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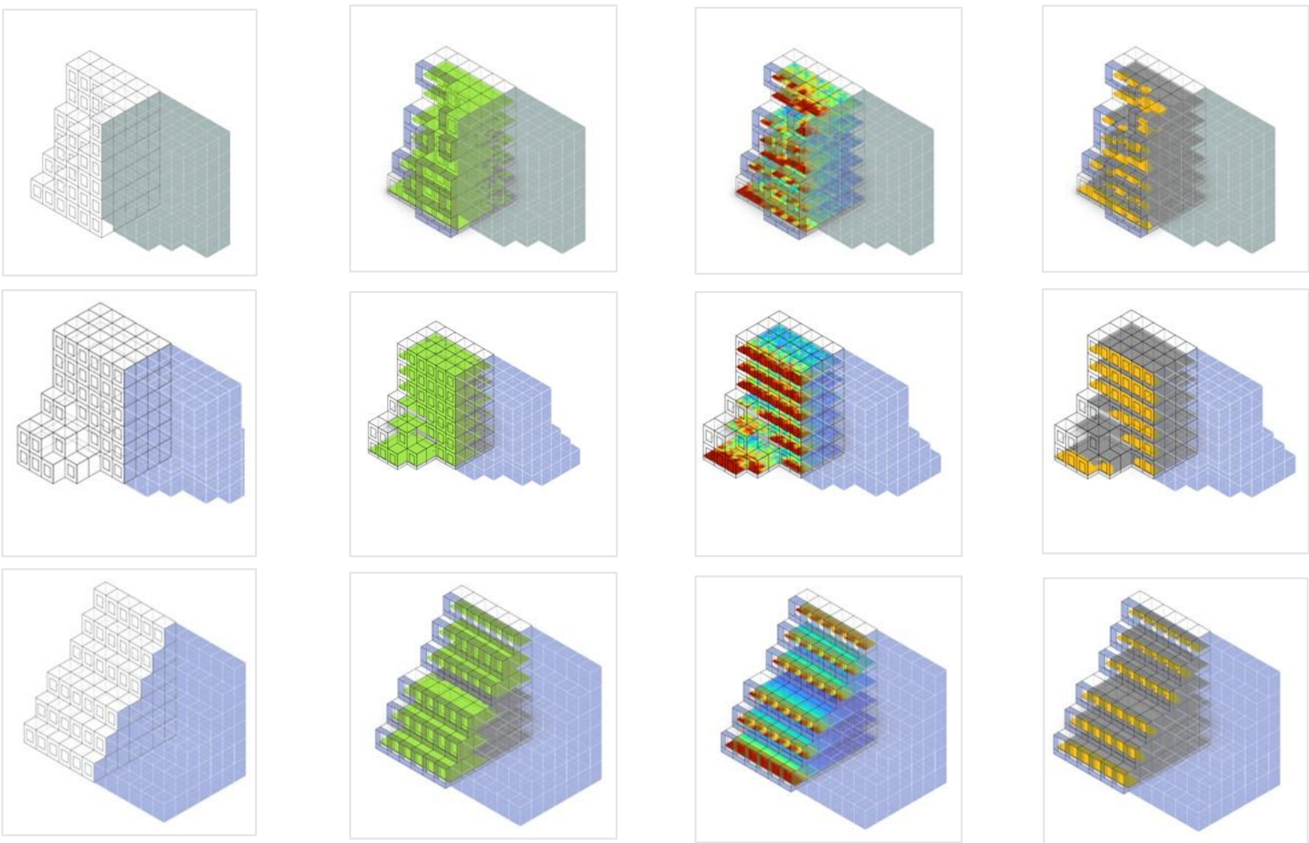
Master of Science degree course in
Building and Architectural Engineering
Track: Building Engineering

ENERGY AND BUILDING FORM:

An Optimized Form Finding Toolkit for Early-Stage Design

Analyzing Generic Algorithm-Based Performance Metrics



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Master thesis presented to the Graduate Program in Building and Architectural Engineering of Politecnico di Milano as a prerequisite to obtain the master's degree in Building and Architectural Engineering.

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"*Scientist investigate that which already is. Engineers create that which has never been"*

(Albert Einstein)

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Although we faced several challenges during the thesis process, the 2023 Turkiye – Syria Earthquake was a significant obstacle that claimed the lives of approximately 60,000 people, including some of our friends and colleagues. Despite this tragedy, we were able to overcome the challenges with the help of our tutors and the unwavering support of our loved ones.

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It has been an absolute pleasure to share this experience with a such wonderful atmosphere, and we will cherish the memories we have created together forever.

ABSTRACT

The building sector is a crucial contributor to climate change, accounting for around 40% of global energy consumption and 33% of CO_2 emissions [1] [2]. Energy demand in buildings is driven by a range of factors, including heating, cooling, lighting, and appliances, which are in turn influenced by building forms, such as orientation, shape, and size. Climate change is exacerbating energy demand in buildings, leading to a rise in energy consumption and emissions. However, implementing sustainable building design and energy-efficient approaches, along with the use of renewable energy sources, aims to reduce energy consumption and carbon emissions in the building sector. According to research by the United Nations Environment Program, using renewable energy sources and energy-efficient building materials could potentially reduce global CO_2 emissions from buildings by 84% [2]. Therefore, addressing the energy demand of the building sector and promoting sustainable building design is critical to achieving global climate change targets and mitigating its impact on the environment.

To expand the knowledge base on building massing in the design stage, this study aims to explore building typologies in different scales and assess their energy performance. Specifically, the study aims to evaluate the extent to which building forming methodology can meet accounting for the role of daylighting, which is a crucial factor in ensuring occupant comfort, reducing energy demand, and maximizing solar potential.

The study examines a courtyard case with a floor-to-area ratio of 6 and evaluates its daylighting, solar potential, and energy demand, giving equal weight to all three indicators. The research explores different typologies to understand their strengths and weaknesses and concludes. For example, results of the Angular Shadings with Waving Method has lower energy requirements and higher solar production, making it an attractive option, particularly for buildings with good daylighting. Although courtyards have limited daylighting, they require less energy. The research also finds that massing decisions have a significant impact on building performance, and careful consideration must be given to the design process to avoid negative outcomes, even with other passive strategies applied to the envelope.

Consequently, by focusing on building in different scales and energy performance, the study aims to provide valuable outcomes.

Keywords: Climate Change, Sustainable Design, Energy Efficient Buildings, Solar Potential, Energy Demand, Daylight Factor, Point Scanning, Energy Plus.

ABSTRACT

Il settore delle costruzioni è un contributore cruciale al cambiamento climatico, rappresentando circa il 40% del consumo globale di energia e il 33% delle emissioni di CO_2 [1] [2]. La domanda di energia negli edifici è guidata da una serie di fattori, tra cui il riscaldamento, il raffreddamento, l'illuminazione e gli elettrodomestici, che a loro volta sono influenzati dalle forme degli edifici, come l'orientamento, la forma e la dimensione. Il cambiamento climatico sta aggravando la domanda di energia negli edifici, portando ad un aumento del consumo energetico e delle emissioni. Tuttavia, l'implementazione di progettazione edilizia sostenibile e approcci energeticamente efficienti, insieme all'uso di fonti di energia rinnovabile, mira a ridurre il consumo di energia e le emissioni di carbonio nel settore delle costruzioni. Secondo la ricerca del Programma delle Nazioni Unite per l'Ambiente, l'uso di fonti di energia rinnovabile e materiali edilizi energeticamente efficienti potrebbe potenzialmente ridurre le emissioni globali di CO_2 degli edifici dell'84% [2]. Pertanto, affrontare la domanda di energia del settore delle costruzioni e promuovere la progettazione edilizia sostenibile è essenziale per raggiungere gli obiettivi di cambiamento climatico globali e mitigare il suo impatto sull'ambiente.

Per ampliare la base di conoscenza sulla massa edilizia nella fase di progettazione, questo studio mira ad esplorare le tipologie edilizie in diverse scale e valutarne le prestazioni energetiche. In particolare, lo studio mira a valutare in che misura la metodologia di formazione degli edifici possa soddisfare il ruolo dell'illuminazione naturale, che è un fattore cruciale per garantire il comfort degli occupanti, ridurre la domanda di energia e massimizzare il potenziale solare.

Lo studio esamina un caso di cortile con un rapporto pavimento-area di 6 e valuta la sua illuminazione naturale, il potenziale solare e la domanda di energia, attribuendo lo stesso peso a tutti e tre gli indicatori. La ricerca esplora diverse tipologie per comprendere i loro punti di forza e di debolezza e conclude. Ad esempio, i risultati delle Ombreggiature Angulari con Metodo Ondulato hanno un minor fabbisogno energetico e una maggiore produzione solare, rendendolo un'opzione attraente, in particolare per gli edifici con una buona illuminazione naturale. Anche se i cortili hanno una limitata illuminazione naturale, richiedono meno energia. La ricerca evidenzia inoltre che le decisioni di massa hanno un impatto significativo sulle prestazioni degli edifici e che una particolare attenzione deve essere data al processo di progettazione per evitare risultati negativi, anche con altre strategie passive applicate all'involucro.

Di conseguenza, concentrandosi sulla costruzione in diverse scale e sulle prestazioni energetiche, lo studio mira a fornire risultati preziosi.

Parole Chiave: Cambiamento Climatico, design sostenibile, edifici ad alta efficienza energetica, potenziale solare, domanda energetica, fattore di luce diurna, point scanning, energia plus.

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INTRODUCTION

Buildings has a significant impact on their energy consumption and greenhouse gas emissions, which are major contributors to climate change. While the buildings designed with poor insulation or inefficient heating and cooling systems require more energy to maintain a comfortable temperature, leading to higher energy consumption and emissions. On the other hand, buildings that are designed with energy efficiency in mind can significantly reduce their energy consumption and greenhouse gas emissions, helping to mitigate the impact of climate change. Since the Climate change is one of the most pressing global issues of our time, and it is largely driven by the increase in energy consumption and the use of fossil fuels. According to the International Energy Agency, global energy-related carbon dioxide (CO_2) emissions reached a record high of 33.1 gigatons in 2019, with the power sector accounting for the largest share of emissions [3]. Furthermore, global energy consumption has been steadily increasing over the years, with the World Bank reporting a 21% increase in energy use per capita between 2010 and 2018 [4].

To address the challenge of climate change, there is a need to increase energy gain while reducing our carbon footprint. This can be achieved through various means such as increasing energy efficiency, using renewable energy sources, and reducing energy waste. In recent years, some countries have made noteworthy progress in achieving these goals.

For example, Iceland has been successful in using renewable energy sources to achieve an important level of energy gain while reducing carbon emissions. According to the National Energy Authority of Iceland, 98% of the country's electricity production and 87% of its primary energy consumption come from renewable sources [5]. Norway is another country that has made considerable progress in promoting energy efficiency. The Norwegian government has set a target of reducing energy consumption by 20% by 2020 compared to 2008 levels [6].

However, globally, the use of fossil fuels still dominates energy generation, with renewables accounting for a much smaller share. Table 1 shows the breakdown of global primary energy consumption by source between 2010 and 2018.

Table 1: Global Primary Energy Consumption by Source (2010-2018)

Source	*2010 (% of Total)*	*2018 (% of Total)*
Fossil Fuels	81.7	80.3
Renewables	8.5	11.5
Nuclear	4.9	4.5
Others	4.9	3.7

Source: World Bank [4]

As can be seen from Table 1, the use of fossil fuels still dominates global primary energy consumption, accounting for more than 80% of the total in both 2010 and 2018. However, there has been a gradual increase in the use of renewables, which rose from 8.5% of total energy consumption in 2010 to 11.5% in 2018.

Table 2 shows the breakdown of global electricity generation by source between 2010 and 2018.

Table 2: Global Electricity Generation by Source (2010-2018)

Source	*2010 (% of Total)*	*2018 (% of Total)*
Fossil Fuels	67.5	63.2
Renewables	19.5	26.3
Nuclear	12.1	10.4
Others	0.9	0.1

Source: International Energy Agency (2021) [7]

As can be seen from Table 2, the share of fossil fuels in global electricity generation has decreased from 67.5% in 2010 to 63.2% in 2018, while the share of renewables has increased from 19.5% to 26.3% over the same period. The use of nuclear power has remained relatively stable, accounting for around 10% of total electricity generation.

Another way to increase energy gain while reducing our carbon footprint is by reducing energy waste. Table 3 shows the breakdown of global energy consumption by end-use sector between 2010 and 2018.

Table 3: Global Energy Consumption by End-Use Sector (2010-2018)

Sector	*2010 (% of Total)*	*2018 (% of Total)*
Buildings	32.9	31.7
Industry	40.7	42.1
Transportation	22.8	24.2
Others	3.6	2.0

Source: International Energy Agency (2021) [7]

As can be seen from Table 3, the industrial sector accounts for the largest share of global energy consumption, followed by transportation and buildings. By reducing energy waste in these sectors, significant energy gains can be achieved. For example, a study by the International Energy Agency found that implementing energy-efficient technologies in the industrial sector could reduce global energy consumption by up to 15% by 2040 [7].

In addition to reducing energy waste, improving energy efficiency is also a key strategy for increasing energy gain while reducing carbon emissions. Energy efficiency measures can range from simple actions such as turning off lights when leaving a room to more complex measures such as upgrading building insulation or replacing old appliances with more energy-efficient models.

Governments and organizations around the world are recognizing the importance of improving energy efficiency. For example, the European Union has set a target of reducing primary energy consumption by 20% by 2020 compared to 2005 levels [8]. In the United States, the Department of Energy has launched the Better Buildings Initiative, which aims to improve energy efficiency in commercial, industrial, and residential buildings by 20% by 2020 [9].

Renewable energy sources such as solar, wind, and hydropower also play a significant role in increasing energy gain while reducing carbon emissions. The cost of renewable energy has been steadily decreasing over the years, making it more competitive with fossil fuels. In fact, a report by the International Renewable Energy Agency found that the cost of renewable energy could be lower than fossil fuels by 2020 in many parts of the world [10].

Despite the progress made in increasing the use of renewable energy sources, there are still challenges to be addressed. One of the main challenges is the intermittency of renewable energy sources, which can make it difficult to ensure a stable supply of electricity. This challenge can be addressed through the development of energy storage technologies such as batteries or pumped hydro storage.

In conclusion, addressing the challenge of climate change requires a concerted effort to increase energy gain while reducing carbon emissions. This can be achieved through various means such as increasing energy efficiency, using renewable energy sources, and reducing energy waste. While some countries and organizations have made considerable progress in this regard, there is still a long way to go to achieve a sustainable energy future.

Given the full picture, the question of balancing sustainability and environmental concerns with comfort in building design is a complex one. One approach is to focus on increasing knowledge and expertise in the areas of architectural design that consider climate change and energy optimization. This can involve developing strategies for optimizing building forms and neighborhood design to reduce energy consumption and minimize environmental impact.

To achieve this, architects and engineers can look for ways to incorporate sustainable materials and technologies into their designs, such as using energy-efficient lighting and heating systems, incorporating green roofs and walls, and designing buildings with passive solar heating and cooling. They can also consider the local context and climate when designing buildings, taking into account factors such as prevailing winds, solar exposure, and topography.

Yet, even for architects and engineers, incorporating and being able to provide sustainable buildings can be challenging. Thus, in this thesis, the aim is to provide a toolkit that can show the behavior of different scales of building solutions and assist them to decide on designing buildings.

LITERATURE REVIEW

In order to conduct this research, it was necessary to recall and review some fundamental concepts. This was crucial in setting a firm conceptual foundation for the study. Especially given that the research questions were inspired by the daily challenges overlooked by architects, engineers, and designers. A variety of literature sources were examined to gain a comprehensive understanding of the topic, including foundational principles as well as comparative studies on issues such as building form, daylighting, energy efficiency, and solar potential. For the purpose of understanding foundational principles related to building form and energy, the evolution process of building forming should be observed. To observe that, the book Energy Form by Knowles is utilized.

In the book of Energy Form [11] evolution of primitive and early development of form stated that:

> *"It is difficult to determine the beginning step of very early or primitive development that have since come to be regarded as purposeful, but in all likelihood the emergence of the purpose in man-made arrangement must have been gradual. It emerged as form emerged; as stones accumulated and as the earth was scooped out, some purpose arose beyond the single act. It is not likely that the builders began with an image of ultimate form. Thought their tenacious and prolonged efforts to shape and structure an immediate response to environment, form and purpose blended to become inseparable in mind of the builder."* (Knowles R. 1980) [11]

At the outset of this investigation, to understand the conceptual approach behind the building form and process of man-made manifestation of adaptive systems is represented by structure and natural phenomena that arose from experiments of trials and errors that will ultimately reach final form this shows that the expectancy of the process produces slow development in a building covering small area also as form initially correlates to function therefore not looking through what maybe other factors determining overlooked. Therefore, the need for form finding data-driven is shown to be important to produce an overview of all the possible configurations of the building aspects.

Therefore, two important aspects of sustainable architecture form of today are energy and the environment. and the integration of these two facets in architectural design can lead to the creation of green buildings that are energy-efficient, environmentally friendly, and provide a healthy and comfortable living environment, this study which can be seen by International Journal of Thermal and Environmental Engineering (volume 14) as it dictates [12] “hypothesizes that using solar shading devices with suitable design decisions of the fenestration affects the daylight level, solar heat gain, visual comfort, and thermal comfort for users. The study examines the relationships between building envelope design and building energy efficiency through research and simulations.”

For this reason, this study draws upon several definitions of environmentally conscious design that shed light on the topic. The affordability and versatility of renewable technologies, such as building-integrated photovoltaic systems, have contributed to the rise of sustainable or green buildings, in which are described by the combination of design and technology, especially renewable energy systems, to meet occupants' needs while minimizing carbon emissions [12]. Passive houses, for example, are designed to maintain a comfortable interior climate without relying on active heating and cooling systems. Additional energy requirements are met using renewable energy sources. In contrast, zero-energy buildings are designed to generate as much energy from on-site renewable energy sources as they consume. Excess energy can be stored in batteries or thermal storage [12].

Another unique development in contemporary construction is the emergence of net energy plus buildings, which produce more energy than they consume annually. This excess energy is often derived from solar cells, solar heating and cooling systems, insulation, and thoughtful site selection and orientation [13]. The results of our simulations and case studies will enable us to categorize the type of building we are investigating. Although the application of passive strategies for energy efficiency is a priority, the aim of maintaining internal comfort prevents passive houses. Finally, we will determine whether decisions made during the early design phase, such as massing, can signal whether the design will result in a "sustainable building," a "zero-energy building," or an "energy-plus building."

This study is a continuation of three prior studies conducted by Pietro Pavesi in his MSc thesis, "A parametric design workflow applied to a responsive curtain wall system for daylight optimization of an existing building" [14],Daniele Compagnoni, Michele Pozzi, and Benedetta Ravicchio and their MSc thesis, "Chameleon: Shaping Visual Comfort. - A parametric tool for façade form-finding in the early design phase" [15] and Rafaella Monteiro and her MSc thesis Building massing and performance" [16]. By building upon their work, our research aims to provide a toolkit that combines all prior studies and is used as a methodology to form a building in terms of energy efficiency.

Pavesi's MSc thesis [14] focused on a form-finding process that prioritized indoor visual comfort and energy efficiency by optimizing the façade shape. His work proposed a design method and a script to identify the most effective combination of shapes and materials for achieving both daylighting and energy savings. Pavesi's, article also introduced a new architectural language that visually communicates the building's energy and material flows through formal features.

An investigation was conducted to assess the potential of folded façade geometries to achieve the desired daylighting goals and enhance solar energy generation, in comparison to a flat surface curtain wall. Against Pavesi's Linear and specific workflow, this study provides a wider perspective by combining conducted Master Thesises about and aiming to seek and improve the newest most effective typology for an optimized building. In addition to this, it should be noted that Pavesi's research uses daylight metrics derived from LEED requirements, such as spatial daylight autonomy and annual solar exposure, which will also be assessed in this study.

Pavesi’s results of his investigation of different folding configurations for the building envelope reveal that combining opaque and transparent panels in three dimensions can significantly enhance visual comfort compared to a flat design. Additionally, the research indicates that manipulating the envelope geometry presents a promising opportunity for innovative design, especially in high-rise constructions located in densely populated urban areas, where site constraints and legal regulations often dictate the building's form, layout, and orientation.

Furthermore, Compagnoni, Pozzi, and Ravicchio [15] have conducted similar research on optimizing the building envelope's shape to evaluate energy and daylight performance. However, their approach is different in that they created a Grasshopper plugin named Chameleon to execute the optimization process more consistently, making it applicable to various projects rather than tailored solely to one model.

On the other hand, in Rafaella Monteiro’s study [16] , the emphasis shifted from optimizing solely the façade to achieving optimal energy and daylight performance right from the beginning, at the stage where the designer is deciding on the building's forms. Although the same principle was followed, starting from the assumption that the shape indeed affects building performance, here the changes start in a broader spectrum, changing the typology and building massing instead of the façade.

Her study developed accordance with the Research by Sattrup and Stromann, named “Building typologies in northern European cities: daylight, solar access, and building energy use” [17] which analyses the potential of passive solar energy daylight and their impact on the total energy performance of typical urban typologies in Copenhagen, Denmark, as a reference.

They point out while there is a plethora of literature on building design, there appears to be a notable lack of information regarding the impact of massing, density, and urban form on low energy buildings.

In their study [17], researchers analyzed different types of urban blocks, including Courtyard (Type A), Indented (Type B), Perimeter (Type C), Bar-code (Type D), Slab (Type E), and Tower (Type F) blocks, as shown in Figure [17]. As Monteiro said [16]: Their research showed that the Courtyard blocks had the highest density and lowest energy use compared to the other types. While there were minor variations in energy consumption among types B, C, D, and E (between +2% and +8%), the Tower block (Type F) consumed significantly more energy (16% higher than Type A) due to its higher surface-to-floor-area ratio. This finding aligns with the Monteiro’s study focus on the energy performance of different urban block typologies [16].

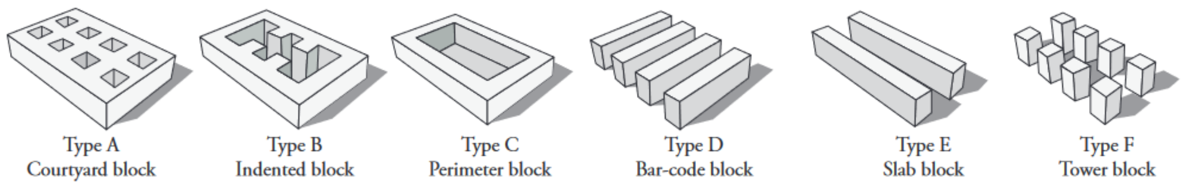


Figure 1: Six Traditional Urban Building Type Patterns [17]

Based on review from Monteiro's and conclusion from Sattrup and Stromann [17] it is noted that researchers stated that the impact of choosing a specific *typology "may affect up to 16% of the total energy performance and up to 48% of the daylight autonomy in buildings at similar urban densities"* [4], which is proof that the definition of the building geometry is a key factor affecting energy consumption and daylight levels.

Previous research by Monteiro [16], Sattrup, and Stromann [17] indicates that selecting a particular building typology can impact up to 16% of the total energy performance and up to 48% of daylight autonomy in buildings with similar urban densities . With these findings Monteiro [16] underscore the significance of building geometry as a critical factor affecting energy consumption and daylight levels.

Moreover, another publication that studies the relationships between building forms and referenced by Monteiro was "Urban Form, Density and Solar Potential" [18]. In this publication, the researchers created eighteen generic models, each representing a specific combination of built form and density. They also introduced randomness in either the horizontal pattern, vertical pattern, or both, that represented in below figure to simulate real-world variations.

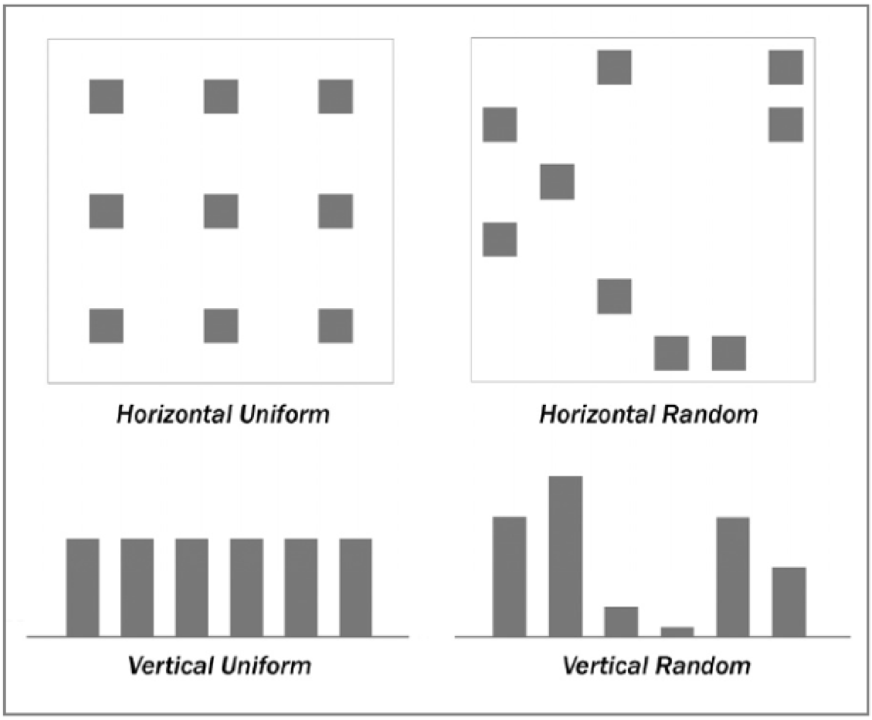


Figure 2: Horizontal and Vertical Urban Layouts [17]

With this study [18] Monteiro [16] presents several key metrics that are relevant to building energy performance. One of the metrics that will be applied in this research is the Daylight Factor (DF), which is discussed in detail on Metrics content.

According to N. Baker and K. Steemers study [19], if a room is 3 meters high and at a distance greater than 6 meters from the window, the DF on the work plane will fall to typically less than 1%, which is outside the acceptable range of 2 to 5%. This rule-of-thumb suggests that the inner central zones of buildings deeper than 12m will need to be permanently artificially lit, while the intermediate zone between 3m and 6m will be daylit for fewer hours than the outer zone. The penetration of daylight is also dependent on the ratio of room height to depth.

Other main metrics are Energy demand that is the term used to describe the consumption of energy by human activity. It drives the whole energy system, influencing the total amount of energy used, Solar Potential that refers to the amount of energy that can be generated from solar photovoltaic (PV) panels installed on the building's roof or façade and thermal collectors for domestic hot water.

One up to short by comparing the two references that Monteiro's stated that "there are two conflicting requirements for an ideal energy performance: reducing the building envelope, which is beneficial to heat losses, and increasing it, which is favorable to the availability of daylight and natural ventilation" [16]. As a result, she concludes the relative importance of the two requirements will be climate dependent.

Based on the learned information from the references [17] [18], she introduces three methodologies such as below and starts to compare by forming them.

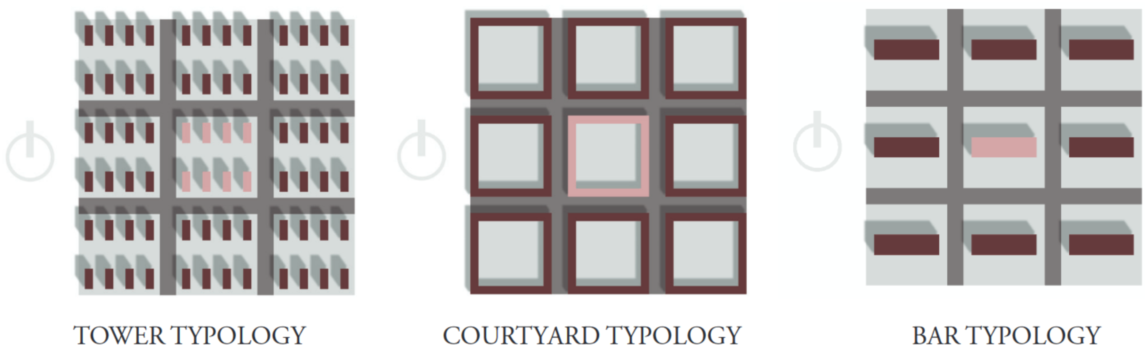


Figure 3: Plot area in the centre block, with the studied building in light red. Context blocks surrounding it and the buildings working as surrounding urban fabric in light red. [16]

Among the typologies offered in her study [16], tower, and courtyard typologies appear to offer better performance than the bar typology, although this must be considered to other factors such as site constraints. Passive design approaches, such as overhangs and louvers, as well as manipulation of the building envelope, as demonstrated in Pavesi's work [14] and other studies, should be incorporated throughout the design process to achieve desired performance. However, it is important to recognize that the starting point should be the appropriate typology, as selecting an unsuitable one could result in poor performance at the end of the process.

As a conclusion of Typologies when they are compared with each other, Monteiro resulted that: [16]

- The tower case became an energy-plus building (producing more energy than it consumes) with excellent daylighting conditions.

- The courtyard case had its final energy demand from the grid decreased to a very low number that can certainly be further improved to reach a zero-energy building and its daylight conditions were improved greatly, reaching a very satisfactory level.

- The bar case was the one that least improved with the actions taken in the attempt of its enhancement, making it clear that one output from this research is that the decision for a bar typology in the early-stage design can lead to a least performing building regardless of the strategies applied afterwards.

Acquiring this knowledge was crucial to establish fundamental assumptions that form the basis of the research. These include determining parameters for the building envelope, identifying the threshold for solar radiation required for optimal solar production, selecting the most suitable glazing ratio for a residential program, and other critical decisions that will be elaborated upon in this study.

Ultimately, the conclusion and knowledge mentioned in Literature review leads the initial steps of this study. By having the information of typologies, context end envelope, now it is possible to provide a toolkit that improves and incorporates with all studies done before by using introduced metrics.

STUDY FRAMEWORK

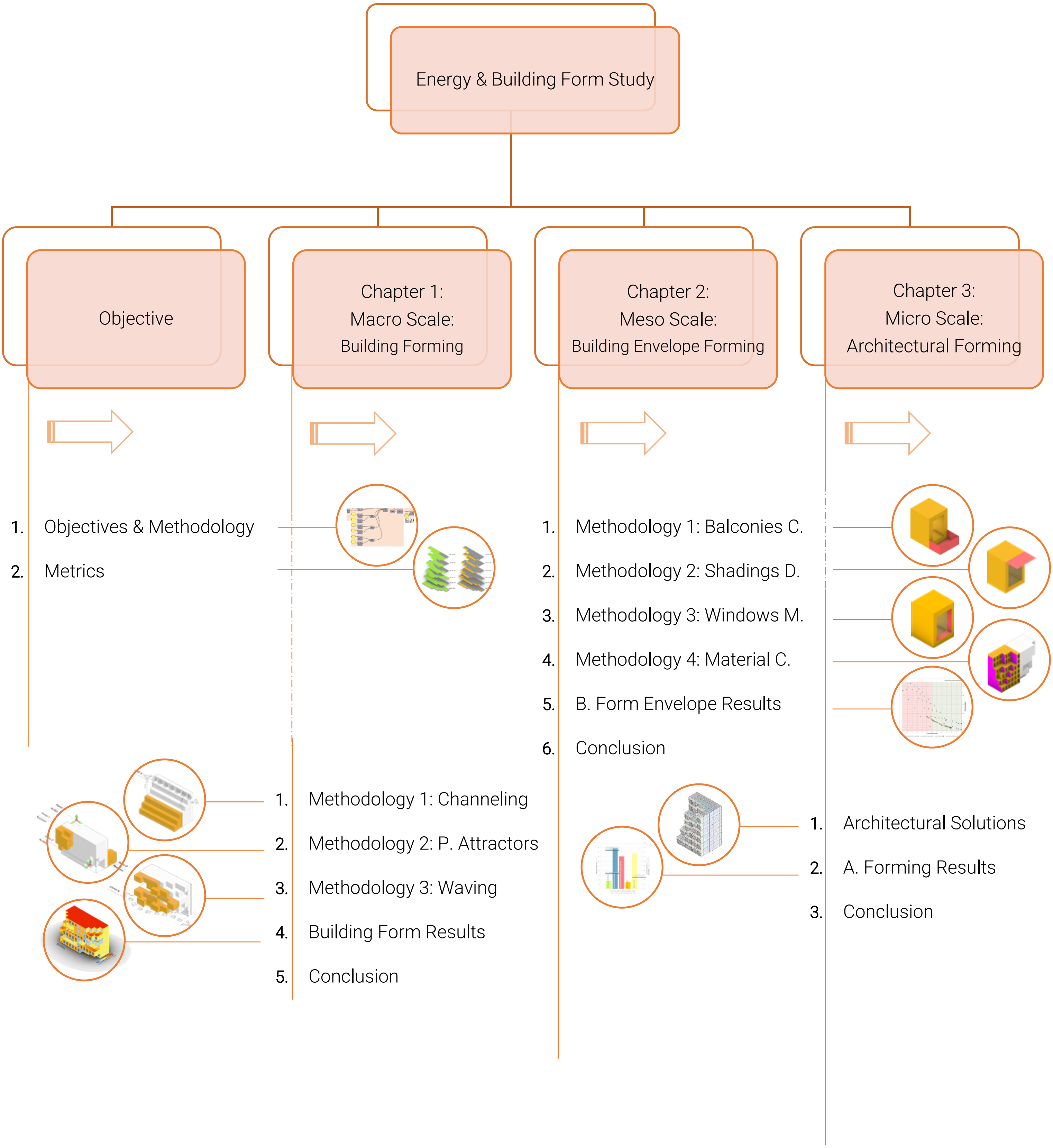


Figure 4: Study Framework [Source: Authors]

OBJECTIVE AND METHODOLOGY

With the aim of increasing the need for sustainable and green designs, building performance plays a main role in shaping this decision though many aspects of the building geometry, building envelope, window sizes construction materials, and external elements are essential in the early-stage process of the building form that helps designer evaluate and take the decision not only based of the aesthetics and building function but also towards daylighting, energy demand, and solar potential, thus the development of green and high-performance building while it's important to reduce the energy consumption it is not to sacrifice the indoor user environment [20]

Thus, indeed there are relationships between building form and solar capture and it should be the designer driver towards net zero energy as it affects many other metrics of daylighting and solar potential of energy production using passive strategies of the building optimizations including orientation of the building shape of the building and windows to wall ratio and façade design these determine the solar radiation capture and while increasing other aspect need to take in consideration such as annual solar exposure and glare risk probability through building envelope devices. [20]

This research takes the consideration of further developing one of the building typologies of the previous thesis by Rafaella Belmonte Monteiro at a granular level for form manipulation considering daylighting, energy use, and building façade including Shading devices, balconies, WWR, etc., and implementing active systems of PV and ST systems with the aim to reach positive net energy.

Therefore, the aim is to meet three performance criteria through (MOO) Multi-objective optimization that will influence the design directions.

1. Energy Demand [energy needed for Heating, cooling, Lighting, equipment, etc.]
2. Solar Potential [solar radiation on the surface envelope receives to produce solar energy through PV and ST systems].
3. Average Daylight Factor.

Thus, these energy performance metrics are based on selected climate and building morphological characteristics therefore the optimization of the method of the early design stages is based on:

a. Specific Site and Climate Parameters
b. Specific Building Parameter: Building Height and Orientation.

These parameters will ground the building design decisions for the study of the research [reference rafae].

The research will study the building typology: and courtyard on a granular scale to look through many cases of variable sets of manipulation using the three parameters of performance mentioned to understand the building form and how it impacted the building performance and how each methodology: Horizontal channeling, point scanning, and waving contribute to each metric.

Then further taking sets of components to form a toolkit that will allow the designer to choose based on a particular design aim and what are the tradeoff of each set and how combining them will contribute to variable outcomes.

Research Questions

- Building form can be influenced by quantitative parameter dictating form finding?
- How will orientations influence façade solutions?
- What other parameters will impact the user's comfort?
- After form design how will the building envelope enhance the building's performance?

Method

This study is using climate data of Milan of climateZone [4A] in which is defined as: Mixed-humid zone.

Thus, this research will use the three main indicators: energy demand Solar potential and average daylight factor as well as other parameter to other aspects of the outcomes. Using a generic algorithm model in process of direct evolution that regulate the development of the building performance.

Consequently, all the cases investigated will have the same Floor-to-Area-Ratio FAR 6 And it represents the ratio of building of the total floor area to the size of the plot.

$$FAR = \frac{\text{Gross floor area}}{\text{Area of the plot}}$$

Building selected portion of 6 stories.

30 m x 10 m x 6 = 1800 m^2

Plot 30 m x 10 m = 300 m^2

FAR = 6

In this study the selected portion of the building is divided into voxels of 2.5x2.5x3.5

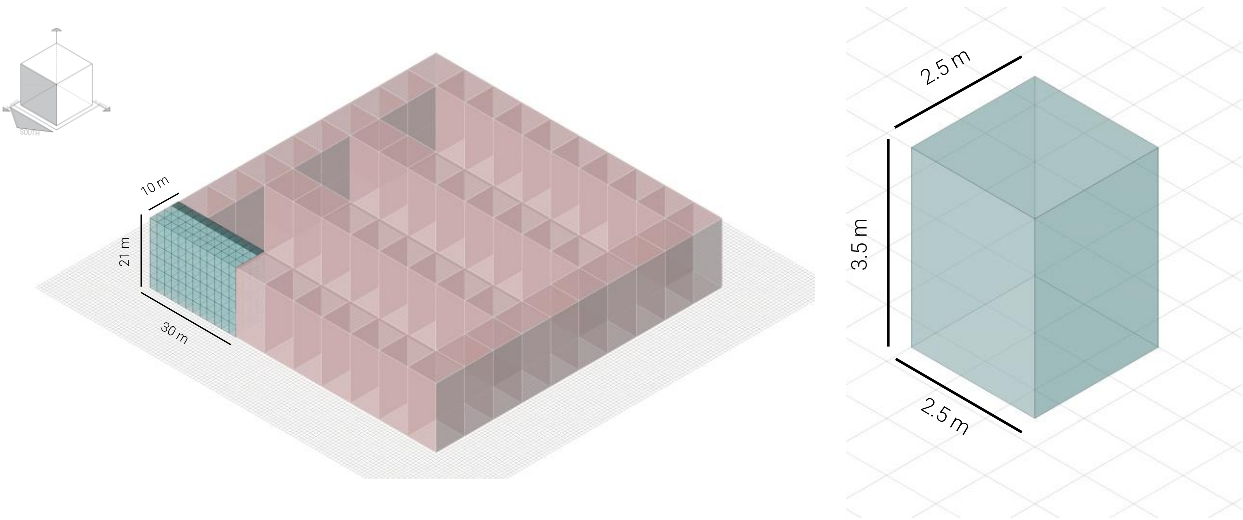


Figure 5: Selected Portion & Voxel Unit Sizes [Source: Authors]

Plot

The plot in the study is 100x100 m in which the building typology was placed into a subdivided grid of 5x5 m and taking the selected portion understudy of 30x10 m into voxels of 288 boxes of 2.5x2.5x3.5 m allowing various reconfiguration and distribution on the plot.

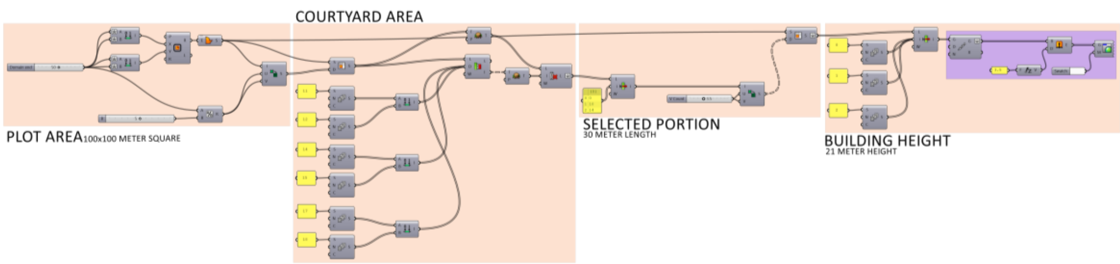


Figure 6: Script in Grasshopper Rhino3D, "Geometry Modelling for the Plot Area and Context" [Source: Authors]

Building Typologies

1.1.1 CASE I - Channeling

The purpose of exploring this method is to control the amount of natural light entering a building and to reduce the amount of solar heat gain. This can help to improve the energy efficiency of the building and make the interior more comfortable for occupants.

Channeling into two Stages:

A. using Curve closest points to manipulate into stages by re-arranging the row of voxels of each floor from top to bottom by increasing area at the bottom and decreasing at the top.

B. using trials of curve closest point into varies angles of finding 20 ° to allow to decrease daylight factor average.

CASE I WORKFLOW

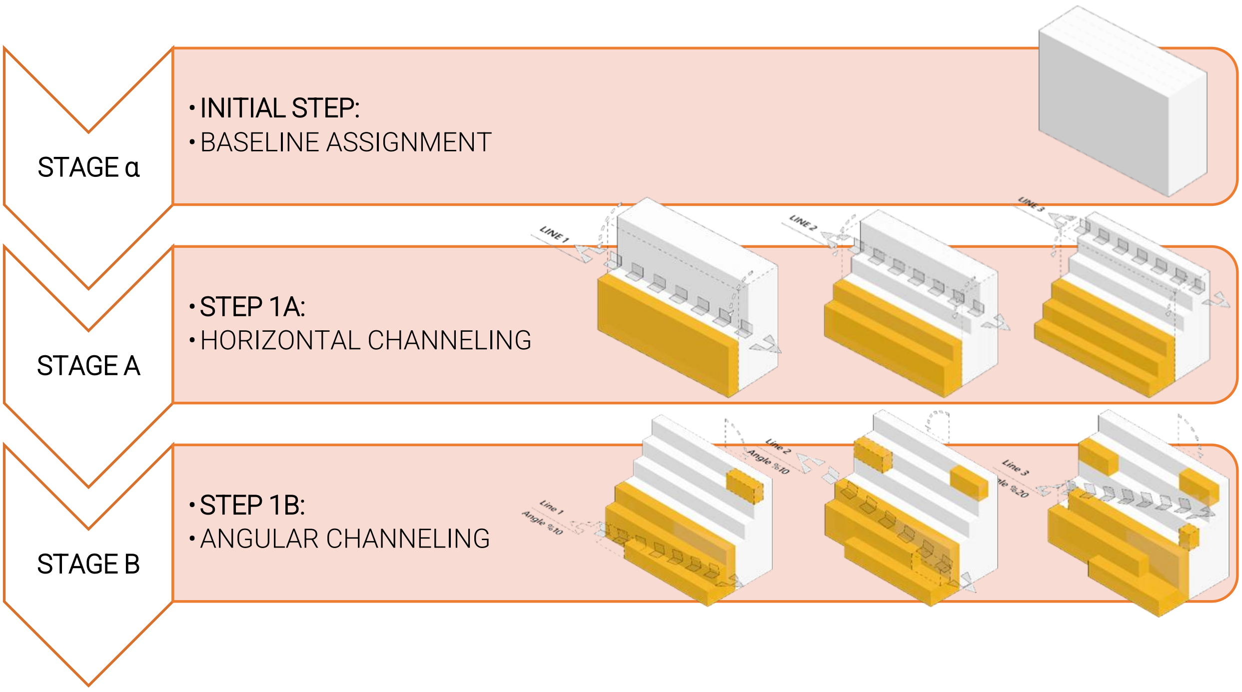


Figure 7: Case I Channeling Methodology Workflow [Source: Authors]

1.1.2 CASE II – Point Attractors

A horizontal carving analysis was performed on an attractor point in order to create gaps along the facade through the utilization of independent number sliders. The objective of this analysis was to determine the optimal design that would maximize solar potential and natural light while ensuring that no more than 30% of the total volume was impacted.

Void Stages:

A. One point subtracts 30% percentage of total area.

B. Two points subtract 30% percentage of total area.

CASE II WORKFLOW

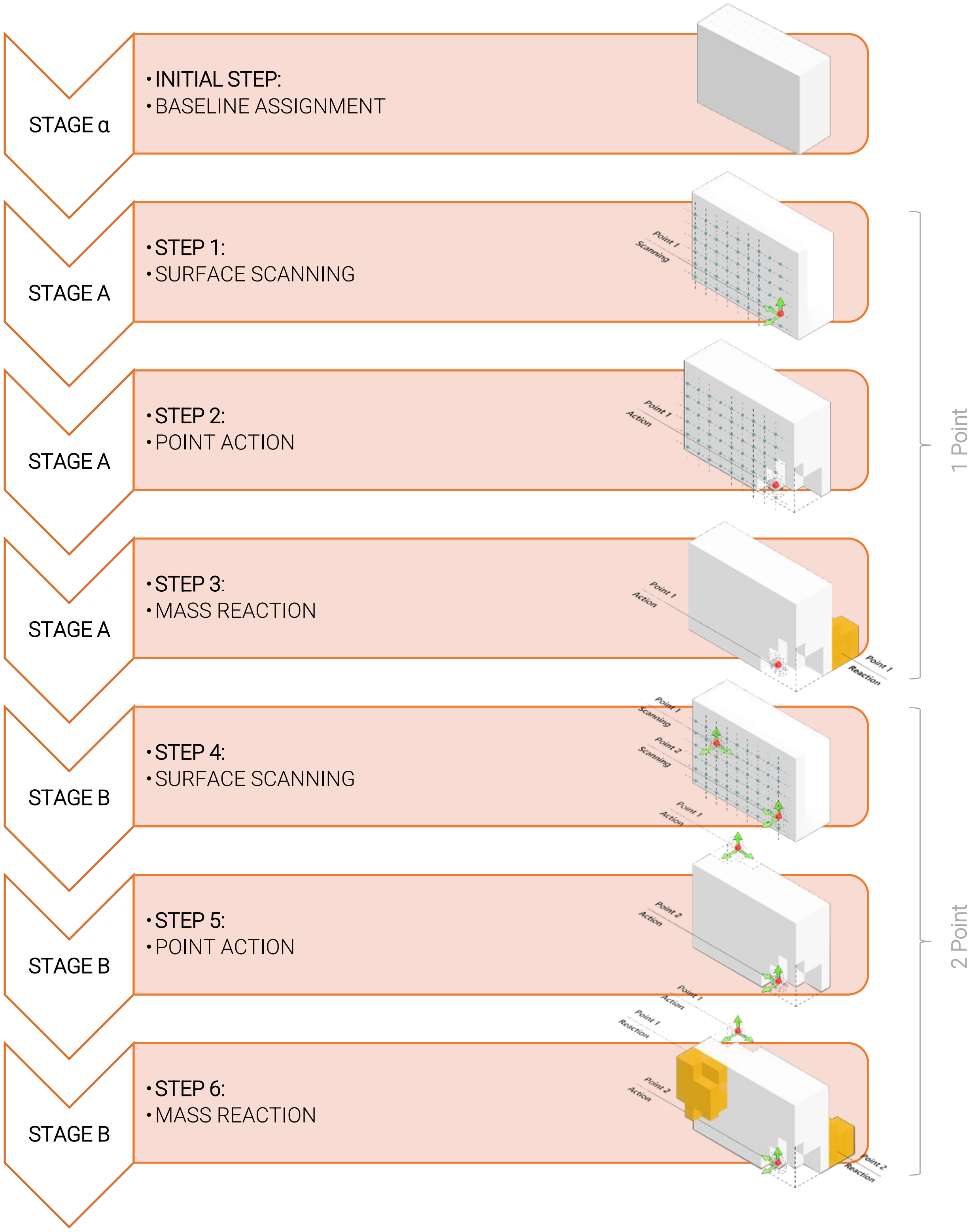


Figure 8: Case II Point Attractor Methodology Workflow [Source: Authors]

1.1.3 CASE III - Waving

The purpose of exploring this method is to create a series of peaks and valleys on the facade which allow light to enter the building while also providing shade. The peaks allow more daylight to enter the building while the valleys provide shade and reduce solar heat gain.

