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Parameters of High-Performance Facades for the Design of Sustainable High-Rise Buildings in the Arab Region

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Abstract
The construction of high-rise buildings has expanded in the last decade in Arab countries. Accordingly, the facades of these buildings are one of the most significant building components that help to separate the internal and external environments, where they have an effective impact on energy consumption and carbon emissions. Thus, facades play a significant role in the quality of high-rise buildings. Their performance is challenging and has a great effect on its design, construction, operation and maintenance. The study explores the concept and purpose of building façades. It highlights particularly high-performance facades in high-rise buildings in terms of some environmental control systems and design methods to manage energy consumption, comfort levels and indoor environmental quality. Also, it analyzes different facades for high-rise buildings in the Arab region and their positive impacts on these buildings. At the end, the paper concludes the main environmental control systems and especially their design parameters for high-performance facades that can be applied in high-rise buildings to achieve sustainability in the arid region generally and in the Egyptian context particularly. The main aim of the study is to raise the awareness of architects to determine the design approaches of high-performance façades in the early design stages in order to enhance the overall performance of high-rise buildings, particularly in hot temperatures.

Keywords*:* energy efficiency; indoor environmental quality; facades; high-performance; high-rise buildings; thermal comfort.

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1. Introduction

In recent years, contemporary architecture has been deeply influenced by the urgent need for reducing harmful emissions of carbon dioxide in the atmosphere. The building sector constitutes in fact one of the most energy consuming sectors of the world economy where approximately, 30% of the global carbon emissions and 40% of the energy consumption originate from construction activities (Esener and Cosgun, 2020). Due to the rapid urbanization that is combined with the availability of cheap energy for heating and cooling, inefficient high-rise buildings have evolved. They are fully glazed towers that have limited daylight access and that are fully air-conditioned which neither comply with fundamental energy efficiency strategies nor any specific environmental considerations (Ghrabra, 2017). High-rise buildings constitute a large part of all buildings. Therefore, facades of buildings have significant effects on the operation of high-rise buildings since they are the boundary between the external and internal surroundings.

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Façades significantly influence how effectively occupants interact with the surrounding conditions, consumption of energy and the quality of the indoor environment, such as lighting, heating, ventilation and air conditioning systems (HVAC) and energy peak periods to preserve appropriate lighting conditions and thermal comfort.

Due to the dependence on both mechanical and electrical systems, high-rise buildings are currently consuming greater amounts of energy due to the use of air conditioning, heating and lighting systems and all other systems necessary to create a suitable and comfortable indoor environment. These systems not only require energy input, but also advanced environmental control systems to continuously monitor the change of external conditions. Such increasing need leads to the development of manufactured interior spaces covered with building facades, which often serve as barriers to prevent any connection between the buildings' indoor and the surrounding environment. Hence, the design of facades is crucial and the study of high-performance façades is extensively important in terms of energy conservation and raising the internal comfort levels of users.

Generally, one problem is that conventional facades are usually static and cannot react to the changes of climate conditions. Also, recent advancements in high-rise building techniques have resulted in an endless number of buildings with facades that are identical to one another regardless the used materials, techniques and design strategies employed. This has led to the creation of uncomfortable interior spaces that are isolated from external environments and completely based on both mechanical and electrical systems for long periods of time in order to meet the users' demands. Another problem is that in Arab countries, the majority of high-rise buildings are not environmentally conscious and are considered the highest energy consumers. This results in heat gain, glare and illumination (Addington and Schodek, 2005).

Thus, controlling the indoor environmental quality (IEQ) within high-rise buildings has long been a challenge for architects and high-performance façade design is one of the key elements of a building that shapes the interior environment.

The impact of design strategies and parameters are critically important for employing high-performance facades energy and achieving energy efficiency in high-rise buildings (Ragi, 2018). Although the studies have shown to lead significant energy savings and reductions in energy demand, the effectiveness of design parameters is still immature in the Arab region. Therefore, the existing literature knowledge is inadequate to design sustainable high-rise buildings in the hot region, as other environmental control systems and integrated design parameters could significantly reduce energy consumption. Thus, it is vital to improve the determination of design parameters of high-performance facades in high-rise buildings.

The move towards high-performance systems may provide options to take advantage of innovative technologies with respect to high quality of design and environmental solutions. Consequently, this makes it possible to shift from "manufactured indoor environments" to "indoor environments that are naturally lit and ventilated".

This poses some important questions such as is there anything to be done to this specific part of the high-rise building (façade) in order to positively influence the overall energy demand and its interior comfort? Another question is there a difference between environmental control systems and design parameters of high-performance facades? What are the guidelines for designers, architects and policy makers to improve the energy efficiency of high-rise buildings?

