# Benefits of High-Performance Facades to improve building performance and achieve Sustainable Designs

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**Abstract**

New architectural trends have evolved recently, such as the need for buildings to be designed with performance criteria to reduce energy consumption and improve thermal comfort for building occupants. As a result, façade systems have recently evolved from basic passive components to more sophisticated and intricate designs. One of the biggest influences on a building's comfort levels and energy usage is a high-performance façade. The performance of these facades is still difficult to evaluate, which makes it difficult to create, operate, and maintain efficiently.

Through the integration of contemporary environmental trends and high-performance facade design techniques, this article aims to transform the perception of façade design while taking human interactions with façade systems into account, ultimately leading to the realization of sustainable façades. The study's primary goal is to assist and motivate architects in developing a process for creating high-performance façade systems after they have a deep understanding of their design techniques, control systems, and framework application on a variety of designs. In return, sustainable designs will be achieved that enhance indoor environmental quality, overall building performance under various climatic circumstances, and energy consumption and cost.

**Keywords:**

Thermal comfort, sustainability, high-performance facades, indoor environmental quality, and energy efficiency.

## 1. Introduction

The interface that separates a building's internal and external surroundings is called the façade, while the components of the building envelope that offer weather resistance, as well as thermal, acoustic, and fire resistance, are called facade systems. In addition, it significantly affects how well people interact with their surroundings, energy efficiency, and the indoor environmental quality of a building, including lighting, HVAC, power loads, and peak loads to preserve appropriate lighting levels and thermal comfort. Therefore, to save energy and improve user comfort, the design of facade applications is essential, and the study of high-performance façades is significant.

Since conventional building facades are usually static and cannot react to changes in the outside climate, the move to high-performance systems may present opportunities to take advantage of contextually and functionally appropriate material selection, cutting-edge technology, excellent detailing, and installation. This makes it possible to switch from "manufactured indoor environments" to "indoor environments that are naturally lit and ventilated." Recent advancements in building design techniques have resulted in an endless number of structures with facades that are identical to one another, regardless of the materials, styles, and design strategies employed. This has led to the creation of uncomfortable interior spaces that are completely reliant on mechanical and electrical systems for extended periods to meet user demands. The use of mechanical ventilation, air heating and cooling systems, lighting systems, and all other systems required to provide a suitable and comfortable indoor environmental quality has increased buildings' energy consumption rates (Mekhamar and Hussein, 2021).

## 2- Research structure

The research hypothesizes that by tracking and evaluating the impact of high-performance facades on residential buildings, it will be possible to improve interior thermal comfort, lower energy usage, and raise occupant satisfaction and output.

There are three primary sections of the paper. The definition, characteristics, and purpose of high-performance building facades are covered in the first section. To create a comfortable interior environment and lower energy consumption, the second part presents design techniques that achieve sustainability and Design Methods with control systems for achieving High-Performance Façades such as choosing the window-to-wall ratio, properly treating different building orientations, and more. It also emphasizes contemporary environmental approaches that have an impact on building façades. Finally, the second stage ends with the framework that can help with building design through energy and thermal comfort modelling.

The final section is a case study (building a chalet in Aswan) that uses a variety of contemporary trends to create a high-performance façade and the paper shows the implementations and design interventions that were applied on the initial design to reach sustainability. A conclusion is then derived from the previous study, analysis, and implementation of a high-performance facade.

## 3. High-Performance Building Façade: Concept and Motivation

The processes for creating high-performance, sustainable facades and the actions required to guarantee that the user experience concept, energy efficiency plans, and environmental considerations are integrated with the façade design process are the most important parts of the design stage. This means that building facades are more than just partitions separating the inside from the outside of a building; rather, they are structural elements that can dynamically respond to the internal and external environment of a building, creating comfortable spaces while also lowering the building's energy usage (Aksamija, 2015) (Tabadkani, Roetzel, Li and Tsangrassoulis, 2021).

Building façade was originally used to emphasize the separation of the structural component from the cladding, but in more recent times, it has come to refer to the envelope's idea as an environmental system capable of exchanging materials, energy, and information. (Barozzi, Lienhard, Zanelli and Monticelli, 2016).