Waving Stages:

A. Using curve closest point using normal distribution formula to manipulate the voxels in to rearranging them to the furthest point from the curve creating mountain sculpting layers that will have more balconies shading area.

CASE III WORKFLOW

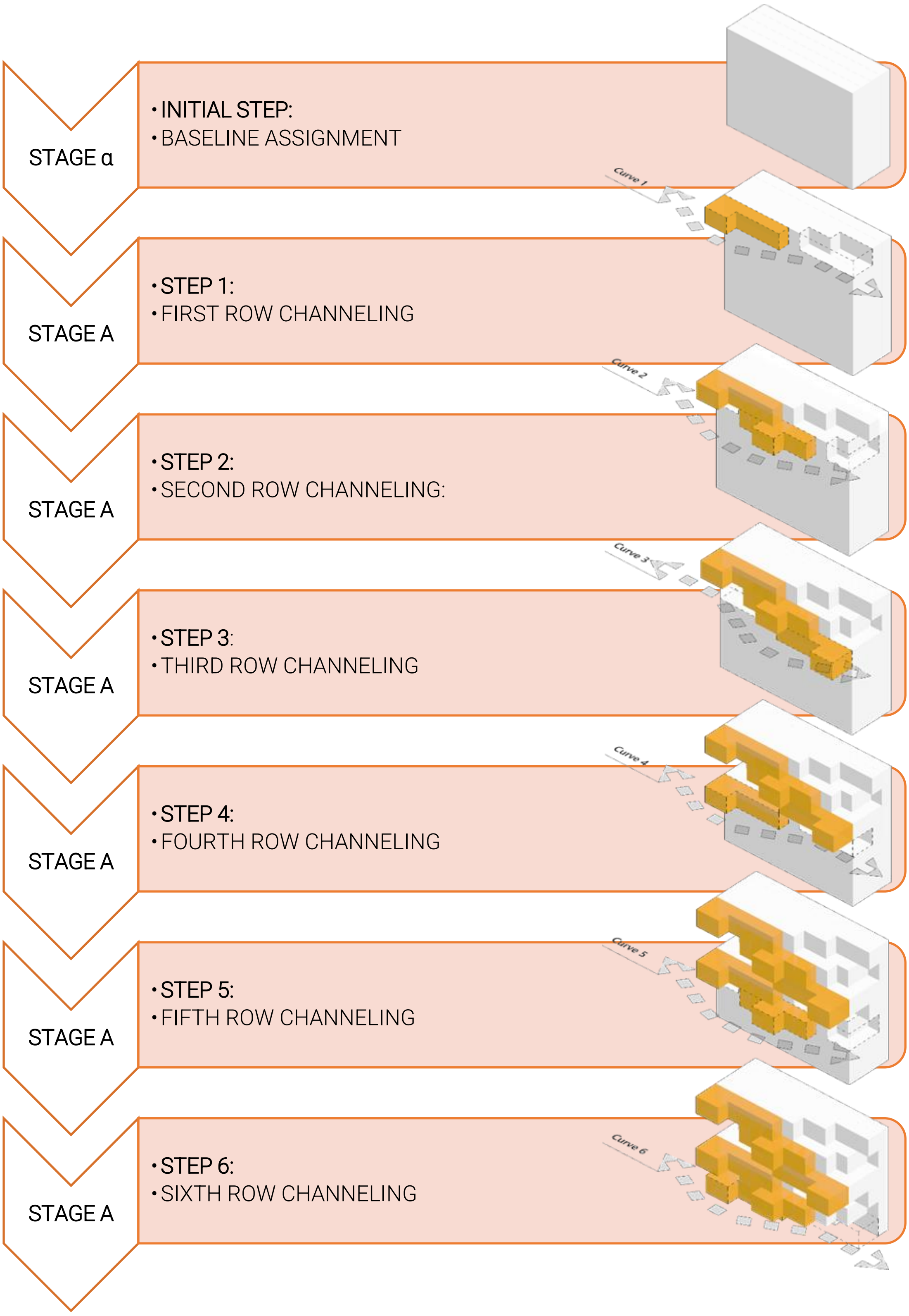


Figure 9: Case III Waving Methodology Workflow [Source: Authors]

Building properties

Table 4: Baseline Material Characteristics

EXTERNAL WALL	ROOF	FLOOR	GLAZING UNIT
U VALUE (SI) 0.38 W/M²K	U value (SI) 0.38 W/m²K	U value (SI) 0.15 W/m²K	U value (SI) 1.9 W/m²K SHGC 0.4

[Source: [21]]

The construction properties be selected based on ASHRAE 90.1- 2007 in standard using recommended climate zone [4A] and building program Residential in this case. And the using U values indicated in the table that applied in all case simulations.

Thus, fixing all building properties and building programs: Mid Rise apartment, and window-to-wall ratio 0.3 of opaque surfaces of the residential building.

And finally using all the parameters indicated and the building properties it is now the goal to find the best-performing cases of low energy and net production with that it should follow a procedure of optimization.

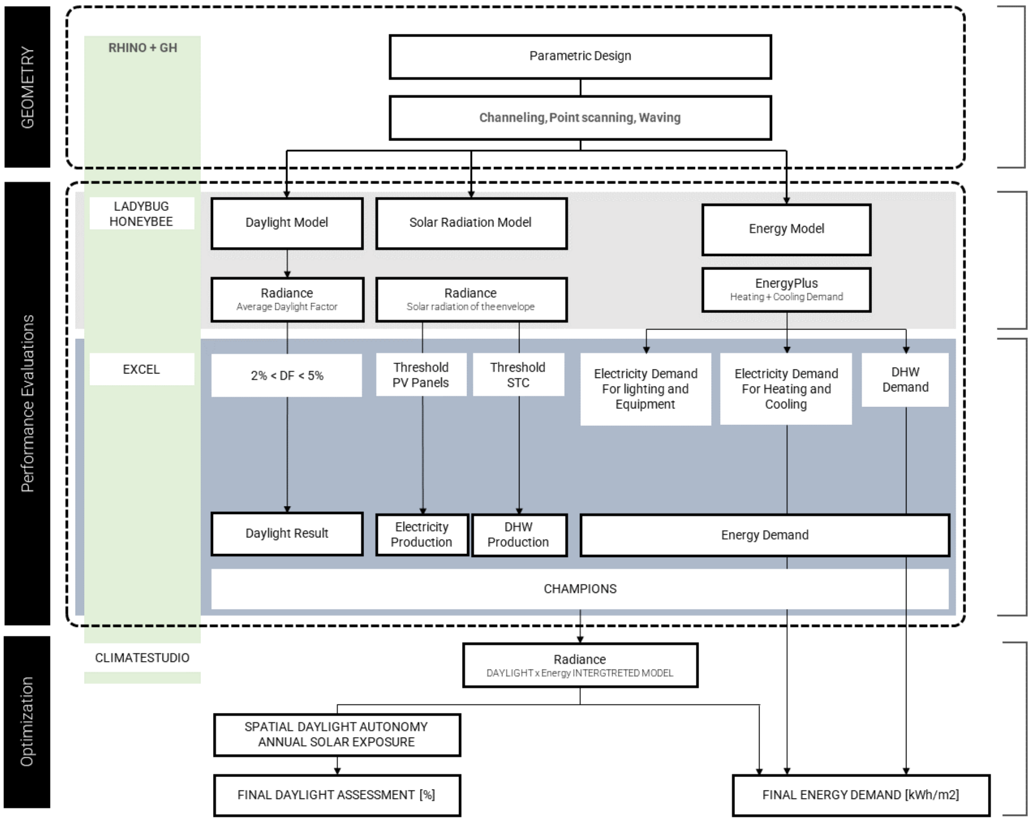


Figure 10: Daylighting x Radiation x Energy Process and Tools [Source: Authors]

This figure shows the four steps of the approach to reaching positive net energy. The first step is parametric modeling of the three methods, and the variability of reconfiguring based on the outcome of step two which is the development of the energy model, and the daylighting, and step three is to understand and reach the conclusion of the outcome of the cases and the effects of each parametric variable indicate the results reaching best-performing cases to further analysis in step four in which to reach a file assessment of the analysis of daylighting energy and final energy demand.

Therefore, following this process and tools of approach for the study of the thesis will produce more accurate and precise values to analyze and reach high-performing buildings.

METRICS

Building performance metrics are supposed to be “quality measures” for buildings with respect to their energy efficiency, safety, quality of design, etc. [22]. As mentioned earlier, it is important to note that one of the critical elements of this research is the three primary indicators of building performance: energy demand, energy production, and daylighting conditions, which have equal significance. To assess these factors and enable an accurate comparison between case studies, it is essential to comprehend the available metrics for each indicator and choose the suitable ones for each phase of the research. These metrics are elaborated in this study.

Energy Demands

Energy demand in buildings is the amount of energy required to operate a building's systems, such as heating, cooling, ventilation, lighting, and appliances, over a given period. The energy demand can be expressed in units of power, typically watts (W), or in units of energy, such as kilowatt-hours (kWh).

To promote sustainable building practices, energy demand in buildings should be minimized. Minimizing energy demand reduces the carbon footprint of the building, as well as operational costs. The reduction of energy demand can be achieved by optimized orientation and forming. With this, the building can minimize heat gain and loss while allowing for natural light to enter the building. Furthermore, shading and WWR strategies can further reduce the need for artificial lighting, heating, and cooling.

The formula for calculating energy demand is:

$$\boldsymbol{E\ (kWh) = P\ (kW) \times t\ (h)}$$

E=Energy demand, P=Power, t=Time

Power (kW) is the rate at which energy is used and is typically measured in watts or kilowatts. The time (h) is the duration of energy usage and is measured in hours.

To calculate the energy demand for a specific period, the power consumption must be recorded and multiplied by the duration of usage in hours. The resulting value is expressed in units of energy, typically in kWh.

Solar Potential (Energy Production)

Solar potential / Energy Production in buildings refers to the amount of energy that can be generated from solar photovoltaic (PV) panels installed on the building's roof or façade and thermal collectors for domestic hot water. It is an important aspect of building performance as it allows buildings to generate their own electricity, reducing reliance on grid-supplied energy and contributing to the adoption of renewable energy sources.

The Energy Production can be calculated using the following formula:

$$\boldsymbol{E\ (kWh) = A(m^2) \times H(kWh/m^2/day) \times 365\ day/year}$$

E=Energy, A=Total Solar Panel Area, H= Annual Average Solar Radiation

The units of solar potential are expressed in kilowatt-hours per square meter per year (kWh/m2). This indicates the amount of energy that can be generated.

Solar potential or energy production in buildings should be maximized because of main renewable energy resources for the buildings is solar energy [23]. By increasing the amount of energy generated from on-site renewable sources, buildings can reduce their carbon footprint and contribute to a more sustainable energy system. However, while maximizing solar potential excessive sunlight should be taken into consideration. Excessive sunlight can cause glare, which is a visual discomfort resulting from the excessive contrast and brightness in the visual field. Alternatively, the use of shading devices can be employed to reduce the amount of direct sunlight on the facade and minimize glare.

A well-designed building balances solar potential and glare reduction to ensure optimal energy generation and user comfort. This requires careful analysis of the building's orientation, surrounding environment, and the angle and placement of the solar panels, as well as the use of shading devices or other architectural strategies to reduce glare.

Daylighting

The levels of daylight illumination within a given space are characterized by their dynamic and ever-changing nature. This variability in both intensity and spatial distribution is due to the interaction between two key sources of daylight - the sun and the sky - with a range of factors including the geometric layout and physical properties of the space, the surrounding exterior context, and the various internal conditions within the space. As such, the interplay between these various factors contributes to the unique and constantly evolving nature of daylight illumination within a given space. [24] The amount and distribution of natural daylight levels significantly impact the lighting design of a building's interior, affecting both aspects. [25]

Indoor daylight quality can be evaluated using various metrics, which can be categorized into two types: static and dynamic. The widely used static metric, Daylight Factor, calculates the illumination level at a single point in time, without considering other factors that may affect daylight levels or changes in daylight over time. To address these limitations, dynamic daylight performance metrics were later introduced. These metrics utilize time series data of illuminances or luminance within a building, spanning the entire year, and based on annual solar radiation data for the building's location. Dynamic metrics have a key advantage over static metrics in that they account for the quantity and quality of daily and seasonal variations of daylight, including irregular meteorological events, at a specific building site. [22]

To comprehensively evaluate indoor daylight quality, both static and dynamic metrics will be employed in this research. The key metrics will be explained in detail below. However, it is important to emphasize that the specific metrics chosen for each stage of the research will be highlighted in their respective chapters.

STATIC METRICS

Daylight Factor

The inception of the Daylight Factor (DF) concept dates back to the early 20th century in the United Kingdom. The metric represents the ratio of the indoor illumination available to the outdoor illumination present simultaneously under overcast sky conditions. Typically, DF is obtained by dividing the indoor horizontal work plane illumination by the horizontal illumination on the roof of the building being tested and then multiplying by 100.

Daylight Factor is designed to be used under overcast sky conditions only. This metric is widely used in physical models to test daylighting designs in ‘overcast sky simulators. Calculating DF in real buildings or physical models with illumination meters is relatively simple. However, when using digital models, caution must be taken to understand the ‘sky model’ that is being referenced, and the data must be interpreted accordingly. [26]

Daylight Factor results are useful for quick comparisons of relative daylight penetration under overcast sky conditions, but it is less effective in regions with important levels of sunshine. However, most regions across the Europe have considerable periods of overcast skies, and DF is a valuable metric to inform design decisions during these periods.

In early versions of the US Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system, achieving indoor environment credit 8.1 required a DF % 2 for at least 75% of the critical visual task zones. On the other hand, the British Standard Institution, BS 8206-2, requires DF % 2 or 5, depending on electric lighting requirements to support human well-being.

Daylight Factor can be reported with either static or dynamic measures, but it is commonly considered statically (at a single point in time) as shown above. The metric's stability regardless of the time of day and year (assuming an overcast sky) is one of its advantages. [27]

The formula for calculating the Daylight Factor is as follows:

$$DF = (Ei/Eo) \times 100\%$$

Ei= illuminance on the work plane inside Eo= illuminance on a reference plane outside the building under an overcast sky

The units of the Daylight Factor are expressed as a percentage (%), indicating the proportion of exterior illuminance that penetrates inside the building.

In general, daylighting in buildings should be maximized among 2% - 5% to improve energy efficiency, occupant well-being, and building aesthetics. This can be achieved through careful building design, placement of windows and skylights, and use of shading devices to control the amount and distribution of natural light inside the building.

DYNAMIC METRICS

This particular section presents an alternative method of evaluating daylight performance, commonly known as dynamic metrics. In contrast to previous daylight factor-based approaches, dynamic metrics aim to capture the architectural dimension of daylighting, albeit lacking the capacity to predict a comprehensive measure of "good" daylighting [22].

Attaining comfortable daylighting necessitates the consideration of a scenario that involves the combination of suitable daylighting metrics with building design features that meet occupants' needs, guarantee their comfort, minimize electricity usage, and regulate solar gains. The accomplishment of this objective mandates the implementation of interventions across multiple domains, such as building architecture, engineering, facade design, interior design, furniture, and material selection.

Moreover, elucidated below are certain metrics that aid in achieving this objective. The intention is to facilitate a well-informed decision regarding the selection of appropriate metrics for application in this study.

Daylight Autonomy (DA)

The metric known as daylight autonomy (DA) measures the percentage of time during which a point in a space is illuminated to a specified target level by natural daylight. As defined in [28], DA is calculated by determining the percentage of occupied hours in which a target illuminance of 300 lux or higher is met.

The DA metric is designed to measure the duration for which pre-defined minimum levels of daylight have been attained every day. It is noteworthy, however, that this metric does not consider whether the available daylight is excessively bright for practical use within the space, particularly in the absence of a daylight management mechanism.

Currently, the Illuminating Engineering Society of North America (IESNA) recommends a threshold DA of 50%, meaning that daylight levels above 300 lux are achieved for at least 50% of the time that a space is occupied. [21]

Spatial Daylight Autonomy (sDA)

Spatial Daylight Autonomy (sDa) pertains to the percentage of the floor area in which a minimum 300 lux of illumination is achieved for at least 50% of the workday. Elevate sDA values signify that a larger internal area receives a minimum of 300 lux of daylight illumination for at least half of the workday. Typically, sDA is calculated using a daylight simulation tool that refers to EPW data file and determines the daylight levels in the space for each hour of the year.

Amongst various Daylight Autonomy (DA) metrics, sDA has gained popularity owing to its inclusion in LEED v4 and the WELL Building Standard.

The analysis involves evaluating "whether a space receives enough daylight during standard operating hours (8 a.m. to 6 p.m.) on an annual basis using hourly illuminance grids on the horizontal work plane." [22]

Table 5: sDA Value Range

sDA	*LEED Point*	*Comment*
> 75%	2	Occupants would be able to work comfortably there without the use of any electric lights and find the daylight levels to be sufficient
55% < sDA < 74%	1	Nominally Accepted by the occupants
< 54%	-	Not Acceptable

[Source: [25]]

Therefore, the objective is to attain Spatial Daylight Autonomy (sDA) values of 75 percent or greater in extensively used spaces, such as an open-plan office or a residential living room, and a minimum of 55 percent in areas where some amount of daylight is crucial.

Useful Daylight Illuminance (UDI)

UDI is a metric that quantifies the quantity of functional daylight that a space receives. The concept of functional daylight centers around the level of daylight that can be admitted into an area without inducing glare or impairing the visual environment. This range of useful, glare-free daylight is typically deemed to be between 100 and 2000 lux at the work plane. The Useful Daylight Illuminance (UDI) metric represents the percentage of operational hours where the illuminance from daylight in a space fall within the range of 100 and 2000 lux.

Its objective is to ascertain the "effectiveness of the daylight levels for the occupants" and the corresponding timing.

The dissimilarity from Daylight Autonomy (DA) lies in the recommended range of acceptability, which was established based on occupant feedback on daylit spaces [22] and is outlined below:

Table 6: UDI Range of Acceptability

UDI	*Unit*	*Comment*
< 100	lux	Underlit
100 < UDI < 2000	lux	Lux Comfort Range
>2000	lux	Overlit

[Source: [22]]

To achieve visual comfort in the workplace, the values shouldn't be <100 lux which means too dark, or >2000 lux which means too bright, but it should be between them. The purpose of the upper threshold is to identify potential discomfort related to visual or thermal conditions, which may arise from factors such as solar gains or glare from the sunlight that could lead to overheating.

Annual Solar Exposure (ASE)

The Annual Solar Exposure (ASE) is a quantifiable measure that aims to assess the occurrence of highly luminous or direct sunlight within an indoor environment. This particular metric denotes the proportion of floor space that receives intense illumination greater than 1000 lux, for more than 250 operational hours annually. It is regarded as a crucial design consideration in both the LEED v4 rating system and the WELL Building Standard. To illustrate, to attain the LEED v4 Daylight credit, a project must adhere to an ASE value of no more than 10 %. [29]

Daylight Glare Probability (DGP)

The Daylight Glare Probability (DGP) is a metric that assesses the perception of glare within a space. This metric quantifies the perceived glare from daylight as experienced by occupants, and it considers several factors, including the intensity of the light, the size of the glare source, contrast, and its position in the occupant's visual field. DGP is currently considered the most effective metric to evaluate glare potential in indoor spaces. In other words, it is an indicator of the percentage of individuals who may be disturbed by the level of vertical eye illuminance. Typically, DGP is presented using fish-eye images that identify areas of glare, and specialized software can classify it according to predetermined thresholds represented below.

Table 7: Definition of Daylight Glare Comfort Classes

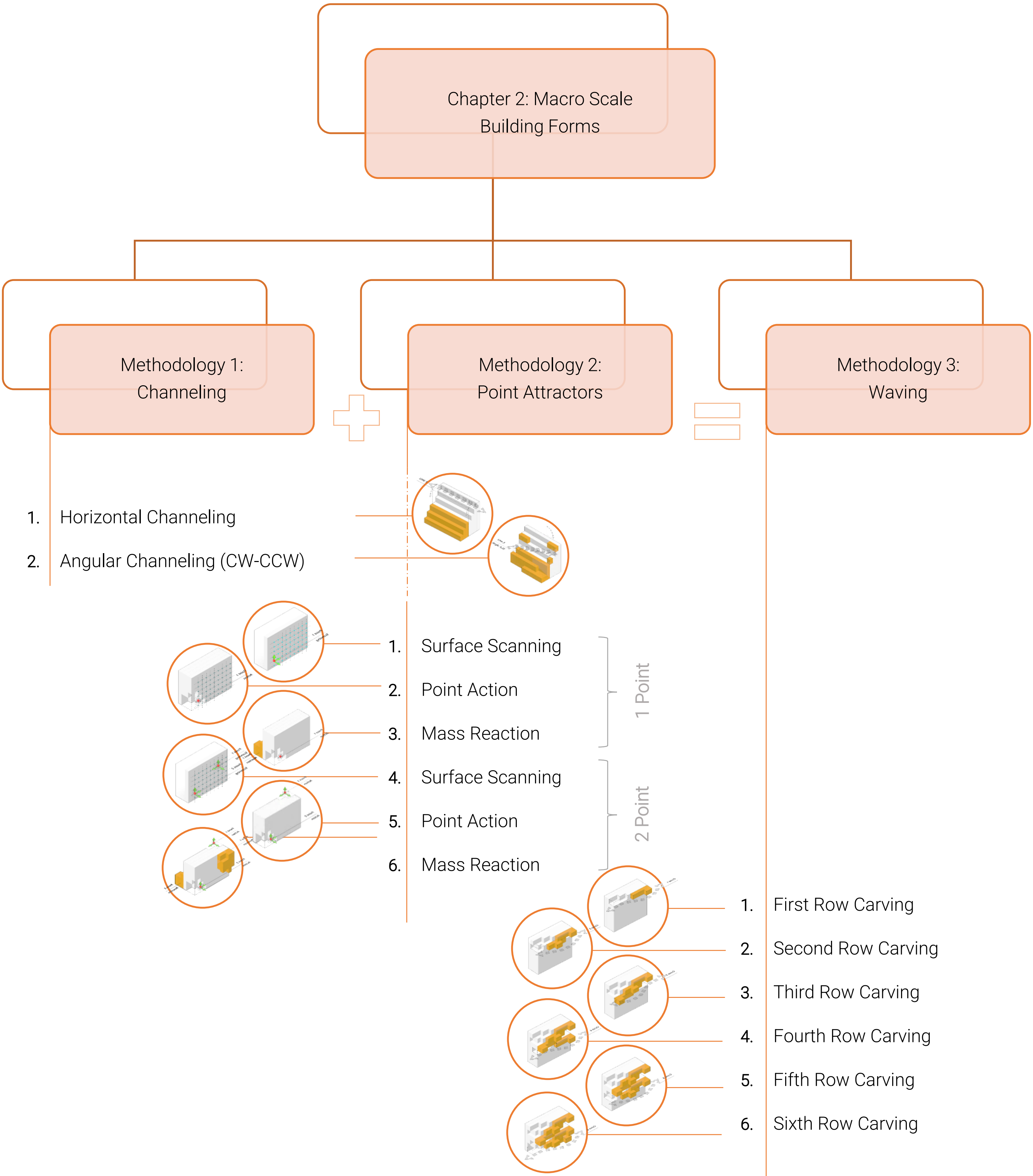
DGP	*Comment*
< 0.35	Imperceptible
0.34 <DGP < 0.4	Perceptible
0.39 <DGP < 0.45	Disturbing
DGP > 0.455	Intolerable

[Source: [30]]

CHAPTER 01.

BUILDING FORMS & PERFORMANCE

1.2 CHAPTER FRAMEWORK



C.W Clockwise

C.C.W Counter-Clockwise

Figure: Chapter 01 Framework [Source: Authors]

1.3 METHODOLOGY

After taking an overview of the procedure and tools taken to simulate a building energy model through parametric modeling dependent based on the Grasshopper and Rhino software and simulated and analyzed by plugin Ladybug and Honeybee using Daysim, Radiance, and Openstudio in order to study the three metrics of energy modeling, and how it impacts the variation of the building form.

Thus, looking through the parametric modeling of each method will help to understand how each case forms based on the path of individual performance indicators it follows to reach building optimization, therefore, allowing us to make the comparison of the outcomes of the methods to understand that massing can indeed play the key role in early-design stages of design how performing these manipulations drive the design towards high-performance passive buildings.

Using the wallacei plugin for Grasshopper as a multi-objective optimization tool allows us to iterate the geometry parameters based on the outputs of the energy demand, daylighting factor, and solar potential thus understanding the relationship between the building form and the performance based on the design variables.

1.3.1 CASE I - CHANNELING

This method corresponds to relocating the voxel linearly creating a stepping method by increasing the floor plan area gradually of having a smaller floor area at the top towards a bigger floor area at the bottom while can be seen in the figure, a centralized line on each row of the floor area and moving on the z direction gradually with number sliders culling the stack of row and replacing to bottom, consequently to increase the variation of this outcome the line move by number slider input creating an angular action to the curve within a 20 degrees range of counter-clockwise and clockwise rotation keeping in mind a fixed core area of 2.5x30, however, these manipulations are kept by maintaining the FAR = 6 fixed along the outcome of each variation of the building outcomes.

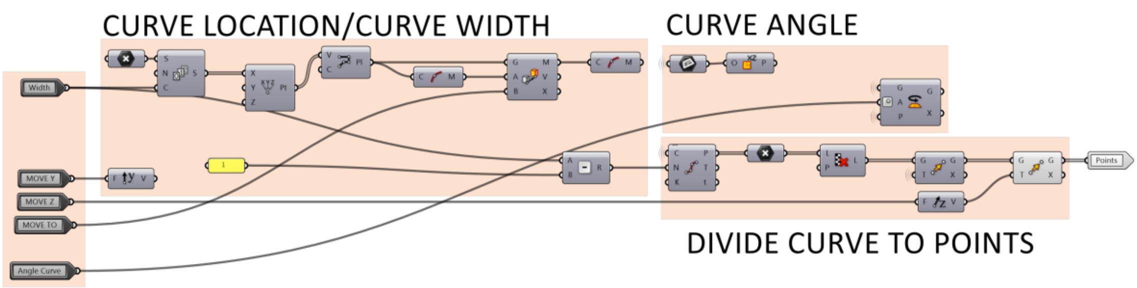


Figure 11: Script in Grasshopper Rhino3D, "Setting of Channeling Methodology" [Source: Authors]

1.3.2 CASE II – POINT ATTRACTORS

This process is controlled by point scanning along the surface of the building envelope reparametrized and thus can move freely in x-coordinates, creating a push and pull effect in both directions by the y-number slider on the building form and making sure the FAR =6.

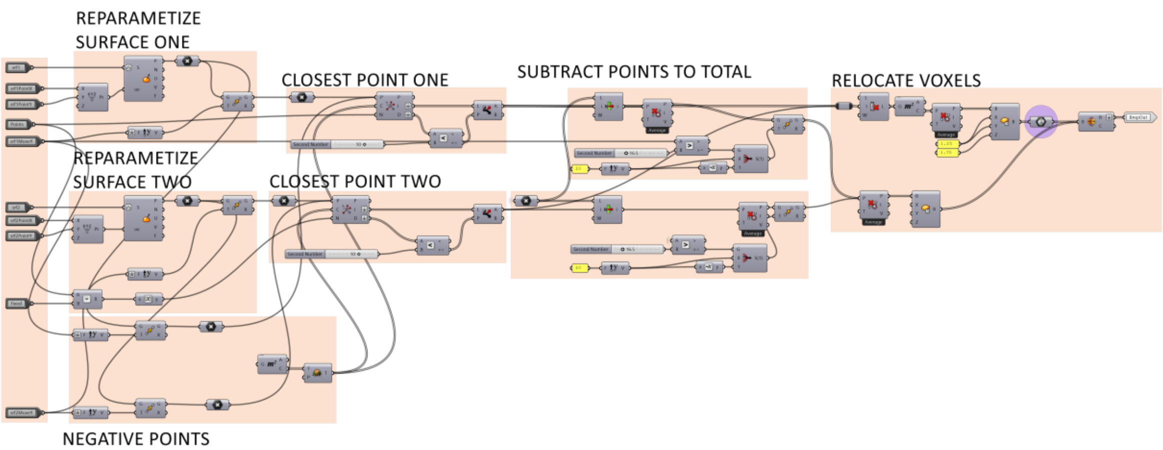


Figure 12: Script in Grasshopper Rhino3D, "Setting of Carving Methodology" [Source: Authors]

1.3.3 CASE III - WAVING

In the case of Waving, it is controlled by a curve centralized on each floor plan and using the normal distribution formula creating a bell-shaped curve moving along the floor plan level allowing to relocating voxels by a number slider based on horizontal waving actions.

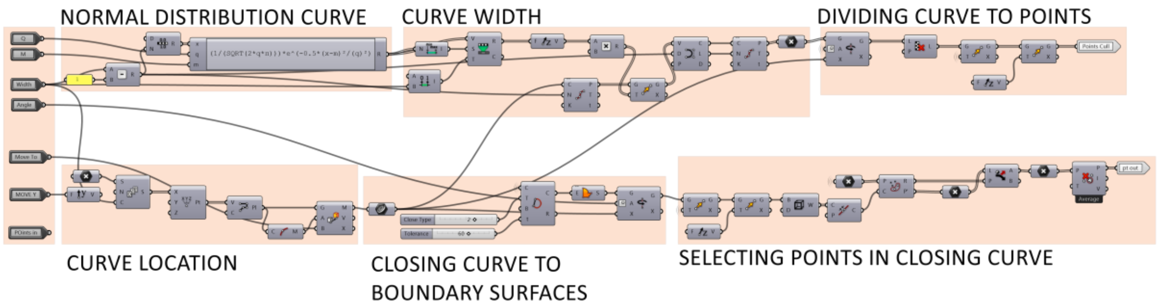


Figure 13: Script in Grasshopper Rhino3D, "Setting of Waving Methodology" [Source: Authors]

And therefore, all these parametric models are connected to the performance analysis scripts for the energy modeling allowing the results to dictate the change of the number sliders for various iterations and testing all the possible outcomes for further consideration.

1.4 BUILDING PERFORMANCE SIMULATION

Using the grasshopper plugins for Ladybug and Honeybee for building performance analysis tools that integrate Energyplus and Daysim in a single simulation workflow these tools have been used in various studies to evaluate buildings forms in terms of their interior comfort and daylighting and energy saving [31].

1.4.1 ENERGY DEMAND SIMULATION

The models require preparations to start the simulation process. Firstly, the building program in this analysis assigned the Midrise Apartment program this will give several parameters to the software to adjust to the selected program as well it is important that the surfaces of each voxel are adjacent in the proper way to calculate the conductive heat flow throughout the form these component shown of the figure allows to join the adjacent wall surfaces to produce more precise results and it is it important to define the glazing ratio creating a transparent surface on the envelope of the wall to window ratio of the façade of the analysis and in this case, it is south façade.

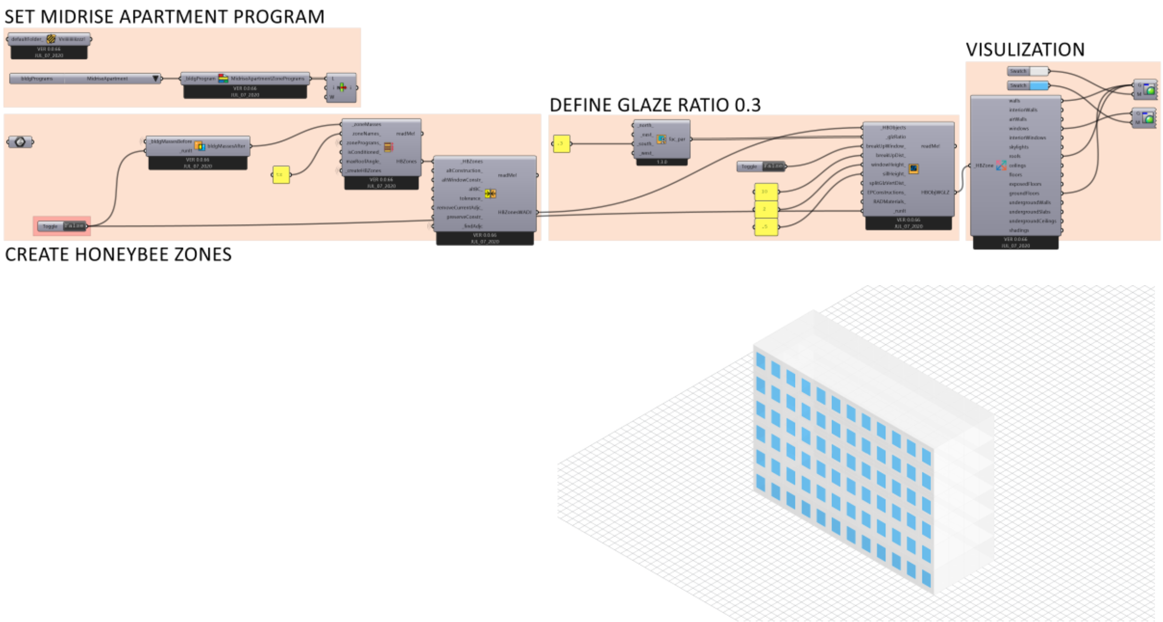


Figure 14: Script in Grasshopper Rhino3D, "Setting of Building Program & Zones" [Source: Authors]

Table 8: Baseline Wall Composition

EXTERNAL WALL	ROOF	FLOOR	GLAZING UNIT
U VALUE (SI) 0.38 W/M^{2}K	U value (SI) 0.38 W/m^{2}K	U value (SI) 0.15 W/m^{2}K	U value (SI) 1.9 W/m^{2}K SHGC 0.4

[Source: [21]]

Also considering the building construction material and the thermal performance it shows the baseline values associated with the building performance. These values will determine how the building envelop will perform using the selected weather File "ITA_Milano-Linate.160800_IGDG.epw" of the city of Milan of airport Linate of climate zone [4A] defined Mixed-humid zone and the selected standard of ASHRAE 90.1 2007 this will allow producing more precise results of the analysis.

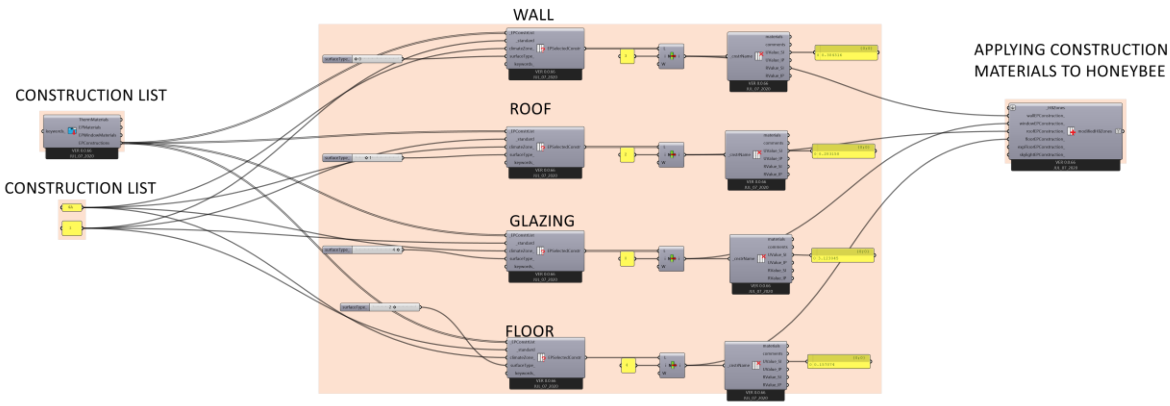


Figure 15: Script in Grasshopper Rhino3D, "Setting of Standardized Material for Energy Modeling in Open-Studio" [Source: Authors]

After setting up the honeybee zones of the parametric model and assigning the standardized material the building energy modeling is performed and Energy Plus simulation using an open-studio tool supports the energy modeling. It is important to set up the shadow parameter so that run the solar distribution calculation, in this case, using option 4 as "full interior and exterior with reflection" which accounts for light bouncing indoors and outdoors of the zone and taking into consideration the monthly time step and the generated output "zoneEnergyUse" running the simulation will export the results in IDF file data in [kWh] in which post-processing is need to normalize the data by the floor area.

However, it is essential to assign the occupancy schedule considering which it corresponds to the energy data outcome. It is a very simple approach, where one assumes 100% of the occupants will be at home from 6 pm until 9 am, and that 50% of the occupants will be at home from 9 am to 6 pm. During the weekday also assumed that during the weekends is assumed that everyone is at home 100% of the time. This is visible in the weekly occupancy schedule also, the part in which the Honeybee Zones are modified to the new heating and cooling set-points, previously calculated, to 20 and 26 °C, respectively. [ref Raf]

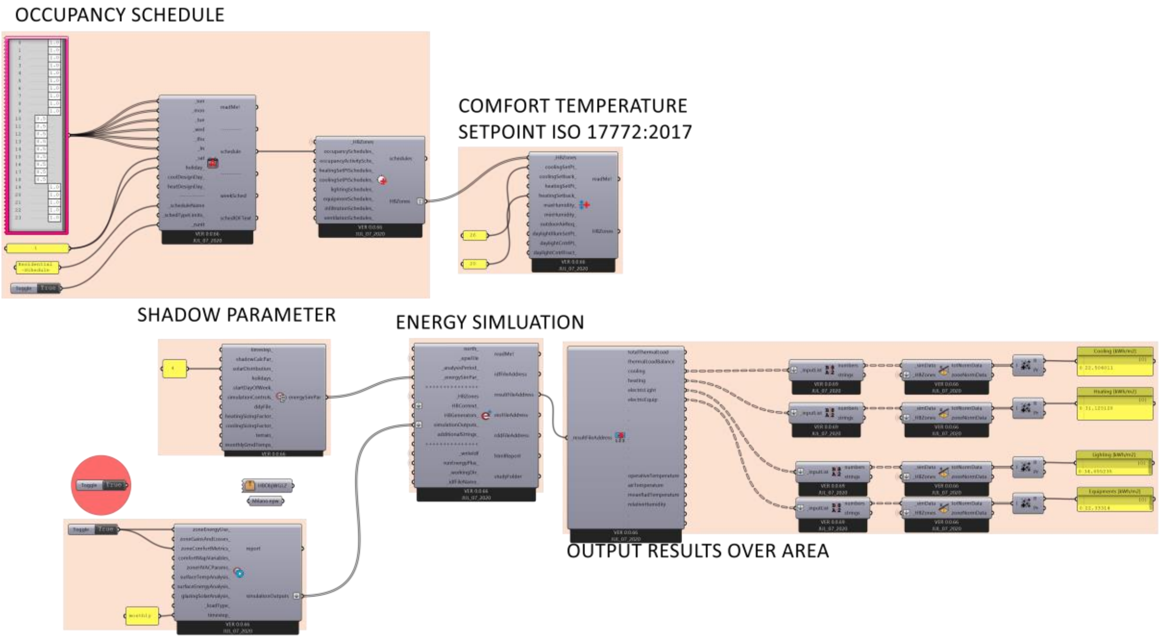


Figure 16: Script in Grasshopper Rhino3D, "Setting of Occupancy Schedule" [Source: Authors]

1.4.2 DAYLIGHT SIMULATION

The average daylight factor is a metric used to evaluate the amount of natural light that enters a building. Honeybee, a parametric building performance analysis tool, can be used to simulate and analyze the average daylight factor in buildings [31]. The tool has been used in various studies to evaluate the daylighting performance of buildings and to optimize building form for energy-saving [31].

In this case, the honeybee zones are connected to the test point which is connected to a grid sensor of 0.5 m and a work plane of 0.8 m. it is important to apply the radiance parameters shown in the table that are responsible for the distribution and reflection of the light indoors while it may increase the time of the process it is important to produce more accurate results of the simulation. Starting the simulation producing and DF outcome of each sensor along the gride defined earlier can be post-processed by averaging the values into one value average.

The radiance parameters show the values predefined to process the simulations while in this case, the “min” gives the fastest results but draft results and for the sake of the time and computer power the bold numbers were used for the process of the simulations.

Table 9: Radiance Parameters

Parameter	Description	Min	Fast	Accurate	Max	Notes
ab	ambient bounces	0	0	**2**	8	It is the maximum number of diffuse bounces computed by the indirect calculation. A value of zero implies no indirect calculation.
ad	ambient divisions	0	**32**	512	4096	-
as	Ambient super samples	0	**32**	256	1024	Super-samples are applied only to the ambient divisions which show a significant charge.
ar	ambient resolution	8	**32**	128	0	This number will determine the maximum density of ambient values used in interpolation. The maximum ambient value density is the scene times the ambient accuracy.
aa	ambient accuracy	.5	**0.2**	.15	0	This value will approximately equal the error from indirect illuminance interpolation. A value of zero implies no interpolation.

[Source: Authors]

1.4.3 SOLAR POTENTIAL SIMULATION

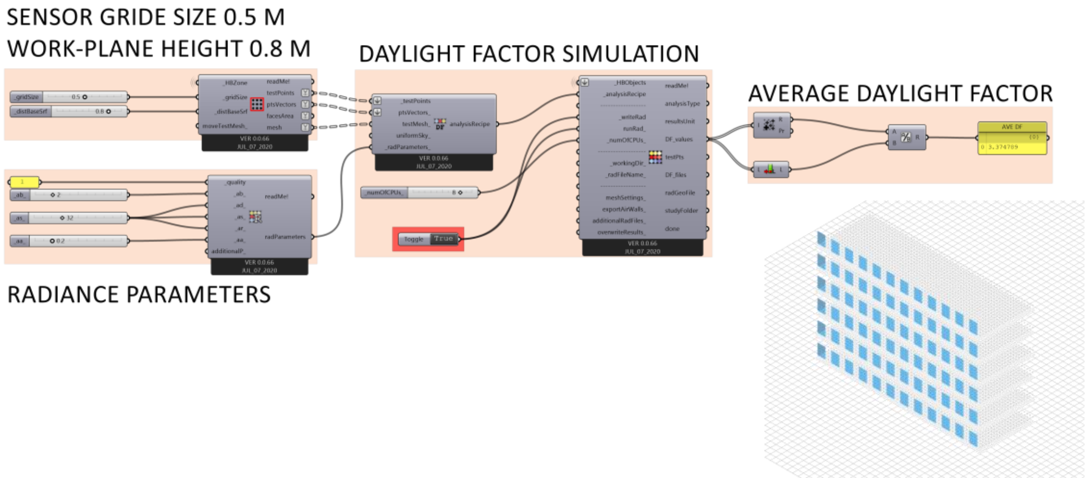


Figure 17: Script in Grasshopper Rhino3D, "Setting of Grid Vector Size for ADF Simulations" [Source: Authors]

Measuring the irradiance on the building envelope using the Radiance model using a point gride vector the gride size is 1 meter and it is the grid of the cell using the EPW weather file to set up the irradiance of the sky model during the whole year will produce an outcome of radiation that is filtered based on the that of radiation received on the surface.

a. The area that receives more than 400 kWh/m^2 is used for the production of electricity using PV panels.
b. The area that receives between 200 to 400 kWh/m^2 is used for the production of electricity using thermal Solar collectors.

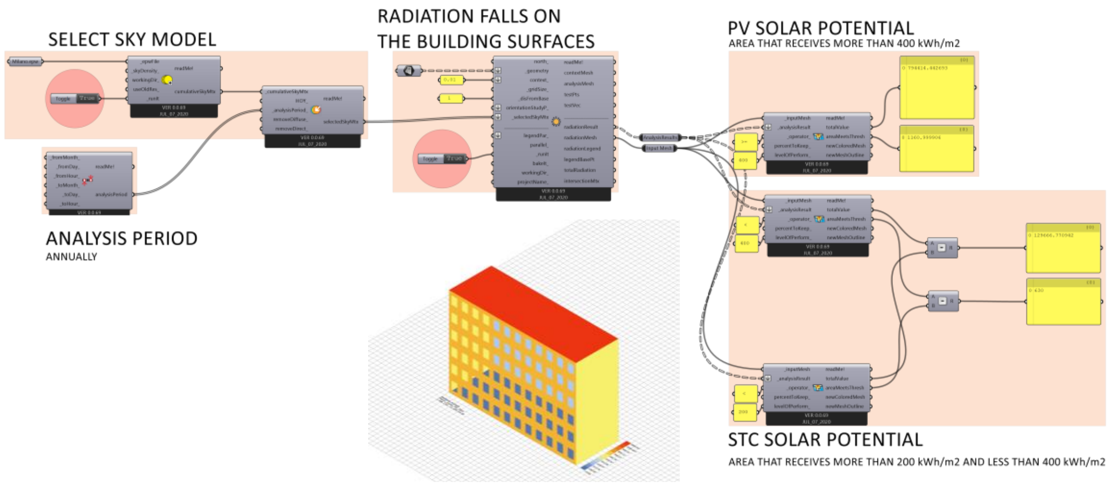


Figure 18: Script in Grasshopper Rhino3D, "Setting of PV & STC Solar Potential Analysis" [Source: Authors]

And finally, it is important to mention that the information process by the software in this case the creating honeybee zones and the glazing ratio applying materials and post-processing through simulations software is for the study of building performance to guide the design of the form-producing pool of the building benchmark against other buildings.

1.4 BUILDING FORMS RESULTS

1.4.1 CASE I - CHANNELING

Case I of the "Channeling" Method was possible to simulate 40 cases due to the limitation of the variation of solutions, the first cases are horizontal channeling by moving the upper rows to the bottom rows and stacking on top of each other, and further case through curve alterations by rotating the counterclockwise and clockwise ranging between (0 - 20 degrees) independently of each two levels of building form.

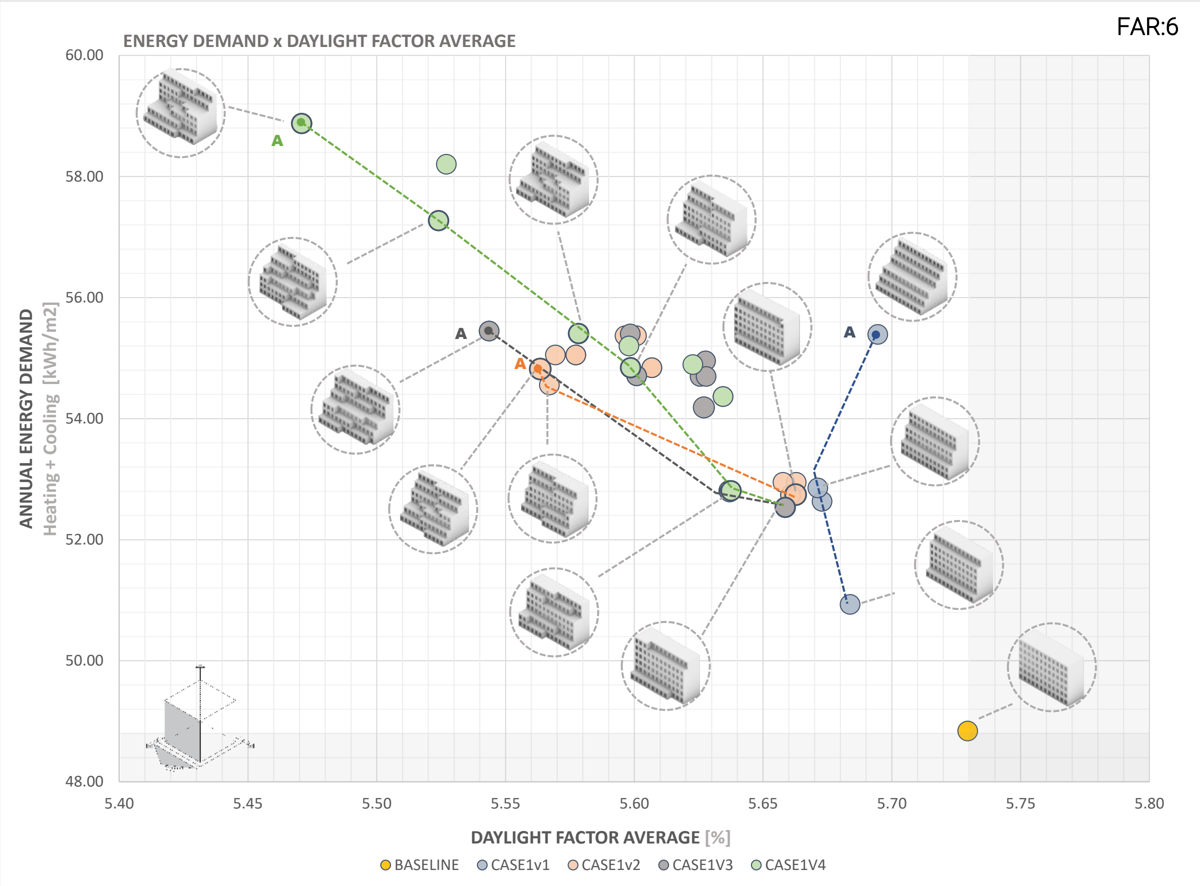


Figure: Case I Energy Demand x Daylight Factor Average Graph [Source: Authors]

To enhance the potential of solar energy, a common strategy is to increase the affected surface area. To this end, Case 1 was subjected to further refinement resulting in four different versions. The primary goal of these versions was to increase the surface area of the mass and maximize its solar potential.