The paper assumes that by analyzing and balancing thermal comfort, energy consumption and indoor environmental quality through customizing and improving the design of building façade parameters in passive ways can further enhance the interior thermal comfort of spaces, improve the occupants' productivity and reduce energy consumption inside the building in hot and dry climate (generally in the Arab region and particularly in Egypt).

The study focuses on the impact of the different environmental control systems on the design of high-performance facades in high-rise buildings that can reduce energy consumption and achieve sustainability in the Arab region. This process can be achieved through three main sections. The first section is a theoretical review of the literature that is currently available worldwide on this topic. It includes an explanation for the concept and purpose of high-performance building facades and the current trends in their design. Also, it presents the approaches and control systems of high-performance façade and its design techniques including effective orientation of building facade, determination of window-to-wall ratio, properties of façade materials and its color, … etc. Then, the second section is an analytical study that analyzes and compares relevant examples of high-rise buildings with high-performance facades in the Arab region. Finally, the paper ends up with the main environmental control systems and design parameters that can be applied on high-rise building facades especially in hot climates. These guidelines and outcomes can be used by designers and architects to enhance energy efficiency and can be used as an optimization approach to generate high-performance facades for high-rise buildings in Egypt. These facades can create comfortable indoor environments and reduce energy consumption (Figure 1).

The main aim of the study is to provide an optimization strategy for the building façade design and to create environmental high-performance façade guidelines and parameters for multi-functional high-rise buildings in the Arab region that is characterized by being hot and dry. These parameters aim to maximize indoor air quality, minimize energy consumption and provide thermal and visual comfort for building occupants.