High-performance Building facades serve as a structure's external shell and divide the interior from the outside are known as high-performance building facades. Air barriers, ventilation systems, shading devices, insulation, and efficient glazing are common components of high-performance building facades. Together, these parts regulate heat transfer, air leakage, and moisture infiltration, all of which can significantly affect a building's energy consumption and overall performance. They also contribute to a building's aesthetic appeal while giving residents access to natural light and views (Sharma, 2023).

Therefore, the term "high-performance facade" is not only introduced symbolically; it is also regarded as a life film that serves as a barrier between the inside and outside of a building and as a medium that consumes the least amount of energy and material, thereby improving the occupants' productivity and health. It refers to designing buildings and spaces (interior and exterior) using local climatic conditions to improve thermal and visual comfort (Fig. 2). (Wigginton, Micheal and Jude, 2002).

High-performance façade systems" refers to the entire façade assembly, which includes the parts intended to function as an integral part of the structure and that can be delivered individually on site or preassembled in factories as prefabricated pieces. (Attia, Bilir, Safy, Struck, Loonen and Goia, 2018).

Dynamic capabilities such as heat transfer, natural ventilation, sound and air transition, and daylighting control are increasingly integrated into building facade components. Building facades are thought to be an active component in the process of conserving energy and improving the building's energy efficiency because they are the largest portion of the structure that is exposed to weather variations. Because of the new design methodology, the building façade is now seen as a behavioral feature as well as a robust physical element, creating a new avenue for communication across various technical specialties (Addington, Michelle and Schodek, 2005).

## 4. High-Performance Facades as a Mediator to Sustainable Buildings

### 4.1 Thermal Performance

A facade cannot function at its best or attain energy efficiency without effective insulation. High-performance insulation materials can decrease energy loss through the building envelope and increase thermal comfort in a structure. Examples of these materials include cellulose, mineral wool batts, foam boards and spray foam. By limiting heat transfer, the application of low-emissivity coatings on glazing can improve the building facade design's thermal efficiency even more (Sharma, 2023).

In the past, user engagement with facades has been essential to guaranteeing users' contentment with their degree of autonomy (e.g., opening a window or drawing a curtain). Modern technologies and the introduction of intelligent materials have resulted in the creation of "high-performance facades," which have the ability to lower building energy consumption and raise indoor environmental quality standards. (Attia, Bilir and Goia, 2018).

By controlling temperature, air quality and ventilation, daylighting, humidity, and other factors that contribute to occupant comfort, high-performance facades can also minimize operating costs and energy consumption rates of buildings by using less electricity and, in certain cases, even converting electrical energy from various renewable natural resources rather than just lowering electrical demand and energy consumption rates. (Mekhamar and Hussein, 2021).

The mutual influence between the design of high-performance facades and human considerations characterizes their connection. The process of designing the façade is concerned with adaptability which achieves a variable response that depends on the type and the need for compatible responses to achieve the characterized interior comfort within the building through the façade, which presents the building's first element to protect it, human factors present and determine the negative effects on humans and how to avoid it.

### 4.2 Energy Performance

High-performance facades serve as a partition between the internal and outdoor environments, serving various purposes, but their primary objective is to create a comfortable inside space. As a result, its design is oriented towards external circumstances, and it is the primary factor influencing interior circumstances. (Koyaz, Prieto, and Knaack, 2022).

With the use of intelligent materials or massing and orientation, the high-performance system may adjust to the ambient conditions. They can come together to create a striking structure that draws people in and encourages interaction. In order to improve building performance and lower the amount of solar radiation entering the structure, buildings can react to the weather and surrounding conditions (Tabadkani, Roetzel, Li, Tsangrassoulis, 2021).

### 4.3 Structural Durability

The durability of high-performance facades can be increased by the use of durable building materials and techniques. This can shield the structure of the building from environmental elements like moisture (Sharma, 2023).

## 4.4 Natural lighting

Daylighting is an important design feature that can reduce a building's electricity consumption and has a profound effect on both buildings and their occupants. It is also vital to human health, well-being, and productivity. Windows and light shelves composed of materials that diffuse light are features of high-performance building facades that let plenty of natural light into the structure. As a result, less artificial lighting is used during the day (Zelenay, Perepelitza and Lehrer, 2011).