It is worth noting that Case 1v2 and Case 1v3 were limited in their range of motion, as they were only capable of rotating about a single side counterclockwise and clockwise respectively.

In contrast, Case 1v4 exhibited a greater degree of independent rotation per floor. However, despite achieving a greater degree of variation in solar exposure, this optimization method was unable to reach energy demands lower than the baseline as the best case can reach 50.93 kWh competing with the baseline of 48.84 kWh. Moreover, when increasing the surface area to maximize solar exposure, the energy transfer among voxels decreased, and voxels began transferring energy with the surrounding space, leading to higher energy demands to compensate for this loss to the environment.

In contrast, the daylight factor exceeds the acceptable range threshold (2% - 5%) This was primarily because less self-shading causes the best case to reach 5.68 % compared with the 1v4 worst case daylight factor has better self-shading which reaches 5.47% with (4.54%) improvement with the baseline.

To understand each alteration effect, refer to the table presented on the subsequent page.

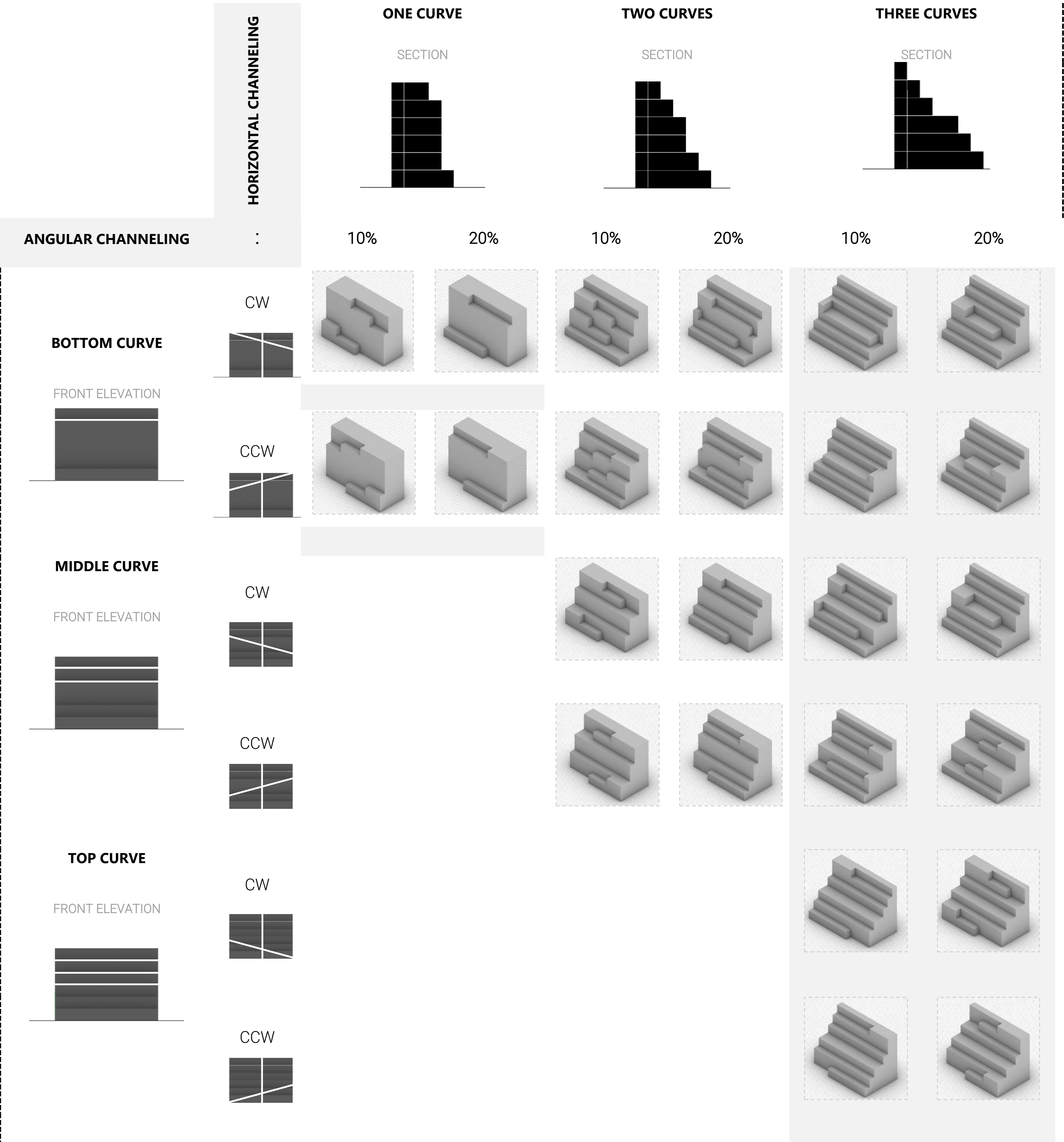


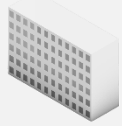
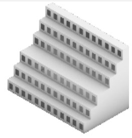
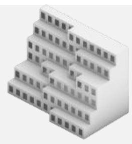
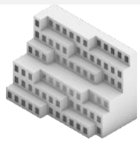
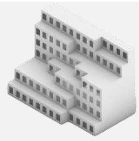
Figure 19: Behaviors of Case I Channeling Methodology

C.W Clockwise

C.C.W Counter-Clockwise

Comparing cases 1v2 and 1v3 of each worst form on the trendlines it shows a difference in energy demand/daylight factor that applying counterclockwise rotation increases heating need and vice versa corresponds to blocking southwest of solar heat gain. As a results worst cases of 1v4 starts with top line rotation of [CCW] and lower line rotation of [CW].

Table 10: Channeling Methodology CW-CCW Results Comparison

CASE I		*Daylight Factor [%]*	*Solar Potential [kWh]*	*Energy Demand [kWh/m2]*	*Visual*
BASELINE		5.73 (a)	794414.44 (a)	48.84 (a)	
CASE 1V1	POINT A	5.66 (↓1.22%)	923122.29 (↑16.20%)	56.13 (↑14.92%)	
CASE 1V2 [CCW]	POINT A	5.56 (↓2.97%)	843777.64 (↑6.22%)	54.82 (↑12.24%)	
CASE 1V3 [CW]	POINT A	5.54 (↓3.32%)	821856.81 (↑3.45%)	55.45 (↑13.54%)	
CASE 1V4	POINT A	5.47 (↓4.54%)	911181.3 (↑14.69%)	58.87 (↑20.53%)	

[Source: Authors]

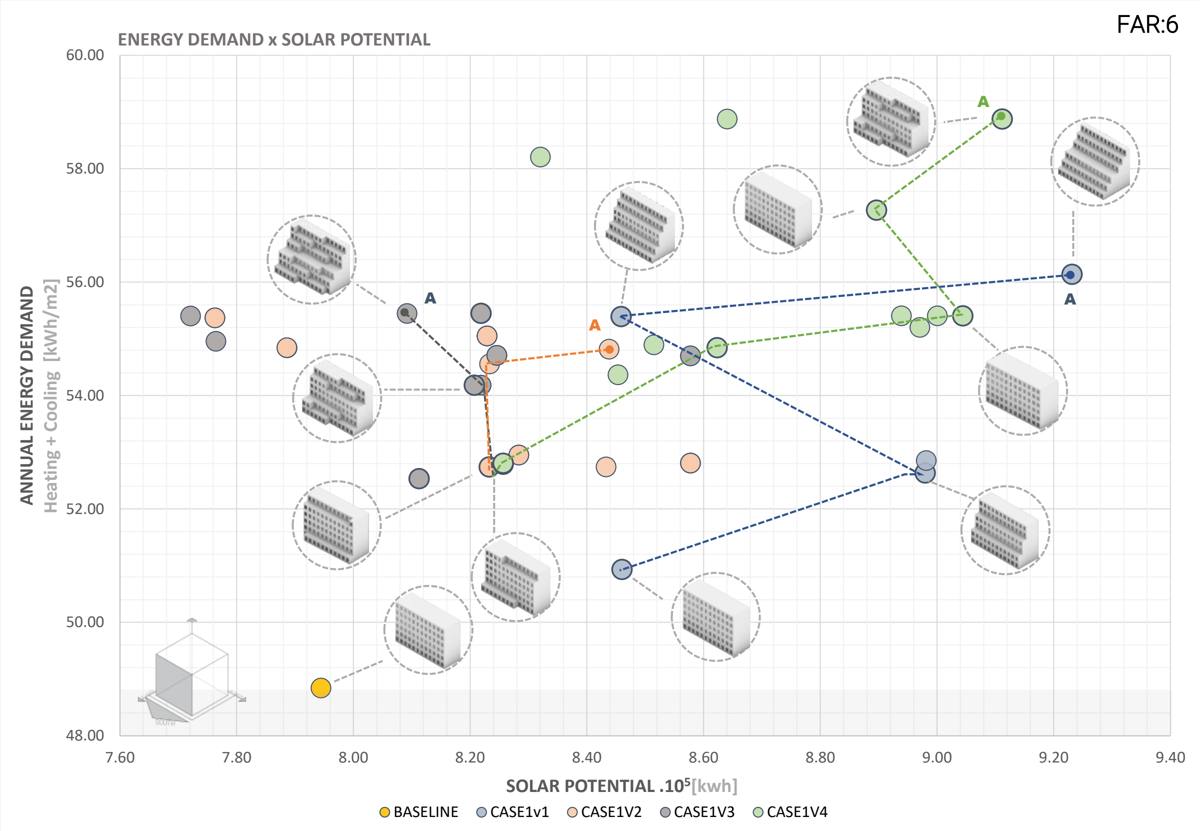
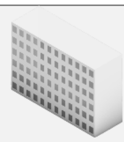
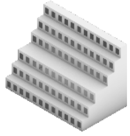
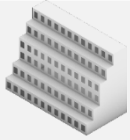
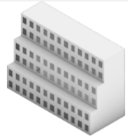
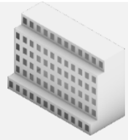
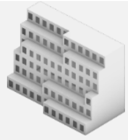
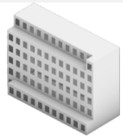
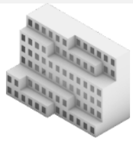
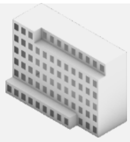


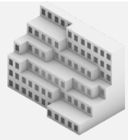
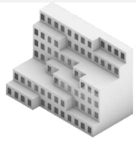
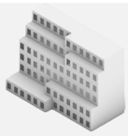
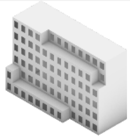
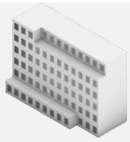
Figure 20: Case I, Energy Demand x Solar Potential Graph [Source: Authors]

For the case 1v1 the trendline takes the zigzag shape because of the form increase on the y axis casing more solar exposure on the of the surfaces area with no obstructions by the adjacent voxel visible from the worst CASE1v1 solar potential 9.2X10^5 kWh (+16.20%) improvement with baseline while best case 8.46X10^5 kWh due to less surfaces exposed.

The trendlines of CASE1v1 is far left correspond to higher solar exposure while cases 1v1 and 1v2 has the lowest of this method since are limited to rotate on one direction and as result case 1v4 is mixture of both cases of curve angular causing to have higher solar potential.

Table 11: Channeling Methodology Results Comparison

CASE I		*Daylight Factor [%]*	*Solar Potential [kWh]*	*Energy Demand [kWh/m2]*	*Visual*
BASELINE		5.73 (a)	794414.44 (a)	48.84 (a)	
CASE 1V1	POINT A	5.66 (↓1.22%)	923122.29 (↑16.20%)	56.13 (↑14.93%)	
	POINT B	5.67 (↓1.04%)	898122.88 (↑13.05%)	55.39 (↑13.41%)	
	POINT C	5.69 (↓0.70%)	845872.64 (↑6.48%)	52.63 (↑7.76%)	
	POINT D	5.68 (↓0.87%)	846014.16 (↑6.49%)	50.93 (↑4.28%)	
CASE 1V2 [CCW]	POINT A	5.56 (↓2.97%)	843777.64 (↑6.21%)	54.82 (↑12.24%)	
	POINT B	5.58 (↓2.61%)	823321.40 (↑3.64%)	54.56 (↑11.71%)	
	POINT C	5.66 (↓1.22%)	823278.74 (↑3.63%)	52.74 (↑7.98%)	
CASE 1V3 [CW]	POINT A	5.54 (↓3.32%)	821856.81 (↑3.46%)	55.45 (↑13.53%)	
	POINT B	5.63 (↓1.75%)	820725.67 (↑3.31%)	52.87 (↑8.25%)	
	POINT C	5.66 (↓1.22%)	811261.76 (↑2.12%)	52.53 (↑7.55%)	

CASE I		*Daylight Factor [%]*	*Solar Potential [kWh]*	*Energy Demand [kWh/m2]*	*Visual*
CASE 1V4	POINT A	5.47 (↓4.54%)	911181.3 (↑14.70%)	58.87 (↑20.53%)	
	POINT B	5.52 (↓3.67%)	889638.5 (↑11.99%)	57.27 (↑17.26%)	
	POINT C	5.58 (↓2.61%)	904411.8 (↑13.84%)	55.40 (↑13.42%)	
	POINT D	5.60 (↓2.27%)	862320.82 (↑8.54%)	54.84 (↑12.29%)	
	POINT E	5.64 (↓1.57%)	825660.44 (↑3.93%)	52.80 (↑8.10%)	
	POINT F	5.66 (↓1.22%)	811261.76 (↑2.12%)	52.53 (↑7.55%)	

[Source: Authors]

1.4.2 CASE II – POINT ATTRACTORS

In the context of the present study, the Method of "Point Attractors" for Case II was employed, which enabled the simulation of 100 distinct scenarios involving the distribution of building form. This was achieved through point scanning in the first case and two-point scanning in the second case, with each point action voxels that pulled or pushed the building form, thus resulting in a variation of the building form.

Upon analysis of the simulated scenarios, the first visible trend observed was similar to that of Case I, "Channeling," wherein there was a clear division in how the scenarios developed. Specifically, in the top corner, cases were pushed inwards, leading to an increase in the shading effect on the south façade. The effect gradually decreased as one moved towards the bottom corner, where cases were pulled outwards.

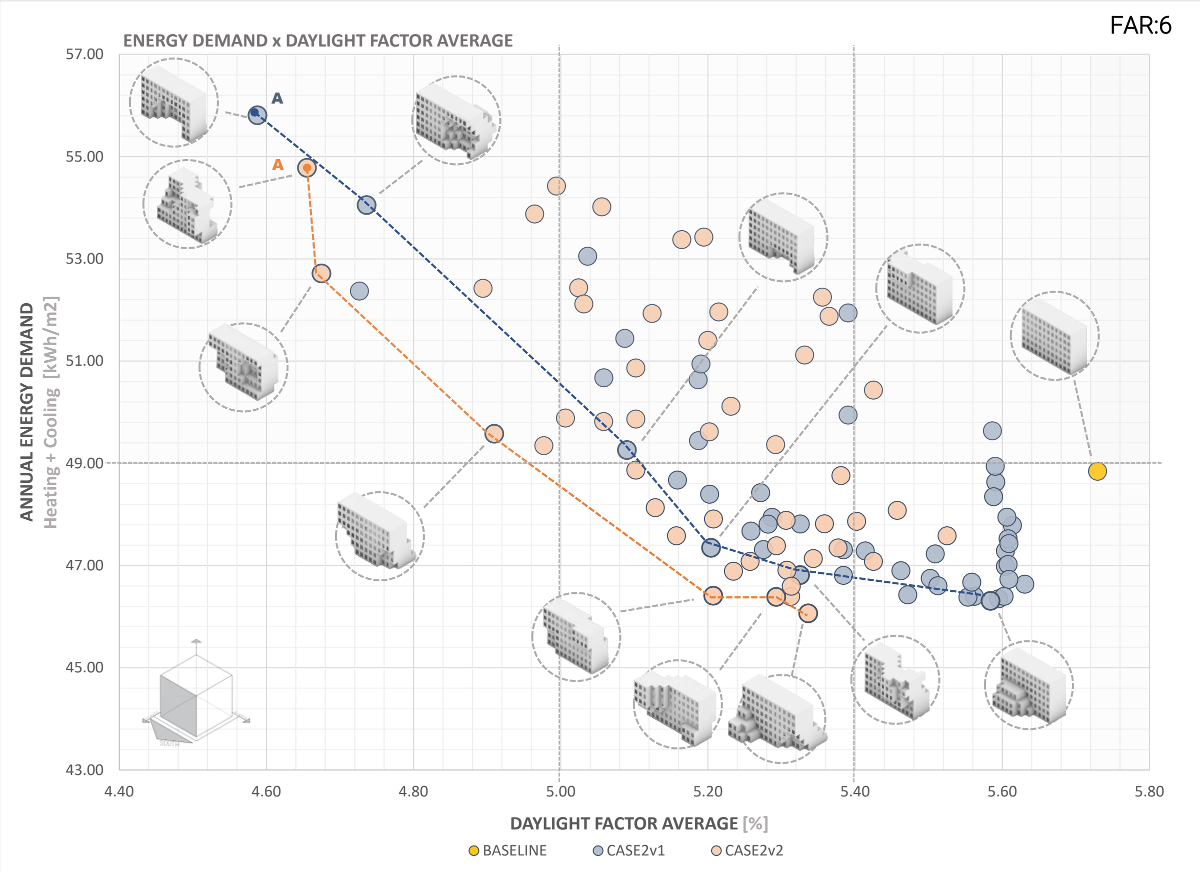


Figure 21: Case II, Energy Demand x Daylight Factor Average Graph [Source: Authors]

Upon analyzing the trend line of CASE2v1, it is evident that the worst-case scenario yields a result of 55.81 kWh/m2. This observation allows us to comment on how to push and pull actions affect building forms. In the worst-case scenario, pushing the bottom of the mass results in a reduction in the daylight factor due to the self-shading effect created by the surrounding area. This, in turn, reduces the solar potential by $7.5 X10^5$ kWh and increases the heating needed, leading to an overall increase in the total energy demand.

In contrast, pulling the bottom area increases the solar potential and decreases energy demand. However, the daylight factor does not significantly reduce compared to pushing. It is worth noting that pushing the bottom part of the building mass leads to a higher daylight factor, increased solar potential, and decreased energy demand, as evidenced by point F with a 46.31 kWh (5.18 %) improvement in energy demand.

However, the upper corners of the building allow for a reduction in solar exposure due to the increase in shading. Therefore, to optimize building design, it is recommended that two-point attractors be used.

For greater precision regarding two-point actions, it should be noted that pushing below the action results in a reduction in the daylight factor. However, if the second point pushes from the top, this reduction in daylight factor can be minimized. If the pushing top action is located close to the southeast façade, the daylight factor increases because the angle provided by this action allows more solar light to enter without obstruction. However, if this push action occurs in the southwest section, there is a decrease in the daylight factor because the middle part of the building acts as an obstruction to the southwest section during the early and mid-hours of the day. This applies to each level of the mass.

Additionally, as highlighted above, pushing the bottom causes a reduction in daylight factor, and pushing the middle also results in a similar but less severe reduction in daylight factor. However, when the middle portion of the mass is pushed, more voxel surfaces interact with space, leading to energy exchange between space and mass, resulting in higher energy demand compared to pushing the bottom or top.

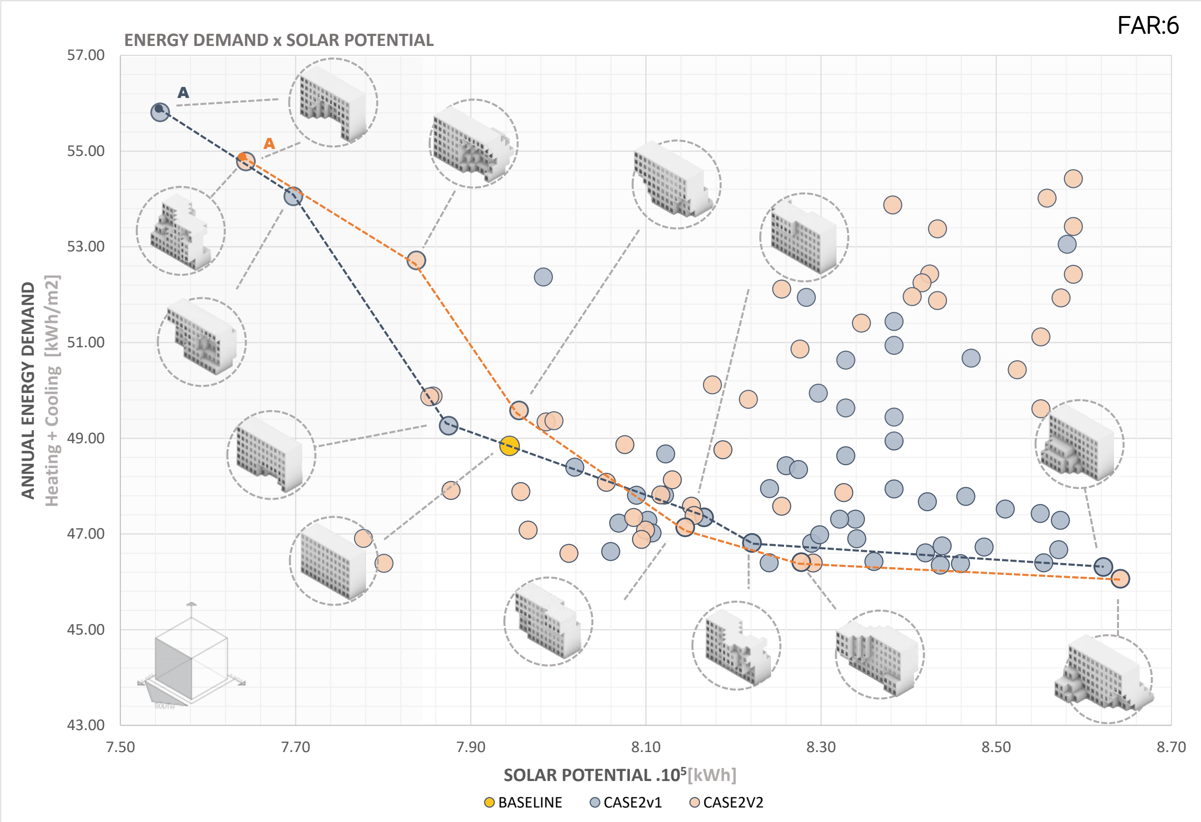
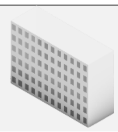
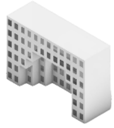
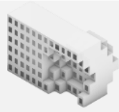
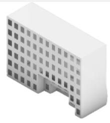
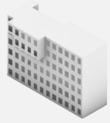
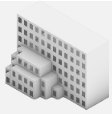
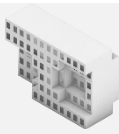
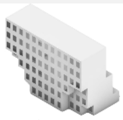
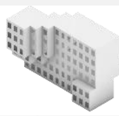
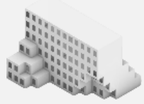


Figure 22: Case II, Energy Demand x Solar Potential Graph [Source: Authors]

Furthermore, based on the simulated and plotted data tables below, it is valid to state that pushing the mass inward, in the north direction, results in increased energy demand, reduced solar potential, and daylight factor. Conversely, pulling the portions forward, in the southern direction, leads to a higher daylight factor compared to pushing and an increased solar potential. This is because the sun can have more interaction with voxels due to its angle.

In conclusion, the findings indicate that the use of two-point actions can be more precise about optimizing building design and enhancing energy efficiency. Overall, it is observed that each different scenario of both cases can be used based on the needs.

Table 12: Point Attractors Methodology Results Comparison

Cases		*Daylight Factor [%]*	*Solar Potential [kWh]*	*Energy Demand [kWh/m2]*	*Visual*
BASELINE		5.73 (α)	794414.4 (α)	48.84 (α)	
CASE 2V1	POINT A	4.59 (↓19.87%)	754537.36 (↓5.02%)	55.81 (↑14.27%)	
	POINT B	4.74 (↓16.39%)	769747.36 (↓3.10%)	54.05 (↑10.67%)	
	POINT C	5.09 (↓11.16)	787478.93 (↓0.87%)	49.26 (↑0.86%)	
	POINT D	5.20 (↓9.24%)	812112.27 (↑2.22%)	47.35 (↓3.05%)	
	POINT E	5.51 (↓3.84%)	841917.87 (↑5.97%)	46.60 (↓4.58%)	
	POINT F	5.58 (↓2.62%)	862235.42 (↑8.53%)	46.31 (↓5.18%)	
CASE 2V2	POINT A	4.66 (↓18.67%)	764339.6 (↑3.78%)	54.78 (↑12.16%)	
	POINT B	4.67 (↓18.50%)	783794.8 (↑1.33%)	52.72 (↑7.94%)	
	POINT C	4.91 (↓14.31%)	795519.78 (↑0.14%)	49.58 (↑1.15%)	
	POINT D	5.34 (↓6.80%)	814485.98 (↑2.53%)	47.14 (↓3.48%)	
	POINT E	5.21 (↓9.07%)	827746.62 (↑4.20%)	46.41 (↓4.97%)	
	POINT F	5.34 (↓6.80%)	864184.66 (↑8.78%)	46.06 (↓5.69%)	

[Source: Authors]

1.4.3 CASE III - WAVING

The objective of this study was to investigate the impact of different methods of voxel rearrangement on the reduction of daylight factor in a building. The third case method, "Waving", was found to be the most effective in achieving the desired reduction in daylight factor.

Specifically, the "Waving" method allowed for the rearrangement of voxels along the horizontal floor line, enabling the simulation of 200 different cases on each floor. This approach led to variations in floor depth, which significantly impacted the reduction of the daylight factor to an acceptable range. Compared to the previous methods, the best cases exceeded the threshold of 5%.

This finding validates the assumption that there is a dependency of the daylight factor on the floor depth, as all cases simulated resulted in an average reduction of 4%. Moreover, stacking the voxels on the Y-axis, up to a maximum of 10 meters, resulted in an increase in the surface area exposed to solar radiation.

The "Waving" method is a highly effective approach for achieving the desired reduction in daylight factor. The results of this study confirm the dependence of the daylight factor on the floor depth and demonstrate the potential benefits of voxel stacking on the Y-axis for increasing the surface area exposed to solar radiation.

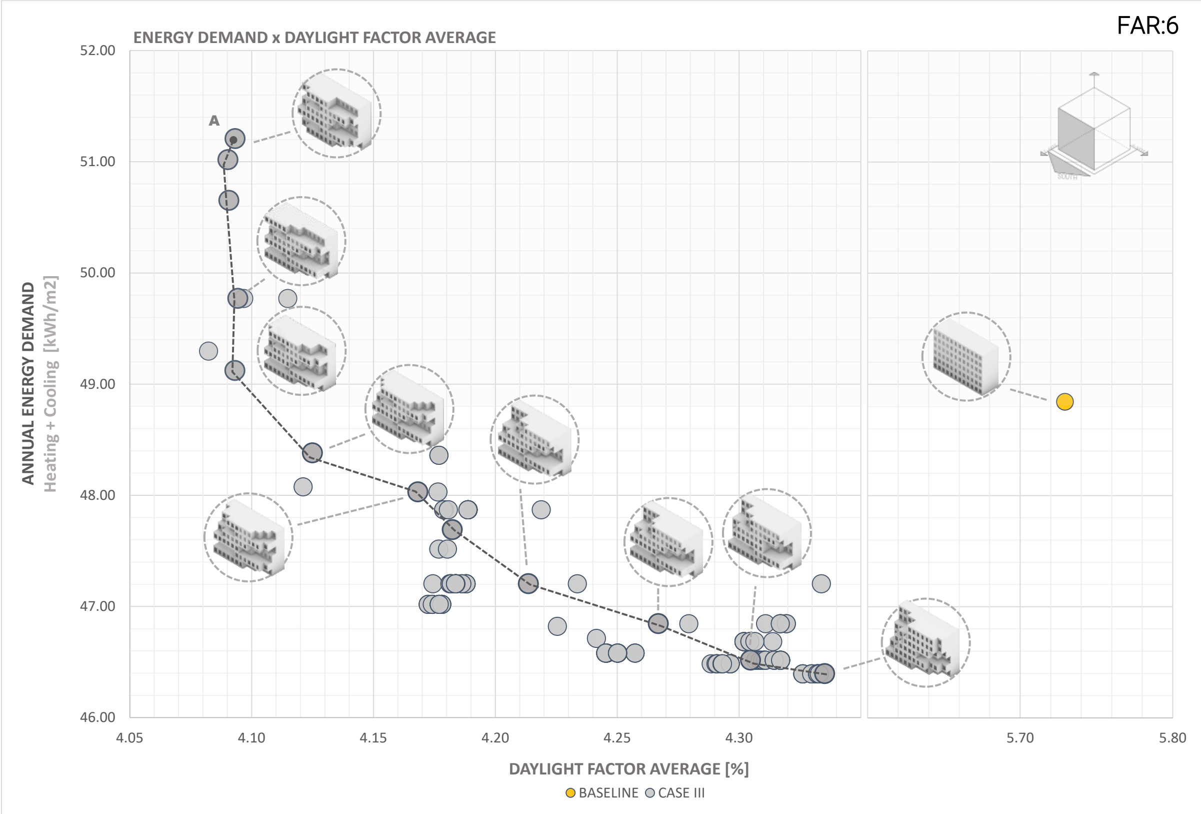


Figure 23: Case III, Energy Demand x Daylight Factor Average [Source: Authors]

Evaluating the configurations as seen there are ≈ 90% cases challenging with the with baseline in heating and cooling and in daylighting during the year.

Looking at the trend line of the parameter of energy demand and daylight factor can be understood that generation of the "worst case" of 51.21 kWh/m2 with higher energy demand and more acceptable daylight while there is relation as the free-floating system during an annual period analysis cooling is less needed while heating need is higher corresponded to higher daylight factor and lower total demand of "best case" reaching 46.40 kWh/m2.

That being said, each floor moves towards higher solar potential lower energy demand as well as allows to decrease the energy demand and daylight factor looking at the worst-case daylight factor 4.09 % (28.62%) of improvement portions of building my not reach acceptable daylight while other can reach higher than the threshold, this causes a non-uniform a spread of annual sunlight during the year. While moving along the trend line forms develop to be more compacted allows to reduce the non-uniformity, causes to lower energy demand needed.

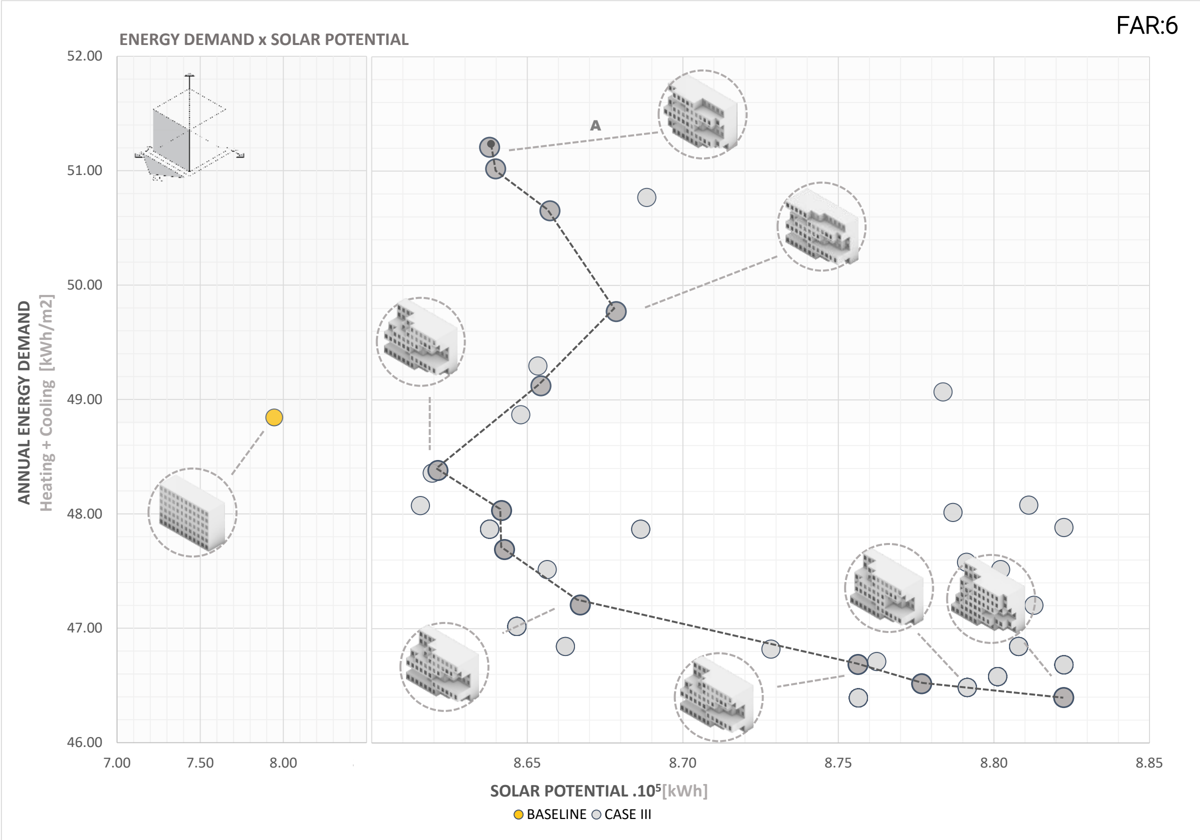


Figure 24: Case III, Energy Demand x Solar Potential Graph [Source: Authors]

It's quite hard to identify a clear pattern through this method to understand how the solar potential increases thus a study of how the floor plan moves along the floor line level shows A comparison of how best and worst case perform, this allows us to see the floor per floor configurations and depth length while in worst case floors have a greater shift in distribution increases the floor area but it's mostly overshadowing by the upper floor while vice versa on the best case as it reaches a greater depth of 5 m Maximum of 9.0X10^5 kWh.

Moreover, looking at how the curve distribution best case requires to have more sun exposure to the southwest on the upper while shifting gradually to the other side on the southeast. And finally, can be seen the more surface exposure of the envelope the higher the solar potential but not in this method due to the limitation of the small building proportion in the study.

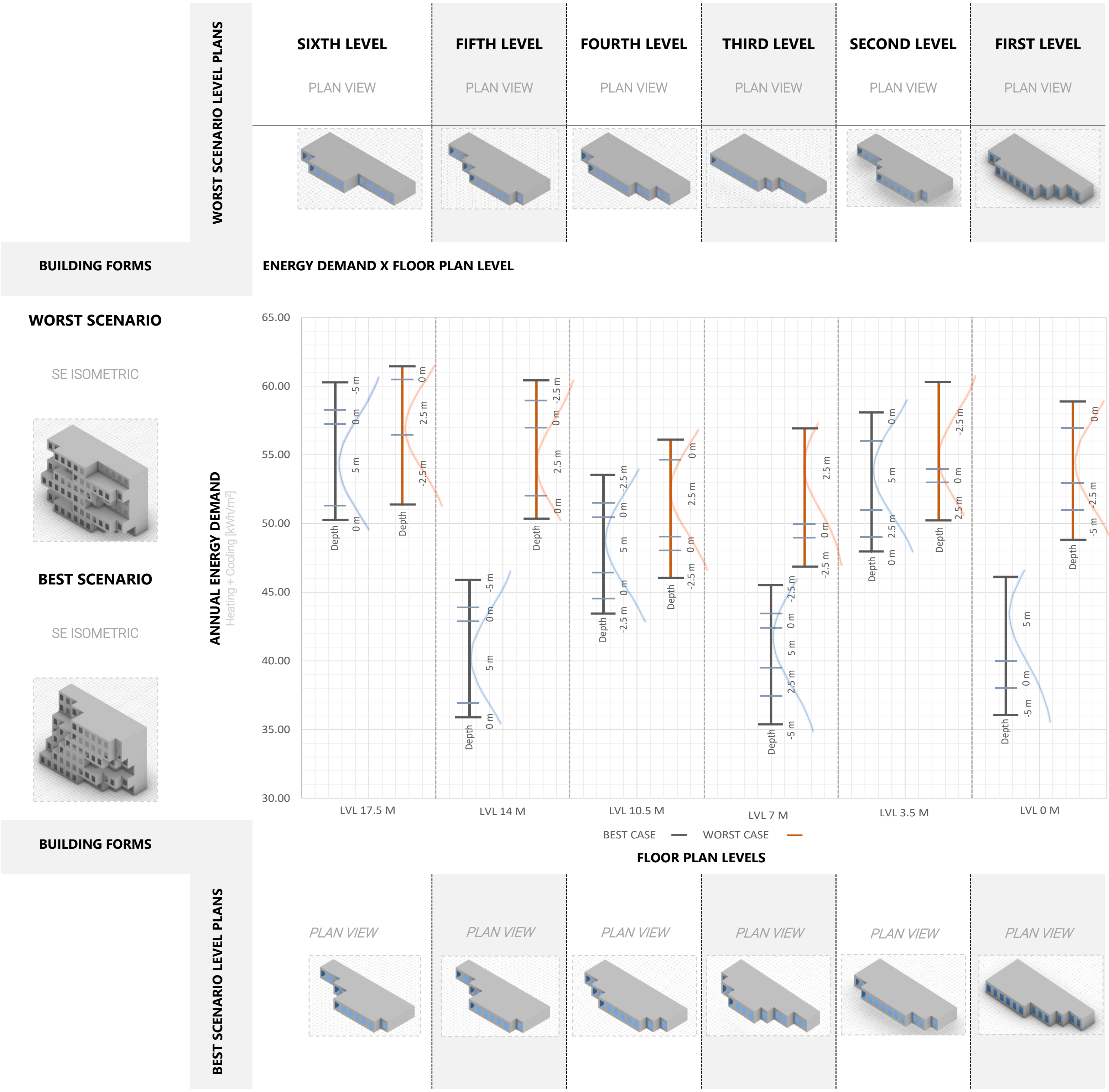
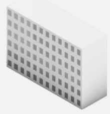
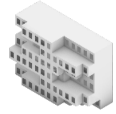
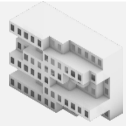
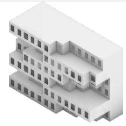
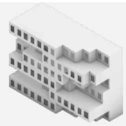
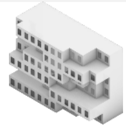
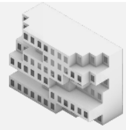
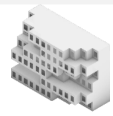
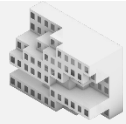
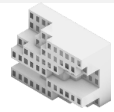
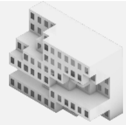
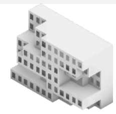
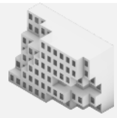


Figure 25: Waving Methodology ED x Floor Plan Based on "How Waves Forms the Floor Plans? " [Source: Authors]

Table 13: Waving Methodology Results Comparison

Cases		Daylight Factor [%]	Solar Potential [kWh]	Energy Demand [kWh/m2]	Visual
BASELINE		5.73 (α)	794414.44 (α)	48.84 (α)	
CASE III	POINT A	4.09 (↓28.62%)	863790.45 (↑8.73%)	51.21 (↑4.86%)	
	POINT B	4.09 (↓28.62%)	863986.54 (↑8.75%)	51.02 (↑4.46%)	
	POINT C	4.09 (↓28.62%)	865731.48 (↑8.98%)	50.65 (↑3.71%)	
	POINT D	4.09 (↓28.62%)	867865.55 (↑9.25%)	49.77 (↑1.90%)	
	POINT E	4.09 (↓28.62%)	865442.19 (↑8.94%)	49.12 (↑0.58%)	
	POINT F	4.12 (↓28.09%)	862132.37 (↑8.52%)	48.38 (↓0.94%)	
	POINT G	4.17 (↓27.22%)	864175.66 (↑8.78%)	48.03 (↓1.65%)	
	POINT H	4.18 (↓27.05%)	889570.24 (↑11.97%)	47.69 (↓2.35%)	
	POINT I	4.23 (↓26.18%)	866707.97 (↑9.10%)	47.20 (↓3.35%)	
	POINT J	4.30 (↓4.95%)	875638.70 (↑10.22%)	46.68 (↓4.42%)	
	POINT K	4.31 (↓24.78%)	877682.64 (↑10.48%)	46.52 (↓4.74%)	
	POINT L	4.33 (↓24.43%)	882247.50 (↑11.05%)	46.40 (↓5.00%)	

[Source: Authors]

1.5 BUILDING FORMS COMPARISON

Looking through the cases and understanding how each method impact the building performance throughout energy and daylight metrics therefore, comparing the three methodologies will indeed provide a better insight on how certain manipulation effect the performance of the main indicators and how some cases couldn't compete with baseline due to ineffective approach of solution optimization.

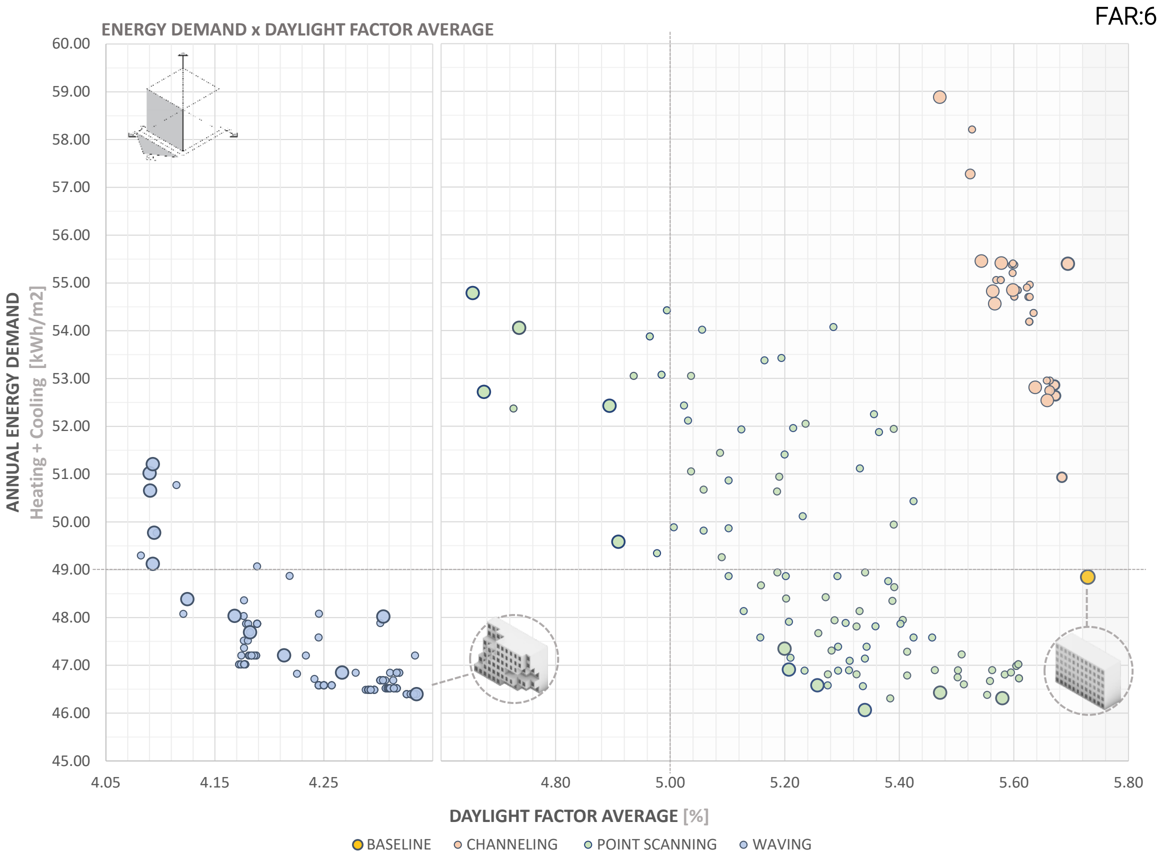


Figure 26: Building Form Comparison ED x ADF Graph [Source: Authors]

In order to look at the different cases all the methodologies have been colored uniformly, the blue color indicates the WAVING method, the green color POINT SCANNING method, the orange color CHANELLING method, and BASELINE in yellow color.

Looking first at the CHANNELING it's clear it provides the highest average daylight factor and energy demand as the building increases the lower floor area and decreases the upper ones it is increasing the daylight and demand needed due to the lack of self-shadow.

POINT SCANNING one and two points indicate a lower energy demand due to the increase of voxels exposure and shading in specific areas while in worst cases showing better average daylight factor caused by the point scanner pushing the mass towards the north façade increasing the shading as well as increase the heating needed.

The WAVING method presents a low daylight factor (24.43%) improvement due to the extension of floor plans while having some cases of lower energy demand it seems that having a 5-meter depth increase partially per the floor plan while others exposed shows better performance in the total. It seems a good compromise of the two other methodologies keeping a more exposed floor plan on the south façade shows the low energy demand needed plus the increased depth of the floor makes for a larger plan area and the self-shade shows a lower average daylight factor.

Therefore, the channeling requires more energy need than waving and point scanning while providing a higher average daylight factor, point scanning reaches lower energy demand but still provides a higher than acceptable average daylight threshold range, therefore the waving methodology can reach lower promising DF.