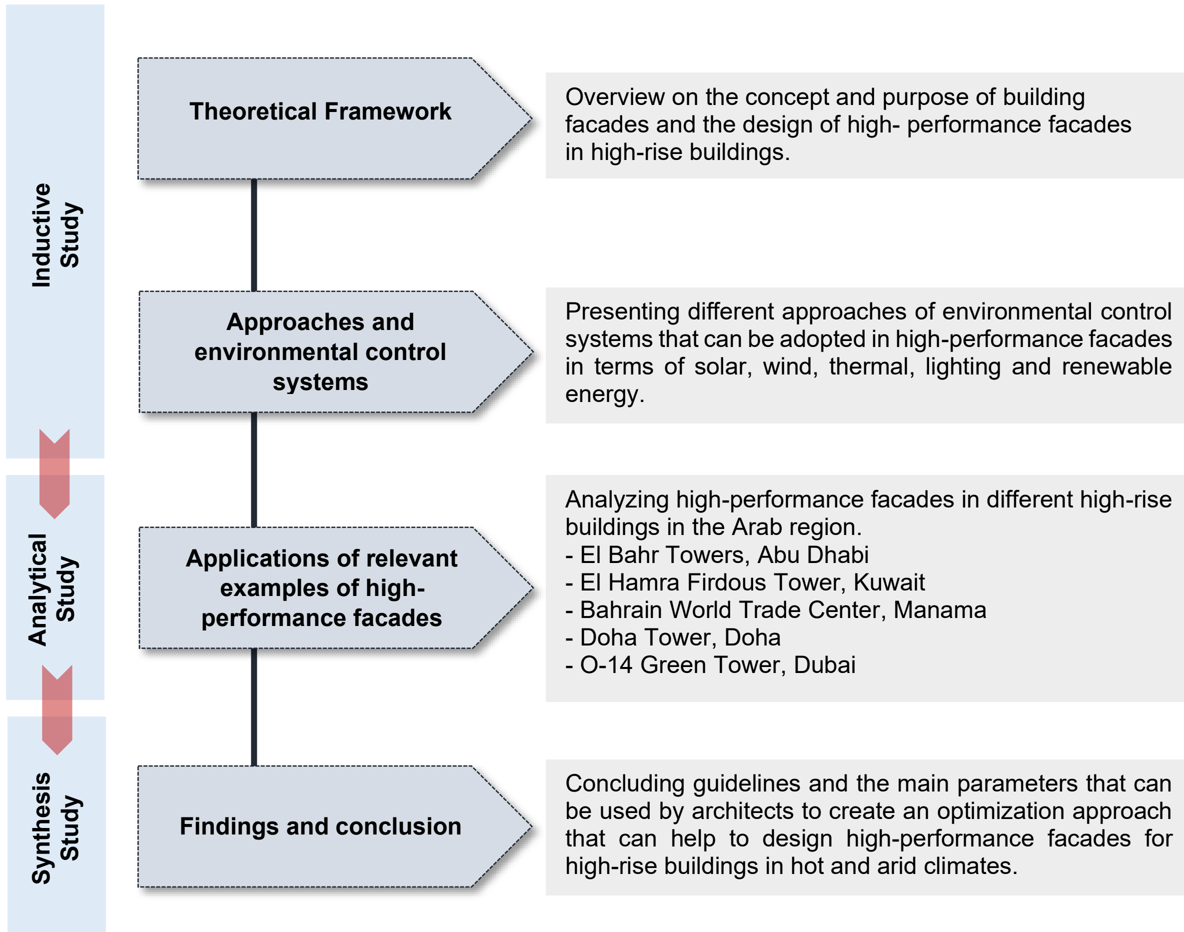

Figure 1. Structure of the study.

2. Theoretical Framework

2.1 Overview of Building Facades (*Concept and purpose)*

The most critical aspects of design stage are the methods to design a sustainable, high-performance facade and the actions required to ensure that environmental considerations, energy efficiency strategies and user experience concept are incorporated into the façade design process.

The word "façade" typically refers to the frontal part of a building or the external side of the wall (Esener and Cosgun, 2020 and Sandak and Kutnar, 2019).

There are numerous studies that investigate "building skin", "building envelope" and "building façade" where they are different terms used to describe the external components of a building. On one hand, the term "envelope", which has gained popularity recently, refers more broadly to the entire building enclosure. A building envelope is "any surface that isolates the thermally conditioned interior of a building from its surrounding environment", according to Prowler and Kelbaugh (1990). The concept of the building envelope comprises roofs, floors, ceiling slabs, foundation walls and exterior walls (facades). All of these components are crucial to the sustainability of the building and its ability to adapt to various needs.

The term "façade" refers to the vertical plane of the building (Barozzi, al., 2016). It traditionally emphasizes the separation between the cladding and the structural part. However, this has more recently been associated with describing the envelope as an environmental system that can interchange information, energy and material (Moloney, 2011). This implies that building facades are more than partitions separating the inside from the outside of a building, but they are structural elements that have the ability to dynamically respond to the buildings' external and internal surrounding and consequently create comfortable interior spaces and also reduce the buildings' energy consumption (Tabadkani, al., 2021).

Thus, introducing the term “high-performance façade” is considered a life film not only separating the outside of the building from the inside, but also as a medium that uses the least possible amount of energy and material to improve the occupants’ productivity and health (Wigginton and Harris, 2002).

2.1.1 High-performance façade design

The facades of buildings establish the structure, the features of architecture and the identities. The design, purposes and integrated components of the façade have evolved overtime in response to the people’s changing lifestyles and the advancement of technology (Herzog, al., 2012). Moreover, the façade is experiencing a trend of increasing complexity in terms of design requirements in order to mitigate climate change and achieve high building energy efficiency. As a result, an increasing number of environmental technologies are being developed for facades to improve users’ comfort while consuming less energy (Knaack, al., 2007).

There are three major patterns for the façade design which are categorized as: first, are the small-scale techniques that have been developed to enhance the façade performance on the micro-level. These techniques include coatings, advanced and sophisticated glazing technologies and intelligent materials. The second consists of large-scale advances such as double-skin facades and all of their different typologies (Figure 2). The third trend, is the installation of renewable energy sources such as photovoltaic cells, solar panels, wind turbines and dynamically controlled facades (Aksamija, 2013).

A high-performance façade refers to creating building and spaces, both inside and outside, taking into consideration the local climate to promote both thermal and visual comfort. All these façade design trends need to fulfil several functions such as providing views to the outside, withstanding wind loads, promoting dead load weight, permitting daylight into interior spaces, preventing unwanted solar heat gain, protecting users from outside noise and extreme temperatures and avoiding air and water penetration (Aksamija, 2009).

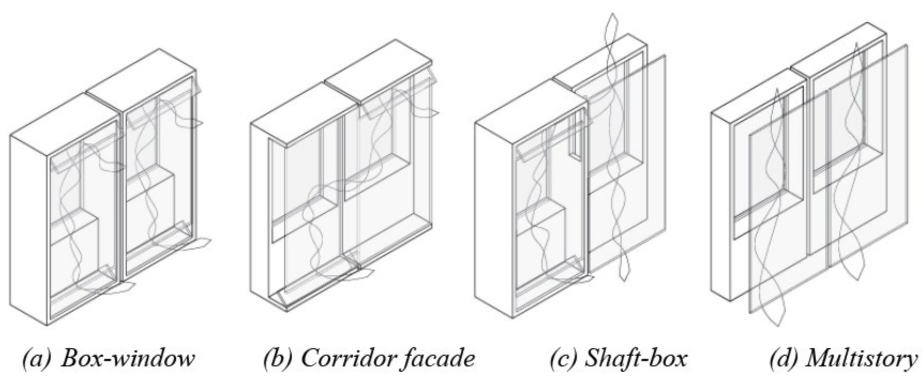

Figure 2. The different types of high-performance facades - Aksamija, 2013.