## 4.5 Acoustic insulation

A building envelope has to eliminate unpleasant noise emissions from the building while protecting the interior conditions from outside noise. When it comes to reducing and absorbing sound energy outside of the building envelope, the façade shape and high-performance elements like overhangs and protrusions must be taken into account by the architect. Additionally, a building's high-performance facade serves as a double skin to accomplish the desired acoustic insulation (Fernando et al., 2023).

## 4.6 sustainability

The term "embodied carbon" refers to the greenhouse gases (GHGs) released during the extraction, manufacture, transportation, construction, replacement, and deconstruction of building materials as well as the end-of-life emissions. Energy use also plays a role in reducing operational carbon. The embedded carbon in building materials accounts for between 39% and 80% of a building's overall carbon footprint. Eighty percent of a building's embodied carbon can be avoided if it is assessed early in the design process (Sharma, 2023).

## 4.7 Aesthetic Value

In fact, the facade is the building's face to the world. Therefore, the architect should be able to work on qualities like variations, texture, colour, reflectivity, gloss level, and the potential to incorporate holes or patterns on the surface for aesthetics, daylighting, or natural ventilation. The overall shape of the envelope is tied to the internal space planning and layouts. The building's appearance is determined by the interaction of these parameters (Kamal, 2020).

## 5. Design Methods and control systems for High-Performance Façades

Most of the building's envelope, which divides the internal and outdoor spaces, is composed of the façade. It is the single most significant component affecting the structure's energy efficiency. The location and orientation of the building, the development of the building's geometry and massing to respond to solar position, the provision of solar shading to control cooling loads and improve thermal comfort, the use of natural ventilation to reduce cooling loads and enhance air quality in climates that permit it, and the reduction of energy used for artificial lighting, mechanical cooling and heating, as well as artificial lighting, all contribute to the design and efficiency of high-per as well as the façade's building materials and techniques (Kamal, 2020).

### 5.1 Solar Control Systems

#### 5.1.1 Location and orientation

The façade's exposure to sunlight is determined by its orientation. The direction of the building affects solar heat gain control strategies. On the one hand, throughout the winter, buildings in cold climates can benefit from solar heat gain. Conversely, interior rooms in hot climes require year-round shading from direct sunlight. From the standpoint of solar heat gain, the façade's ideal orientation strikes a compromise between summertime solar shading and wintertime solar heat gains that are beneficial. It is best to minimize solar heat intake in hot climates all year round, but especially in the summer. The first step in designing a high-performance facade is figuring out how best to orient and shape the structure in relation to its intended function and other constraints (Aksamija, 2015).

#### 5.1.2 Shading elements

By reflexing, absorbing, diverting, filtering, or by combining these options, shading systems can control solar energy. Generally speaking, solar shading systems can carry out a wide range of additional tasks, including as controlling daylighting, controlling natural ventilation, thermally insulating the building shell, converting solar energy into other kinds of energy, cleaning or humidifying the air, and so forth. A basic shading unit or multiple construction parts with distinct roles that may vary in form and material can perform these duties (Hraska, 2018).

### 5.2 Ventilation Control Systems

#### 5.2.1 Window-to-wall ratio

The window-to-wall ratio, or the percentage of glazed to opaque façade area, is a crucial facade measure. The solar heat gain and energy consumption of a façade are significantly influenced by this ratio. Higher window-to-wall ratios usually translate into higher energy usage because even an insulated glazed façade's thermal resistance is usually lower than that of an opaque façade (Aksamija, 2015).

Design strategies for high-performing and sustainable façades should include minimizing the window-to-wall ratio, as energy code recommendations state that the ratio should not be larger than 40%, and specifically addressing building orientation (e.g. maximizing along the north orientation, and minimizing on the east and west facades). Higher window-to-wall ratios in hotter climes result in higher cooling loads because of increased solar heat uptake. enhancing the proportion of opaque façade to glass to decrease the window-to-wall ratio is a crucial tactic for enhancing energy efficiency (Kamal, 2020).