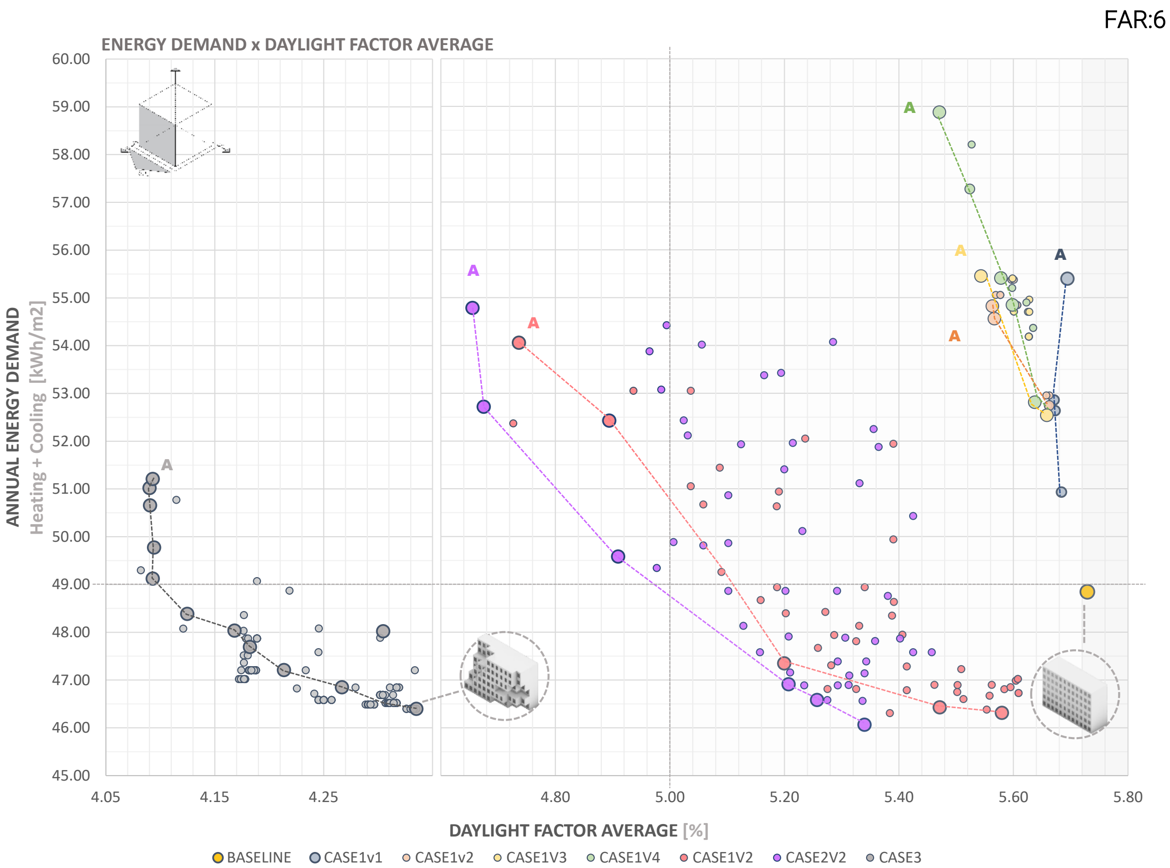


Figure 27: Building Form Comparison Individually, ED x ADF [Source: Authors]

In this figure, individual cases of each methodology with a different color to look at the trendlines holistically. Looking at the waving method as some cases reach below 47 kWh/m2 the energy demand started to not vary as the floor plans cannot exceed more than 10-meter extension for floor depth only varies in daylight factor, moreover the scanning point cases along the trendline of pushing and pulling portions of the voxels meaning when a larger portion of the lower southwest pushed outward and the other inwards on the furthest southeast it decreases the overall energy needed and reaches better-competing cases.

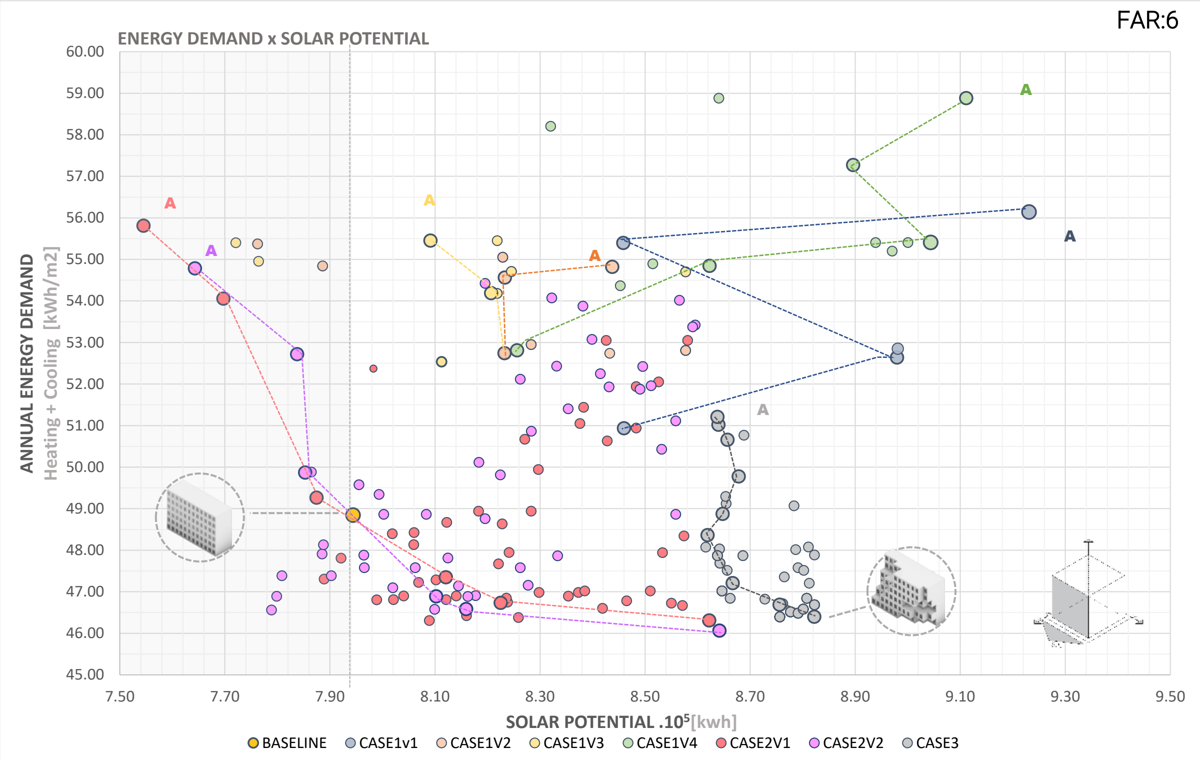


Figure 28: Building Form Comparison, ED x SP [Source: Authors]

Channeling visibility performs best in the solar potential due to the amount of the roof availability without obstructions of the adjacent voxel reaching higher solar potential than of all the other methodologies, this can be seen with CASE1v1 point A since there is a great envelope area exposed to solar radiation.

However, having Waving methodology performs better with low energy demand and somewhat high solar potential due to the surface exposure specifically of the 5-meter floor plan extension. While point scanning method seems to be closer to the baseline as fewer horizontal surfaces are exposed to the useful solar radiation since the forms are more compacted decreasing the amount of solar potential provided. Thus, further exploration was done to understand the best and the worst performance in these figures as it shows an overall impression of the tradeoff of the two metrics along the trendline of the cases considering the solar potential and daylight factor performance metrics. The figure presents the cases from worst to best performance in solar potential in the X axis and worst to best cases in average daylight in the Y axis.

It can be seen that in the channeling method the worst performers are the more compacted shapes whereas improving through more roof exposure is dependent on the radiation falling in the horizontal surface as well as the highest SP due to lack of overshadowing in Point [A] while performing the worst in average daylight factor metric as depth is more narrow decrease to 2.5 meter on the upper floor.

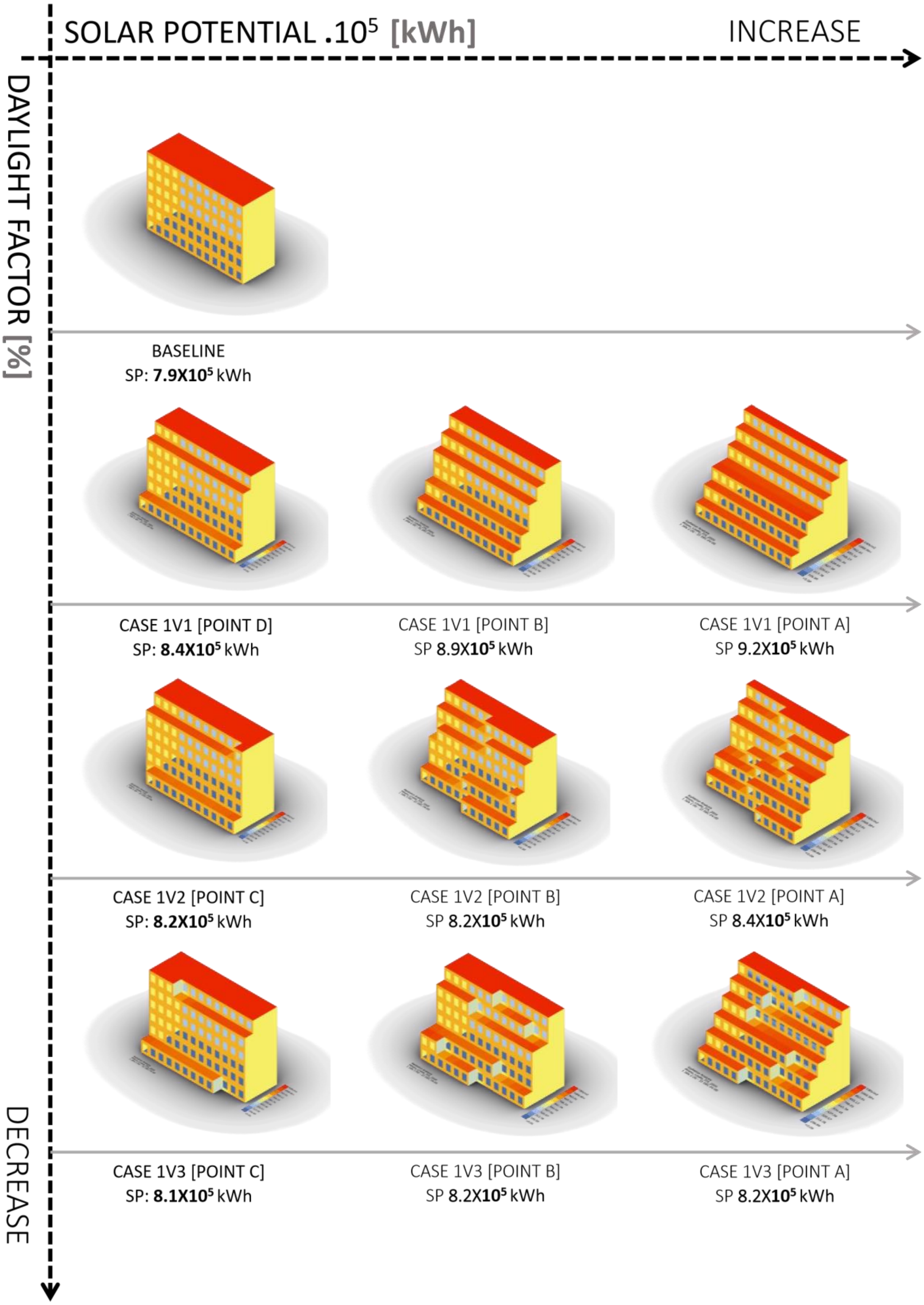


Figure 29: SP & DF Comparison of Case I Trendline [Source: Authors]

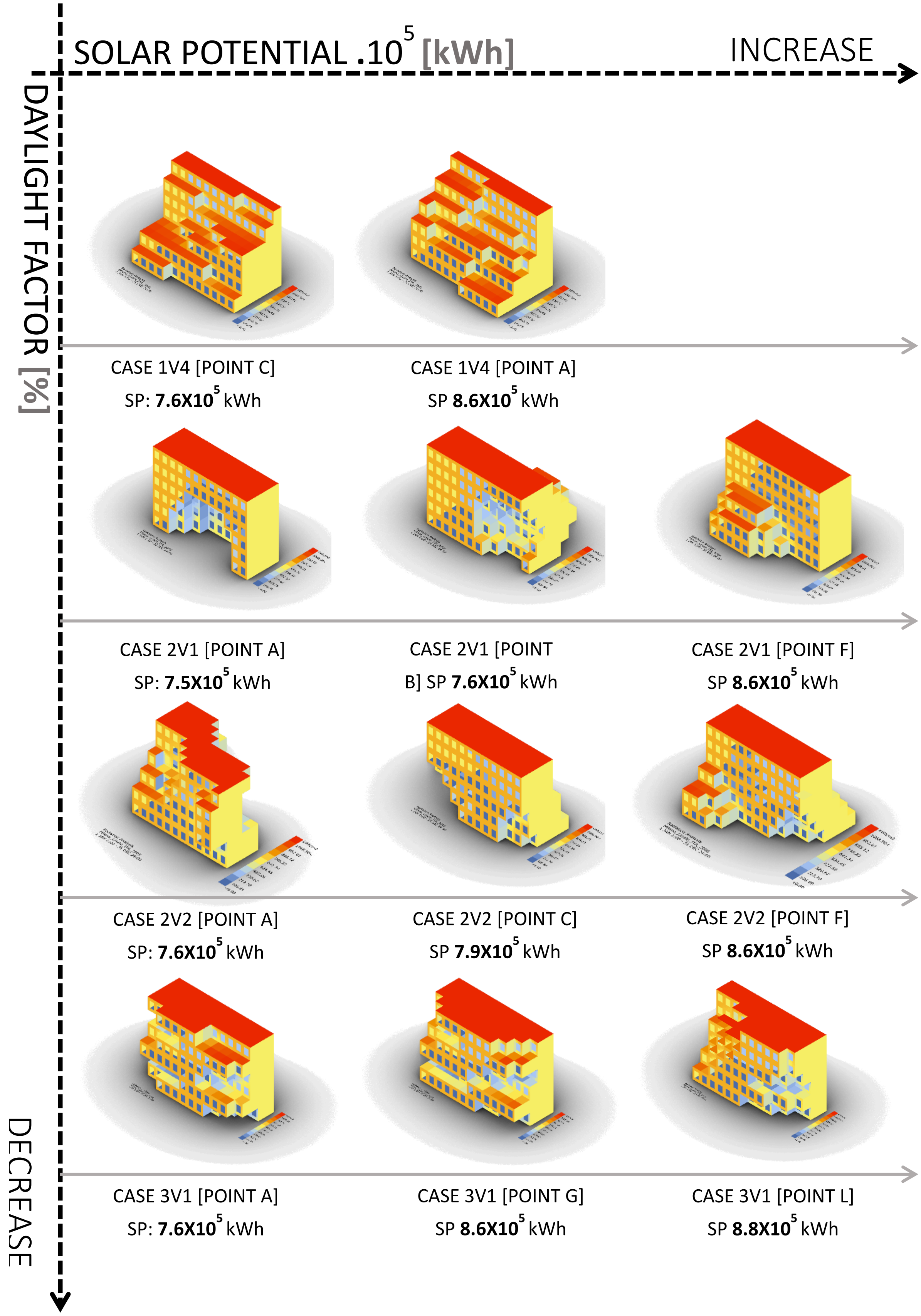


Figure 30: SP & DF Comparison of Case I-III Trendline [Source: Authors]

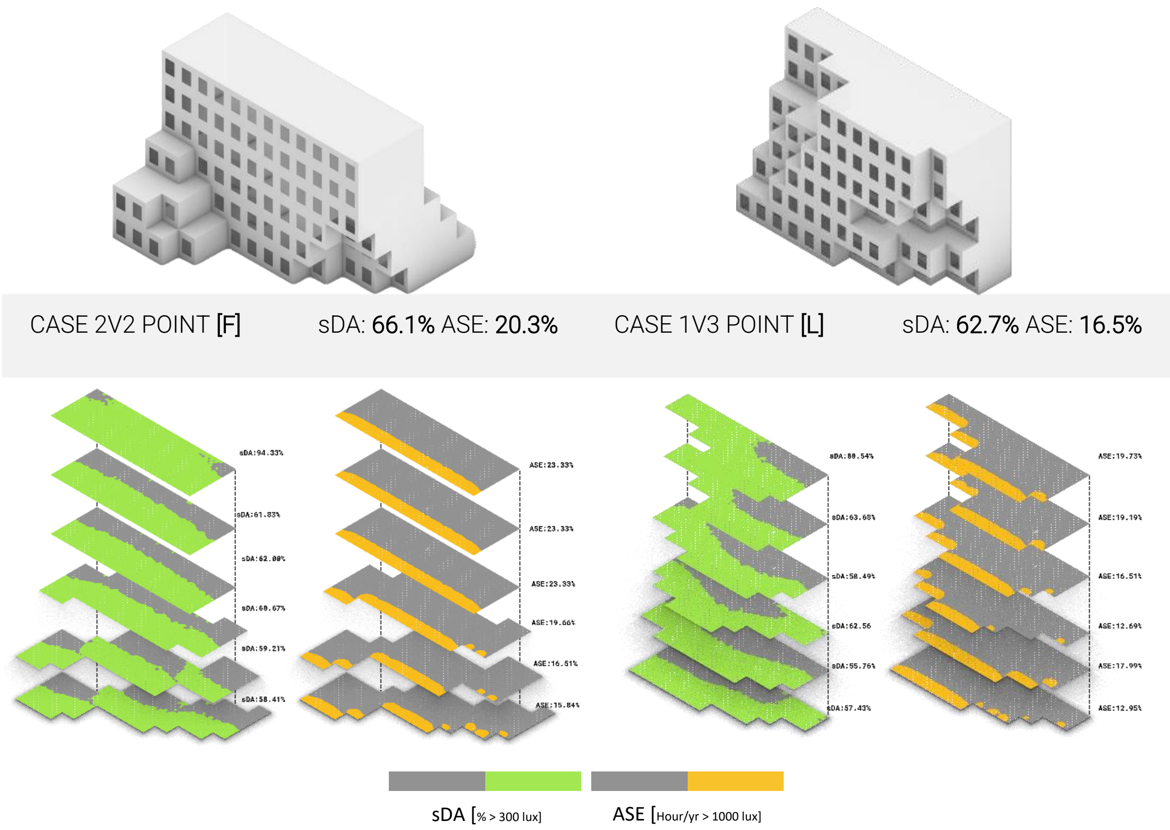


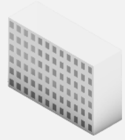
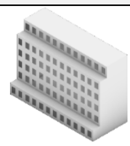
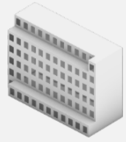
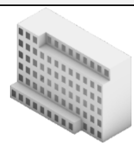
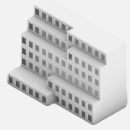
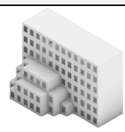
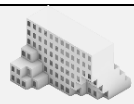
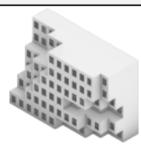
Figure 31: Dynamic Metrics per Level in Selected Best Cases [Source: Authors]

For a further investigation to understand the selected best cases floor plans using dynamic metrics as how many occupied hours it receives a minimum of 300 lux of 50% of the time [sDa] as well as the percentage of the floor area receives more than 1000 lux of 250 hours having more than 10% need to study further Glare strategies [ASE].

This demonstrates having the point scanning method shows better Spatial daylight autonomy, but it also shows Higher ASE which causes an increase in Glare probability, meanwhile waving method shows more decrease in ASE due to the increase of the self-shadings.

It should be mentioned that this is a study to compare the best cases of promising methods, the then further process will improve these conditions such as envelope typologies such as balconies, shading systems, and window ratio Deeping to control glare and excessive illuminance.

Table 14: Dynamic Metrics Results Comparison for Selected Best Cases

Cases		*Daylight Factor [%]*	*Solar Potential [kWh]*	*Energy Demand [kWh/m2]*	*sDA [%]*	*ASE [%]*	*Visual*
BASELINE		5.73 (α)	794414.44 (α)	48.84 (α)	67.5	24.7	
CASE 1V1	POINT D	5.68 (↓0.87%)	846014.16 (↑6.49%)	50.93 (↑4.28%)	65.4	20.6	
CASE 1V2	POINT C	5.66 (↓1.22%)	823278.74 (↑3.63%)	52.74 (↑7.98%)	65.2	20.4	
CASE 1V3	POINT C	5.66 (↓1.22%)	811261.76 (↑2.12%)	52.53 (↑7.55%)	65.2	20.4	
CASE 1V4	POINT D	5.60 (↓2.27%)	862320.82 (↑8.54%)	54.84 (↑12.29%)	61.3	24.0	
CASE 2V1	POINT F	5.58 (↓2.62%)	862235.42 (↑8.53%)	46.31 (↓5.18%)	65.8	20.3	
CASE 2V2	POINT F	5.34 (↓6.80%)	864184.66 (↑8.78%)	46.06 (↓5.69%)	66.1	20.3	
CASE 3	POINT L	4.33 (↓24.43%)	882247.50 (↑13.45%)	46.40 (↓5.00%)	62.7	16.5	

[Source: Authors]

1.6 CONCLUSION

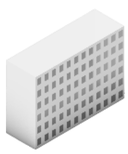
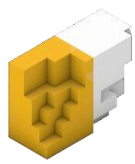
Based on the information obtained through the utilization of methodologies presented in Chapter 01, it is evident that these methodologies possess significant potential to cater to several types of requirements. The application of these explored methodologies has demonstrated a remarkable ability to enhance the solar potential of a given area, owing to their capacity to expose a larger surface area to sunlight, as well as to reduce the overall energy demand.

Moreover, it is noteworthy that these methodologies can maintain an average daylight factor within a range of 2% to 5%. In Chapter 01 Macro-scale simulations provide an overview of the entire facade and are useful for understanding the larger-scale patterns and dynamics of the building. However, to accurately model the behavior of individual buildings envelope elements and their interactions with the surrounding environment, meso-scale simulations are necessary.

To continue the study, the worst-case corner chunk of the south façade was taken. The reason for using the worst-case scenario is that it helps to identify the maximum amount of energy that a building might require in each situation. This information is essential for designing energy-efficient buildings and developing strategies for reducing energy consumption.

The new values for the selected chunk portion are presented in the table below. It should be noted that, for this chapter 2, these values will be considered in further analyses.

Table 15: Scale Change Values Comparison

	Macro Scale Baseline: South Facade		*Meso Scale Baseline: The Taken Chunk*
Average Daylight Factor (%)	5.73	-5.40%	5.42
Solar Potential (kWh/m^2)	794414.44	-51.35%	388247.91
Energy Demand (kWh)	48.84	11.12%	54.30
Visual			

[Source: Authors]

CHAPTER 02.

BUILDING ENVELOPS

2.0 INTRODUCTION

Upon obtaining the updated values from Chapter 01 which is defined as the macro scale, The next step after the macro scale simulations is to move to the Meso scale, where the buildings are modeled in greater detail. In this chapter, simulations run through building envelopes are defined as Meso-scale.

For this Chapter, the common features of the buildings are identified as improvement methodologies. These methodologies comprise balconies, shadings, windows, and materials, listed in order. Each of them is perceived as a potential solution and analyzed accordingly with the objective of the study. It is imperative to note that each of them undergoes a rigorous process of assessment and enhancement.

The aim of Chapter 02 is to enhance the performance of the best-performing case through the optimization of building envelope elements, material, and glazing typologies. One justification for employing these methodologies is their prevalence in the majority of buildings.

Optimizing building envelope elements and materials is essential to achieving energy efficiency in buildings. The use of high-performance insulation materials can significantly reduce the energy required for heating and cooling, thus reducing energy demand and carbon emissions. The selection of appropriate glazing and shading systems can enhance the daylighting performance of buildings while minimizing the risk of glare and overheating.

The optimization of building envelope elements and materials can also improve solar potential, which is critical for achieving sustainability in building design. The use of photovoltaic systems and solar thermal collectors can generate renewable energy that can offset the energy demand of buildings.

The Wallacei plug-in was used to identify the most promising generation of cases and the most suitable chunk to work on. The use of the Wallacei plug-in allows for a systematic evaluation of design options, which is essential for optimizing building envelope elements and materials. The findings of this chapter will contribute to the development of Microscale Chapter 3: Architectural Solutions to address the challenges of energy efficiency and sustainability.

To enhance the comprehensibility of the process, the present study employs an illustrative framework, which is presented on the subsequent page. This framework serves to provide a clear and concise overview of the methodological approach utilized in the study, thereby facilitating a more comprehensive understanding of the research process.

2.1 CHAPTER FRAMEWORK

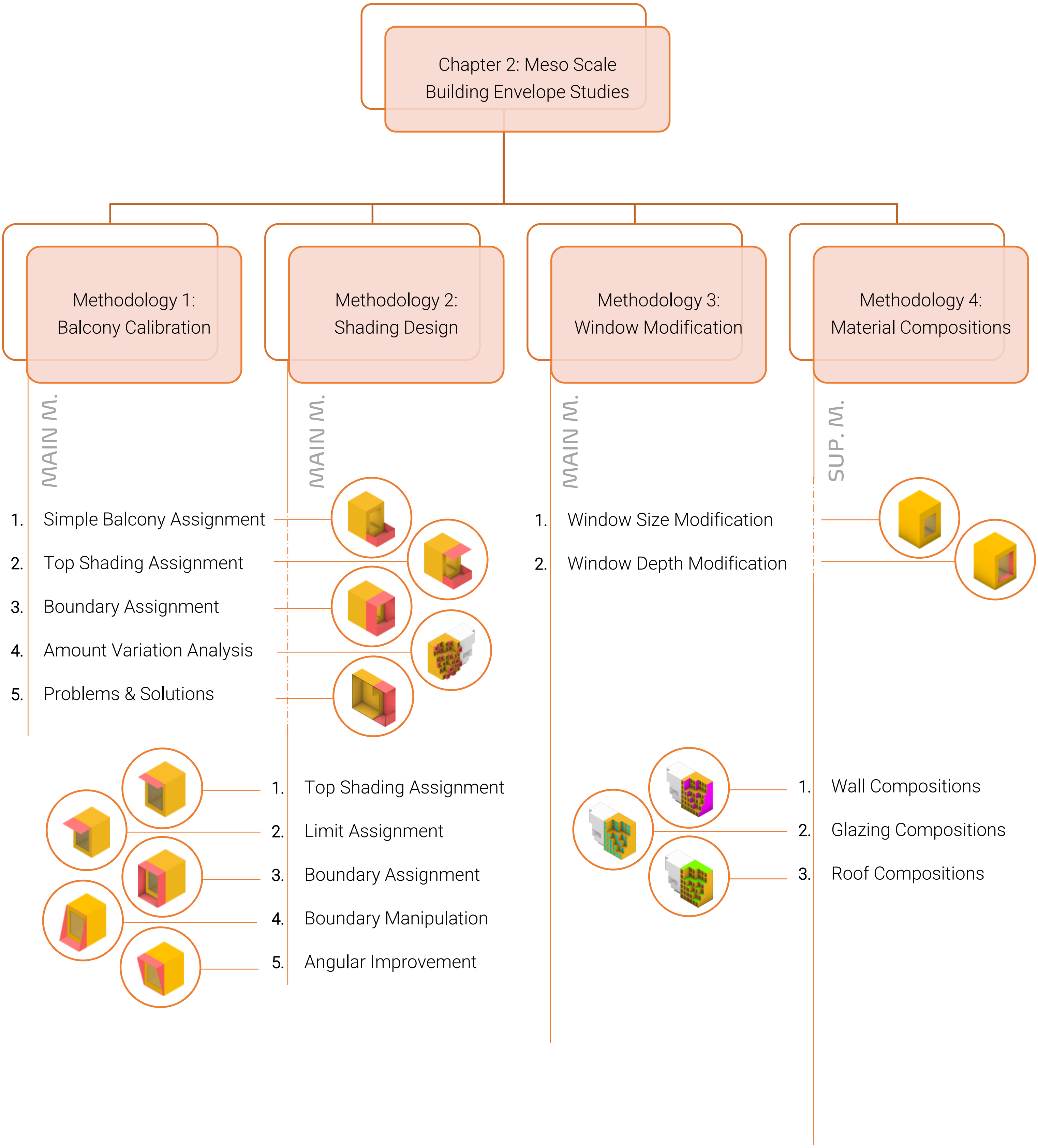


Figure 32: Chapter 02 Framework [Source: Authors]

MAIN M/ Main methodologies: are implemented through Grasshopper scripting to directly influence the building form.

SUP. M/ Supportive methodologies; are utilized to aid the main methodologies in achieving desired values.

2.2 METHODOLOGY

2.2.1 METHOD I: BALCONY CALIBRATION

Balconies calibration scans the surface of the building envelope by serializing the exterior voxels allowing the number slider to place balconies along the facade this results in two paths of the configurations of the Balconies merged Balcones and singular baloney, meaning when balconies are adjacent in index number by one digit the data used in the merged balconies and when index number s are different by two digits it uses the singular balconies.

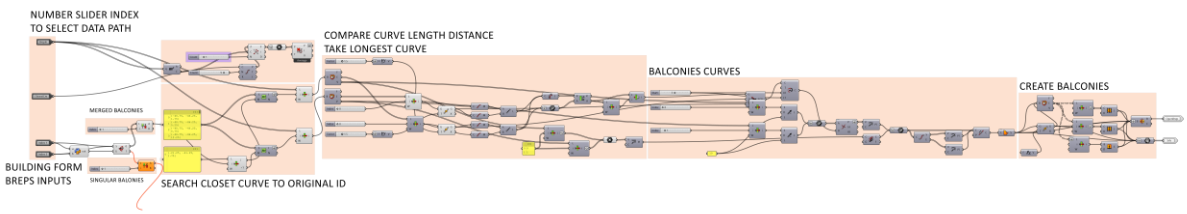


Figure 33: Script in Grasshopper Rhino 3D, "Balcony Scanning and Serializing for Calibration" [Source: Authors]

2.2.2 METHOD II: SHADING DESIGN

Shading design by manipulation boundary box points into the fixed length along the y axis of with number slider and performing angular actions in the z-direction.

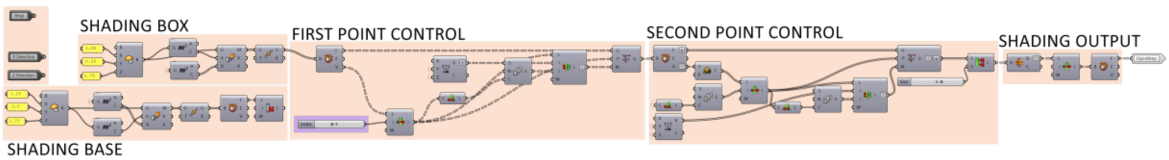


Figure 34: Script in Grasshopper Rhino3D, " Setting Point Controller for Shading Design" [Source: Authors]

2.3 BUILDING ENVELOPS

2.3.1 METHOD I: BALCONY CALIBRATION

The initial methodology employed for Chapter 02 of the present study is Balcony Calibration. This approach is chosen due to the fact that, although balconies are commonly viewed as architectural and structural components rather than integral building envelope features, they may impact a building's energy efficiency in a manner similar to shading elements.

Specifically, the design and placement of balconies can have a significant impact on a building's energy demand, daylight factor, and solar potential. Balconies can affect the amount of natural light and solar radiation that enters a building and impact the amount of heat gained or lost through the building envelope. This knowledge, which has been acquired through extensive research, highlights the importance of starting the design process for balconies by considering their typology.

The design of balconies is a complex process that requires careful consideration of multiple factors. The process steps involved in calibrating balconies are visualized in the next page, and each step will be further clarified in subsequent result pages.

One of the initial steps in designing balconies involves starting with the simplest balcony typologies and observing the resulting effects. This approach allows for a basic understanding of how balconies can impact a building's energy performance and can serve as a starting point for more complex balcony designs.

However, it is important to note that the design of balconies should be tailored to the specific energy performance goals of the building. This may involve incorporating additional features into the balcony design, such as shading devices or solar panels, to enhance their energy performance.

The positioning of balconies is also a critical factor in their energy performance. Balconies should be designed and positioned to optimize their benefits while minimizing any negative impacts on the building's energy performance. Factors such as the building's location, orientation, and overall design must be considered to ensure that the balconies contribute positively to the building's overall energy performance.

Consequently, when performing energy simulations and designing building forms, it may be more pertinent to treat balconies as constitutive constituents of the building envelope, as opposed to solely regarding them as structural elements. In subsequent stages, this objective will be achieved by isolating the voxel balcony elements from the chunk and focusing on them exclusively.

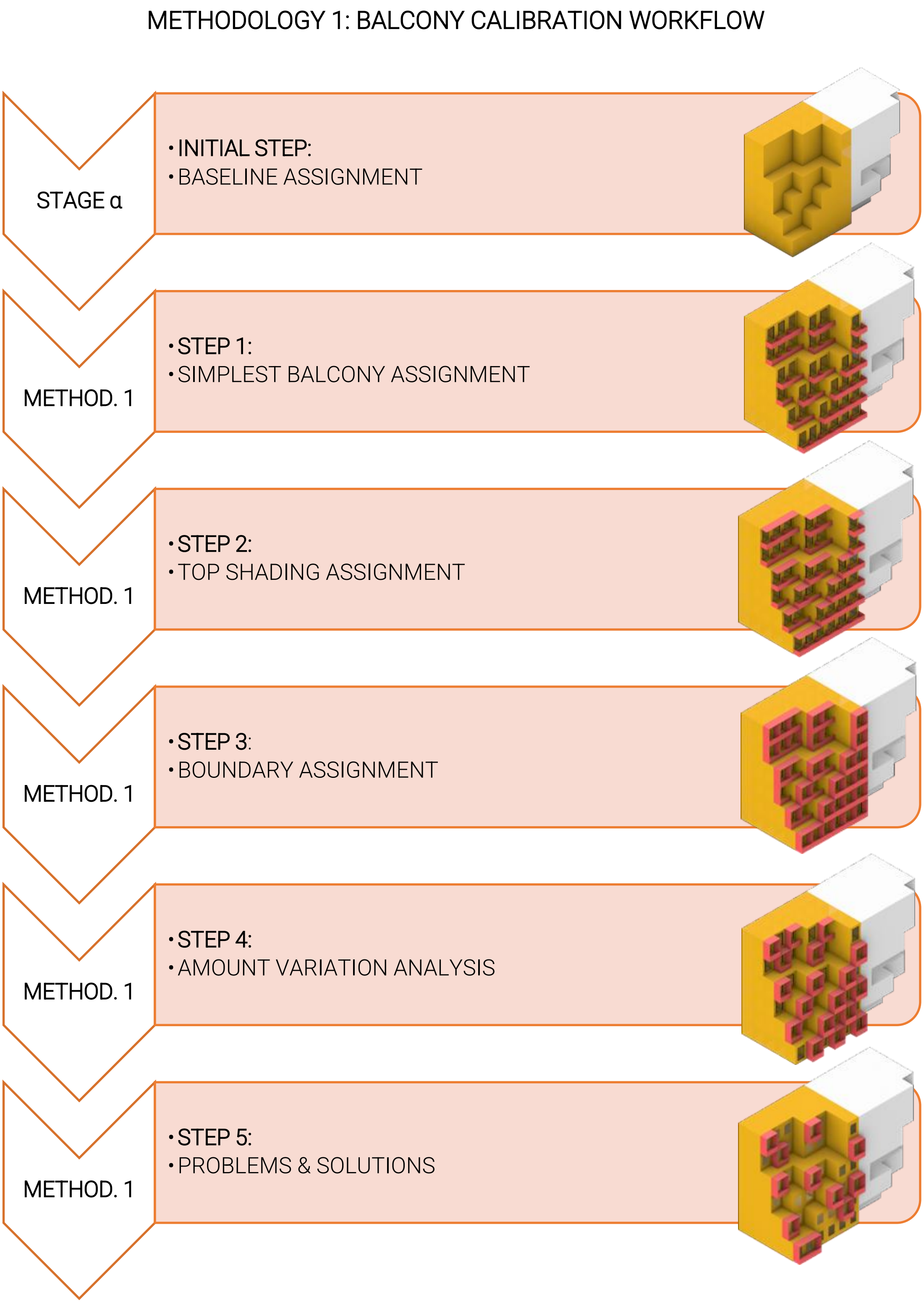


Figure 35: Methodology I Workflow [Source: Authors]

2.3.2 METHOD II: SHADING DESIGN

The second methodology applied in chapter 02 focuses on shading design with an emphasis on Average Daylight Factor and Energy Demand more than a Solar Potential. The design of the shading elements starts with vertical top shading units. The reason why designing shading elements often begins with vertical elements is because of the way the sun's rays move throughout the day. Vertical shading devices are most effective at blocking the sun's rays during peak solar times, which typically occur around midday when the sun is directly overhead. Horizontal shading devices, on the other hand, are more effective at diffusing the sun's rays during morning and evening hours when the sun's angle is lower. [32]

In addition, designing shading elements with vertical elements can also help to reduce glare and improve visual comfort, as they are better at blocking direct sunlight and minimizing contrast between bright areas and shaded areas. This can be especially important in spaces like offices and classrooms where glare can be a significant issue.

However, it is important to note that the most effective shading design will often involve a combination of both vertical and horizontal shading elements, as each type of shading device offers unique benefits and can be used to address different solar angles and shading needs.

The shading chapter aims to accomplish three primary objectives: reducing energy demand, optimizing the average daylight factor, and maximizing the solar potential. By reducing the energy demand and optimizing the average daylight factor, the shading chapter's findings can aid in creating a sustainable and comfortable environment for building occupants [33] [34]. Maximizing the solar potential also contributes to reducing the building's reliance on non-renewable energy sources.

The process steps involved in designing shading are visualized in the next page, and each step will be further clarified in subsequent result pages.

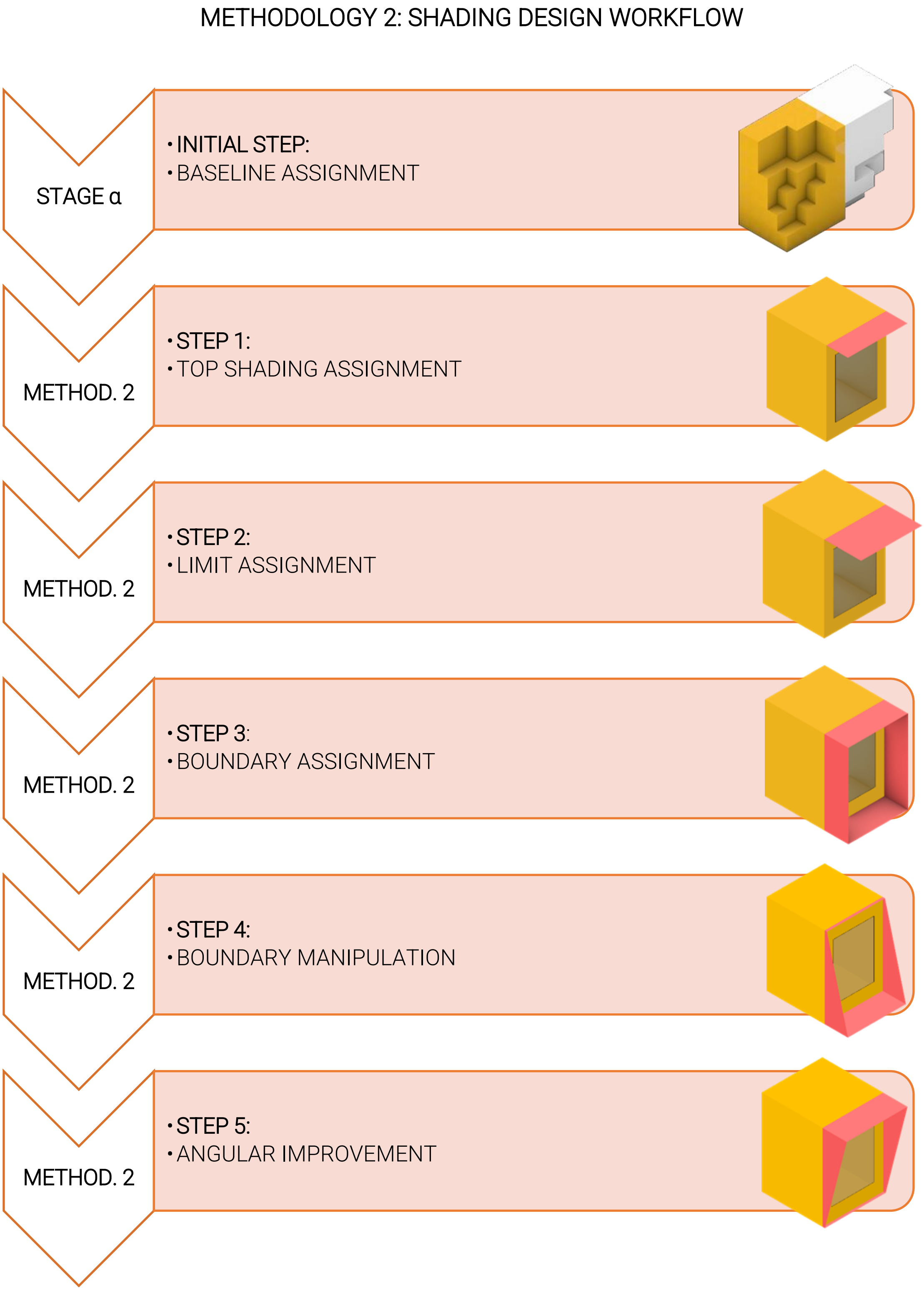


Figure 36: Methodology II Workflow [Source: Authors]

2.3.3 METHOD III: WINDOW MODIFICATION

The third methodology applied in chapter 02 focuses specifically on window modification, with an aim to optimize the energy performance and daylighting quality of the building envelope.

The reason why window modification is important is because windows are one of the primary sources of heat gain or loss in a building, accounting for up to 25% of the total energy used for heating and cooling [35]. Second, the size of windows has a significant impact on building energy demand due to their role in the amount of natural light that enters the building.

Large windows can allow for more natural light to penetrate the building, reducing the need for artificial lighting during the day. However, this can also lead to increased heat gain during the summer months, resulting in higher energy consumption for air conditioning. Conversely, smaller windows can reduce heat gain but may require more artificial lighting, leading to higher energy consumption for lighting. Therefore, the size of windows should be carefully considered to balance the need for natural light and views with the need to minimize energy consumption.

Moreover, the size of windows can also affect glare and daylight factor. The daylight factor is a measure of the amount of natural light that penetrates a building, and it is directly related to window size. Larger windows can allow for more natural light to enter the building, improving the daylight factor and reducing the need for artificial lighting. However, excessive glare can be a problem in buildings with large windows, causing discomfort and reducing visual performance. Therefore, the size of windows should be carefully considered to optimize the daylight factor while minimizing glare.

The orientation of windows is another critical consideration in determining the size of windows. South-facing windows can provide more natural light and solar exposure during the winter months, reducing energy consumption for heating. However, this can also lead to excessive heat gain during the summer months, resulting in higher energy consumption for cooling. Conversely, north-facing windows provide less natural light and solar heat gain but can help to reduce heat gain during the summer months. Therefore, the size of windows should also be considered in conjunction with their orientation to optimize energy consumption, glare, and daylight factor.

In conclusion, the size of windows is a critical consideration in building design that affects building energy demand, glare, and daylight factors. Properly designed windows can help to optimize these factors and ensure maximum occupant comfort and energy efficiency. Therefore, the size and depth of the windows should be carefully considered.

In further steps, the effect of window size and depth modification are investigated, with the aim of optimizing the energy performance and daylighting quality of the building envelope.

METHODOLOGY 3: WINDOW MODIFICATION WORKFLOW

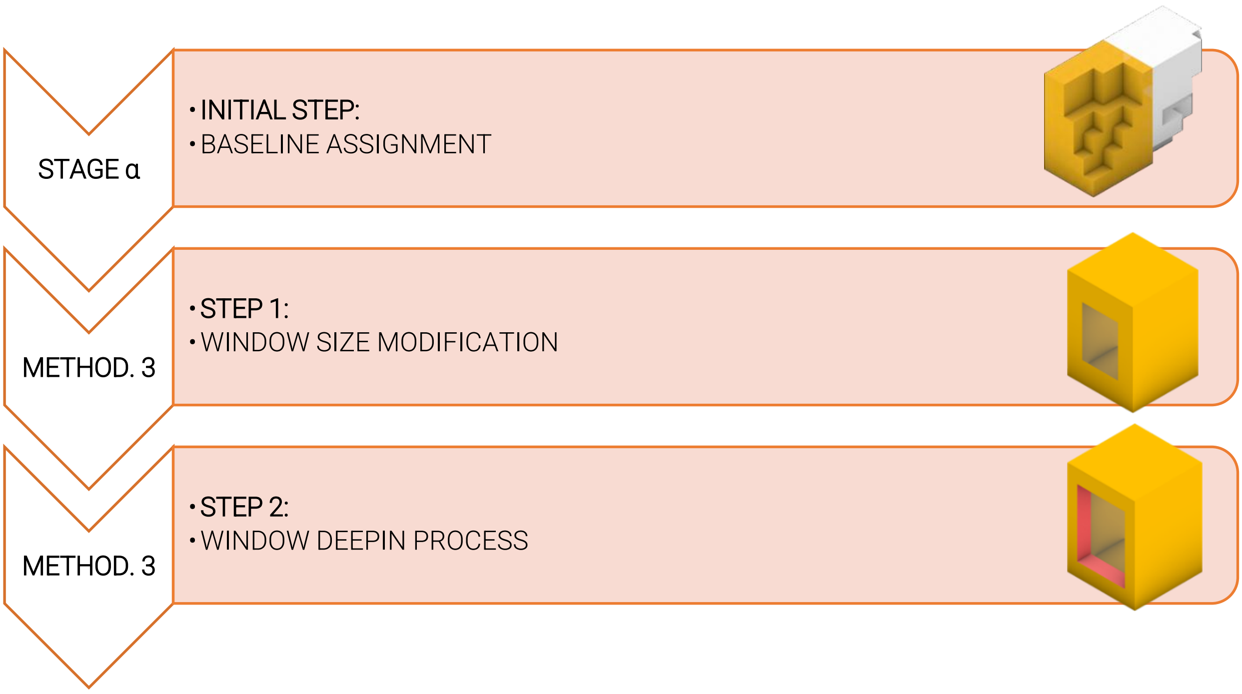


Figure 37: Methodology III Workflow [Source: Authors]

2.3.4 METHOD IV: MATERIAL COMPOSITIONS

The Fourth methodology of Chapter 02 aims to improve the energy efficiency of buildings by focusing on building materials. By optimizing the selection and use of building materials, it is possible to reduce energy consumption in buildings, which in turn can lead to lower energy costs and a smaller environmental impact.

The use of appropriate building materials and insulation with optimal thickness can be a highly effective method for energy conservation in building applications. The selection of suitable building materials can reduce fuel consumption, mitigate the emission of harmful gases from fossil fuel combustion, and enhance thermal comfort by minimizing heat loss from buildings. [36] [37]

Till this chapter, research methods based on morphology of the elements. Yet, building materials such as Energy-efficient ones can sustain construction both ecologically and economically because of their environmentally friendly features [38].

The materials used in the construction of a building have a significant impact on both its energy demand and daylight factor. Materials that are going to be used to design sustainable buildings need to be developed and used properly. [37]. The green roof, glazing, and walls are key components that can influence the amount of heat gain, natural light, and ventilation in a building. Green roofs, for example, can reduce cooling loads by providing natural insulation and absorbing solar radiation. Glazing can affect the amount of natural light entering a building and the need for artificial lighting, but it can also increase cooling loads. Walls can influence the amount of heat transferred into and out of the building and the need for heating and cooling. In this section, study will discuss how the material compositions of green roofs, glazing, and walls can impact energy demand and daylight factor, and explore ways to optimize these factors for more sustainable and efficient buildings. Yet it should keep in mind that the proposed methodology, while undeniably valuable, shall serve solely as a supplementary tool to the primary objective of the study, which concerns the forming of a building.