2.1.2 High-performance façade in high-rise buildings

High-rise buildings have become more and more common as a result of the development of technology after the Industrial Revolution. Due to growing population, transportation problems and demanding work environments combined several functions to produce multi-purpose high-rise buildings. Consequently, the architecture of the Arab region has undergone dramatic transformation in recent decades from traditional settlements influenced by the culture and available local materials to global modern countries full of iconic tall buildings (Esener and Cosgun, 2020).

Designers tried to cope with the challenges caused by construction and also accommodate the increasing demands of users. They decided to create buildings with various uses but with similar architectural styles. Rooms with different uses (daylight, ventilation, privacy, view, … etc.) have identical facades. This had a direct impact on how high-rise buildings facades are designed.

This implies that, in order to preserve and promote the operational requirements of the building envelope with respect to solar heat, rain fall, movement of air and water vapor, durability, stability, fire resistance, noise and aesthetics, high-performance facades offer suitable response to the shifts in the external and internal environments (Yitmen, al., 2022).

High-performance facades prevent high-rise buildings against heat gain in summer, minimize heat loss in winter and make use of the surrounding environment (e.g. sun, air, wind, vegetation, water, soil, … etc.) for cooling, heating and daylighting. High-performance facades in high-rise buildings have the ability to balance human comfort in a number of ways such as providing adequate and sufficient daylight to prevent dark spaces, decreasing glare, improving views of the outside and managing solar gains to regulate thermal comfort while reducing energy costs (Tabadkani, al., 2021).

In conclusion, the building façade being the most part of the building exposed to weather fluctuations, is considered as an active ingredient in the process of saving energy and improving the building's energy efficiency. The new approaches of design have led to viewing the building façade as a behavioral component not only a physical robust element, but also as a new channel that has been established between other branches of engineering (Addington and Schodek, 2005).

2.2 Approaches and Environmental Control Systems of High-Performance Facades

As was previously indicated, the façade plays a significant role in the sustainability of high-rise buildings as it protects the building from the external effects of climate. Building facades actually make an important contribution to energy savings, particularly if the correct measures are taken. The design of high-performance façade is anticipated to be energy efficient and environmentally friendly (Sadineni, al., 2011). In order for the design to be successful in this regard, it is necessary for the design of high-performance facades to achieve energy efficiency, sustainable materials and indoor comfort. In the literature review, various researches were made on building façade technologies and their impact on thermal comfort and energy efficiency.

The design and efficiency of high-performance sustainable building facades can be enhanced by integrating passive systems into its design. There are several environmental approaches that should be included when designing high-performance facades such as the location and orientation of the façade, the development of building's geometry and massing in accordance with solar position. In addition, the incorporation of solar shading devices to regulate cooling demands and enhance thermal comfort and the use of natural ventilation to minimize cooling loads and improve air quality inside the spaces. Also, it is important to reduce the energy used for artificial lighting, mechanical cooling and heating and the selection of façade's building materials and construction techniques that can provide insulation and choosing the appropriate color of the façade material. Each parameter has the potential to define the character and affect the overall perception of a building.

2.2.1 Solar control systems

2.2.1.1 Façade location and orientation

The direction of a façade determines its position to sunlight and affects solar heat gain management strategies. Accordingly, Givoni (1994), the choice of orientation of building façade depends on a number of factors that affect the indoor environment such as the possibility of solar access and the direction of wind. Also, studies have shown that in hot and dry climates, during peak months, large glazing areas oriented to the south east (SE) and south west (SW) attain higher demands on the overall cooling loads compared to the proposed building design that has more facades oriented to north and south directions. Additionally, the exterior walls' materials and structure are more frequently linked to heat gain and loss, making their choice crucial to the design of high-performance facades. It is one of the most energy conservation methods for cooling and heating in high-rise buildings (Al-Anzi and Khattab, 2010).

On one hand, solar heat gain can benefit facades in cold climates during winter months. On the other hand, interior spaces need to be protected from direct sunlight most of the year in hot months. The optimum orientation of the façade balances between summer solar shade and winter solar heat gains. The design of high-performance facade starts with determining the optimal shape and position of the façade in relation to its planned function and other constraints.