## 5.3 Thermal Control Systems

### 5.3.1 Materials selection

When building sustainable facades with great performance, material selection is crucial. Enhancing the building envelope's thermal efficiency and reducing thermal bridging are critical design techniques for sustainable facades. The choice of materials affects the environment as well. Choosing materials with the least detrimental impact on the environment is becoming more and more crucial. The environmental effects of material selection can be ascertained by the application of the life-cycle assessment approach. Making material choices based on embodied energy data is another suitable way to take environmental effects into account (Aksamija, 2015).

### 5.3.2 Light Color in painting

As part of a sustainable design approach, light colour painting uses reflecting paint on building surfaces to lower the amount of heat the structure absorbs. This can enhance building occupants' levels of indoor comfort and reduce the amount of energy needed for cooling (Anna, 2023)

### 5.3.3 Double-skin façade

Buildings with double-skin facades can lower energy consumption, control the internal temperature of the building by blocking direct sunlight and heat from entering the façade. Additionally, because of the building's exposure to strong winds, a double-skin façade was chosen. As air flows between the envelopes, it will eventually aid in cooling the main façade and lessen the strain on air conditioning systems, which will save energy and waste. Double skin façades are therefore an attempt to improve efficiency and lower energy costs for lighting and air conditioning systems, particularly during the day (Ahriz et al., 2022) (Pollard, 2009).

## 5.4 Daylighting Control Systems

For individuals with a range of physiological and psychological demands, including those that occasionally clash, daylighting is the ideal natural source. An efficient façade that can minimize discomfort hazards and the building's energy load while maintaining a balance between daylight harvesting and view-out maximization is the most ambitious challenge for architects. (Attia, Lioure and Declaude, 2020).

### 5.4.1 Smart windows and glass

Windows are essential for regulating how much light enters a building and how much energy is used. There are other uses for smart windows besides cutting down on energy loss. One kind of glazing product called "smart glass" modifies its light-control properties in reaction to an outside stimulus. A relatively new kind of excellent glazing with significant clean technology features is called "smart glass." Other names for it include chromogenic, dynamic, and switchable glazing (Barakat and Faragallah, 2023).

## 5.5 Energy control system

Approximately 40% of the world's energy consumption and carbon emissions come from buildings. The overall energy usage of buildings, particularly for cooling, varies depending on the design quality and local climate. Energy consumption plays a significant role in modern life, as obtaining a comfortable standard of living is largely dependent on it. Energy consumption for comfort has negative effects on the environment and the economy. In hot climes, buildings with proper sun and heat protection and careful control over internal loads can lower their cooling loads to 5 kWh/m2/year, but poorly designed structures can have loads as high as 450 kWh/m2/year (Kamal, 2020).

In conclusion, table (1) is produced based on the previously mentioned elements to evaluate architects' use of high-performance facade control systems in their design processes, which will also aid in the achievement of sustainable architecture.

| | | | | |
|---|---|---|---|---|
| High-Performance Facades Control Systems | Solar Control | Location and orientation | Shading elements | |
| | Ventilation Control | Window-to-wall ratio | | |
| | Thermal Control | Material selection | Light color painting | Double-skin |
| | Daylighting Control | Smart windows and glass | | |
| | Energy Control | Photovoltaic panels | Energy generating systems | |

Table (1): High-performance facade control systems
Source: The researcher

## 6. Framework to Design High-Performance Facades

The purpose of this study is to offer design suggestions for façade treatments that take into account the intended energy efficiency of the façade system. Building performance simulations are an essential component of the design process for energy-efficient, high-performance buildings because they aid in the investigation of design options and the assessment of the environmental and energy impacts of design decisions. This research adopted building performance simulations due to the multitude of variables presented in the literature review that involved the selection of the façade design methods and the use of modern technologies. (Aksamija, 2009).