METHODOLOGY 4: MATERIAL COMPOSITIONS WORKFLOW

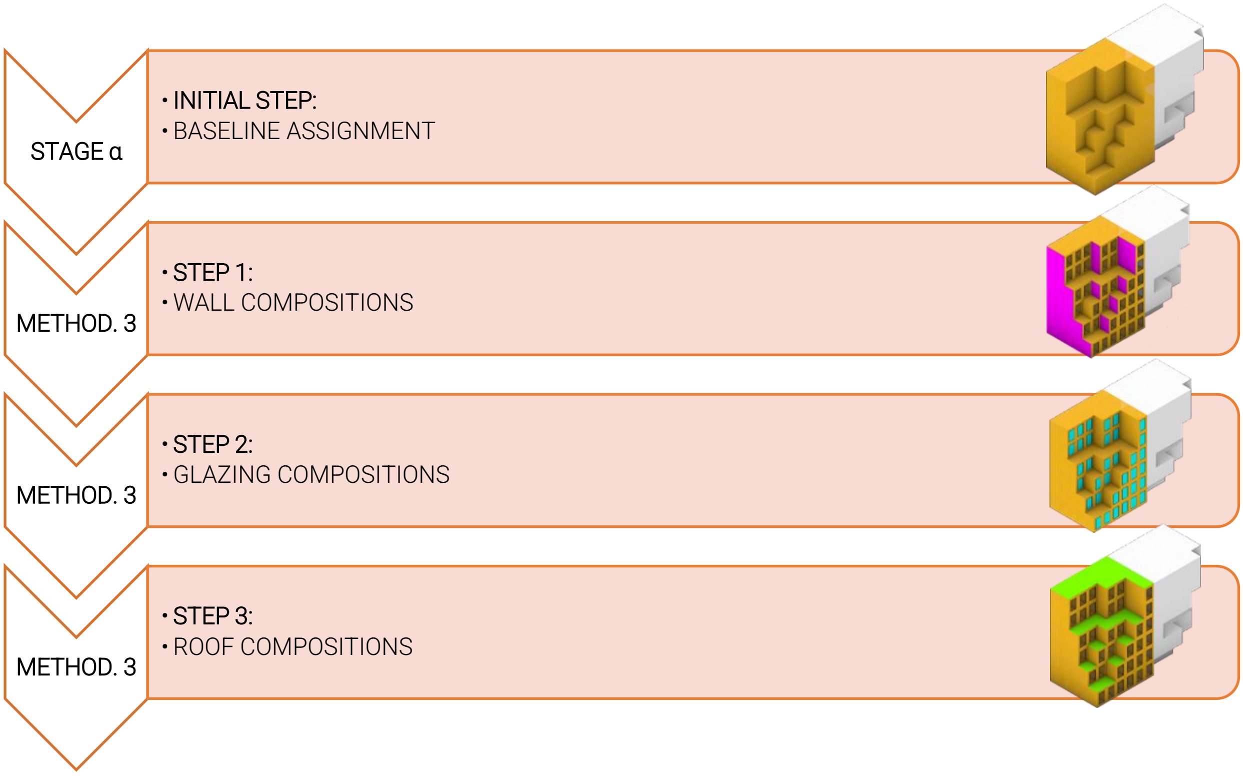


Figure 38: Methodology IV Workflow [Source: Authors]

2.3 BUILDING ENVELOPE RESULTS

2.3.1 METHOD I: BALCONY CALIBRATION

Step 1: Simplest Balcony Assignment

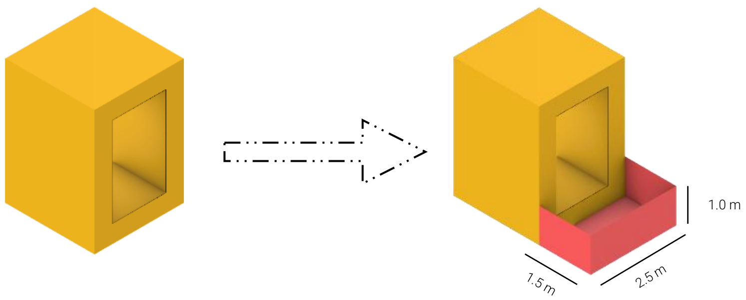


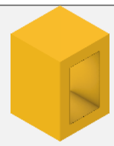
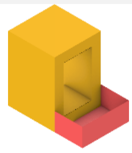
Figure 39: Simple Balcony Assignment Process [Source: Authors]

In the initial stage of this study, each voxel was assigned the simplest balcony type measuring 1.5 x 2.5 x 1 m. The addition of a balcony to a building is expected to provide numerous benefits, including enhancing the daylight factor, reducing energy demand, and increasing solar potential. Specifically, the presence of a balcony has been found to reduce the amount of energy required for cooling or heating a building. By shading windows and walls, the balcony can mitigate heat gain during the summer, consequently decreasing the need for active cooling systems. Similarly, in winter, the balcony can act as an insulator, retaining heat and thereby decreasing the need for heating.

However, it should be noted that due to the base of the balcony, which serves as an indirect shading element to the floors below, it is expected to have considerable decrease in the Average Daylight Factor. Nonetheless, as no shading elements are applied to the building envelope, the Average Daylight Factor supposed to remains acceptable limits. Hence, this decrease may be viewed as an advantage. Furthermore, in the initial step, no solar collector has been allocated to the chunk surfaces, resulting in a negligible solar potential for the building. The rationale behind the absence of photovoltaic allocation to the chunk's surface was to evaluate the net benefit of each application.

According to the findings of this experiment, the results have been graphed, and a data table has been compiled based on the generated data. *It should be noted that all the methodology elements applied to each voxel in the chunk but to observe the difference between shapes, only one element's visualization was exported and plotted to the data tables.*

Table 16: Simple Balcony Assignment Results Comparison

	Energy Demand [kWh/m²]	*Average Daylight Factor [%]*	*Solar Potential [kWh]* *(Without Chunk Mass)*	*Visual*
Without Balcony	54.30 (a)	5.42 (a)	-	
Simple Balcony Assignment	52.50 (↓3.31%)	4.34 (↓19.93%)	73934.92 (a)	

[Source: Authors]

According to the data presented above, the Average Daylight Factor (DF) has decreased from 5.42 to 4.34%, and the Energy Demand has decreased from 54.30 kWh/m2 to 52.50 kWh/m2. These findings confirm the accuracy of the theoretical information presented in this chapter. Furthermore, the addition of a simple balcony has successfully brought the Average Daylight Factor within the acceptable range of 2% to 5%.

It is important to note that this decrease in energy demand was achieved without the incorporation of any solar collectors. Therefore, it can be concluded that even a simple balcony can contribute to a decrease in energy consumption for this case.

The most significant finding from the results is the high potential of solar energy. It is important to note that Chapter 2 will primarily focus on showcasing the various forms of solar potential values and opportunities to increase it in comparison to energy demand. This is because the reduction in energy demand is not substantial.

Furthermore, as long as the daylight factor remains within the acceptable range of 2-5%, there will be no need for any corrective measures. Thus, in Chapter 3, as long as methodologies employed in Chapter 2 shows similar result, chapter 1 will primarily focus on decreasing energy consumption, while Chapter 2 will concentrate on enhancing solar potential.

As Step 1 has yielded satisfactory results, it has become evident that the initial step overlooked an opportunity to capture solar energy. To address this, the next step (Step 2) will involve adding top shadings to enable reach more solar potential, while simultaneously preventing excessive exposure to daylight in the first row of the chunk. This additional measure will help to ensure a more comprehensive and sustainable approach to the design and implementation of the building's energy management system.

Step 2: Top Shading Assignment

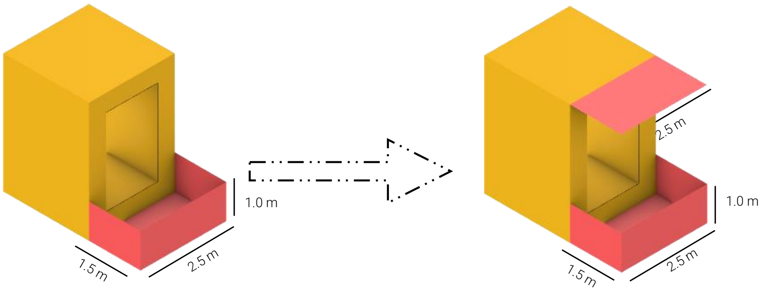


Figure 40: Top Shading Assignment Process [Source: Authors]

Step 2 of this study involves the consideration of additional top shading for simple balcony elements. According to the research conducted by Pereira and Neves [39], balconies that are designed to house outdoor air conditioning units have a depth of 0.5 meters. Conversely, balconies that are intended to be used as a liveable area, which connect indoor and outdoor spaces, are typically deeper, with depths ranging from 1 meter to 2 meters.

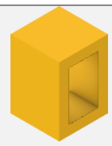
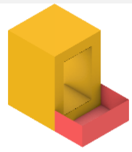
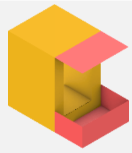
It is essential to note that since the top vertical elements will overlap with the bottom of the balcony, they will form the base for the upper-level balcony. In this regard, an additional top vertical shading length of 1.5 meters is proposed to determine the maximum solar potential that the shading can achieve in a year where balconies are not overlapping and suitable for overlapping balcony elements.

However, it is imperative to restrict the length of the additional top vertical shading to 1.5 meters. According to the research [40], shading devices that project more than one meter from the façade can also have a negative impact on the wind pressure coefficient (Cp) of the building. The study found that shading devices with a depth of one meter or less have a negligible impact on the building's Cp, while devices with a depth of more than one meter can lead to a significant increase in the Cp value [41]. This increase in Cp can lead to increased wind pressures and turbulence, which in turn can reduce the effectiveness of natural ventilation and HVAC systems.

Overall, while assigning such deep shading devices can be effective in reducing solar heat gain and improving energy efficiency, it is also important to consider the potential impact on wind pressure and airflow that may cause damage to the building. Shading devices that extend more than one meter (max. 1.5 meters) from the façade should be carefully evaluated and designed to ensure that they do not negatively impact the building's ventilation and indoor air quality.

Following the inclusion of shading devices and subsequent simulation algorithms, the resulting data has been graphed, and a comprehensive data table has been assembled based on the generated data.

Table 17: Top Shading Assignment Results Comparison

	Energy Demand [kWh/m2]	*Average Daylight Factor [%]*	*Solar Potential [kWh]* *(Without Chunk Mass)*	*Visual*
Without Balcony	54.30 (α)	5.42 (α)	-	
Simple Balcony Assignment	52.50 (↓3.31%)	4.34 (↓19.93%)	73934.92 (α)	
Top Shading Assignment	51.50 (↓5.16%)	3.49 (↓35.60%)	134078.86 (↑81.19%)	

[Source: Authors]

As per the data illustrated above, it can be observed that the Average Daylight Factor (DF) has been reduced from 4.34 to 3.49, and the Energy Demand has decreased from 52.50 kWh/m2 to 51.50 kWh/m2. It was anticipated to witness a reduction in the Average Daylight Factor, and as the value still falls within an acceptable range, no modification is required due to the high solar potential gain. The incorporation of top vertical shading has produced a considerable solar potential of 134078.86 kWh. Therefore, with further enhancements, these findings hold significant promise.

Based on the data generated above, it is reasonable to shift the focus towards maximizing solar potential gain for balcony solutions rather than solely concentrating on Energy demand and Average Daylight Factor. Additionally, balancing the trade-off between Average Daylight Factor and solar potential opens a new path for research and innovation.

To achieve this, the first step is to maximize the solar potential to minimize other factors. Next, new approaches can be implemented to strike a balance between the determining factors. Increasing the surface area for solar collectors is crucial to achieve the lowest band of other factors and maximize solar potential. By adding flaps of similar depth, it will be possible to observe the potential maximization and the corresponding decrease in daylight factor.

Step 3: Boundary Assignment

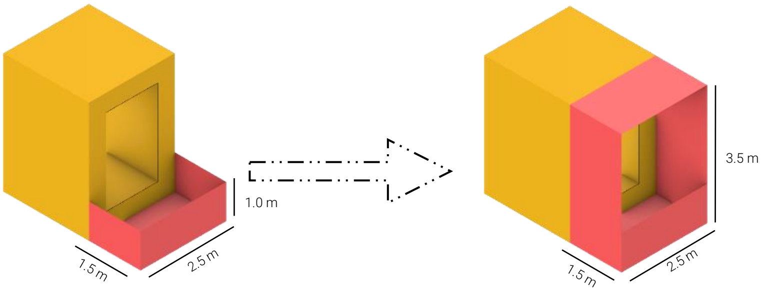


Figure 41: Boundary Assignment Process [Source: Authors]

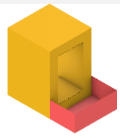
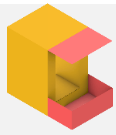
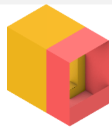
According to the proposal given in Step 2, which involves adding flaps to the balconies, in Step 3, the edge dimensions of the extrusion are 3.5x1.5m. This means that for each flap, there is an additional area of 5.25 m^2, resulting in an overall additional area of 10.50 m2. As compared to the top vertical shading, which has an area of 3.75 m2 and is capable of generating 60514.55 kWh solar potential, it is expected that the flaps will increase the solar potential by more than 90%.

Due to the presence of horizontal shading devices that obstruct direct sunlight from entering the interior space, a significant reduction in the natural light level can be observed, resulting in a low daylight factor. The reduced amount of natural light can be explained as the blocking of sunlight by the horizontal shading devices, which decreases the illumination level within the space. This reduction in natural light is particularly evident when the shading devices are positioned in close proximity to the window, resulting in a considerable amount of shadow on the interior surfaces.

The aforementioned phenomenon is a result of the interplay between the shading device, the incident sunlight, and the interior space. The horizontal shading device modifies the intensity and direction of the incoming sunlight, casting shadows on the interior surfaces, and creating an irregular distribution of natural light. As a result, the illumination level within space is reduced, leading to a lower daylight factor.

Following the inclusion of shading devices and subsequent simulation algorithms, the resulting data has been graphed, and a comprehensive data table has been assembled based on the generated data.

Table 18: Boundary Assignment Results Comparison

	Energy Demand [kWh/m2]	*Average Daylight Factor [%]*	*Solar Potential [kWh]* (Without Chunk Mass)	*Visual*
Without Balcony	54.30 (α)	5.42 (α)	-	
Simple Balcony Assignment	52.50 (↓3.31%)	4.34 (↓19.93%)	73934.92 (α)	
Top Shading Assignment	51.50 (↓5.16%)	3.49 (↓19.58%)	134078.86 (↑81.19%)	
Boundary Assignment	51.36 (↓5.41%)	2.65 (↓38.94%)	143617.40 (↑94.20%)	

[Source: Authors]

As it is noted previously, the solar potential value in Step 2 was initially at 134078.86 kWh. After applying the Boundary assignment method, the value increased significantly to 143617.40 kWh which mean 94.20% as it is expected.

Furthermore, it is important to note that the energy demand decreased negligibly from 51.50 to 51.36. Although this difference is negligible, it is still a positive outcome since it shows that the energy demand did not increase because of the changes made to maximize solar potential value. This means that the building can generate more energy while maintaining the same energy demand, resulting in a more efficient use of resources.

In addition to information given above, it is possible to observe that the Simple balcony assignment method, which resulted in a value of 4.34 average daylight factor, is higher than the boundary assignment value of 2.65. Yet, the goal of step 3 is based on maximizing solar potential, in this case keeping the average daylight factor value inside the range of 2-5% is good to pave the way for upcoming improvements.

Overall, the results of Step 3 demonstrate that the chosen method was highly effective in maximizing solar potential while maintaining energy demand. These results provide a strong foundation for future building design decisions aimed at maximizing energy efficiency and sustainability. Yet, it should not be overlooked that till this chapter the balconies applied to each voxel. Since it is rare and mostly not applicable to have a balcony along the whole façade for each room, different amounts of balconies in the façade should be examined to see how this methodology reacts to different architectural scenarios.

Step 4: Amount Variation Analysis

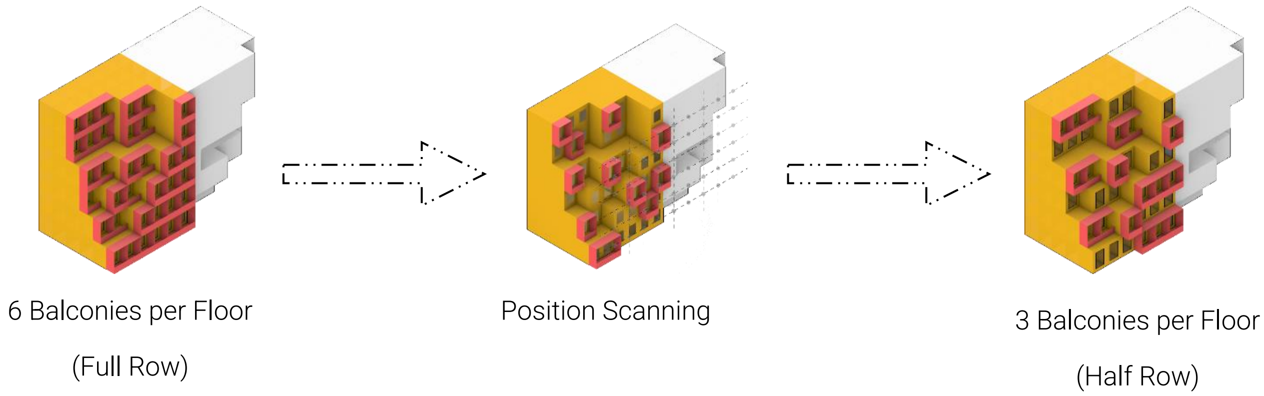


Figure 42: Amount of Variation Process [Source: Authors]

As it is mentioned in Step 3, to observe the behavior of the final formalized balcony for different amounts of balconies, an amount variation analysis held on. Common fact about balconies that they have traditionally been designed to offer outdoor access but in this study, they are also designed to maximize the solar potential of buildings. As such, the decision to include a balcony in a room is based on several factors, including the design of the building and the intended use of the room. In some cases, a balcony may not be necessary or feasible due to practical considerations such as space constraints or building codes.

Furthermore, it has been observed that the addition of more balconies can lead to a lower average daylight factor, according to experiments conducted till this step. Therefore, while balconies can be a valuable addition to a room or building, the number of balconies should be determined by various factors.

To further investigate the impact of balcony quantity on the building envelope, a data table was generated comparing different numbers of balconies, ranging from 6 to 2 assigned to the building envelope. The results of this analysis can provide valuable insight into the optimal number of balconies for a given building design.

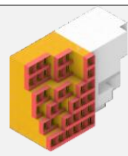
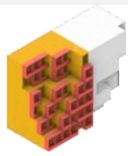
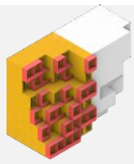
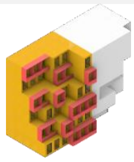
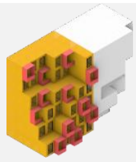
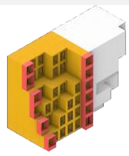
While locating the balconies, it is taken into account that balconies in the same column are not overlapped as possible.

To address these issues, a logical methodology is required. The Position Scanning Methodology, which forms the basis of Step 4, has been designed using the Grasshopper tool by authors. This algorithm scans all the surfaces and identifies the most beneficial voxels for balcony placement. In cases where balconies overlap with those on the floor above, the algorithm automatically selects the second-best option among all possible options.

The evolutionary script method employed by the authors of this study creates a promising path for future researchers working in the areas of building form, energy, and building envelope elements. To validate the Position Scanning Methodology, simulations have been conducted, and the resulting data has been plotted in a data table.

At this stage, it is important to clarify that data tables are not used to determine the best scenario. Rather, the decision should be based on observed differences and data analysis under specific conditions. It must be noted that due to the variety of scenarios, the behavior of each modification must be carefully observed.

Table 19: Amount Variation Resulst Comparison

		Energy Demand [kWh/m2]	*Average Daylight Factor [%]*	*Solar Potential [kWh]* *(Without Chunk Mass)*	*Visual*
Amount Variation Analysis	6 Balconies per Floor *(Scenario in Use)*	51.36 (α)	2.65 (α)	143617.40 (α)	
	5 Balconies per Floor	51.46 (↑0.19%)	2.89 (↑9.06%)	133507.10 (↓7.0%)	
	4 Balconies per Floor	51.66 (↑0.58%)	3.04 (↑14.7%)	125947.20 (↓12.3%)	
	3 Balconies per Floor	51.98 (↑1.21%)	3.35 (↑26.4%)	109689.24 (↓23.6%)	
	2 Balconies per Floor	52.63 (↑2.47%)	4.03 (↑52.0%)	87074.21 (↓39.3%)	
	2 Balconies per Floor *(Overlapped Scenario)*	55.07	4.64	82339.79	

[Source: Authors]

Keeping the statement given on the previous page in mind, the values for different numbers of balconies, ranging from 6 balconies down to 2 balconies, exhibit significant differences.

For instance, 2 balconies per floor achieve a daylight factor of 4.03, which is average value and highly sufficient for quality indoor lighting, with a solar potential of 87074.21 kWh, on the other hand, when 3 balconies per floor are considered, the solar potential reaches to 109689.24 kWh which is approximately 23.6% lower than the 6 balconies per floor scenario and the average daylight factor reaches 3.35% which is 26.4% higher which makes it medium value among scenarios.

Considering the information presented above, this analysis of variations provides a good example of how to address low average daylight factor through architectural solutions while mostly maintaining high solar potential. Moreover, it is better to see capability of how much average daylight factor can get close to 4% which is average value. At step 5, what kind of problem keeps it low specifically will be determined and based on it, solution will be offered.

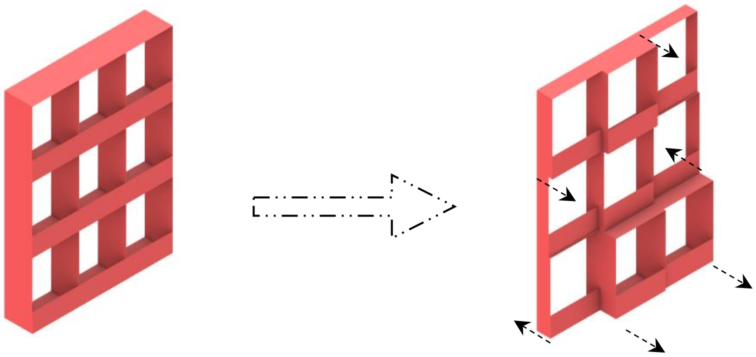


Figure 43: Exploration Process [Source: Authors]

In order to investigate the impact of varying balcony depth on performance, a study was conducted that focused on six different balcony configurations. The study sought to determine how changes in balcony depth which can be seen from the figure, specifically widths ranging from 0.5 to 1.5 meters, affected performance outcomes such as solar potential and average daylight factor.

By varying balcony depth, the study aimed to increase the amount of exposed surface area and thereby improve the overall solar potential of the building. Additionally, the study sought to enhance the average daylight factor, which is a key metric for assessing the quality of natural lighting within a building.

Overall, this investigation represents a significant step forward in the design of buildings that are optimized for performance and sustainability.

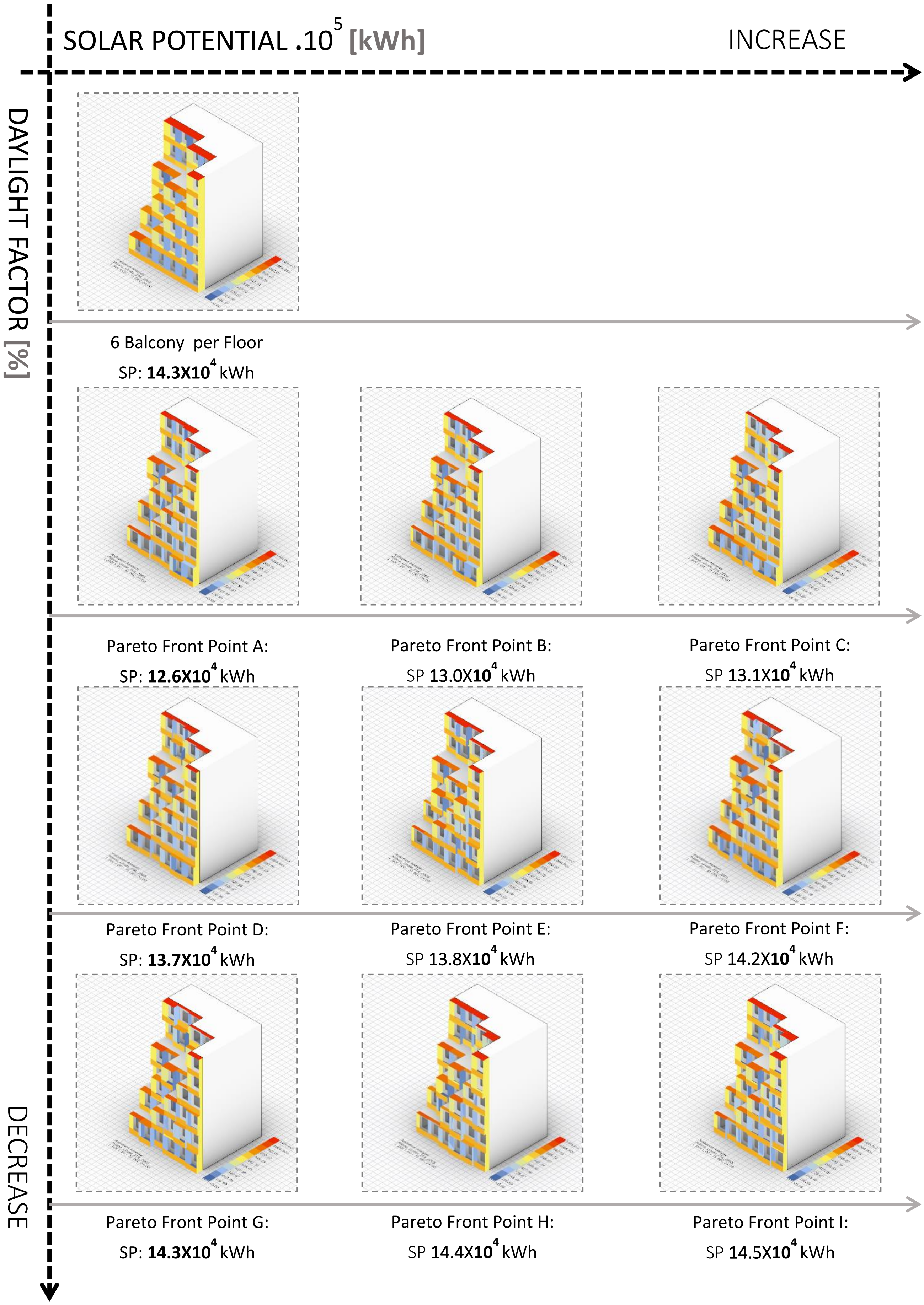


Figure 44: SP & DF Comparison of Exploration Trendline [Source: Authors]

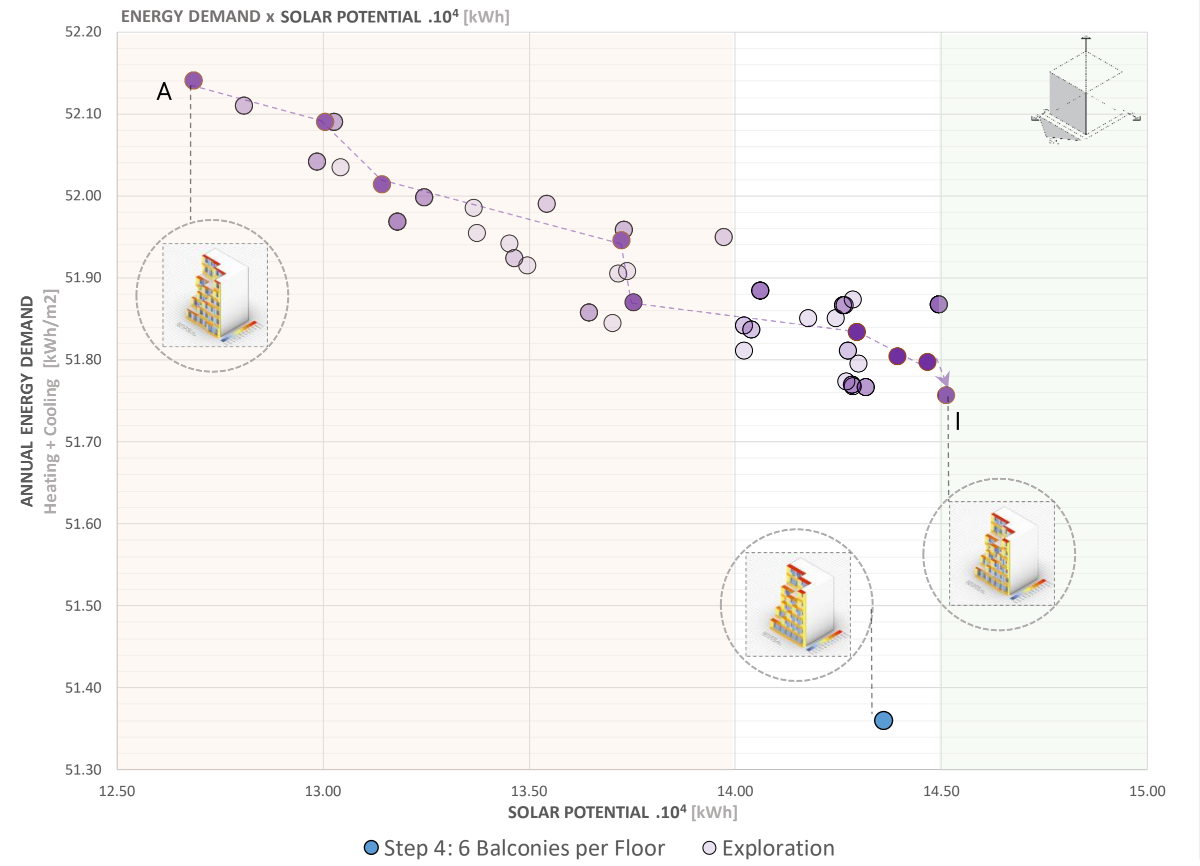


Figure 45: Exploration ED x SP Graph [Source: Authors]

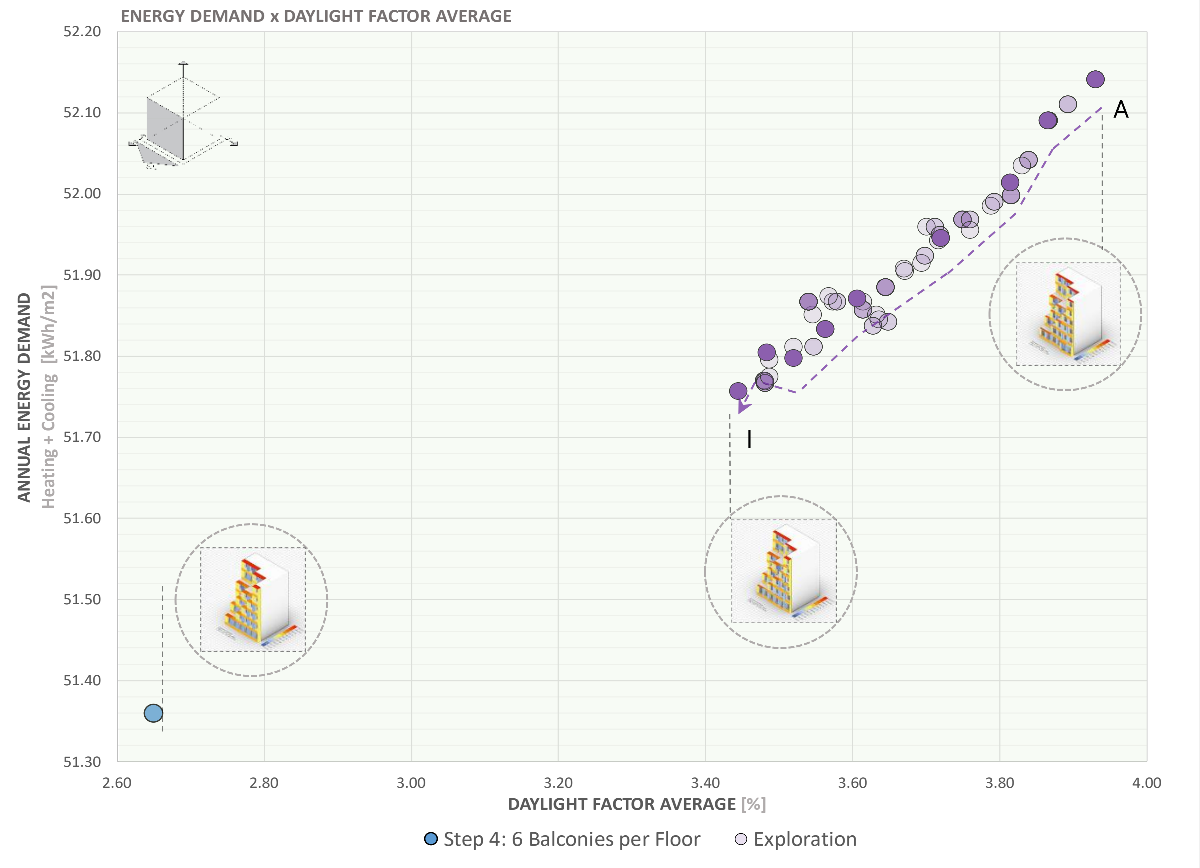
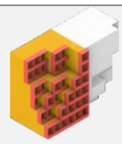
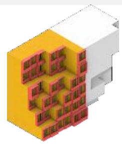
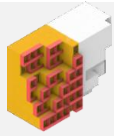
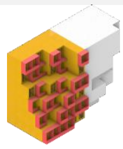
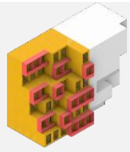
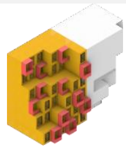


Figure 46: Exploration ED x ADF Graph [Source: Authors]

Table 20: Exploration Results Comparison

		Energy Demand [kWh/m2]	*Average Daylight Factor [%]*	*Solar Potential [kWh]* *(Without Chunk Mass)*	*Visual*
Amount Variation Analysis	6 Balconies per Floor *(Scenario in Use)*	51.36 (α)	2.65 (α)	143617.40 (α)	
	6 Balconies per Floor *(Exploration Champion: I)*	52.14 (↑1.52%)	3.93 (↑48.30%)	145131.85 (↑1.05%)	
	5 Balconies per Floor	51.46 (↑0.19%)	2.89 (↑9.06%)	133507.10 (↓7.0%)	
	4 Balconies per Floor	51.66 (↑0.58%)	3.04 (↑14.7%)	125947.20 (↓12.3%)	
	3 Balconies per Floor	51.98 (↑1.21%)	3.35 (↑26.4%)	109689.24 (↓23.6%)	
	2 Balconies per Floor	52.63 (↑2.47%)	4.03 (↑52.0%)	87074.21 (↓39.3%)	

[Source: Authors]

As a result of the amount variation analysis with exploration, compare to other amounts, exploration provides more solar potential and can reach the average value of the daylight factor. Against this, there is a negligible energy demand increase.

What should be pointed out in this methodology is while using 6 balconies, the daylight factor value shows 2.65 but while using exploration with six balconies it is possible to increase is 48.30% amount. This is because exploration varying the depth of each element which does not make the same depth per unit, allows more daylight to go inside.

On the other hand, the reason why, the solar potential is higher than the highest scenario of other amounts is that exploration tries to expose more surfaces that can perform better efficiently.

Consequently, Exploration values are consistently high throughout the generation; ergo, it becomes promising alteration for solutions of balcony calibration.

---END OF EXPLORATION

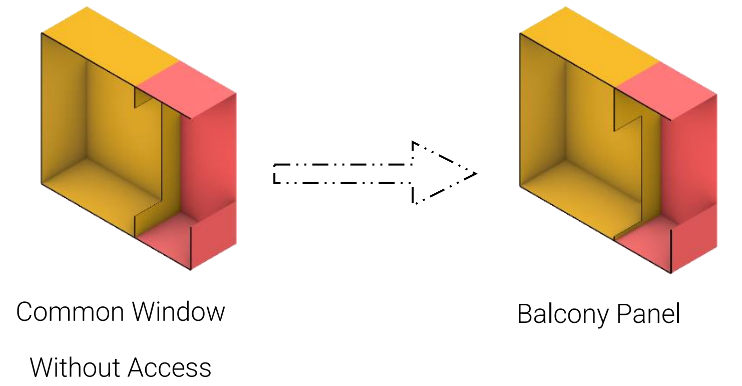


Figure 47: Problems & Solutions Process [Source: Authors]

In the fifth step of the study, it was observed that the lack of access to balconies had an impact on the dimensions of balcony windows. To address this issue, a standard panel size was assigned to voxels that contained balconies. To analyze the effect of this modification each scenario consider again. As a result, areas with balconies were equipped with Balcony Panels (2.20m x 1.40m), whereas areas without balconies were equipped with Common Window Size (1.90m x 1.40m).

In the initial design, common windows were in the voxels and occupied approximately 30% of the facade surface. The headers of these centered windows were situated 2.70m above the ground level of the voxels. Although the height of the Balcony Panel was greater than that of the Common Windows, the balcony panel header extended only up to 2.30m. As a result, it was observed that a 1m parapet was blocking the Balcony Panel glazing at 0.9m after the panel threshold. Consequently, only the remaining 1.40m of the panel was able to effectively receive daylight.

While it may initially seem that larger glazing would result in a higher daylight factor, the reasons described above suggest that it is expected to this implementation would yield a slightly lower average daylight factor. The blocked portion of the panel, which corresponds to 0.9m below the header, would receive less daylight than the remaining 1.40m.

Table 21: Problems & Solutions Results Comparison

	6 Balconies (Scenario in Use)	6 Balconies (Exploration)	5 Balconies	4 Balconies	3 Balconies	2 Balconies
	BEFORE					
Energy Demand [kWh/m2] (a)	51.36	52.14	51.46	51.66	51.98	52.63
Average Daylight Factor [%] (a)	2.65	3.93	2.89	3.04	3.35	4.03
Solar Potential [kWh] (a) *(Without Chunk Mass)*	143617.40	145131.85	133507.10	125947.20	109689.24	87074.21
	AFTER					
Energy Demand [kWh/m2] (↑2.4~2.5%)	52.69	53.39	52.69	52.90	53.23	53.90
Average Daylight Factor [%] (↓0.99~1.01%)	2.62	3.89	2.86	3.01	3.32	3.99
Solar Potential [kWh] (No Change) *(Without Chunk Mass)*	143617.40	145131.85	133507.10	125947.20	109689.24	87074.21

[Source: Authors]

The presented data table verifies that the predicted outcomes have been met. Specifically, the average daylight factor has observed a slight reduction with the range of 0.99-1.01% which can be attributed to the changing of the glazing location that allows more natural light to penetrate the interior spaces. It's noteworthy that the solar potential has remained unaffected, as the balcony surface area has not been modified.

It is also worth noting that the increase in glazing area has led to a 2.4-2.5% rise in energy demand. This was an anticipated outcome, and despite slightly lower performance values compared to centered common windows, the modification successfully resolves the issue of limited balcony access. Furthermore, the changes in energy demand are not significant enough to offset the benefits of the design improvement. Therefore, the proposed modification is considered an improvement.

Given that the behavior of balconies has been examined in different scenarios, and the issue of restricted access has been successfully addressed another consideration that should be considered is when two balconies are positioned side by side. In this scenario, the shared flap between the two balconies becomes the middle flap. However, this results in an unnecessary flap that only serves to lower values. As such, the algorithm has been scripted to merge two adjacent balconies into one to eliminate this middle flap.

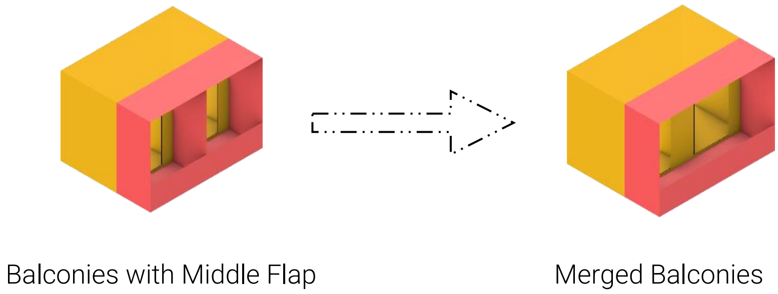


Figure 48: Merging Process [Source: Authors]

In conclusion, the results of this study demonstrate the importance of considering balcony design in terms of energy demand, daylight factor, and solar potential. Before deciding on the best balcony design for a particular chosen chunk, it is essential to understand how each step of the balcony design stage is behaving, how to improve and use them, and how to locate them depending on the need.

2.3.1.1 ENERGY DEMAND SIMULATION / DAYLIGHT SIMULATION

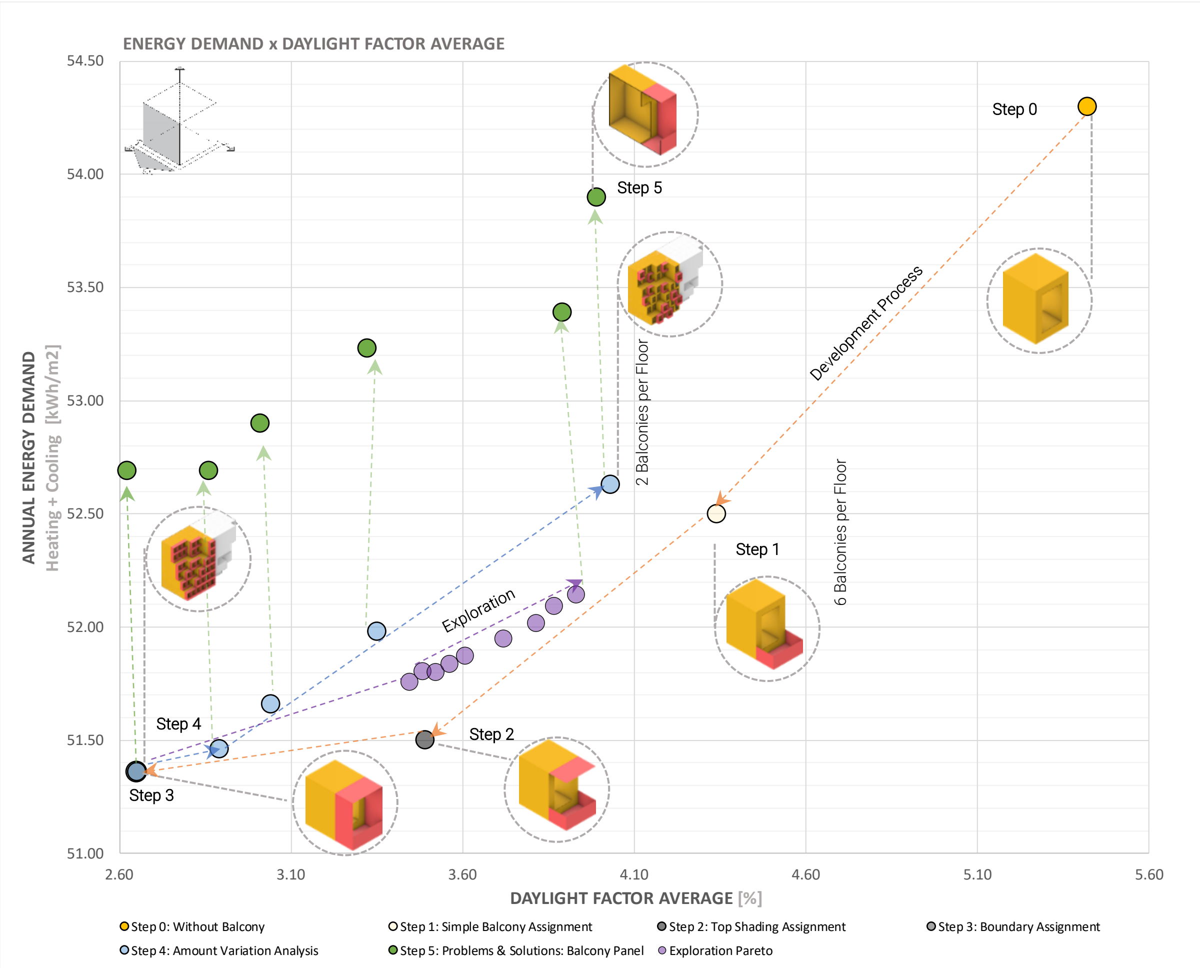


Figure 49: Balcony Calibration, ED x ADF Graph [Source: Authors]

In terms of energy demand and average daylight factor, the chart above represents each step and process and how the values are showing different behaviors.

The decrease in the Average Daylight Factor of Step 1 is because balconies on every floor is overshadowing the level below except the first floor since there is no more floor above it. Plus, energy demand decreases because these balconies are showing a shading effect thus overheating is prevented at some level which is leading to a reduction in cooling load.

About step 2, additional shading elements above the voxel are aiming to maximize solar potential. Yet, in terms of the Energy Demand x Average Daylight Factor graph, when these shading elements are applied, even the first level is affected which leads to a significant reduction in energy demand and also the cooling loads.

The comments of step 2 are applies to step 3 as well. About step 4, due to the necessity of observing the behavior of different amounts of balconies, simulations run through. And it acted as expected, with an increase in daylight factor and energy demand due to removing boundaries and shading which are causing overshadowing. Meanwhile, it also experimented that keeping the balconies everywhere but changing the depth singularly and the result of this is quite promising compared to other amounts. Exploration offers reliable results but the application of it may not be preferable due to having different construction for each unit.

With step 5, access to balconies is provided by changing generic windows with panel windows. Despite the Balcony Panel being taller than the Common Windows, it was noted that the balcony panel header had a limit of only 2.30m. This led to an obstruction of the Balcony Panel glazing by a 1m parapet, located 0.9m after the panel threshold. Consequently, only 1.40m of the panel was able to receive adequate daylight. As a result of this, the daylight factor did not change a lot, but due to having more glazing surfaces, energy demand increased for each scenario.

Consequently, given that Chapter 02 mainly focuses on maximizing solar potential, methodologies of it such as balconies have a significant effect on the daylight factor. Yet, due to keeping the daylight factor in the range of 2-5%, the first methodology proves that it is safe to apply it in terms of average daylight factor criteria.

2.3.1.2 ENERGY DEMAND SIMULATION / SOLAR POTENTIAL

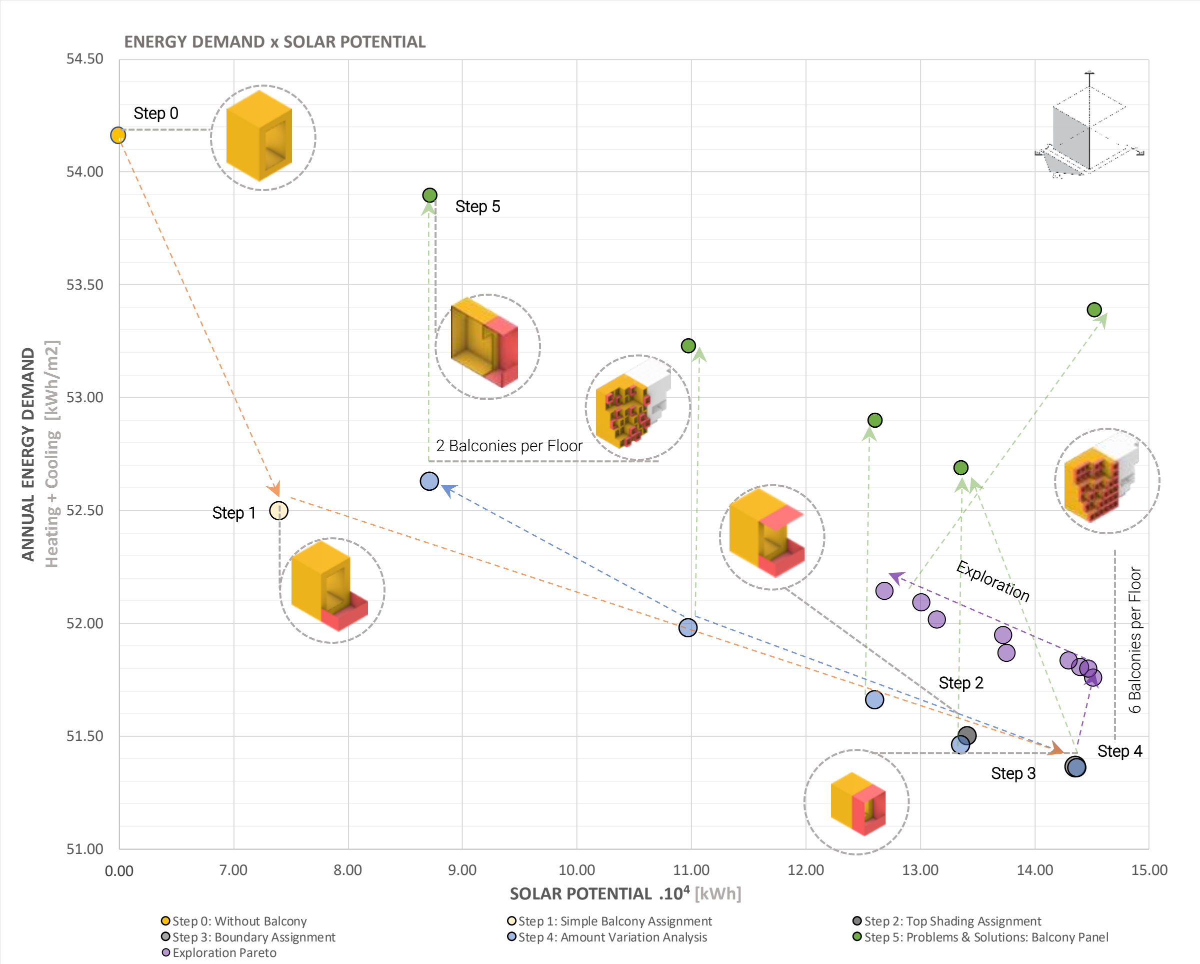


Figure 50: Balcony Calibration, ED x SP Graph [Source: Authors]

Based on energy demand and solar potential, the chart above represents each step and process and how the values are showing different behaviors.

