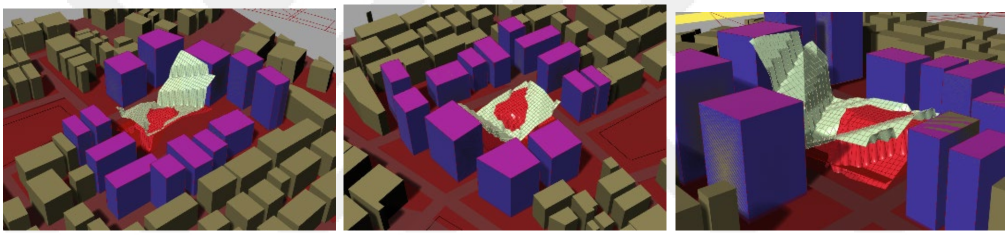


Figure 5.3: The result when the solar envelope method is run with the condition (Green Envelope: Solar Collection envelope / Red Envelope: Solar rights envelope)(produced by author)

The solar envelope method cannot provide a consistent volume when the surrounding structures are higher than the building to be designed. However, the height required for the building to receive the sun can be read by the solar collection envelope (green envelope) shown in Figure 5.3. Analyzing this situation at the beginning can prevent a critical insolation error.

Within the scope of this study, considering both the limits of the context and the working principle of the method, it was decided that it could be used when designing at a height similar to the surrounding buildings to achieve the most consistent result. Since the site's constraints were already such, the design continued with this method.

6. FUTURE STUDY

This study is an initial study on the cumulative progress of energy-efficient design. It discusses energy-efficient design through solar passive strategies. Some possible future work can be done to improve this study or to increase its usability.

One of the issues where this study can be improved is the addition of wind-related strategies to this process, which provides energy saving for the buildings to be designed.

One of the issues that can be studied to increase the use of this study is the chance of collecting this workflow in a centralized system. Programs such as Climate Consultant can give design strategies depending on the climate. Thanks to this workflow, it is possible to produce a system that can provide project-specific design suggestions that are different from Climate Consultant. The idea of gathering these strategies in a single interface can contribute to energy-efficient design without slowing down the project processes by accelerating the integration of energy-efficient strategies into the design processes.

The scope of this workflow can be expanded by incorporating new strategies or adapting existing ones, as long as the appropriate conditions are met. This flexibility allows for a more comprehensive approach to design, accommodating various building types, climates, and technological advancements. By continuously evaluating and integrating additional strategies, the workflow can evolve to address emerging challenges and optimize building performance. This adaptability ensures that the workflow remains relevant and effective, regardless of changes in building standards, materials, or environmental considerations.

The strategies employed in this study were selected based on the assumption that their inherent characteristics would contribute to energy efficiency. To validate this assumption, these strategies can be tested through a detailed calculative and comparative analysis. By quantitatively evaluating their performance under various conditions, it is possible to determine the actual impact of each strategy on energy efficiency. This approach would provide a more empirical basis for understanding the effectiveness of the strategies, allowing for adjustments and improvements where necessary.

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