The design process for high-performance, sustainable building facades involves several key components. It is now crucial for designers to assess the energy performance of buildings before creating a comprehensive energy model. This keeps the project from undergoing significant adjustments because of false energy objectives. Nonetheless, the evaluation of building performance is a drawn-out procedure that typically involves multiple steps (fig.1)

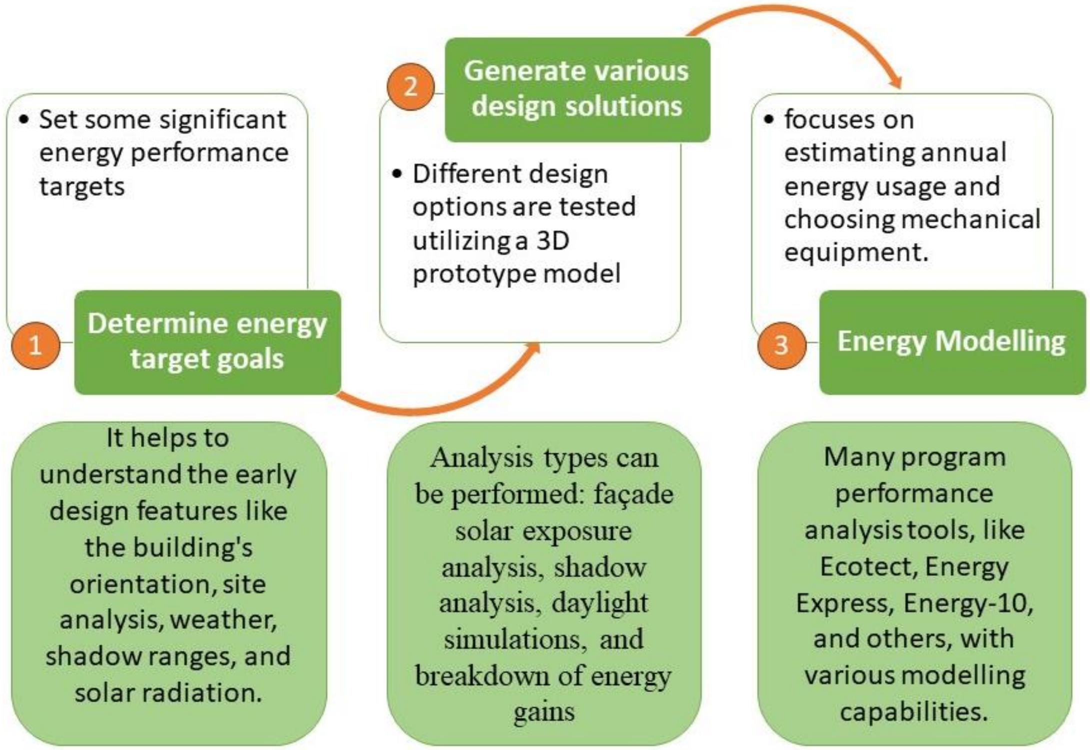



Figure 1: Framework to Design High-Performance Facades

Source: Researcher

## 7. Case Study: Designing a Front Nile Chalet in Aswan

Residential buildings are assumed to use the most energy because it is where people spend most of their time. Due to the lack of environmental consciousness in the majority of Egyptian residential buildings, large glass or solid surfaces raise energy consumption, electricity prices, and carbon emissions. As a result, the case study is chosen to be a building with residential use, therefore it is a chalet on the Nile River near Aswan (fig.2).

The framework for designing high-performance facades, which was previously covered in the paper, will be applied to the case study to determine the energy target goals and generate various environmental solutions for the building. Lastly, use energy modeling to assess the building's energy efficiency.

## 7.1 Determine energy goals

The primary obstacle is lowering building energy consumption while including the concept of a high-performance façade, energy conservation, and thermal comfort. Therefore, it is important to analyse the site and understand special climatic conditions.The city of Aswan is situated south of the Nile Valley, bounded by the eastern and western deserts, at 24.10 North latitude and 32.90 East longitude (Fig.3). The yearly average temperature is 26.80 degrees, with an annual precipitation of approximately 1 mm (Fig. 4). This area has a hot desert climate, which is defined by intense summer heat waves and extreme dry spells. In such a climate, there are periods of day and night when the air temperature is hot to the point of discomfort (Abdelhafez, 2018).