The increase in the Solar Potential Factor of Step 1 is because balconies on every floor are additional surfaces to collect more solar. Yet, due to overshadowing each other, not all the additional balcony surfaces are showing the highest potential. To recover the lost possible alterations are considered in the following steps such as steps 2 till step 3.

Step 2 with additional shading elements there is an ↑ 81.19% increase from 73934.92 kWh simple balconies to 134078.86 kWh shading assignment. Due to increasing surface leads to higher solar potential, at step 3, adding side flaps caused a ↑ 94.20% increase from the simple balcony assignment.

Changing the number of balconies in Step 4 means decreasing the surface area. And having the feedback from previous steps, as it is expected, solar potential decreased in all the variations of amounts.

Meanwhile, when exploration methodology is applied, it can be observed that exploration is keeping the solar potential as much as higher while keeping the other factors in range.

In a conclusion, each amount and possibility were inspected in terms of balcony calibration methodology and offered to be in use. Based on different scenarios, all values are showing reliable treatments and can be applied.

2.3.2 METHOD II: SHADING DESIGN

Step 1: Top Shading Assignment

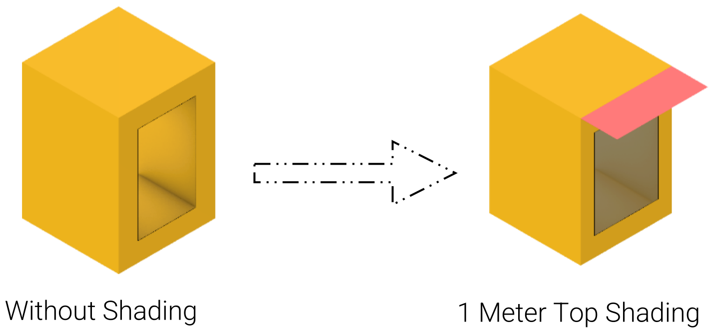


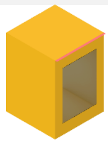
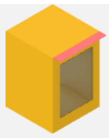
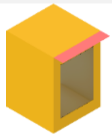
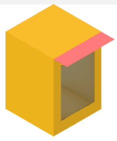
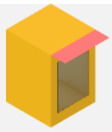
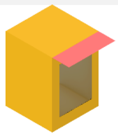
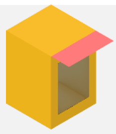
Figure 51: Top Shading Assignment Process [Source: Authors]

In the first step of the process, the simplest and effective shading elements were assigned to all voxels in every row, and the behavior of different depths was observed to determine which length was most appropriate based on specific factors. To ascertain the optimal length for shading elements, an empirical study was conducted, which evaluated the performance of shading elements with lengths varying from 0.1 to 1.0 meters. The primary objective of this study was to identify the optimal shading element length for a given application by considering several factors, such as the angle of solar radiation, building orientation, and shading efficiency.

Due to the vast number of results generated by the shading analysis, only constructive and inferable findings are presented in data tables to facilitate easy interpretation.

In some cases, increasing the length of top shading elements alone may result in similar performance behavior. However, in the upcoming stages, further enhancements will be made to these top shading elements to increase the number of scenarios that can be evaluated.

Table 22: Top Shading Assignment Results Comparison

Length (m)	*Energy Demand (kWh/m²)*	*Average Daylight Factor (%)*	*Solar Potential (kWh)* *(Without Chunk Mass)*	*Visual*
No Shading	54.30 (α)	5.42 (α)	-	
0.1 *Point A*	54.24 (↓0.11%)	5.41 (↓0.18%)	7782.90 (α)	
0.4 *Point B*	53.99 (↓0.57%)	5.25 (↓3.13%)	31198.33 (↑300.94%)	
0.5 *Point C*	53.81 (↓0.90%)	5.14 (↓5.17%)	39102.36 (↑402.33%)	
0.6 *Point D*	53.61 (↓1.27%)	5.02 (↓7.38%)	46452.87 (↑496.80%)	
0.7 *Point E*	53.39 (↓1.68%)	4.86 (↓10.33%)	54013.01 (↑594.49%)	
0.8 *Point F*	53.10 (↓2.21%)	4.70 (↓13.28%)	61915.74 (↑695.87%)	
0.9 *Point G*	52.84 (↓2.69%)	4.53 (↓16.42%)	69731.19 (↑795.71%)	
1.0 *Point H*	52.60 (↓3.14%)	4.36 (↓19.56%)	77471.40 (↑894.26%)	

[Source: Authors]

The reason why not experiment more than 1.0 meters is shading elements blocks direct sunlight are not preferred because they can reduce daylighting and views, which can negatively impact occupant satisfaction and productivity, moreover safety conditions [40] [41]. To determine whether the potential risks associated with the limitations of the study are worth considering, a simulation was conducted in Step 2. The findings of Step 1 indicate that the values obtained for all factors, especially the Daylight Factor are both sufficient and promising.

Step 2: Limit Assignment

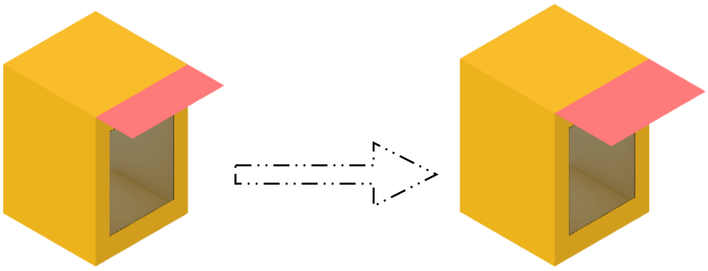


Figure 52: Limit Assignment Process [Source: Authors]

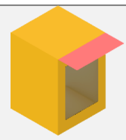
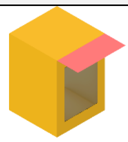
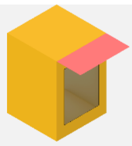
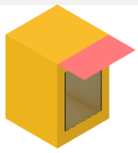
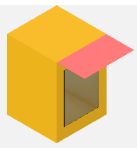
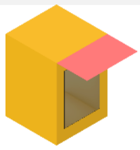
As previously outlined in Step 1, the objective of Step 2 is to evaluate the potential risks associated with using shading elements greater than 1 meter and determine whether the potential benefits outweigh the risks. To reduce these risks, a minimum threshold of the optimum 4% daylight factor [42] [43] has been established, which is widely recognized as providing a desirable average level of indoor lighting and visual comfort in residential buildings.

Moreover, the literature suggests that a 10% reduction in energy demand [7] is a significant achievement and is often used as a benchmark for evaluating the effectiveness of energy-saving strategies. A reduction of this magnitude can result in considerable cost savings, reduce the environmental impact of the building, and improve indoor comfort and air quality.

However, it is important to note that although the solar potential observed in Step 1 is expected to see a notable increase, this factor alone cannot be the sole decision-maker.

Given the above considerations, it is concluded that if the average daylight factor is 4% or greater and a 10% reduction in energy demand can be achieved, then taking the risk of using shading elements greater than 1 meter is deemed worthwhile.

Table 23: Limit Assignment Results Comparison

Length (m)	*Energy Demand (kWh/m²)*	*Average Daylight Factor (%)*	*Solar Potential (kWh)* *(Without Chunk Mass)*	*Visual*
1.0	52.60 (↓3.13%)	4.36 (↓19.55%)	77471.40 (↑895.40%)	
1.1 *Point A*	52.30 (↓3.68%)	4.19 (↓22.69%)	84639.61 (↑987.51%)	
1.2 *Point B*	52.18 (↓3.90%)	4.03 (↓25.64%)	90722.91 (↑1065.67%)	
1.3 *Point C*	52.03 (↓4.18%)	3.88 (↓28.41%)	98280.82 (↑26.83%)	
1.4 *Point D*	51.91 (↓4.40%)	3.73 (↓31.18%)	105800.70 (↑1162.72%)	
1.5 *Point E*	51.80 (↓4.60%)	3.59 (↓33.76%)	112391.50 (↑1344.08%)	

[Source: Authors]

Analysis of the data table revealed that none of the shading elements exhibited a 10% energy demand reduction, which is considered a significant reduction. Thus, the use of shading elements longer than 1 meter does not seem to be a viable option for achieving significant energy savings [7]. On the other hand, while 1.3, 1.4 and 1.5 meter respectively length are showing less than optimum 4% average daylight factor [42] [43] only 1.1 and 1.2 meters are showing the results around 4%. In this case, it is clear to not take the risk of having more than 1 meter length of shading due to the risk mentioned in [40] [41] .

Up until this point, the research has primarily focused on analyzing the observed behavior of shading elements with regards to their impact on energy demand and average daylight factor. However, future experiments will extend this investigation to incorporate a third factor, namely the solar potential. To optimize the solar potential, a common approach involves increasing the surface area. To achieve this objective, the boundaries for each voxel will be allocated in the third step of the process.

Step 3: Boundary Assignment

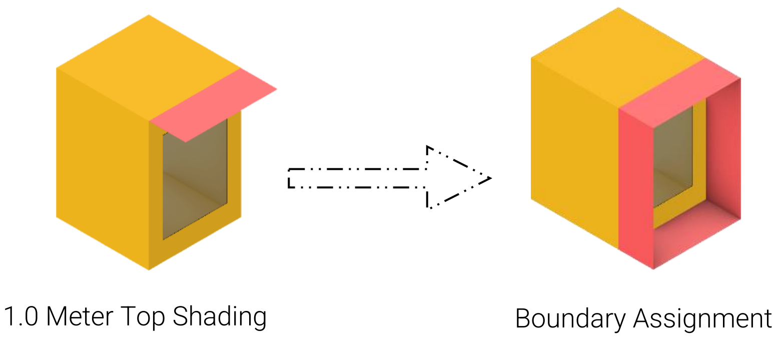


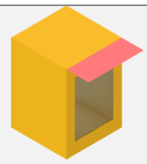
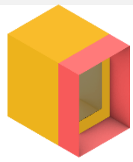
Figure 53: Boundary Assignment Process [Source: Authors]

The process of assigning boundaries for shading elements is a crucial step in increasing solar potential. As demonstrated in step 2 of the experimentation process, an increase in surface area significantly enhances the solar potential. However, it is essential to consider the wind load pressure risk associated with the added weight of shading elements beyond 1 meter in length [40] [41]. Therefore, it is recommended to limit the increase in shading element length to 1 meter, unless significant improvements in limitation factors are observed.

Building on the findings of step 2, step 3 involves the addition of vertical surfaces (flaps) to shading elements, thus creating a boundary. Since the boundary length is limited to 1 meter, the pressure risk is reduced at this point, and limitations do not have to be applied.

Based on the introduction, boundaries are assigned to each voxel, and simulations are conducted to investigate three main factors: energy demand, daylight factor, and solar potential.

Table 24: Boundary Assignment Result Comparison

Length (m)	Energy Demand (kWh/m^2)	Average Daylight Factor (%)	Solar Potential (kWh) (Without Chunk Mass)	Visual
1.0	52.60 (α)	4.36 (α)	77471.40 (α)	
1.0	52.06 (↓1.03%)	3.80 (↓12.84%)	107105.12 (↑38.25%)	

[Source: Authors]

In the data table provided, it is observed that the introduction of boundary leads to a substantial increase in solar potential from 77471.40 to 107105.12, indicating a 38.25% increase. There is also a reduction in daylight factor values, which decreased by 12.84%. The optimal range for the average Daylight Factor is typically considered to fall within the range of 2% to 5%. In the present study, it is noted that the observed reduction in the Daylight Factor from 4.36% to 3.80% is within an acceptable range and does not necessitate any immediate corrective action. Although, as such, it is recommended that this decline is carefully monitored in all subsequent studies.

It is important to consider these findings when investigating the solar potential and daylight factor values in architectural designs, as they provide valuable insights into the effects of boundary assignment on these factors. Further research is necessary to explore the implications of these findings in greater detail and to identify potential solutions for improving daylight factor values without compromising solar potential.

On step 4, these further research and explorations are considered and provided.

Step 4: Boundary Manipulation

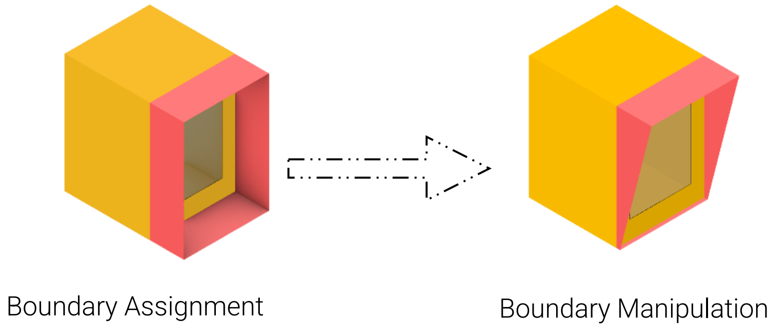


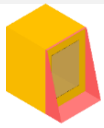
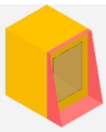
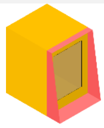
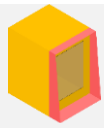
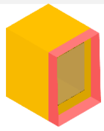
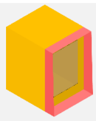
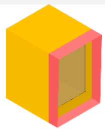
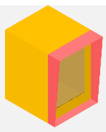
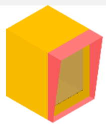
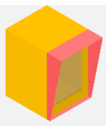
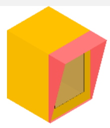
Figure 54: Boundary Manipulation Process [Source: Authors]

The objective of the previous step which is third is to increase the solar potential of a designated area by applying a 1-meter limit across the region. The observed improvement is noteworthy; nevertheless, it resulted in a reduction in the average daylight factor, as commented in step 3. To see the potential treatment for this reduction a subsequent simulation was carried out, where a maximal boundary of 1 meter was assigned. This meant that the total length of the parallel shading elements could not exceed 1 meter, i.e., if the upper shading was 0.95 m, the lower shading should be 0.05 m.

Over and above, it was determined that when the upper limit increased, the lower limit must decrease proportionally to maintain an acceptable average daylight factor. With this approach, it is expected not to experience lower daylight levels since the total surface area is conserved. Additionally, the minimum length was decided as 0.05 m due to the shading frame. The simulation began with the maximum bottom panel to the maximum top panel to examine how these two edges are challenging among themselves.

These modifications were made to ensure that the optimization of solar potential did not compromise visual comfort.

Table 25: Boundary Manipulation Results Comparison

Length (m)	Energy Demand (kWh/m²)	Average Daylight Factor (%)	Solar Potential (kWh) (Without Chunk Mass)	Visual
1.0 (No Manipulation)	52.06 (α)	3.80 (α)	107105.12 (α)	
0.05 Point A	53.16 (↑2.11%)	4.78 (↑25.79%)	27497.18 (↓74.33%)	
0.15 Point B	53.26 (↑2.30%)	4.86 (↑27.89%)	33517.14 (↓68.70%)	
0.25 Point C	53.36 (↑2.49%)	4.92 (↑29.47%)	40377.26 (↓62.30%)	
0.35 Point D	53.44 (↑2.65%)	4.96 (↑30.53%)	47572.99 (↓55.58%)	
0.45 Point E	53.45 (↑2.67%)	4.97 (↑30.79%)	53812.26 (↓49.75%)	
0.50 Point F (Equal Sides)	53.45 (↑2.67%)	4.97 (↑30.79%)	57092.92 (↓46.69%)	
0.55 Point G	53.31 (↑2.40%)	4.89 (↑28.68%)	59762.15 (↓44.20%)	
0.65 Point H	53.13 (↑2.40%)	4.75 (↑25.00%)	66063.08 (↓38.32%)	
0.75 Point I	52.88 (↑1.57%)	4.57 (↑20.26%)	72472.98 (↓32.33%)	
0.85 Point J	52.60 (↑1.03%)	4.39 (↑15.52%)	78730.18 (↓26.49%)	
0.95 Point K	52.37 (↑0.59%)	4.22 (↑11.05%)	85021.43 (↓20.61%)	

[Source: Authors]

Upon examining the presented table, it is discernible that the Boundary Manipulation Technique has exhibited a substantial and dependable enhancement. This improvement can be attributed to the reduction in the bottom panel and the corresponding increase in the top panel, which has caused a shift in the vertical shading elements, leading to a significant increase in the daylight factor.

It is remarkable that the alterations achieved through simulations can be applied to diverse requirements. Though, it should be acknowledged that the primary increase in the bottom plane functions as a shading element for the voxel situated beneath it. Consequently, prolonging the top plane is more efficacious than lengthening the bottom plane. Nonetheless, restricting shading modifications solely to the y-axis may result in a suboptimal solution, as it limits the potential for effective shading strategies. Thus, it is recommended to conduct additional experiments in the z direction, accounting for angular variations. In the subsequent step, step 5, simulations will be executed with such angular improvements duly considered. This consideration is critical for ensuring optimal and sustainable daylighting solutions in architectural designs.

Step 5: Angular Improvement

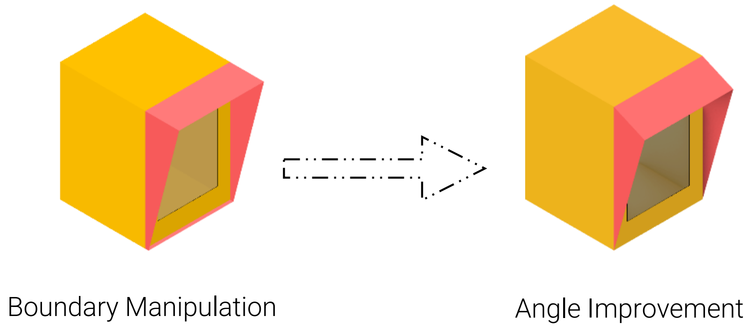


Figure 55: Angular Improvement Process [Source: Authors]

Step 5 of this study is conducted after identifying effects resulting from the previous steps. The main objective of this step is to enhance the efficiency and reliability of the shading elements. To achieve this goal, an innovative improvement strategy inspired by the concept of "angular shading elements" has been proposed.

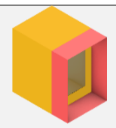
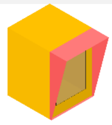
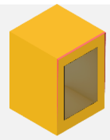
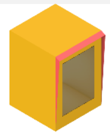
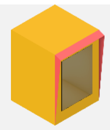
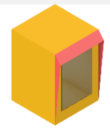
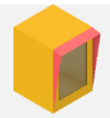
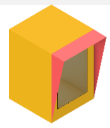
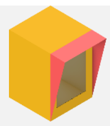
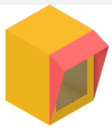
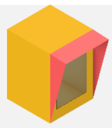
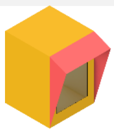
Although the newly created shading elements have successfully incorporated two out of the three main shading element typologies, namely, vertical, and horizontal, the integration of the third shading typology is expected to improve their efficiency further. The decision to add angular shading elements is based on the fact that they offer better performance in terms of light and heat control.

To determine the optimal angle for the shading elements, angles are assigned to all dimensions, as it is not possible to identify the best angle generation without conducting simulations. Through these simulations, the impact of the assigned angles on the shading elements' performance can be evaluated, and any necessary adjustments can be made to enhance their efficiency.

Overall, by incorporating the third main shading typology of angular shading elements, this step aims to improve the overall performance of the shading elements, increase their efficiency, and reduce their negative effects, thereby achieving the ultimate goal of optimizing the visual and thermal comfort of the designated area.

Due to having a vast amount of data, only remarkable values that clarify the behavior are plotted.

Table 26: Angular Improvement Results Comparison

Length (m)	*Angle (%)*	*Energy Demand (kWh/m^2)*	*Average Daylight Factor (%)*	*Solar Potential (kWh)* *(Without Chunk Mass)*	*Visual*
1.0 *(No Manipulation)*	-	52.06	3.80	107105.12	
0.95 *(Champion of Step 4)*	-	52.37 (a)	4.22 (a)	85021.43 (a)	
0.05 *Point A*	16	54.23 (↑3.55%)	5.41 (↑28.20%)	4685.24 (↓94.48%)	
0.25 *Point B*	27	54.08 (↑3.26%)	5.36 (↑27.01%)	16504.61 (↓80.58%)	
0.35 *Point C*	22	53.93 (↑2.97%)	5.27 (↑24.88%)	24757.01 (↓70.88%)	
0.50 *Point D*	52	52.01 (↓0.68%)	5.15 (↑22.03%)	32834.10 (↓61.38%)	
0.55 *Point E*	11	53.47 (↑2.10%)	4.97 (↑17.77%)	37994.42 (↓55.31%)	
0.75 *Point F*	2	52.94 (↑1.09%)	4.62 (↑9.47%)	67768.85 (↓20.29%)	
0.85 *Point G*	1	52.59 (↑0.42%)	4.38 (↑3.79%)	78058.11 (↓8.19%)	
0.85 *Point H*	24	52.17 (↓0.38%)	3.87 (↓8.29%)	97767.49 (↑14.99%)	
0.90 *Point I*	3	52.38 (↑0.02%)	4.20 (↓0.47%)	85366.80 (↑0.40%)	
0.95 *Point J*	22	52.04 (↓0.63%)	3.71 (↓12.08%)	103937.60 (↑22.24%)	

[Source: Authors]

This study analyzed dozens of results, selecting ten for plotting. Two had the same length but different angles, while the other eight had different lengths and angles. Results show that as length and angle increase, solar potential increases, but daylight factor decreases. Energy demand decreases with greater shading element angles due to reduced shadowing from above. In conclusion, angular shading has better solar potential and can inform the design of shading systems that maximize solar potential while minimizing energy demand.

2.3.2.1 ENERGY DEMAND SIMULATION / DAYLIGHT SIMULATION

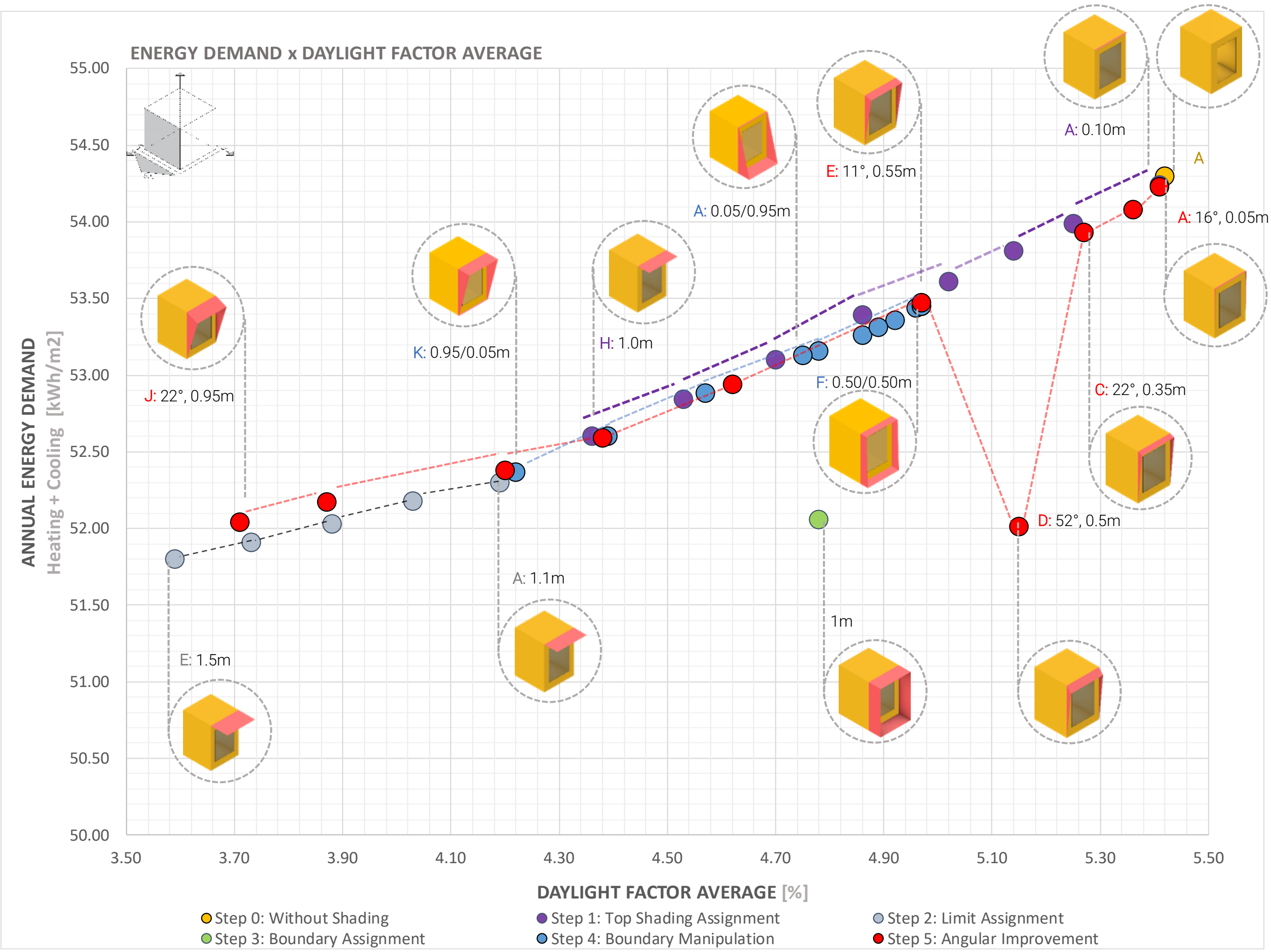


Figure 56: Shading Design, ED x ADF Graph [Source: Authors]

Upon examining the available data, it can be inferred that there exists a correlation between the length and angle of a shading element and its influence on overshadowing, daylight factor, and energy demand. Specifically, an increase in both the length and angle of a shading element led to a corresponding increase in overshadowing, thereby resulting in lower values of daylight factor and lower energy demands.

When Point K of Step 4: Boundary Manipulation and Point J of Step 5: Angular improvement compared, while the length is similar, due to Point J having a 22° angle, it reduces Daylight factor from 4.22 to 3.71 which means 12.08% reduction. It is because Angular Shading decreases the daylight factor more due to blocking more of the direct sunlight that enters a space.

When the sun is high in the sky, such as during summer months, horizontal shading devices may not be able to block direct sunlight from entering space. However, angular shading devices can be positioned to block the sun's rays at a wider range of angles, reducing the amount of direct sunlight that enters the space throughout the day.

Additionally, angular shading devices can be designed to reflect and redirect sunlight toward the ceiling, providing more uniform and diffuse light in the space, which can further decrease the daylight factor.

Consequently, the effectiveness of shading devices in reducing the daylight factor depends on various factors, such as the orientation of the building, the location of the windows, the time of day, and the time of year. However, angular shading devices can generally provide more effective shading than horizontal shading devices in blocking direct sunlight and reducing the daylight factor.

2.3.2.2 ENERGY DEMAND SIMULATION / SOLAR POTENTIAL

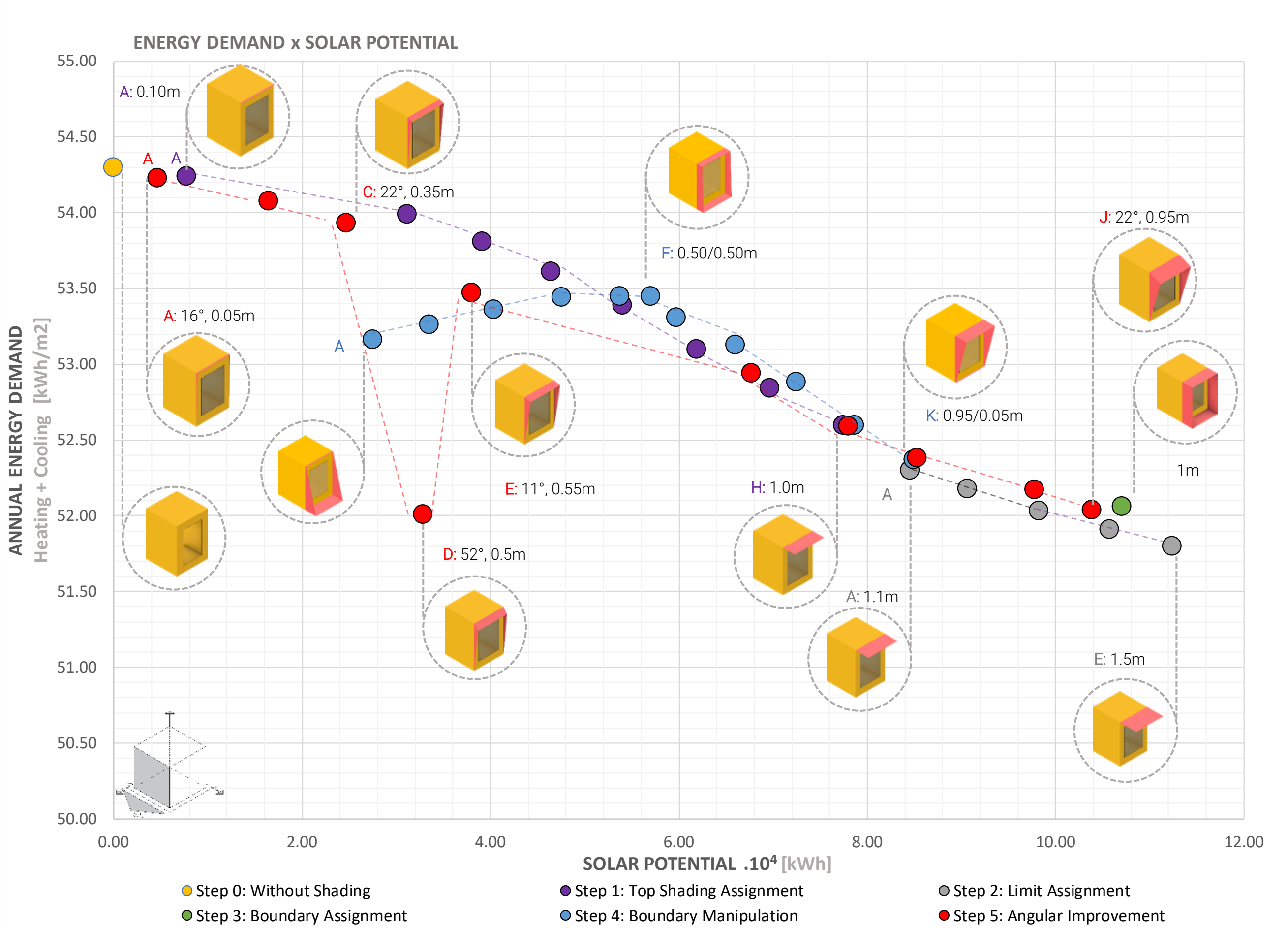


Figure 57: Shading Design, ED x SP Graph [Source: Authors]

In conclusion, the chart reveals that shading depth plays a critical role in determining the solar potential of shading devices. As shading depth increases, the surface area of the shading element increases, resulting in higher solar potential. The chart also shows that Point E Step 2: Limit Assignment has the highest solar potential, followed by Step 3: Boundary Assignment, indicating that these shading devices are more efficient due to having higher depth.

Furthermore, it can be observed that the angular shading elements are more efficient at catching direct sunlight, which is why they are more effective at maximizing solar potential than horizontal elements. However, it is important to note that this statement is based on the angle of the shading element.

In summary, the resulting chart emphasizes the significance of shading depth and angle in determining the solar potential of shading devices, and based on the required criteria, one of the solutions can be preferable.

2.3.3 METHOD III: WINDOW MODIFICATION

Step 1: Windows Size Modification

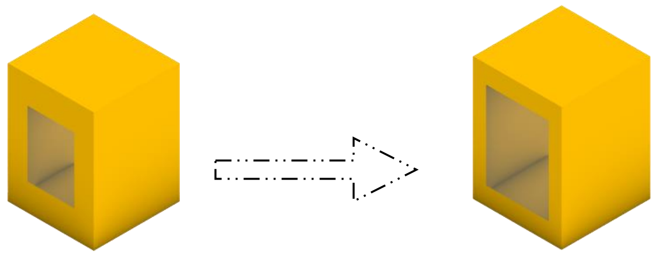


Figure 58: Window Size Modification Process [Source: Authors]

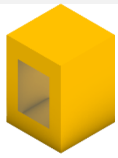
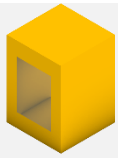
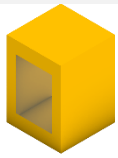
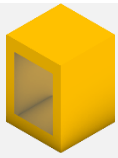
The effect of window size variations on energy demand, daylight factor, and glare will depend on several factors, including the building form, orientation, and location. Generally, larger windows will allow more natural light to enter the building, reducing the need for artificial lighting and potentially lowering energy demand. Even so, larger windows can also lead to increased solar heat gain, which can increase cooling loads and energy demand.

At this step 1, window size is increased proportionally, and shape of the window chosen and preserved as rectangular since rectangular windows produces the most glare compared to circular, ribbon and arched windows [44]. The reason why shape of the windows chosen as most challenger shape is because to challenge with edge point. Simulation run through, baseline windows with clear surface and unpainted.

It is expected that with larger windows, higher daylight factor which allows providing more natural light and potentially reducing the need for artificial lighting. However, too much natural light can also cause glare, which can be uncomfortable and affect the ability to see and increase the solar heat gain in the building, leading to increased cooling loads and potentially increased energy demand.

In order to validate the theoretical assumptions, a simulation was conducted on June 21 13:30 where glare is maximum, and the resulting data was plotted in a table presented on the following page.

Table 27: Window Size Modification Results Comparison

Size (m)	*% Surface*	*Energy Demand (kWh / m²)*	*Average Daylight Factor (%)*	*Glare (%)*	*Visual*
1.90 x 1.40 *Point A*	30	54.30 (a)	5.42 (a)	0.41 (a)	
2.05 x 1.50 *Point B*	35	54.33 (↑0.06%)	5.93 (↑9.41%)	0.44 (↑7.32%)	
2.20 x 1.60 *Point C*	40	56.23 (↑3.55%)	6.43 (↑18.63%)	0.48 (↑17.07%)	
2.35 x 1.70 *Point D*	45	58.13 (↑7.05%)	6.89 (↑27.12%)	0.51 (↑24.39%)	
2.50 x 1.80 *Point E*	50	60.06 (↑10.60%)	7.35 (↑35.60%)	0.54 (↑31.71%)	

[Source: Authors]

Based on the plotted data table presented above, it can be observed that increasing the window size results in an increase in all values. In the absence of any form of solar shading elements, the glare percentage increases by 31.71% when the window size is increased from 30% to 50%, rendering it "intolerable" as opposed to "disturbing". Additionally, the daylight factor also experiences a substantial increase from 5.42 to 7.35, indicating a 35.75% increase. Both values exceed the acceptable range, highlighting the adverse effects of window size increase in the absence of shading elements.

Nevertheless, increasing the window size can be advantageous in situations where daylight values fall below the acceptable range, as long as glare values do not surpass 0.34.

Step 2: Window Depth Modification

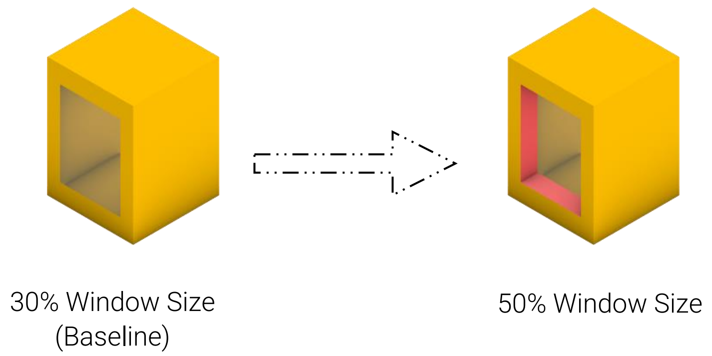


Figure 59: Window Depth Modification Process [Source: Authors]

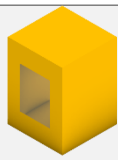
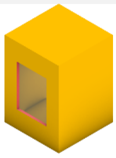
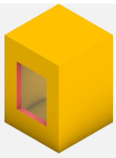
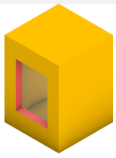
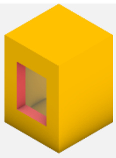
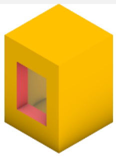
The impact of window depth on glare, energy demand and daylight factor are dependent on the specific conditions. In some cases, a deeper window may help to control direct sunlight and reduce the potential for glare. However, in other cases, a deeper window may increase the potential for glare by allowing lighter to enter the space from a low angle.

A deeper window may also allow more natural light to enter space and increase the daylight factor. Nevertheless, it may reduce the daylight factor by limiting the amount of light that can penetrate into the building.

Additionally, deeper windows may provide better control of solar radiation and reduce the need for artificial lighting, which can lower energy demand. Yet, deeper windows may also lead to increase the cooling load in the summer months, which could increase energy demand for air conditioning.

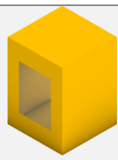
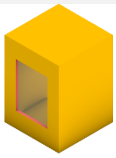
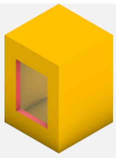
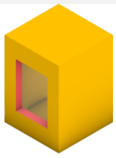
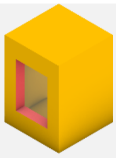
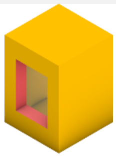
To see how the window deepening process affects the values, variation of windows from 30% to 50% surfaces to 50 cm depth is simulated and plotted into data table below.

Table 28: Window (30%) Depth Results Comparison

Size (m)	*% Surface*	*Depth (m)*	*Energy Demand (kWh / m²)*	*Average Daylight Factor (%)*	*Glare (%)*	*Visual*
1.90 x 1.40	30	0.0 Point A	54.30 (α)	5.42 (α)	0.41 (α)	
		0.1 Point B	54.20 (↓0.18%)	5.08 (↓6.27%)	0.40 (↓2.44%)	
		0.2 Point C	54.07 (↓0.42%)	4.75 (↓12.36%)	0.40 (↓2.44%)	
		0.3 Point D	53.94 (↓0.66%)	4.43 (↓18.26%)	0.39 (↓4.88%)	
		0.4 Point E	53.81 (↓0.90%)	4.13 (↓23.80%)	0.39 (↓4.88%)	
		0.5 Point F	53.58 (↓1.33%)	3.85 (↓28.96%)	0.38 (↓7.32%)	

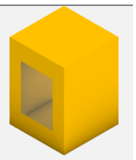
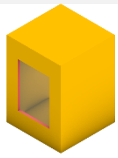
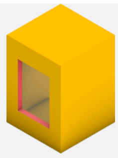
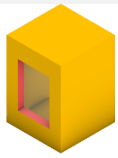
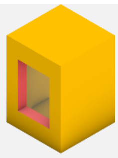
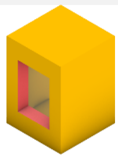
[Source: Authors]

Table 29: Window (35%) Depth Results Comparison

Size (m)	*% Surface*	*Depth (m)*	*Energy Demand (kWh / m²)*	*Average Daylight Factor (%)*	*Glare (%)*	*Visual*
2.05 x 1.50	35	0.0 Point A	54.33 (α)	5.93 (α)	0.44 (α)	
		0.1 Point B	56.23 (↑3.50%)	5.60 (↓5.55%)	0.43 (↓2.27%)	
		0.2 Point C	55.98 (↑3.03%)	5.27 (↓11.14%)	0.43 (↓2.27%)	
		0.3 Point D	55.75 (↑2.62%)	4.94 (↓14.98%)	0.42 (↓4.54%)	
		0.4 Point E	55.50 (↑2.15%)	4.63 (↓18.14%)	0.42 (↓4.54%)	
		0.5 Point F	55.14 (↑1.49%)	4.34 (↓29.07%)	0.41 (↓6.82%)	

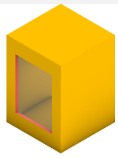
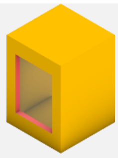
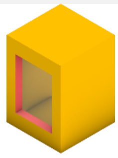
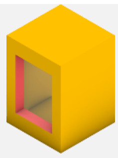
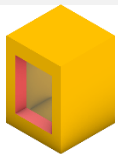
[Source: Authors]

Table 30: Window (40%) Depth Results Comparison

Size (m)	*% Surface*	*Depth (m)*	*Energy Demand (kWh / m^2)*	*Average Daylight Factor (%)*	*Glare (%)*	*Visual*
2.20 x 1.60	40	0.0 Point A	56.23 (α)	6.43 (α)	0.48 (α)	
		0.1 Point B	58.26 (↑3.61%)	6.10 (↓5.12%)	0.47 (↓2.08%)	
		0.2 Point C	57.90 (↑2.95%)	5.76 (↓10.42%)	0.46 (↓4.17%)	
		0.3 Point D	57.54 (↑2.33%)	5.43 (↓15.54%)	0.45 (↓6.25%)	
		0.4 Point E	57.18 (↑1.69%)	5.12 (↓20.29%)	0.45 (↓6.25%)	
		0.5 Point F	56.69 (↑0.82%)	4.81 (↓25.25%)	0.44 (↓8.33%)	

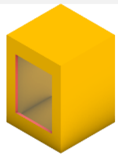
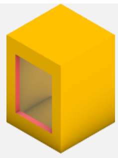
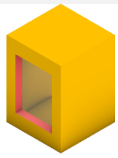
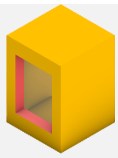
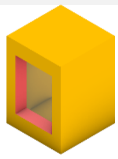
[Source: Authors]

Table 31: Window (45%) Depth Results Comparison

Size (m)	*% Surface*	*Depth (m)*	*Energy Demand (kWh / m²)*	*Average Daylight Factor (%)*	*Glare (%)*	*Visual*
2.35 x 1.70	45	0.0 Point A	58.13 (α)	6.89 (α)	0.51 (α)	
		0.1 Point B	60.28 (↑3.71%)	6.59 (↓4.35%)	0.50 (↓1.96%)	
		0.2 Point C	59.80 (↑2.86%)	6.25 (↓9.28%)	0.50 (↓1.96%)	
		0.3 Point D	59.30 (↑2.01%)	5.92 (↓14.06%)	0.49 (↓3.92%)	
		0.4 Point E	58.82 (↑1.19%)	5.60 (↓18.99%)	0.49 (↓3.92%)	
		0.5 Point F	58.15 (↑0.03%)	5.29 (↓23.24%)	0.48 (↓5.88%)	

[Source: Authors]

Table 32: Window (50%) Depth Results Comparison

Size (m)	*% Surface*	*Depth (m)*	*Energy Demand (kWh / m²)*	*Average Daylight Factor (%)*	*Glare (%)*	*Visual*
2.50 x 1.80	50	0.0 Point A	60.06 (α)	7.35 (α)	0.54 (α)	
		0.1 Point B	60.33 (↑0.45%)	7.05 (↓4.08%)	0.53 (↓1.85%)	
		0.2 Point C	61.70 (↑2.73%)	6.72 (↓8.57%)	0.53 (↓1.85%)	
		0.3 Point D	61.08 (↑1.69%)	6.40 (↓12.93%)	0.52 (↓3.70%)	
		0.4 Point E	60.44 (↑0.63%)	6.05 (↓17.69%)	0.52 (↓3.70%)	
		0.5 Point F	59.63 (↓1.90%)	5.76 (↓21.50%)	0.51 (↓5.56%)	

[Source: Authors]

The simulations conducted on window surfaces ranging from 30% to 50% and with a depth of till 0.5m have demonstrated positive outcomes. In all scenarios, the results were constructive and promising. Specifically, in the 30% window size, the Daylight Glare Probability (DGP) decreased from 0.41 to 0.38, indicating a 7.32% reduction, and the Average Daylight Factor (ADF) decreased from 5.42 to 3.85, which is a 29.01% decrease. Similar outcomes were observed in other window surface options.

Thus, the window deep-in process indicates that the effects of the necessity of making larger size windows can be reduced by deepening the windows. This implies that the window modification process applied to the structure is a practical and effective solution that can be tailored to specific scenarios and conditions.

2.3.3.1 ENERGY DEMAND SIMULATION / DAYLIGHT SIMULATION

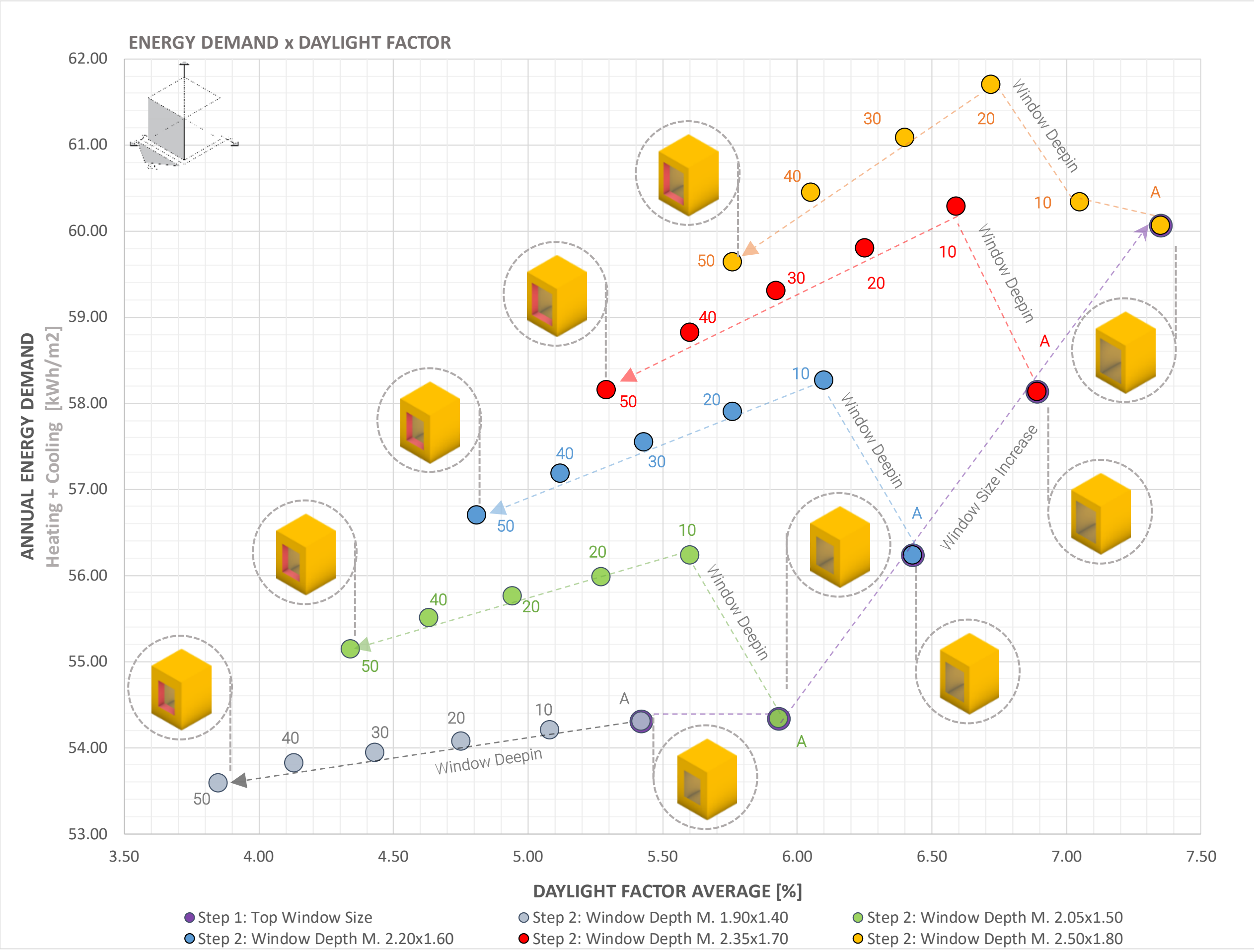


Figure 60: Window Modification, ED x ADF Graph [Source: Authors]

Based on simulated results, as the depth of a window increases, the amount of direct sunlight that can penetrate the interior of a building decreases. This is because the light must travel a greater distance through the glass before it enters the building, which causes it to scatter and lose intensity which causes the daylight factor to decrease.