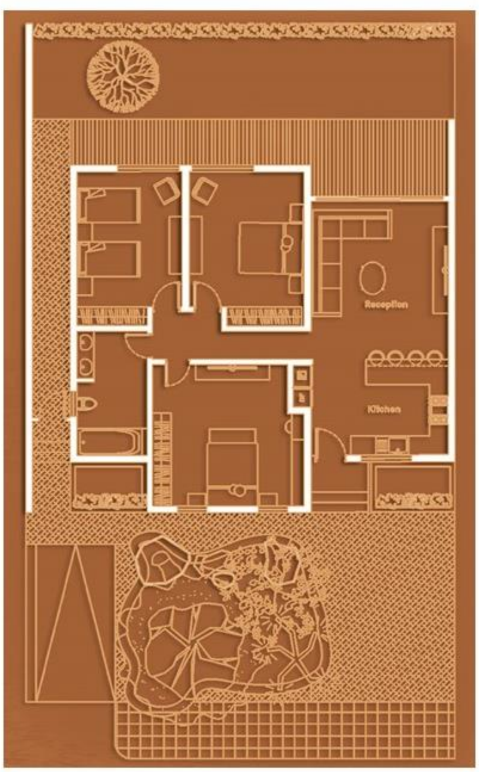



Fig. (2): The initial design of the chalet before any modifications
Source: The researcher


Fig. (3): The location of the chalet
Source: The researcher

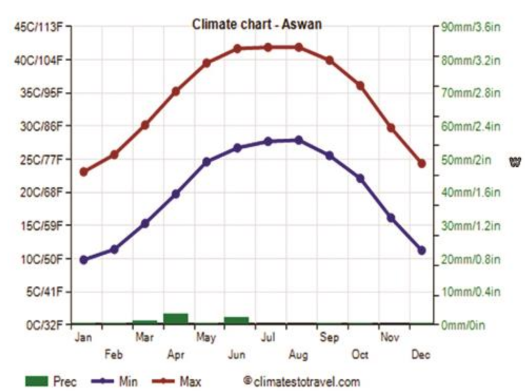
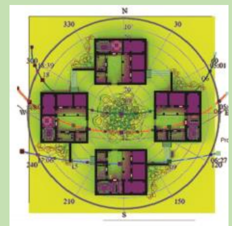
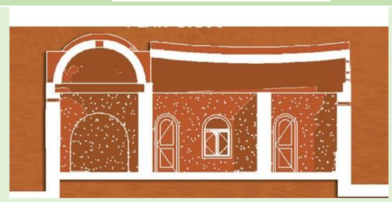



Fig. (4): Climate in Aswan
Source: The researcher

## 7.2 generate various design solutions

At this stage, the chalet building's design methods and control systems for high-performance facades are developed and implemented in table (2) in accordance with Aswan City's environmental guidelines and established energy goals.

| Type of Control System | | Environmental Solutions Applied in the Façade of the chalet | |
|---|---|---|---|
| Solar Control | **Orientation** | The building was oriented in the direction north-south. |  |
| | **Shading Elements** | Light shading elements were used on the south and west side windows. |  |
| Thermal Control | **Material selection** | using sundried mud bricks, which have been shown to be a suitable and thermally resistant material for attaining thermal comfort. Numerous elements are taken into consideration, including colour, surface polish, texture, pattern, and durability. |  |
| | **Light color in painting** | Light-colored paint is applied to external facades to reflect sunlight and lessen heat absorption. |  |

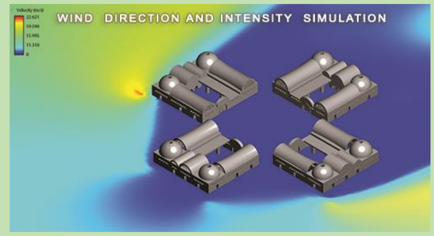
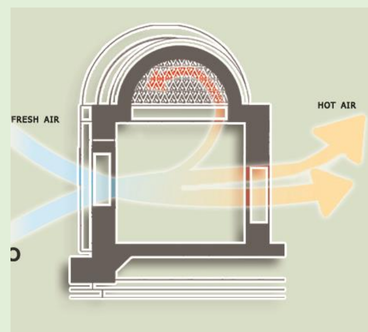
| | | | |
|---|---|---|---|
| Ventilation Control | **Window-to-wall ratio** | Reducing the number of windows in the façade increases the area of solid walls, which aids in reducing the amount of heat transfer from the exterior to the interior. As hot air rises and enters through upper apertures, upper windows aid in proper ventilation. |  |
| Daylighting Control | **Glazing** | Low e-glass was used in all windows to enhance cooling |  |
| | **Smart windows** | To keep undesired sunlight out of the areas, smart windows and smart glass were installed. | |
| Energy Control | **Energy generation** | Energy management in buildings seeks to minimize and maximize energy use in a way that is both economically viable and does not degrade thermal comfort. One approach to supply the necessary energy for the structures is to use photovoltaic systems in responsive facades. Kinetic panels in these facades follow the path of the sun to supply the building's energy. |  |

Table (2): High performance facade design methods applied on case study
Source: The researcher

## 7. 3 Energy modeling

The energy performance of the building façade is assessed in this study using the modeling program "Insight" both before and after integrating contemporary environmental treatments to create a high-performance facade. One tool available for analyzing and assessing each system's effect on indoor thermal performance is the simulation software. By identifying the system with the most effective and efficient thermal performance, this analysis will aid in the decision-making process. Another crucial factor in lowering cooling is the use of double-skinned facades. Additionally, the structure is shaded from the sun by the expanded photovoltaic array on the façade. Furthermore, by integrating modern technologies into building envelopes, environmentally high-performance facades are created that can control energy consumption associated with the use of energy-efficient performance strategies, like operable windows with integrated smart glass, which enhance daylight and reduce artificial lighting while allowing for personal control over ventilation. (Fig. 5 and 6).

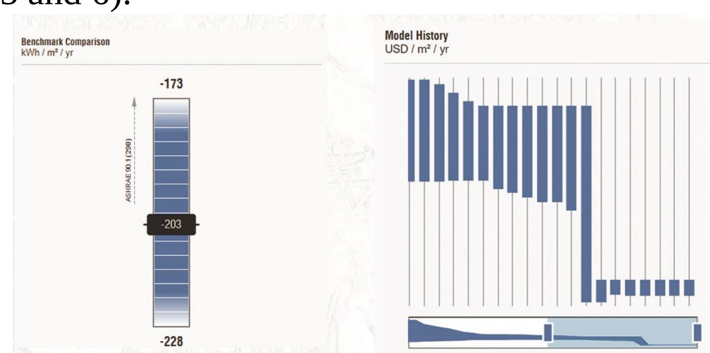



Figure (5): The overall energy saving
Source: The researcher

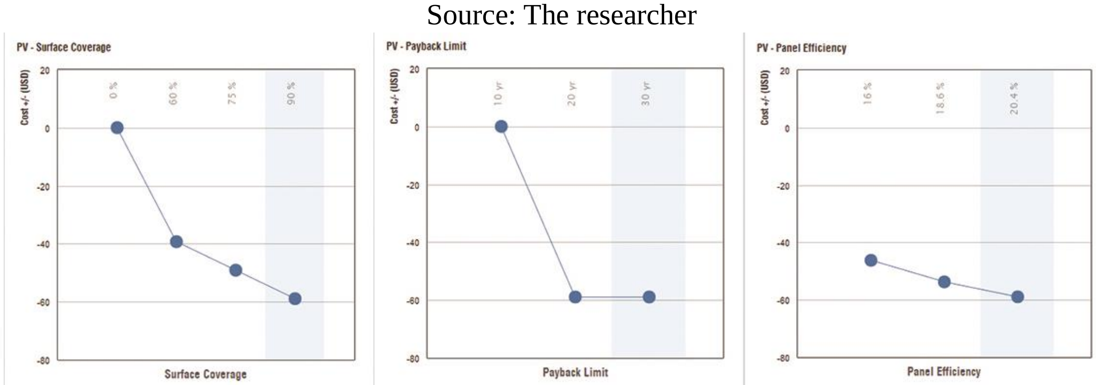



Figure (6): The energy saving after adding PV

## 8. Results and Discussion

Drawing from the literature review, analysis, and evaluation of the case study, it is evident that creating a high-performance façade necessitates research on the variables impacting the energy performance of the façade in addition to employing the right contemporary environmental technologies to get around the challenges associated with designing facades, particularly in hot climates.