On the other hand, when the size of a window increases, more natural light can penetrate the interior of a building which leads to an increase in the daylight factor.

However, it is important to note that the relationship between window depth, or size, daylight factor, and energy demand is not always straightforward. Other factors, window typology, the shading devices, and the type of glass used, can also affect the amount of natural light that enters the building and the amount of energy needed for lighting.

2.3.4 METHOD IV: MATERIAL COMPOSITIONS

Step 1: Wall Compositions

Wall compositions play a crucial role in the energy efficiency of buildings. The type of materials used and the way they are arranged in the walls affect the amount of heat that is transferred through them, both from the interior to the exterior and vice versa. To determine the magnitude of heat gain through the walls, a mathematical formula will be employed;

Heat gain through Opaque Elements: Roof and Walls

The mean rate of heat transfer through an opaque building element can be mathematically represented as follows.

$$Q_{opaq} = A_{opaq}\, U_{opaq}\, (T_{so} - T_{Ro})$$

where,
T_{so} = Average Sol-air Temperature or effective temperature of the opaque surface (^oC),
T_{Ro} = Average Room Temperature (^oC),
U_{opaq} = Overall Conductivity of Opaque surface (W/m^2K), and
A_{opaq} = Surface Area of opaque component (m^2).

For example, walls that are well-insulated with materials such as fiberglass, foam, or cellulose can reduce the amount of heat that is lost through conduction, convection, and radiation. This means that less energy is required to heat or cool the interior of the building, resulting in lower energy requirement and a reduced environmental impact.

In contrast, poorly insulated walls with materials that have a low thermal resistance, such as thin concrete walls, can lead to significant energy losses and high heating and cooling costs.

Therefore, carefully selecting the wall compositions is crucial for energy efficiency and reducing a building's overall carbon footprint. Step 1 involves the consideration of various wall configurations to observe the impact of wall elements.

Table 33: Wall Compositions' Characteristics

Wall Compositions	*Thermal Conductivity (W/m²K)*	*Layers*		*Thickness (mm)*	*Energy Demand (kWh / m²)*
Baseline	0.80	Wood Siding	20	215	54.30 (a)
		Steel Frame	100		
		Insulation	80		
		Gypsum Wallboard	15		
Timber Stud Wall with Insulation	0.45	Exterior Sheathing	20	215	52.17 (↓3.92%)
		Timber Stud	100		
		Insulation	80		
		Interior Lining	15		
Aerated Concrete Wall with Insulation	0.20	Block	200	310	51.30 (↓5.52%)
		Insulation	100		
		Plaster	10		
Rammed Wall with Insulation	0.20	Rammed Earth	300	410	50.86 (↓6.33%)
		Insulation	100		
		Plaster	10		
Double Brick Wall with Insulation	0.10	Brick	125	400	44.06 (↓18.86%)
		Cavity	50		
		Insulation	100		
		Brick	125		

[Source: Authors]

Based on the assignment of different typologies of wall compositions to the chosen chunk, simple modifications to the layers can cause a significant decrease in energy demand. In the most effective scenario assigned to the simulation, the energy demand decreased from 54.30 kWh/m2 to 44.06 kWh/m2, representing an 18.86% decrease.

As this study primarily focuses on building form, material assignment is not considered as one of the primary solutions, such as balconies, shadings, and window size changes, to minimize energy demand. However, it is encouraged to use these solutions to further minimize energy demand.

Additionally, it should be noted that the applied methodologies were directly affecting the form of the building. Since this is the goal of the study, for now, it is evident that walls are highly effective in reducing energy demand based on the difference between 54.30 kWh/m2 to 44.06 kWh/m2 but this effective method may be used if the desired form cannot reach the net zero.

Step 2: Glazing Compositions

Glazing compositions are significant contributors to building energy demand due to their impact on the thermal performance of the building envelope. The amount of heat gain or loss through windows directly affects the indoor temperature and thus the energy required for heating or cooling.

The phenomenon of heat gain through windows can be attributed to the absorption of solar heat that penetrates the building through direct radiation as well as the combined effects of conduction, convection, and radiation. To determine the magnitude of heat gain through the windows, a mathematical formula will be employed;

Heat gain through Glazing

$Q_{win} = A_g U_g (T_{ao} - T_{Ro}) + gI_{win} A_g$

where,

A_g = Area of glazing (m^2),

U_g = Overall heat transmission coefficient of the window (W/m^2K),

g = Solar gain factor,

I_{win} = Average sol-air intensity incidents on windows (W/m^2),

T_{ao} = Average ambient temperature (^oC), and

T_{Ro} = Average room temperature (^oC).

In addition, the choice of glazing composition plays a significant role in determining the daylight factor within a building. The visible transmittance of the glazing, which measures the percentage of visible light that passes through the glass, impacts the amount of daylight that enters the building. Additionally, the type and quality of coatings on the glass, such as low-emissivity coatings, can affect the amount and quality of daylight that is transmitted through the glazing. Proper selection of glazing composition can therefore ensure that an optimal level of daylight is achieved within the building, reducing the need for artificial lighting, and resulting in energy savings.

Table 34: Window Compositions' Characteristics

Glazing Name	*Thermal Transmittance (W/m²K)*	*Visible Transmittance*	*Energy Demand (kWh / m²)*	*Average Daylight Factor (%)*
Baseline (Single Pane)	3.12	0.80	54.30 (α)	5.42 (α)
Double-Pane Low-e	1.20	0.50	46.15 (↓14.18%)	5.29 (↓2.40%)
Double-Pane with Vacuum Insulation	0.50	0.80	46.04 (↓15.21%)	5.25 (↓3.13%)
Triple-Pane Low-e	0.80	0.35	44.19 (↓18.61%)	5.04 (↓7.02%)
Triple-Pane with Aerogel Insulation	0.50	0.40	42.37 (↓21.97%)	5.02 (↓7.38%)

[Source: Authors]

When the baseline scenario is replaced with double pane insulated glazing, the energy demand decreases from 54.30 kWh/m2 to 46.04 kWh/m2, which means that the new glazing is more energy efficient. This improvement in energy performance is due to the insulating properties of the double-pane glazing, which reduce heat transfer through the glazing and help to keep the indoor temperature more stable.

Similarly, the average daylight factor decreases from 5.42% to 5.25% with the installation of double pane glazing. This decrease is due to the increased thickness of the glazing, which reduces the amount of visible light that can pass through.

When it is further replaces with triple-pane insulated glazing, the energy demand decreases further to 42.37 kWh/m2, which means that the new glazing is, even more, energy efficient than the double-pane glazing. This improvement in energy performance is due to the additional layer of insulation provided by the triple-pane glazing, which reduces heat transfer even further.

However, the average daylight factor decreased further to 5.02% with the installation of triple-pane glazing. This decrease is likely due to the increased thickness and number of layers in the glazing, which reduce both the amount of visible light and the quality of the light that can pass through.

In summary, the improvements in energy performance with the installation of insulated glazing are due to the reduction of heat transfer through the glazing. This improvement comes at the cost of reduced daylight transmission, which is a trade-off that needs to be carefully considered when selecting glazing for a building.

Step 3: Roof Compositions

Regarding building form, it is true that the benefits of green roofs for energy demand are not directly related to the building form. However, the design and construction of the green roof system, including the materials used, thickness and composition of the growing media, and choice of plants, can impact the effectiveness of the green roof in reducing energy demand.

Increasing thickness is not always resulted in better results. It is because, when thickness increases, the thermal loss may decrease, thus in summer, due to a phenomenon known as the greenhouse effect. When sunlight passes through the windows, it is absorbed by the surfaces inside, such as floors, furniture, and interior walls. These surfaces then emit the absorbed energy as heat in the form of long-wave radiation. However, unlike sunlight, this long-wave radiation is not able to easily pass through the windows and escape the room, creating a trapped heat effect inside the volume. This trapped heat raises the temperature, leading to a much higher temperature than the outside environment. Herewith, energy demand increases significantly due to an increase in cooling.

In this scenario, the phenomenon explained above happened and led to an increase in energy demand. Yet, it should be noted that to see both sides, roof compositions such as green roofs or varied materials may have a significant effect on energy demand.

Table 35: Roof Compositions' Characteristics

Roof Composition	*Net Energy Demand (kWh / m^2)*
Generic Roof	54.30 (α)
Green Roof	57.20 (↑5.34%)

[Source: Authors]

2.4 BUILDING ENVELOPE FORMS COMPARISON

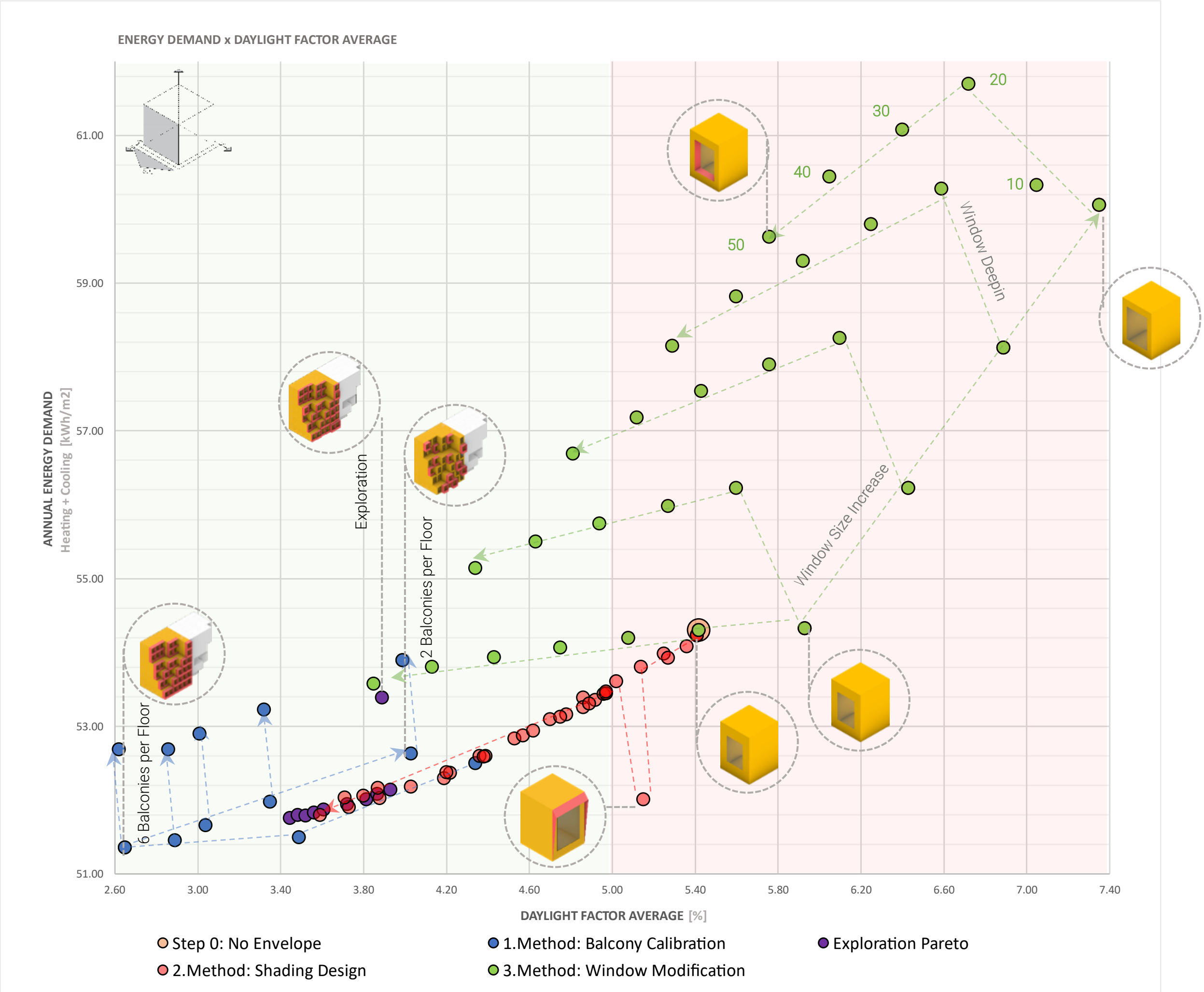


Figure 61: Building Envelope Form Comparison Graph, ED x ADF Graph [Source: Authors]

To look at the different cases all the methodology steps have been colored uniformly, the blue color indicates the Balcony Calibration method, the purple color Exploration Pareto, the red color Shading Design method, the green color Window Modification, and Baseline in yellow color.

Looking first at the Balcony Calibration it's clear it provides the lowest average daylight factor and energy demand as the surface increases affected area by solar energy increases which leads to the reduction in demand needed and daylight factor due to the self-shadow.

Step by step designing a shading element based on data earned from simulations, the design process points out a reduction trend in energy demand by blocking direct sunlight, shading prevents the sun's heat from penetrating the building's interior and thus reduces the need for cooling.

Regarding window modification, compared to other methodologies, It is possible to increase the average daylight factor. This methodology can be applied to buildings where location or orientation causes a very low average daylight factor due to a high amount of obstruction factor. And as long as depth increases, it is possible to decrease energy demand.

Last but not least, exploration methodology provides highly efficient results based on low energy demand, average daylight factor in range and keeping the same balcony amount. This exploration methodology is a golden fish for further researchers who are able to continue the Building Form and Energy topic with parametric methods such as applied in Chapter 1 of this study.

As a result, each methodology has specific behavior where they may be required to specific conditions. As long as high efficiency is a criterion, all provided methodology has perks to reach this goal.

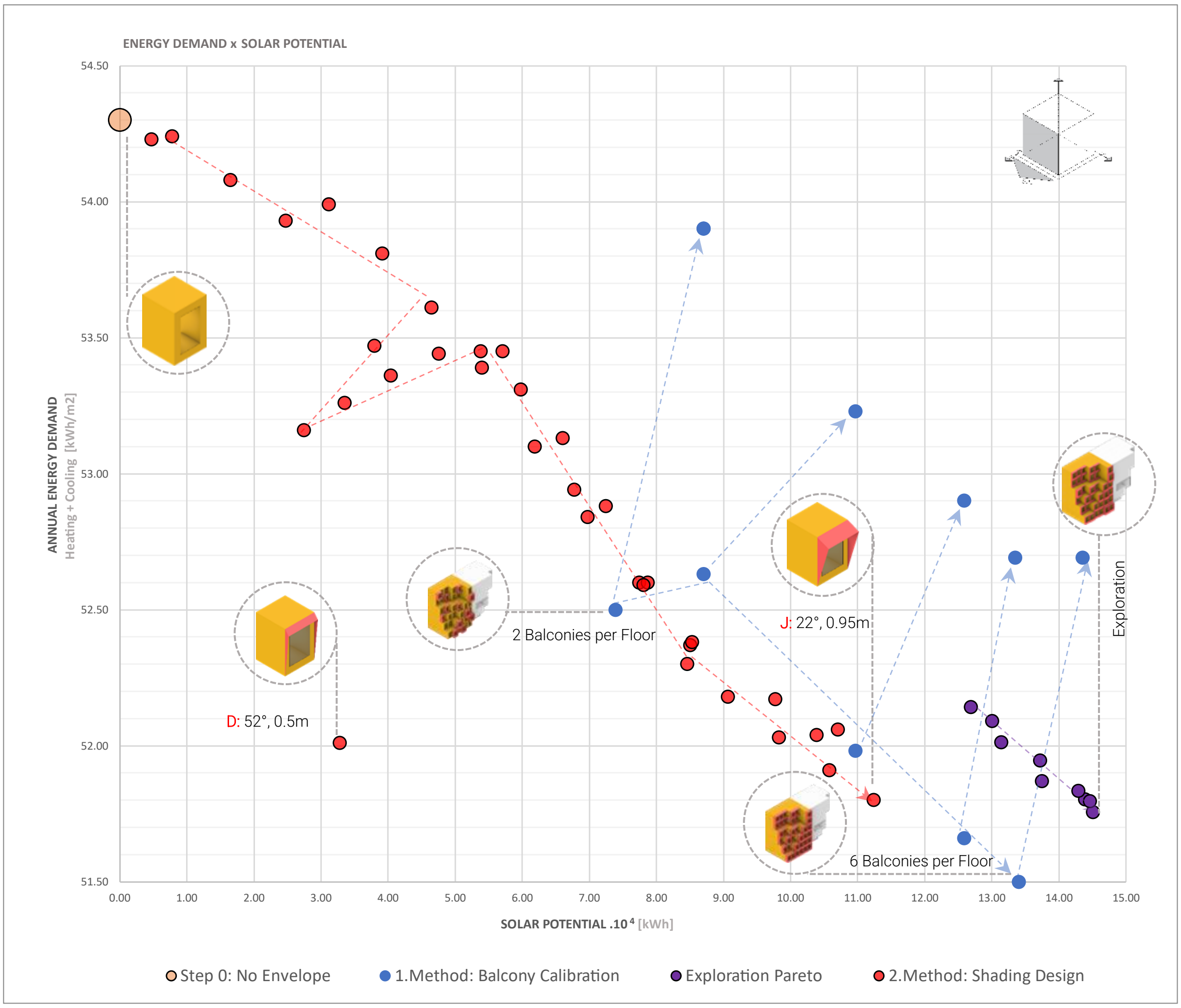


Figure 62: Building Envelope Form Comparison, ED x SP Graph [Source: Authors]

In Energy Demand and Solar Potential graph, methodologies that are related to solar potential are plotted and observed. Keep in mind that the results in the figure are additional results to the chunk. Only for chapter 02, they separated from the chunk results to see how efficient they are clearly.

To look at the different cases all the methodology steps have been colored uniformly, the blue color indicates the Balcony Calibration method, the purple color Exploration Pareto, the red color Shading Design method, and the Baseline in yellow color.

Each process and further step prove that the goal has been reached which is maximizing solar potential. Since maximizing solar potential is based on a bigger surface area and a more efficient angle, in "Balcony Calibration" as long as the surface is kept larger, solar potential increases, and for the shading part as long as a more efficient angle and longer shading are provided, solar potential shows a significant difference from the initial steps.

On the other hand, exploration methodology shows a smaller range among itself than other methodologies. Moreover, it shows the highest potential among all. This is because exploration keeps the same amount of balcony while trying to have maximum solar potential, minimum energy demand, and average daylight factor in the range.

Through all, as it is mentioned in the previous figure, in terms of solar potential, exploration has remarkable potential to consider in architectural solutions. Yet, due to application difficulties, applying it may not be very preferable. Thus, it can be logical to focus on other solutions for many scenarios.

As a result, due to having a significant increase in solar potential, it is explained how to maximize it by keeping other factors safe and providing dozens of possibilities to meet the requirements of any project.

2.5 CONCLUSION

After analyzing the methodologies presented in Chapter 02, it is clear that they have great potential to meet various requirements. These methodologies have proven to be highly effective in improving the solar potential of the chunk by increasing the exposure of the surface area to sunlight.

The new values for the selected chunk portion are presented in the table below. It should be noted that to meet different requirements of different scenarios, the range of values of each methodology is represented in the table.

Table 36: Methodology Values in Range

	***Initial Methodology**: The Chunk*	***Methodology 1**: Balcony Calibration*	***Methodology 2**: Shading Design*	***Methodology 3**: Window Modification*	***Methodology 4**: Material Compositions*
Solar Potential (kWh/m^2)	388247.91 (α)	✚ 145131.85 (Additional Energy)	✚ 112391.50 (Additional Energy)	-	-
Daylight Factor (%)	5.42 (α)	↓2.65%-↓4.34%	↓3.71-↓5.41%	↓3.85-↑7.35%	↓5.02-↓5.29%
Energy Demand (kWh)	54.30 (α)	↓51.36-↓53.90	↓51.80-↓54.24	↓53.58-↑61.70	↓42.37-↑57.20
Glare Probability	0.41 (α)	-	-	↓0.38-↑0.54	-

[Source: Authors]

The summary of the data table reveals that while the first two methodologies exhibit a reduction in energy demand and average daylight factor, with an increase in solar potential, the third method, which involves window modification, shows a drastic upsurge in energy demand and average daylight factor. However, this does not necessarily indicate that the methodology is ineffective. The third methodology can be employed in locations where there is insufficient sunlight throughout the year, such as Fennoscandia, or in areas where buildings are in close proximity to each other, or where there are obstructions near the building, to achieve an average daylight factor range of 2-5%. Furthermore, the study demonstrates that Chapter 2 applications have the potential to decrease glare probability.

Given that the main objective of this study is to maximize solar potential, the first two methodologies provide significant improvements, adding 145131.85 kWh and 112391.50 kWh at peak performance. Consequently, this translates into a 25% increase, from 388247.91kWh to 732377.68 kWh. Although the data table indicates that all possible methodologies have different incomes and outgoings, reducing energy demand is not the primary goal of this study. Nevertheless, the supportive methodology of material compositions offers the possibility of decreasing energy demand from 54.30 kWh/m2 to 42.37 kWh/m2, which represents a 22% reduction.

In conclusion, by employing different characteristic envelope methodologies, it is possible to meet all assigned factor requirements, and these methodologies can be combined to form a building. Further details on the integration of these methodologies in building design are provided in Chapter 03 experiments.

CHAPTER 03.

ARCHITECTURAL FORMING

ARCHITECTURAL SOLUTIONS

Introduction

After studying the building form based on energy metrics. To understand how building massing play a key role and early-stage design in building performance, daylighting and visual comfort, Chapter 01 highlights the potential of various methodologies in fulfilling diverse requirements. The examined approaches have demonstrated a significant ability to increase solar potential in a given area by exposing a larger surface area to sunlight, as well as reducing overall energy demand.

Analysis of the systems presented in Chapter 02 indicates that they can effectively meet various requirements, particularly in improving solar potential by increasing surface area exposed to sunlight. Since the primary objective of this study is to maximize solar potential, the focus is on exploring the different methodologies available. In conclusion, a combination of different characteristics can satisfy all assigned factor requirements.

As seen in the chapter 01 the understudy measure the passive systems taking in account the need of heating and cooling to achieve indoor comfort and it was possible to identify the solar potential to cover the production, and now the goal is to see the real production of the electricity requirement taking role of the designer through using design strategies that allows to apply to each design option that was discussed in chapter 02.

And to understand more the active systems some parameters must be set:

Energy Demand

To fulfill the determined thermal requirement, the generation of electricity is necessary. In this regard, a heat pump system is proposed that can operate for heating, and cooling, and provide domestic hot water. To achieve this, therefore using the Italian company "Vaillant" is used as a reference. To determine the necessary electrical energy required to produce the identified thermal energy, air conditioning systems utilize specific efficiency terms. The efficiency of heating systems is typically represented by the term COP (coefficient of performance) while cooling systems utilize the EER (energy efficiency ratio). The HVAC equipment chosen ranges between the values in table of the energy label [A+] corresponding to residential use.

Table 37: Energy efficiency class and nominal values for EER and COP according to the National Agency for New Technologies, Energy and Sustainable Economic Development, in Italy.

Class of Efficiency Energy	**$EER_{nominale}$**	**$COP_{nominale}$**
A+++	≥ 4,10	≥ 4,60
A++	3,60 ≤ EER < 4,10	4,10 ≤ COP < 4,60
A+	3,10 ≤ EER < 3,60	3,60 ≤ COP < 4,10
A	2,60 ≤ EER < 3,10	3,10 ≤ COP < 3,60
B	2,40 ≤ EER < 2,60	2,60 ≤ COP < 3,10
C	2,10 ≤ EER < 2,40	2,40 ≤ COP < 2,60
D	1,80 ≤ EER < 2,10	2,00 ≤ COP < 2,40
E	1,60 ≤ EER < 1,80	1,80 ≤ COP < 2,00
F	1,40 ≤ EER < 1,60	1,60 ≤ COP < 1,80
G	< 1,40	< 1,60

Source: [45]

And according to the product used values adopted:

COP (Ratio of heating capacity to the effective power input for unit) = 3.7

EER (Ratio of cooling capacity to the effective power input for unit) = 3.4

COP_{dhw} (System efficiency: Domestic hot water) = 2.36

Calculating the daily energy consumption using the formula:

$$E_{dhw} = \frac{Cp \,.\, \rho \,.\, V \,.\, (T_{out} - T_{in})}{3600}$$

Where Edhw is the domestic hot water load, in kWh/day; Cp the specific heat capacity of water (4.187 kJ/kg.K); r the density of water (1,000 kg/m³); and V the daily volume of hot water consumed for each component (m³/day).

Therefore, calculation for the residential use of domestic hot water:

Table 38: Residential Use of Domestic Hot Water

Appliance	DHW Consumption [liters/pp.day]	Water Temperature Outlet [°C]	Water Temperature Inlet [°C]	Daily Consumption Energy Edhw [kWh/pp.day]	Annual Energy Consumption Edhw - tot [kWh/pp]	Annual EnergyConsumption Edhw[kWh]
Bath/shower	10.6	40	10	0.370	0.370	18.096
Wash hand basin	15.8	35	10	0.460	0.460	22.478
Dish washing	14.9	55	10	0.780	0.780	38.155
Clothes washing	11.7	60	10	0.680	0.680	33.290
					[kWh/day]	112.020
					[kWh/yr]	40887.568
					[kWh/m2/yr]	23.875
Total Occupancy	49	person				
Total Area	1712.5	m2				
Occupancy [person per area]	35	m2				

[Source: Authors]

Daylighting

From the study in chapter 01 the solar energy generation potential for both electricity and hot water demand was determined by evaluating the amount of solar radiation that could be absorbed by the building surface throughout the year. After analyzing this data, it was concluded that active solar technologies could be utilized in both the roof and envelope areas of the building. This approach aligns with the current global emphasis on sustainability and renewable energy for buildings and integrating Photovoltaic (PV) technologies is considered an effective active solar strategy.

Thus, calculation the active systems of both PV systems and ST systems it is based on the values threshold indicated in chapter 1.4.

Threshold on solar radiation falling on the envelope:

- Surfaces that receive 200 to 400 kWh/m² over the year receive solar thermal collectors.
- Surfaces that receive more than 400 kWh/m² over the year receive photovoltaic panel

With active systems efficiencies

PV system efficiency 0.15
ST system efficiency 0.70

Thus, Selecting the best cases for optimization should follow the assumptions mentioned previously moreover the radiation range of 200 kWh / m^2 to 400 kWh/m^2 is made of use in summer to heat water while PV electricity covers the other energy demand <u>(Heating + Cooling + Lighting + Equipment) + DHW for Winter Season.</u>

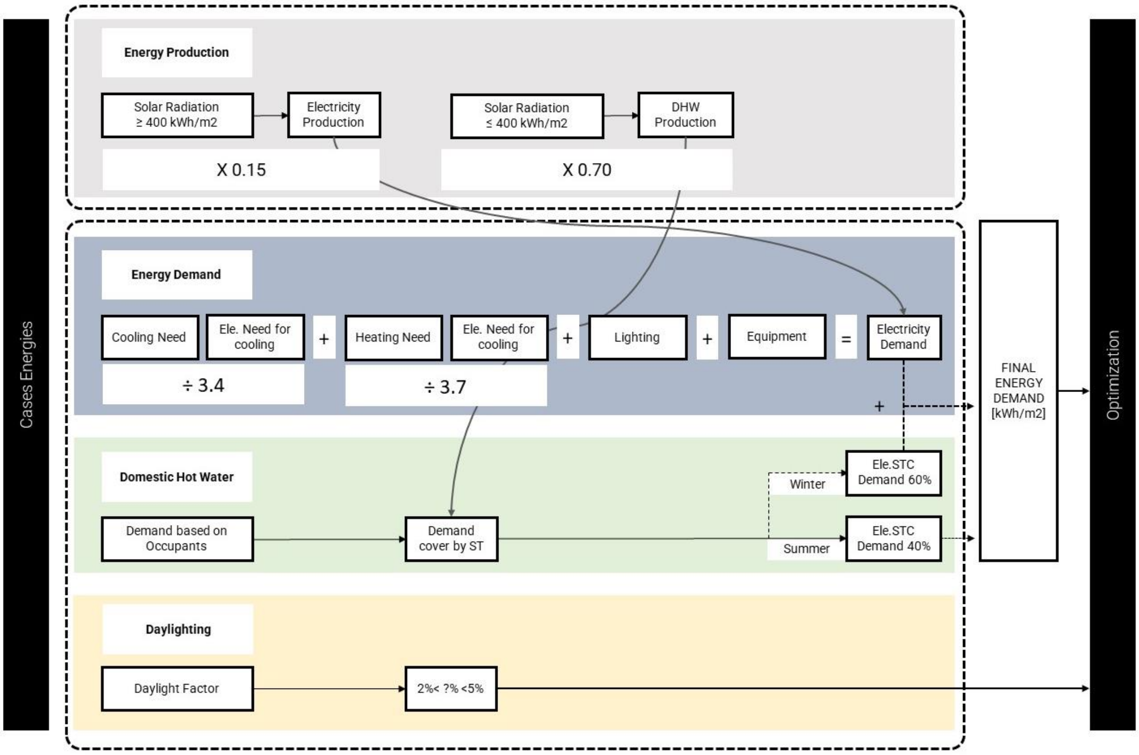
Therefore, calculation for the PV and STC to cover Gross energy needed:

Table 39: Values of Energy Renewables for Calculation

Electricity Generated PV [kWh/m2]	**Electricity Generated ST [kWh/m2]**	**Electricity Needed [Cooling + Heating + Lighting + Equipment]**	**Annual Energy Consumption E_{dhw} [kWh / m²] X 0.6 For winter Season**	**Covered By Renewable [%]**
87.75	74.20	70.15	14.32	103%

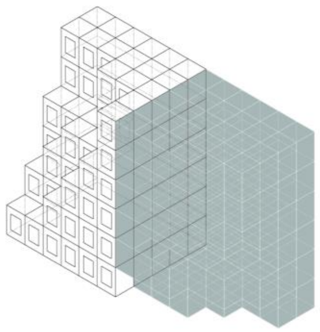
[Source: Authors]

Methodology



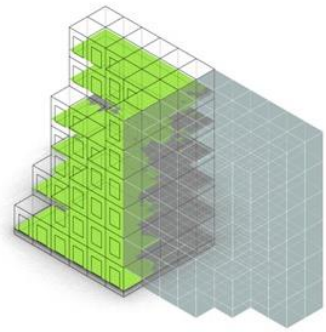
Source: [16]

Table 40: Channeling Baseline Results



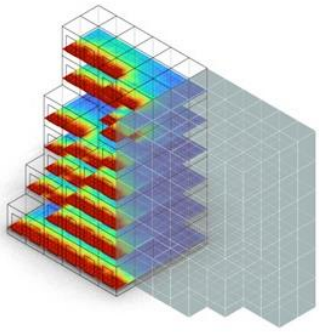
Baseline

- Waving Method



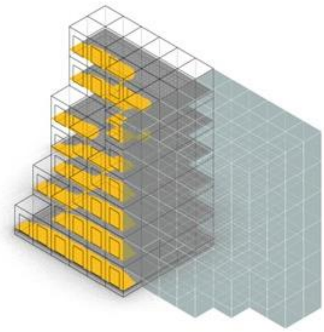
sDA

- 63.7



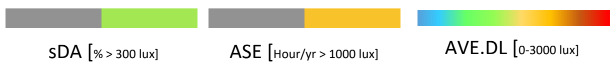
Average Daylight

- 1189



ASE

- 16.8



[Source: Authors]

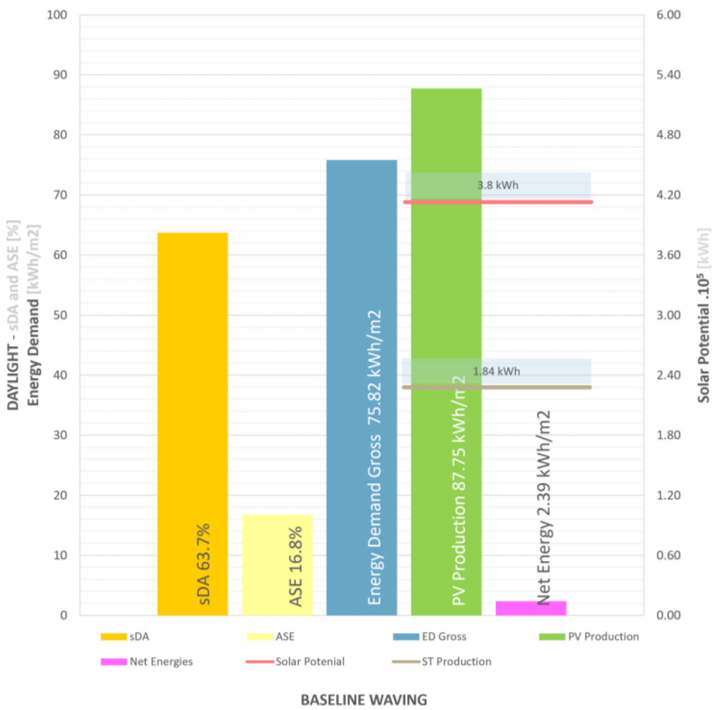


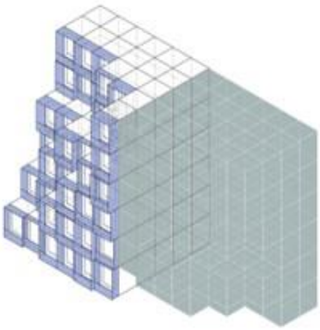
Figure 63: Channeling Baseline [Source: Authors]

As seen from chapter 02 selection the baseline of waving methodology resulted in energy demand 54.3 kWh, although not included the electricity need. furthermore, after taking into account (Heating + Cooling + lighting + Equipment) this resulted 75.82 kWh/m2 need to be covered by renewable systems. <u>in this case Baseline envelope as show still not reaching Net energy Need</u>

As well as looking through indoor visual comfort sDA reaches 63.7% systems. and ASE 16.8 % that would have a glare risk probability.

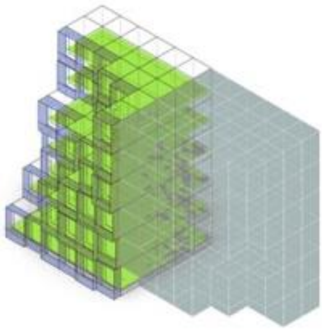
sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV, and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Table 41: Waving Solution #1 Results



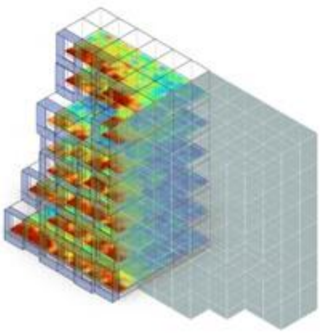
Waving Solution #1

- Win. 50% Ratio
- Exploration
- 0.8 u Win. Opt.



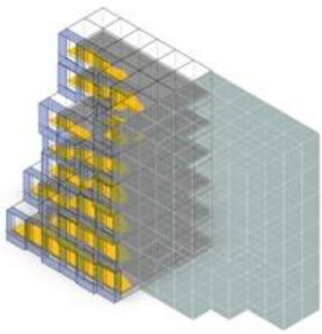
sDA

- 89.2



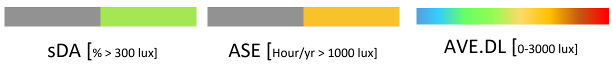
Average Daylight

- 1220



ASE

- 15.1



[Source: Authors]

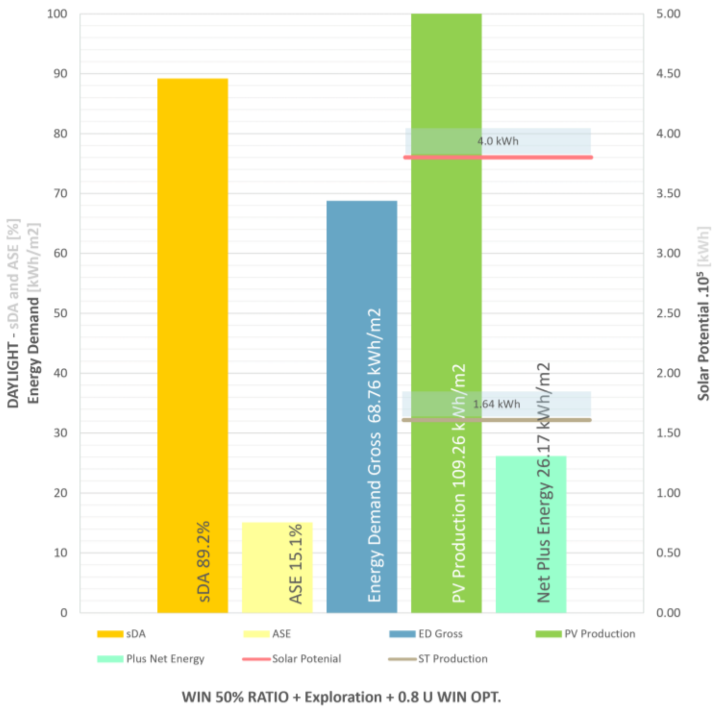


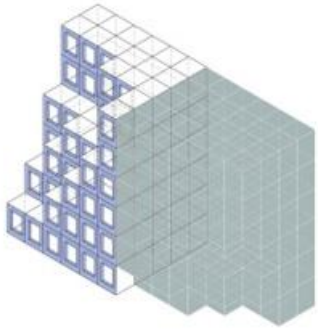
Figure 64: Waving Solution #1 [Source: Authors]

sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Looking at the case of exploration of balconies manipulations reduction of the need to be covered this resulted 68.76 kWh/m2 by renewable systems.

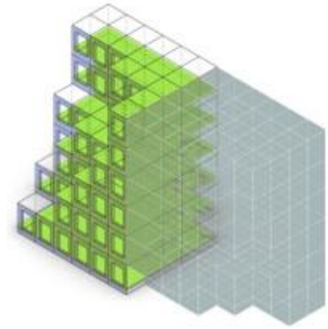
As well as looking through indoor visual comfort sDA reaches 89.2% systems. above 300 lux during the year and an increase of ASE 15.1 % that would have a glare risk probability.

Table 42: Waving Solution #2 Results



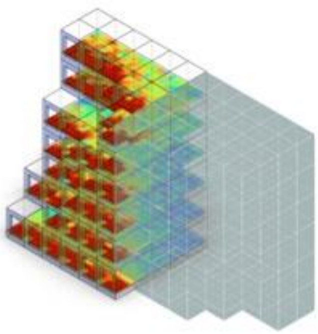
Waving Solution #2

- Win. 40% Ratio
- Win. Depth 0.3
- 0.8 Win. Opt.



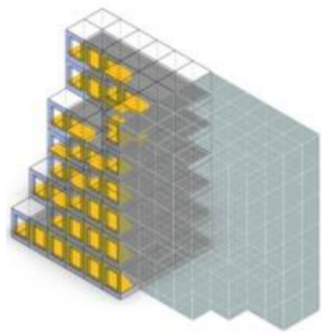
sDA

- 96.2



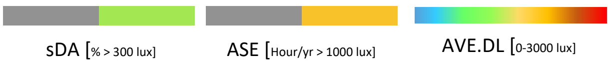
Average Daylight

- 1830



ASE

- 18.6



[Source: Authors]

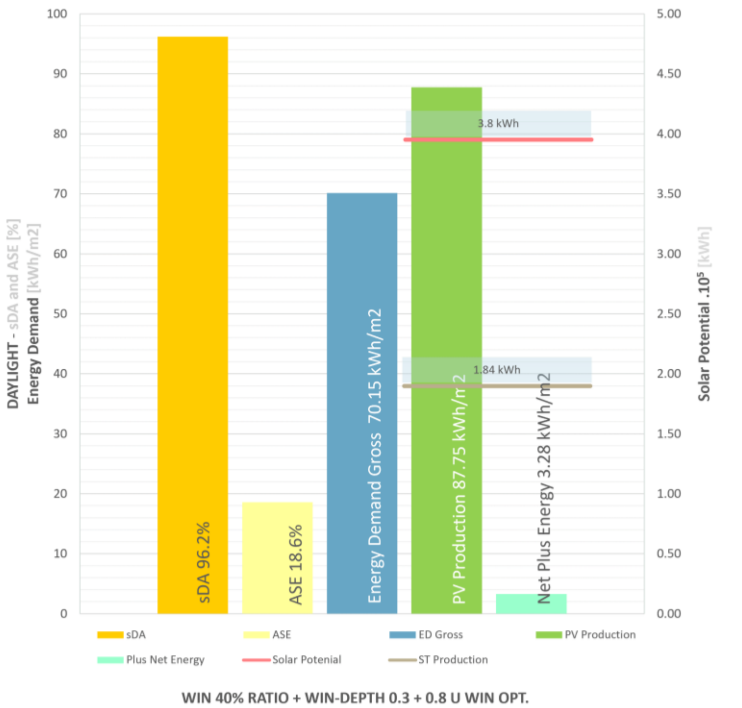


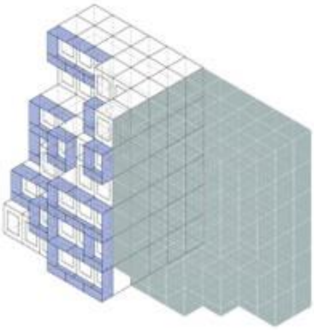
Figure 65: Waving Solution #2 [Source: Authors]

sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Looking at the case of windows depth of 0.3 meters as well as applying higher window-to-wall ratio does contribute to reduction of the need to be covered this resulted 70.15 kWh/m2 by renewable systems the shows.

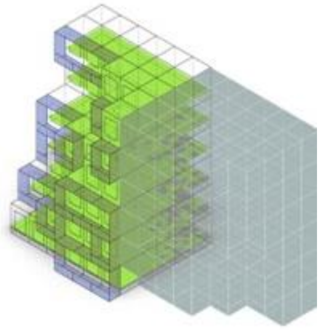
As well as looking through indoor visual comfort sDA reaches 96.2% systems. above 300 lux during the year and an increase of ASE 18.6 % that would have a glare risk probability.

Table 43: Waving Solution #3 Results



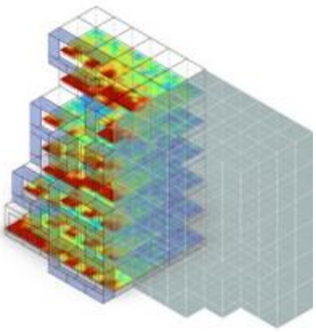
Waving Solution #3

- Win. 45% Ratio
- Three Balconies
- 0.8 Win. Opt.



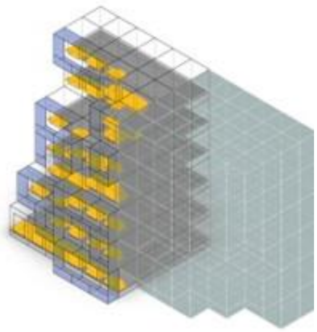
sDA

- 88.4



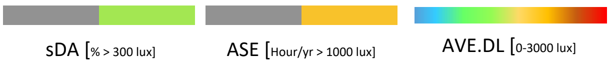
Average Daylight

- 1238



ASE

- 12.3



[Source: Authors]

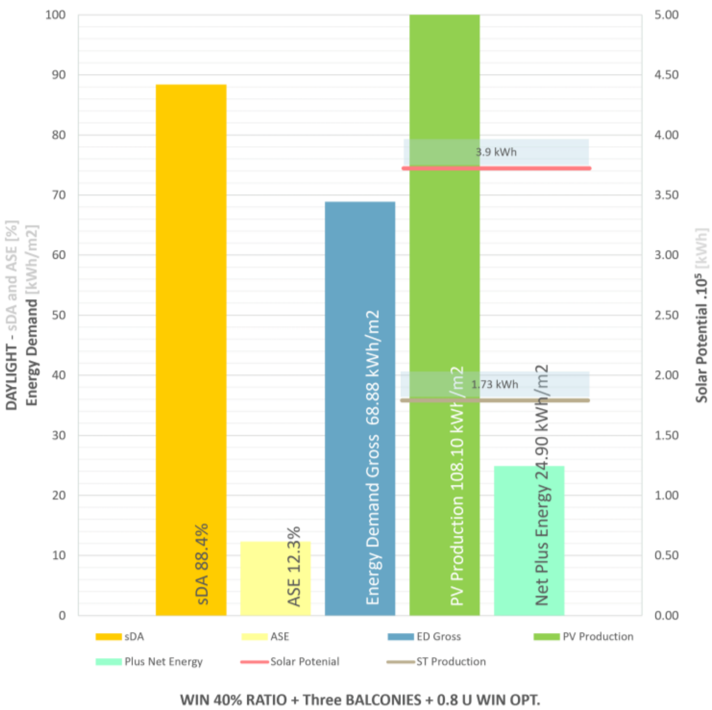


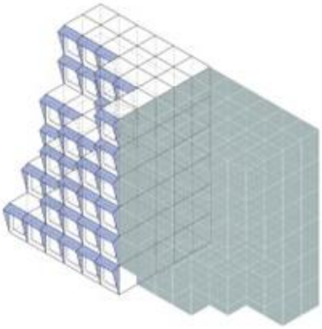
Figure 66: Waving Solution #3 [Source: Authors]

sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

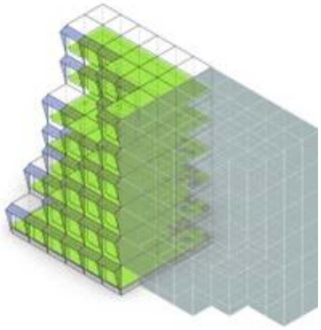
Looking at the case of Three balconies as well as applying higher window-to-wall ratio does contribute to reduction of the need to be covered this resulted 68.76 kWh/m2 by renewable systems the shows.

As well as looking through indoor visual comfort sDA reaches 88.4% systems. above 300 lux during the year and an increase of ASE 12.3 % that would have a glare risk probability.

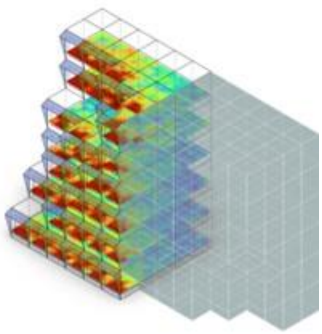
Table 44: Waving Solution #4 Results



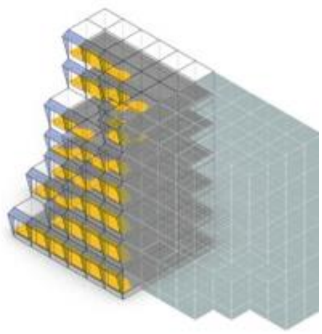
Waving Solution #4
• Win. 40% Ratio
• Angular S. 22°
• 0.8 Win. Opt.