The case study's primary goal is to create high-performance facades that use materials that are readily available locally and include shading components painted in light colors to decrease solar radiation. The window-to-wall ratio, double skin façade, and many other previously described elements led to significant modifications in the chalet design to implement a high-performance facade and accomplish sustainability (fig. 7).

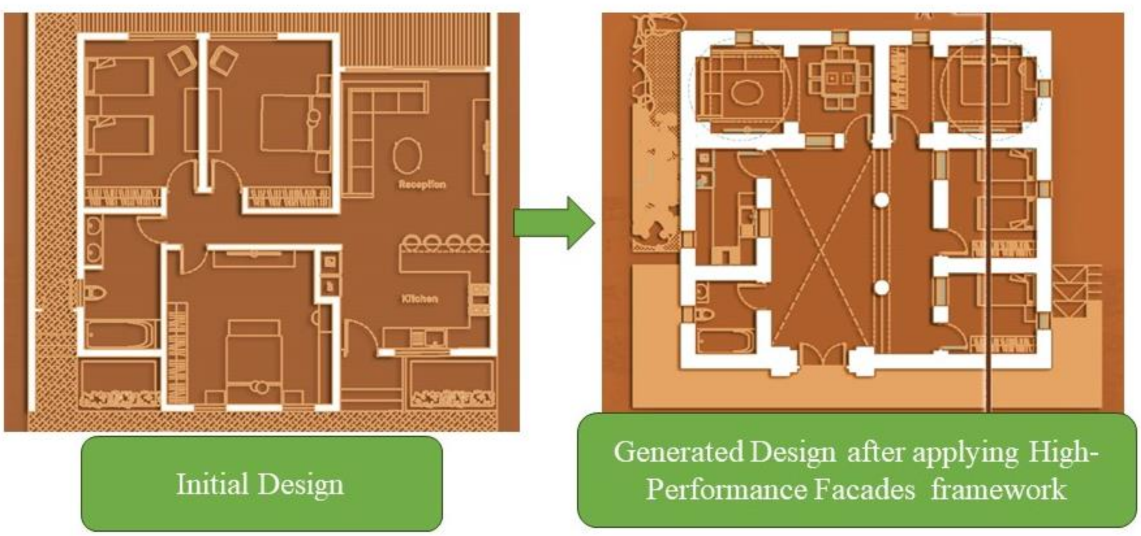



Figure (7): The adjustments occurred on the plan design to achieve a high-performance facade
Source: The researcher

## 9. Conclusion

Architecture faces enormous challenges to decrease the environmental impact of construction, to provide trustworthy and precise performance analysis methodologies for structures. As the link between internal rooms and the outer environment, the façade is a vital architectural element which can considerably influence energy use, indoor climate and occupant comfort levels.

Recently, high-performance façade concepts have become a research topic of significance in the area of sustainable design, given their potential to reduce a building’s energy demand while providing new design opportunities. Because high-performance façade designs can lower a building's energy use while opening up new design possibilities, they have recently gained attention as a significant study topic in the field of sustainable design.

The function of high-performance facades in improving interior environment and energy conservation has been discussed in the article. This research depends on the examination and assessment of a case study that employed a variety of contemporary techniques to produce a high-performance façade. In order to create high performance facades, the analysis highlights how crucial it is to use passive design techniques through orientation, massing, natural ventilation, shading, and lighting strategies in addition to integrating contemporary technology like smart glass, etc. By incorporating energy-efficient technologies and employing passive design techniques, the high-performance façade under analysis effectively reduced the amount of energy that occupants consumed in the hot and dry climate.

In conclusion, The best approach to lower a building's thermal requirements and guarantee the thermal comfort of its occupants is through efficient building design that incorporates high-performing envelopes. Given the lengthy lifespan of buildings and the related expense of the envelope, choosing the right envelope structure and materials is crucial when compared to alternative building option (*Building Envelopes - IEA*, n.d.).

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