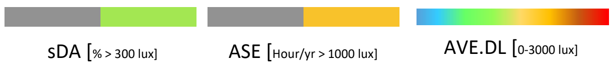
sDA
• 93.7



Average Daylight
• 1337



ASE
• 13.8



[Source:Authors]

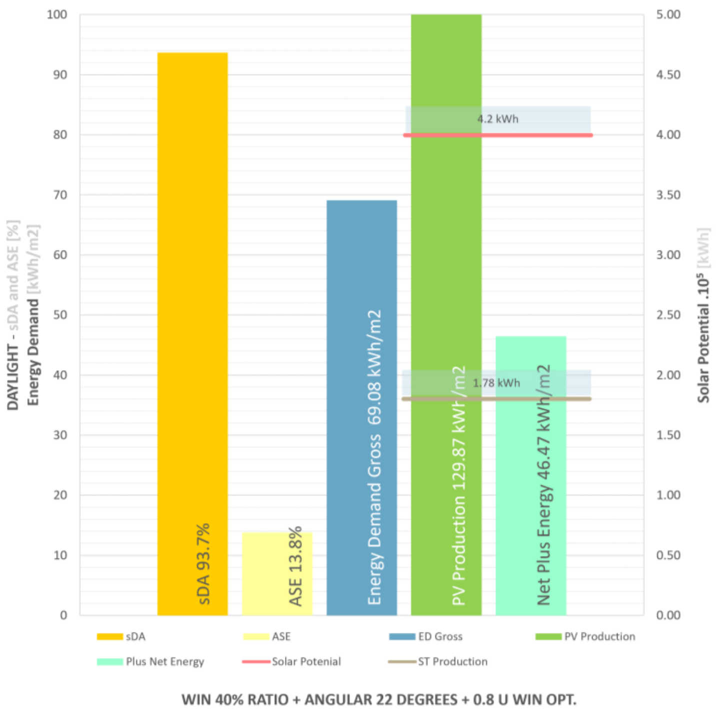


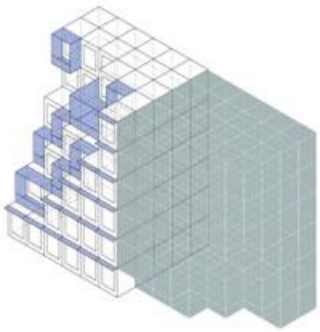
Figure 67: Waving Solution #4 [Source: Authors]

sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Looking at the case of angular shading as well as applying higher window-to-wall ratio does contribute to reduction of the need to be covered this resulted 69.08 kWh/m2 by renewable systems the shows.

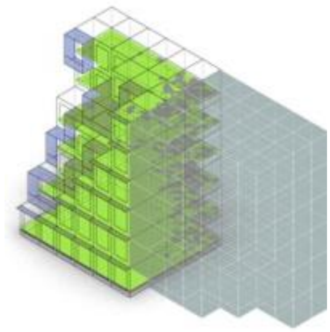
As well as looking through indoor visual comfort sDA reaches 93.7% systems. above 300 lux during the year and a reduction of ASE 13.8 % that would have a glare risk probability.

Table 45: Waving Solution #5 Results



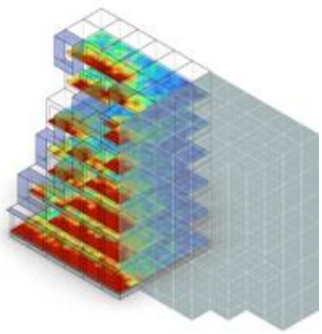
Waving Solution #5

- Win. 45% Ratio
- Two Balconies
- Green Roof
- 1.2 Win. Opt.



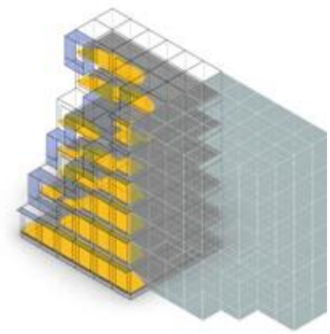
sDA

- 81.6



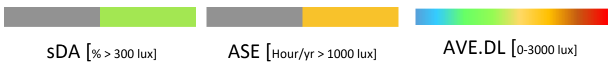
AVERAGE DAYLIGHT

- 1310



ASE

- 18.4



[Source: Authors]

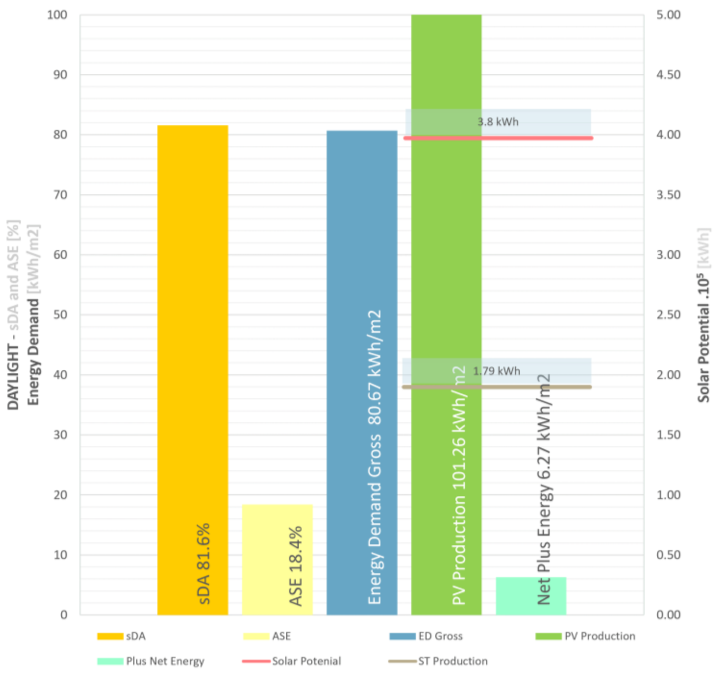


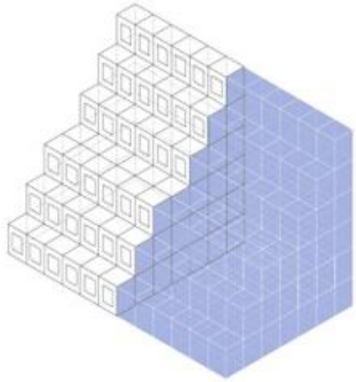
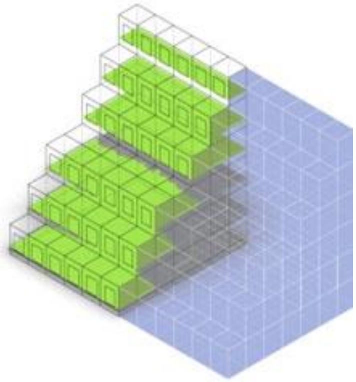
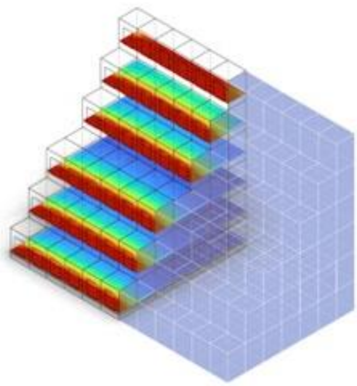
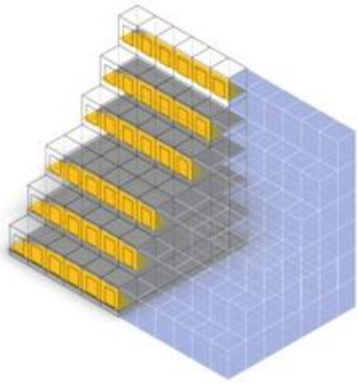
Figure 68: Waving Solution #5 [Source: Authors]

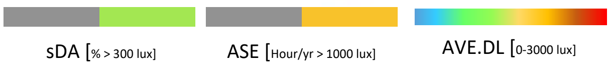
sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Looking at the case of Two balconies and top shading as well as applying higher window-to-wall ratio as well as applying green roof does contribute to higher of the need to be covered this resulted 80.67 kWh/m2 by renewable systems the shows.

As well as looking through indoor visual comfort sDA reaches 81.6% systems. above 300 lux during the year and an increase of ASE 18.4 % that would have a glare risk probability.

Table 46: Channeling Baseline Results

	**Baseline** • Channeling		**sDA** • 55.1
	**Average Daylight** • 1382		**ASE** • 22.4



[Source: Authors]

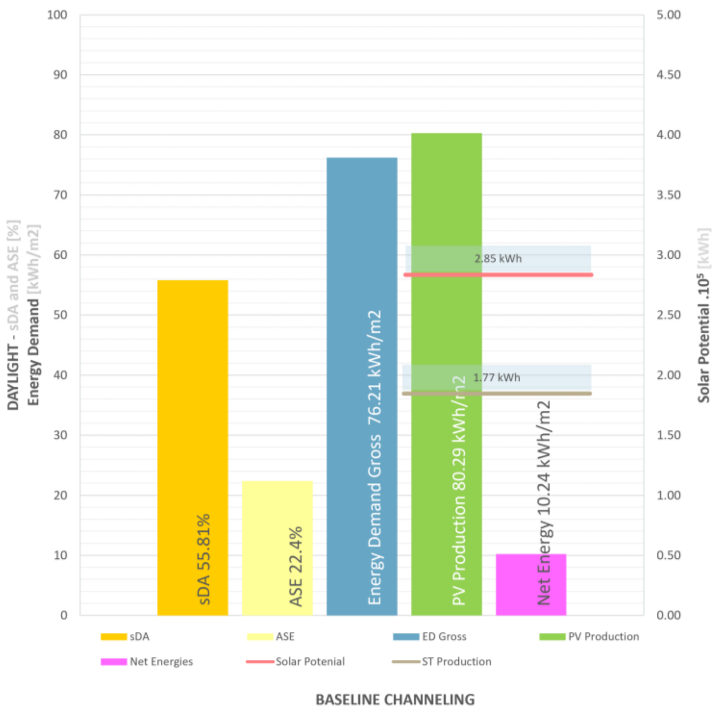


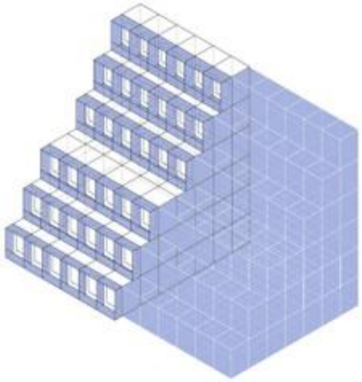
Figure 69: Channeling Baseline [Source: Authors]

sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Selection the baseline of channeling methodology resulted in energy demand 64.4 kWh, although not included the electricity need. furthermore, after taking into account (Heating + Cooling + lighting + Equipment) this resulted 76.21 kWh/m2 need to be covered by renewable systems. <u>in this case Baseline envelope as show still not reaching Net energy Need</u>

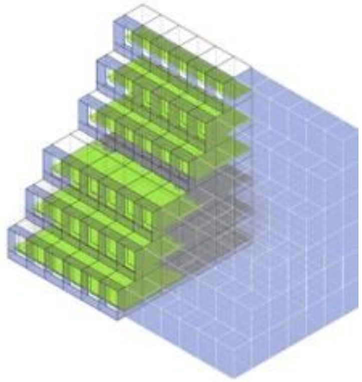
As well as looking through indoor visual comfort sDA reaches 55.81% systems. and ASE 22.4 % that would have a glare risk probability.

Table 47: Channeling Solution #1 Results



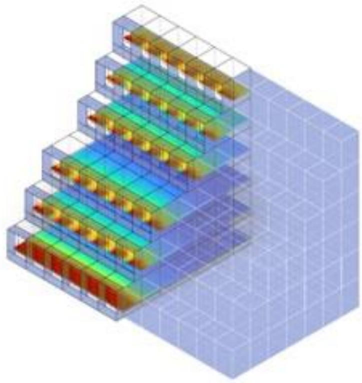
Channeling Solution #1

- Win. 40% Ratio
- Shad. Boundary
- 0.8 Win. Opt.



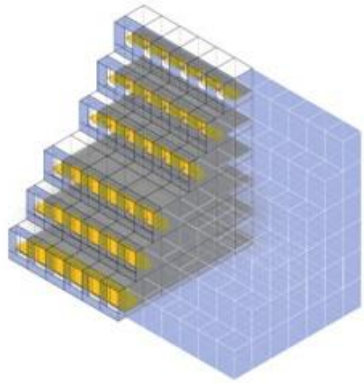
sDA

- 58.3



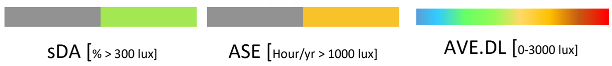
Average Daylight

- 909



ASE

- 16.1



[Source: Authors]

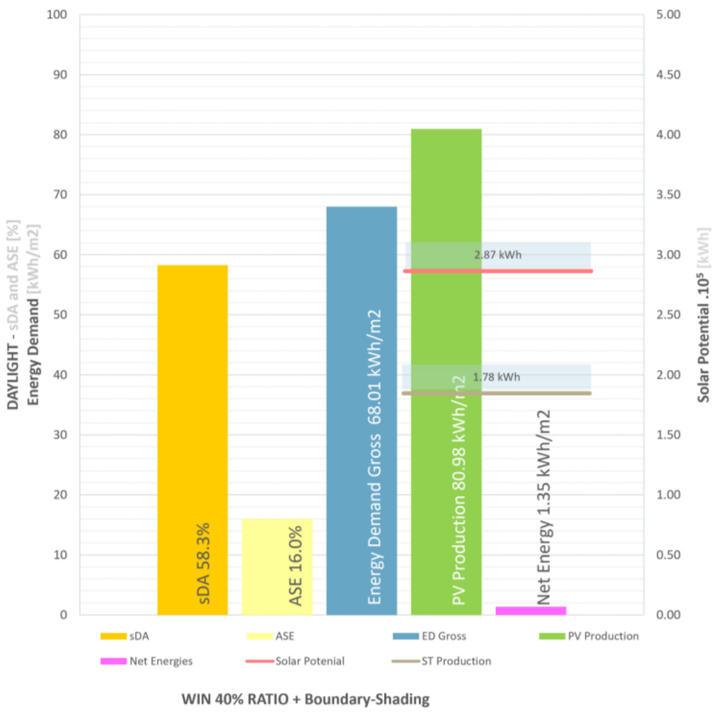


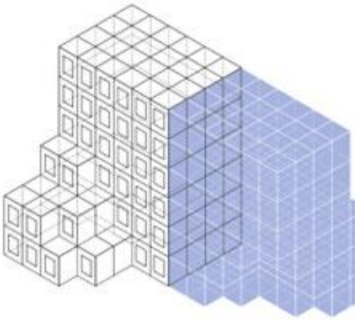
Figure 70: Channeling Solution #1 [Source: Authors]

sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Looking at the case of horizontal shading the need to be covered this resulted 68.01 kWh/m2 by renewable systems the shows. in this case envelope as show still not reaching Net energy Need

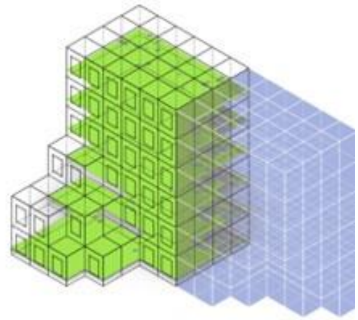
As well as looking through indoor visual comfort sDA reaches 58.3% systems. above 300 lux during the year and an increase of ASE 16.0 % that would have a glare risk probability.

Table 48: Point Attractors Baseline Results



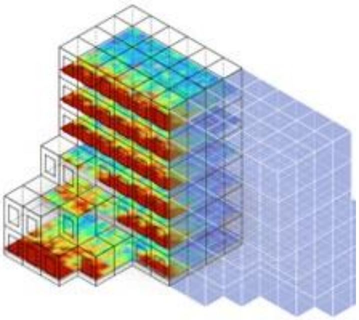
Baseline

- P. Attractor



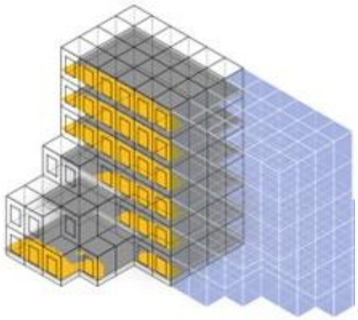
sDA

- 84.1



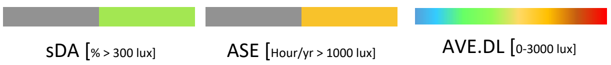
Average Daylight

- 1652



ASE

- 20.4



[Source: Authors]

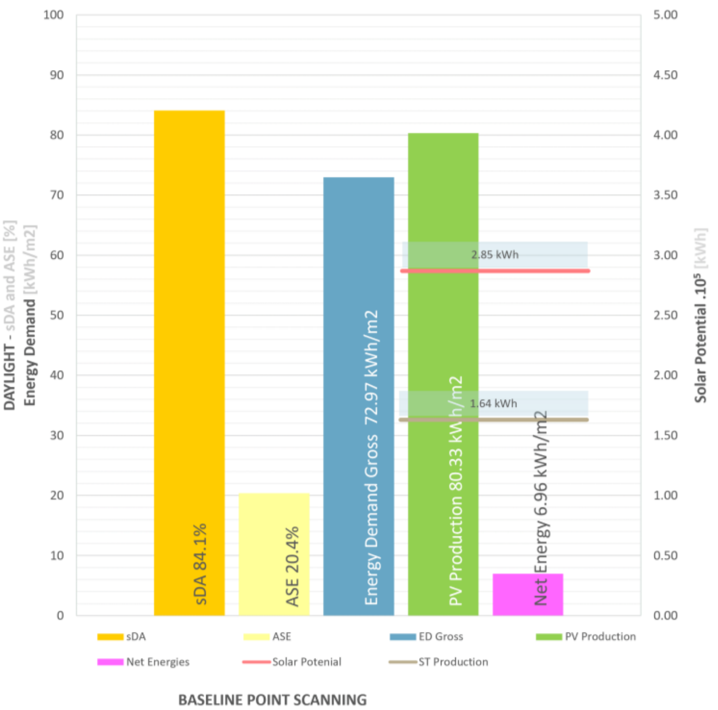


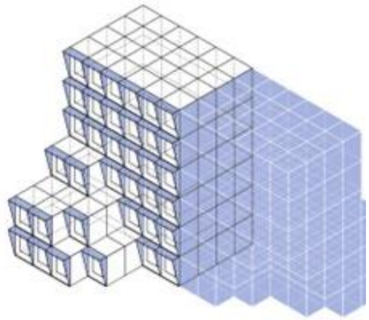
Figure 71: Point Attractors Baseline [Source: Authors]

sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Selection the baseline of point Scanning methodology resulted in energy demand 59.9 kWh, although not included the electricity need. furthermore, after taking into account (Heating + Cooling + lighting + Equipment) this resulted 72.97 kWh/m2 need to be covered by renewable systems. <u>in this case Baseline envelope as show still not reaching Net energy Need</u>

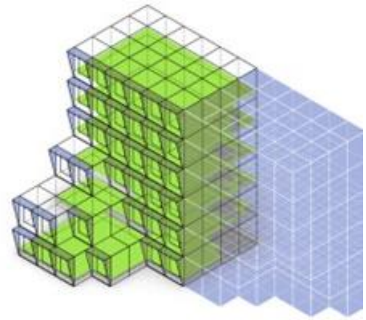
As well as looking through indoor visual comfort sDA reaches 84.1% systems. and ASE 20.4 % that would have a glare risk probability.

Table 49: Point Attractors Solution #1 Results



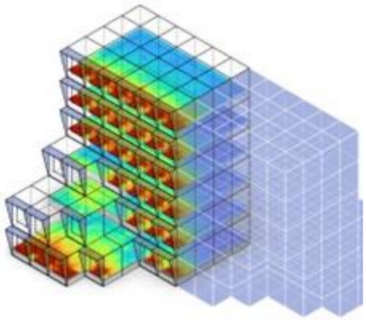
P. Attractor Solution #1

- Win. 40% Ratio
- Horizont. Shading



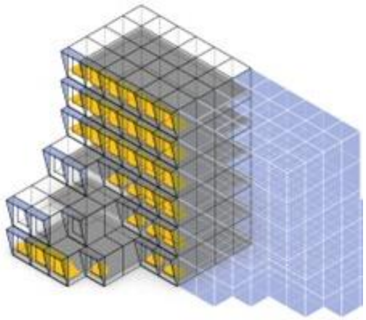
sDA

- 89.9



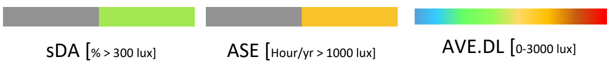
Average Daylight

- 1217



ASE

- 15.15



[Source: Authors]

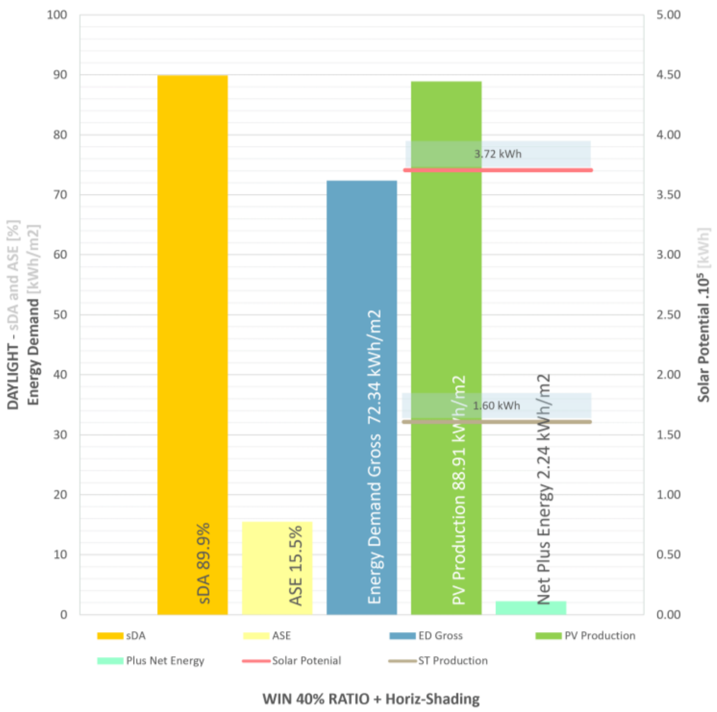


Figure 72: Point Attractors Solution #1 [Source: Authors]

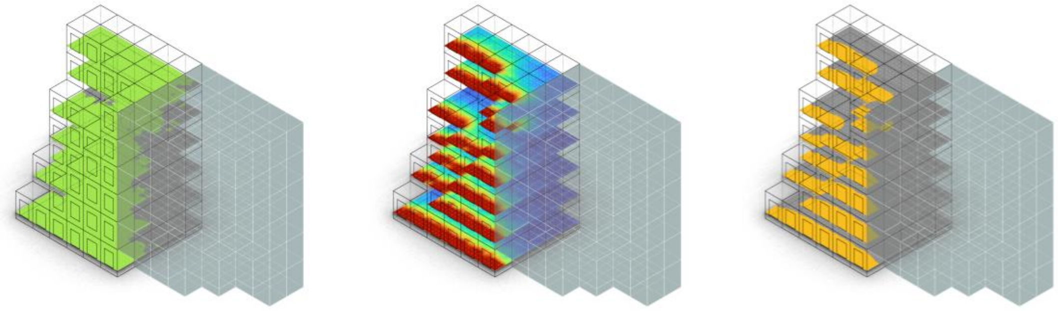
sDA, ASE, Energy (Gross and Net demand) and Solar Potential (Annual solar radiation, PV and ST production) final outputs from Chapter 03, for the three cases studied here after the envelope enhancements.

Looking at the case of horizontal shading the need to be covered this resulted 72.34 kWh/m2 by renewable systems the shows.

As well as looking through indoor visual comfort sDA reaches 89.9% systems. above 300 lux during the year and an increase of ASE 15.5 % that would have a glare risk probability.

BASELINE

WAVING

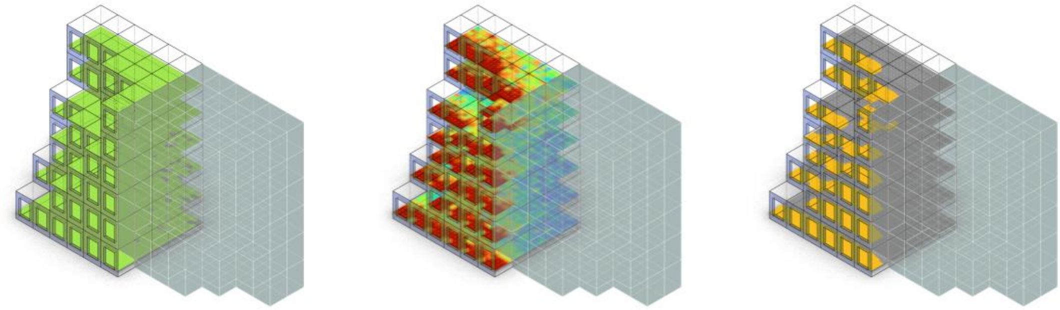


WIN 40% RATIO+

WIN-DEPTH 0.3+

0.8 U WIN OPT.

WAVING

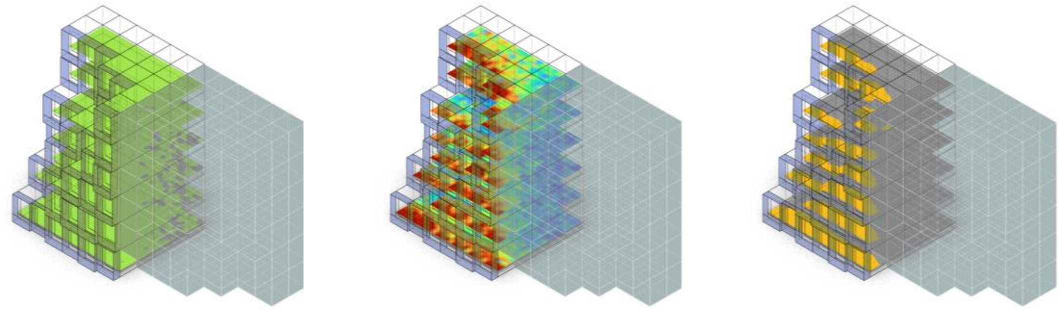


WIN 50% RATIO +

EXPLORATION +

0.8 U WIN OPT.

WAVING

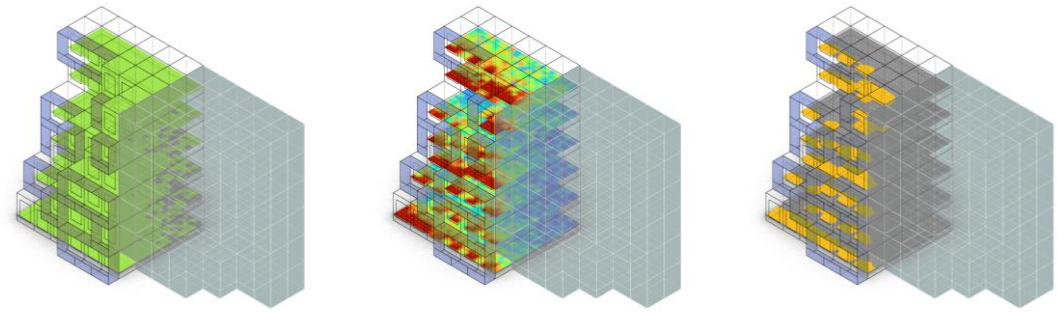


WIN 45% RATIO+

Three BALCONIES +

0.8 U WIN OPT.

WAVING

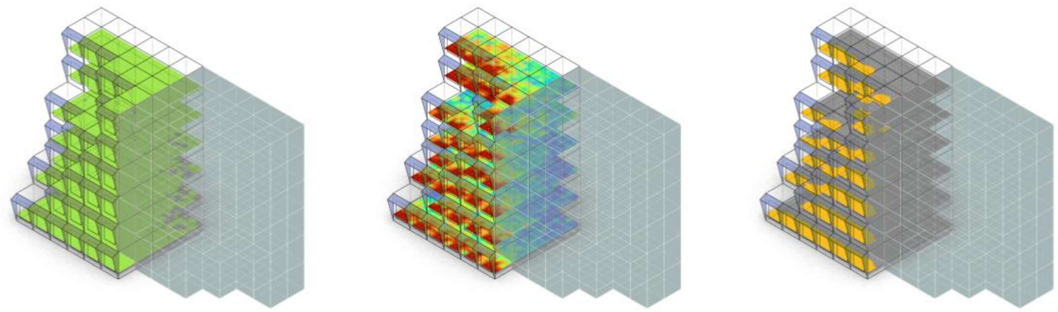


WIN 40% RATIO+

ANGULAR 22 DEGREES +

0.8 U WIN OPT.

WAVING

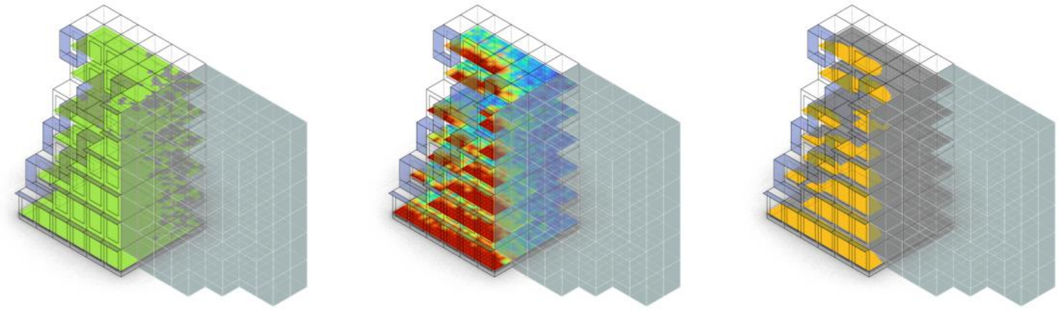


WIN 50% RATIO+

Two Balconies+

1.2 U WIN OPT.

WAVING



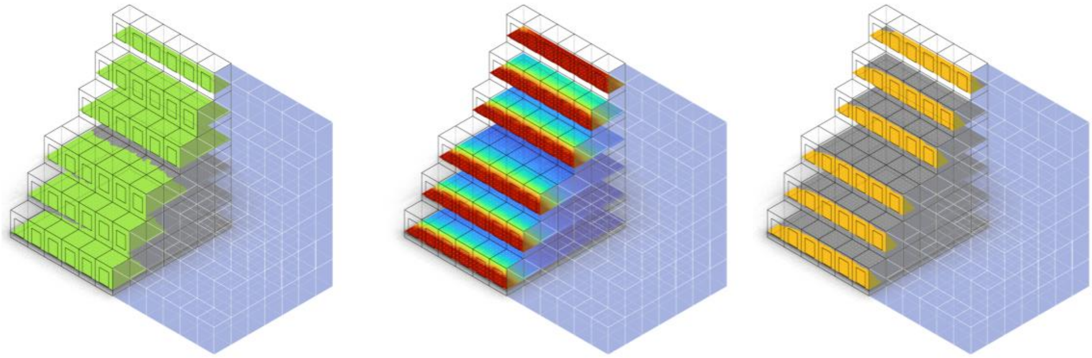
BASELINE

CHANNELING

WIN 40% RATIO+

WIN-DEPTH 0.3+

WIN OPT.

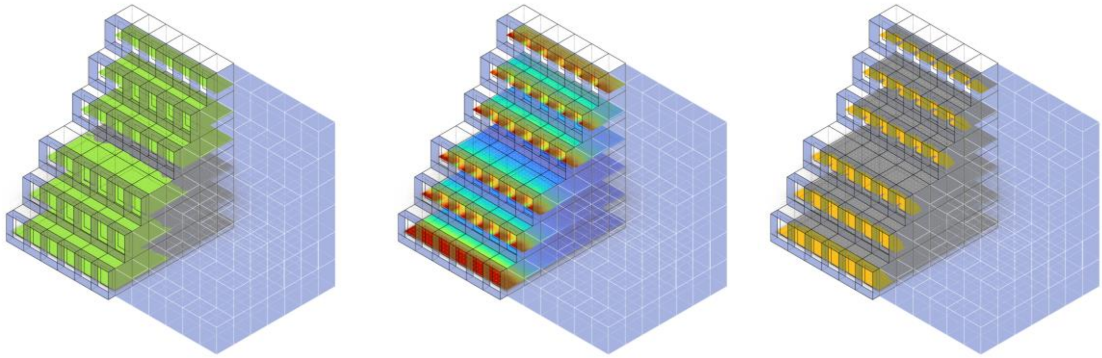


WIN 50% RATIO
+WIN 40% RATIO +

SHADING -
BOUNDARY

EXPLORATION +

WIN OPT.

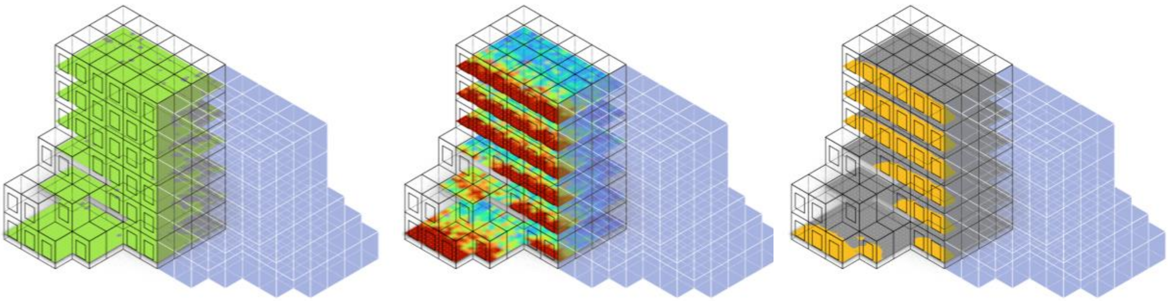


BASELINE

P. SCANNING

WIN OPT.

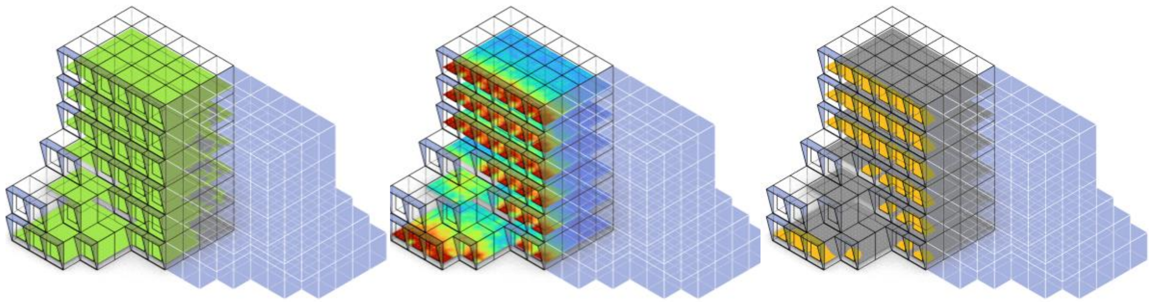
WAVING



WIN 40%
RATIO+WIN 30%
RATIO+

Horiz-Shading +

ANGULAR 22
DEGREES +



Conclusion

It is possible to summarize the results shown above and discussed in this chapter:

The waving methodology shows better gross energy demand need in baseline in applying chapter 03 strategies significantly improve the results, followed by point scanning method and lastly the channeling method.

in the chunk of case 03 also presents the highest (sDA) percentage and lowest ASE percentage,

followed by case 02 and lastly case 01.

- This chunk analysis case 03 baseline presents higher solar potential, followed by case 01 and Case 02
- netting energy production from demand makes case 02 case have the lowest net energy. requirement, followed by case 03 with a significant difference, case 01.

And after suggesting the envelope enhancement strategies discussed and simulated in Chapter 02. The findings visible there are also summarized here:

- Case 03 case has greatly improved the solar potential, while case 01 remained nearly net zero and case 02 improved slightly.
- Case 03 has an increase in daylight conditions (sDA) with lower glare probability.
- The envelope design strategies have adjusted the direction of gross energy demand: case 03 shows great improvement with applying balconies and improving the window u value while using similar strategies for case 01 shows improvement yet still not reaching the net of production.

THESIS CONCLUSION

The research provides supporting evidence for the critical nature of decisions made during the early-stage design process in achieving the desired high performance of buildings. Whether the goal is to attain sustainable buildings, zero-energy buildings, or energy-plus buildings, the massing, site location, and building orientation have a substantial impact on the final efficiency of the building.

The research formed with fundamental research questions into whether from manipulation can serve as a decisive factor during early-stage design will influence building performance metrics and whether it is achievable to determine forms that stands out. Also, if the investigation determines that a building's form affects performance. Furthermore, it would be necessary to explore potential solutions to mitigate any problems caused by incorrect decision-making. This is discussed in chapter 03.

Drawing upon the methodologies outlined in Chapter 01, the findings demonstrate the significant potential of these techniques to fulfill diverse requirements. These approaches have been applied successfully to enhance the solar potential of a given area by increasing exposure to sunlight and reducing overall energy demand. Furthermore, the utilization of these methodologies has yielded an average daylight factor within a range of 2% to 5%.

Chapter 01 highlights the usefulness of macro-scale simulations in providing an overview of the entire building façade and understanding the larger-scale patterns and dynamics of the structure. However, for a precise model of individual building envelope elements and their interactions with the surrounding environment, meso-scale simulations are necessary.

After establishing various scenarios of cases, the simulation outcomes were compared, and grouped by methodologies. A comparison was made between the different methods to assess their respective performance, as illustrated once more. The significant patterns and trends that arose from comparing the results are detailed in figure 30:

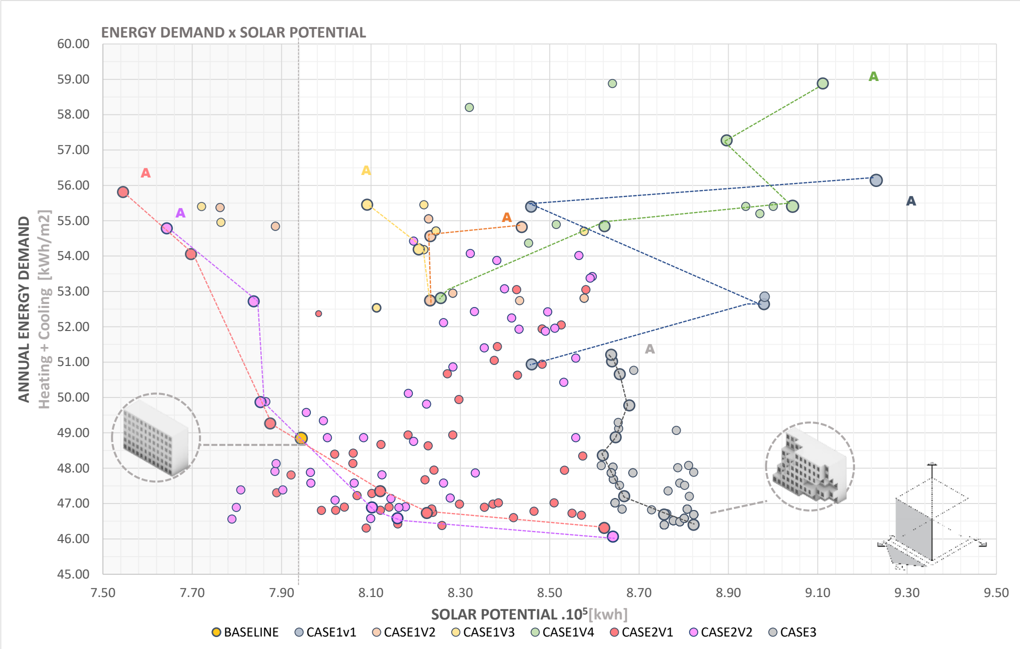
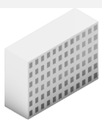
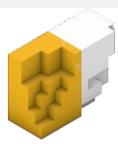


Figure 73: Building Form Comparison, ED x SP [Source: Authors]

The Waving methodology demonstrated prominent performance in scenarios with low energy demand and moderately high solar potential due to its ability to expose a larger surface area, while the point scanning method delivered results with lower energy demand, as its compact form limited exposure of horizontal surfaces to use solar radiation thereby decreasing solar potential, they are however higher daylight factor. On the other hand, since the horizontal channeling action's effects whole façade, it offers wider range but no precise as Waving.

As a prerequisite for proceeding to Chapter 02, it was necessary to select the most precise and least energy-demanding cases. The logic behind this is to see the capability of Chapter 02 Solutions on the case that can be considered as the least energy demand a chunk of Chapter 01.

Table 50: Scale Change Values Comparison

	Macro Scale Baseline: South Facade		*Meso Scale Baseline: The Taken Chunk*
Average Daylight Factor (%)	5.73	-5.40%	5.42
Solar Potential (kWh/m²)	794414.44	-51.3%	388247.91
Energy Demand (kWh)	48.84	11.12%	54.30
Visual		→	

[Source: Authors]

For the Chapter 02 study, to improve the least energy demand case from Chapter 01, the portion that increases the energy demand of the best case was extracted. After this point, this taken chunk is considered as the worst case due to reducing the performance of the least energy demand case. The worst-case scenarios for the south facade's corner chunk was considered to identify the maximum energy demand that the building may require in each situation.

The chart indicates a summary that the t methodologies result in a decrease in energy demand while increasing solar potential. On the other hand, Chapter 2 applications can be useful in reducing the probability of glare. By utilizing various characteristic envelope methodologies, it is possible to meet all factor requirements, and these methodologies can be integrated into the design of a building. These factors can be considered to achieve an average daylight factor range of 2-5%. Additionally, the study suggests that Chapter 2 applications can be useful in reducing the probability of glare. By utilizing various characteristic envelope methodologies, it is possible to meet all factor requirements.

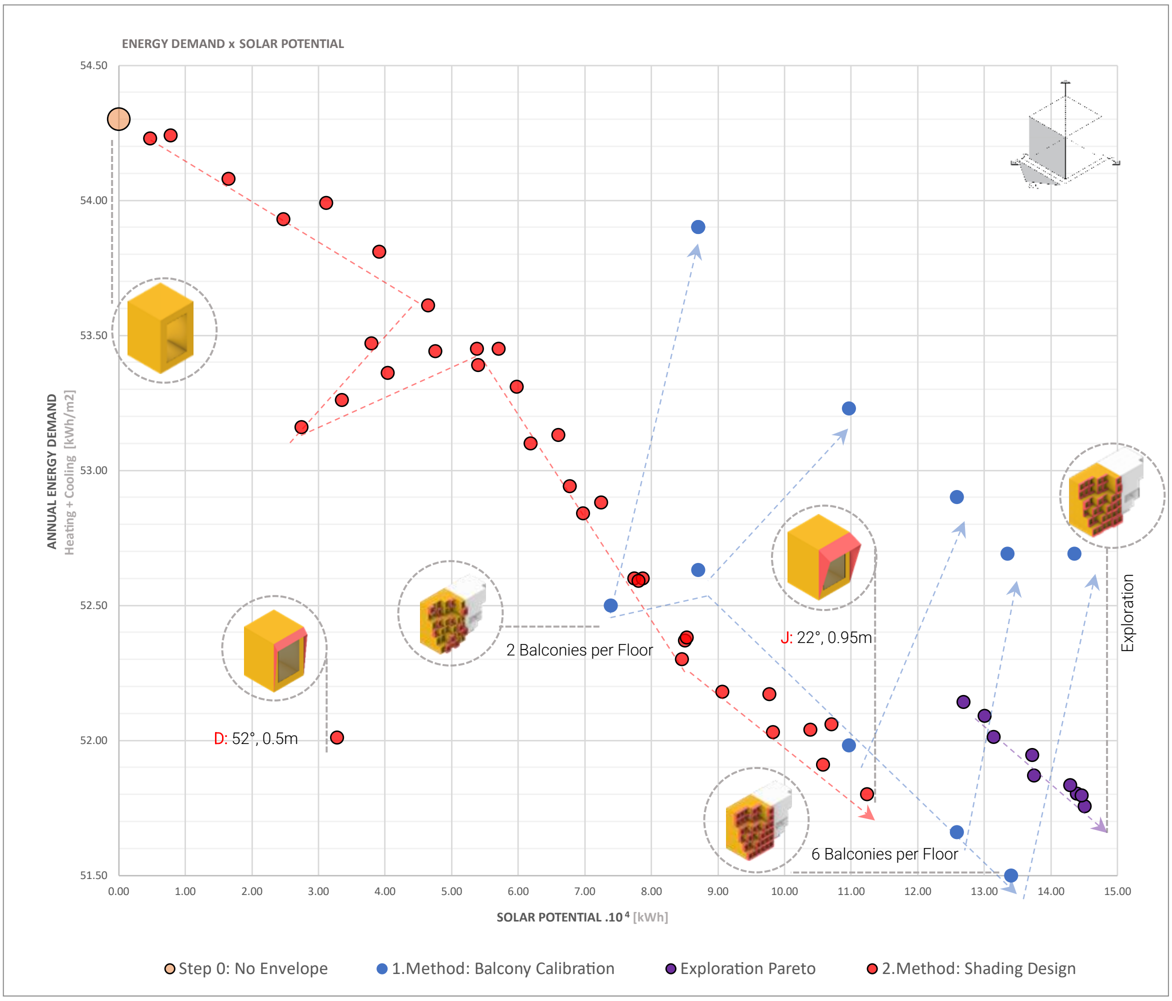


Figure 74: Building Envelope Form Comparison, ED x SP Graph [Source: Authors]

In Chapter 03, the main objective was to optimize building typologies by implementing validated strategies, while assuming the role of a designer.

The waving case stood out as it was transformed into an energy-plus building that generated more energy than it consumed, while also achieving better daylight conditions and reducing glare probabilities. On the other hand, the channeling case exhibited the least improvement despite the actions taken to enhance its performance. Nevertheless, the building's final energy demand significantly decreased, making it possible to reach a nearly zero-energy building. as well as daylight conditions of the channeling case were also greatly improved, reaching a satisfactory level. The point scanning case experienced some improvements in its envelope performance, which were counterbalanced by the energy generated by renewables, resulting in an energy-plus building.

And after analyzing all the steps in this research, it is important to recall a which was discussed in the Literature Review. This study found that waving cases had optimal performance in daylighting compared to other methods, while point scanning had the lowest energy use but significantly lower solar potential. These results were confirmed in the research, The results showed that energy consumption could be counterbalanced by renewable energy production, indicating that channeling has a higher energy demand but also have a great potential for solar capture.

In conclusion, this study attempted to answer some of the research questions posed on page 33. It was found that careful consideration of each building component and each method can significantly impact building performance as well as further detailing of building massing are, therefore, crucial factors in early-stage design that greatly influence the final results.

FURTHER WORK

In this study, the researchers mainly focused on the common elements of each building typology to develop solutions that could address all possible scenarios. However, it is worth noting that unique buildings often have specific characteristics that may not be present in other buildings. Therefore, it would be interesting for future studies to shift their focus from common points to unique elements and characteristics of individual buildings, which could lead to more customized and efficient solutions for each building. This approach could also open up new possibilities for innovation and creativity in building design and optimization.

Also looking through this study these methodologies are applicable on other facades for further optimization of the entire building and other building typologies.

In addition, there exist other aspects that could provide valuable insights into the building form, such as other optimization methodologies also other factors such as cost, more detailed facade design, and life cycle and sensitivity analysis performance of the building. Future research could expand on this optimization process by applying it to more complex design projects. Also, could be interesting to study the impact of street morphology on the thermal storage of buildings methods

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