2.2.1.2 Shading elements

The quantity of incident solar radiation that enters the façade through glass surfaces may cause major thermal and visual discomfort problems. To mitigate unwanted solar gain and minimize energy consumption, it is crucial to adopt appropriate shading elements. This strategy can help to overcome the problems of heat loss in winter and excessive heat gain in summer.

Shading systems are considered as a passive environmental design strategy for building facades to improve energy saving. In other words, shading elements limit direct sun penetration but enable daylight to enter the space and control the visual environment (i.e. glare, color, light, contrast, view towards outside, … etc.) (Mirrahimi, al., 2016).

By studying the sun path and its relation with façade orientation, shading elements can help lower the internal temperature of the building by about 4 to $8C^0$ and minimize energy use by up to 18-20% when compared to facades without shades. The use of these shading elements on facades particularly in hot climate can minimize both heat transmission and electricity consumption of the air conditioning system.

Generally, solar shading systems can perform a variety of tasks such as controlling daylight and natural ventilation, thermally insulating the building walls, converting solar energy into other forms of energy, humidifying and cleaning the air, … etc. These tasks can be accomplished by simple shading units or several building elements with different functions that may vary in shape, size and material. This is extremely a typical example that can be used as an environmental solution in high-performance facades because of its affordability and convenience usage (Ahmed, al., 2015).

2.2.2 Wind and air flow control systems

2.2.2.1 Natural ventilation

Windows' specifications are also considered as essential elements in the design of the façade of high-rise buildings. They are frequently designed to provide views and to admit air flow and both direct and indirect sunlight. Thus, optimizing window design for daylight and thermal performance is critical in achieving energy conservation and increasing the overall efficiency of a building.

Natural ventilation and uninterrupted air flow through a building can promote its indoor air quality, reduce moisture build-up and control temperature. The use of natural ventilation through adjustable windows can enhance air flow and minimize the need of mechanical cooling systems (Nady, 2017).

2.2.2.2 Window-to-wall ratio (WWR)

The window-to-wall ratio, or the percentage of glazed-opaque façade area, is a crucial façade measure. This ratio is an important contributor to a façade's solar heat gain and energy consumption. Larger window-to-wall ratios usually result into higher energy usage, since thermal resistance of a well-insulated glazed façade is lower than that of an opaque façade. Design for high-performing and sustainable facades should include reducing the window-to-wall ratio (energy code recommendations state that the ratio should not be larger than 40%) and taking into account building orientation (maximizing window-to-wall ratio along the north orientation and minimizing on east and west facades). For hot climates, larger window-to-wall ratios cause higher cooling loads because of increased solar heat gain. An important strategy that improves the energy efficiency is decreasing the window-to-wall ratio by increasing the amount of opaque façade relative to glazing (Kamal, 2020).

2.2.3 Thermal control systems

2.2.3.1 Properties of façade materials

The choice of materials is an essential parameter when designing high-performance and sustainable facades. Enhancing the thermal efficiency of building envelope and reducing thermal bridging are critical design techniques for sustainable facades. The choice of façade materials can influence the building's environmental effect and long-term durability. It is becoming increasingly significant to choose materials that have the least harmful impact on the environment. Furthermore, the life-cycle assessment (LCA) approach can help to identify the environmental effects of various material choices and identify the areas of improvement. Selecting materials based on the embodied energy information is another suitable way for considering environmental impacts.

2.2.3.2 Color of envelope

In a study by Balaras, heat insulation and impermeability strategies on walls could reduce energy use by 20-40%. The same study also found that light colored materials and blind-covered walls contribute around 30% benefit in cooling interior spaces (Balaras, al., 2000). This means that, the color of building surfaces has a significant effect on the impact of solar radiation on heat gain and the resulted indoor temperatures. In general, a light colored material has low-solar absorbance compared to a dark colored material (Cichy, 2011). This can help to minimize the amount of heat absorbed by a facade, minimize the required energy for cooling and improve the indoor comfort levels for building occupants.

2.2.3.3 Double-skin façade

Since building facades receive more solar radiations, therefore, heat exchange from the outside to the inside of the building is considerable. As a result, the cooling system operates less efficiently and uses more energy. Therefore, a double skin façade system, is a key component in the construction of facades to enhance both thermal and acoustic insulation of high-rise buildings with glazed envelopes through an adjustable shading system placed inside the space between the two window systems. The air circulates in the space between envelopes and helps to cool the façade and decreases the load of air conditioning system which saves energy. This system can save the use of energy by 30%, by creating natural ventilation, controlling temperature and heat convection.

Buildings with double-skin facades are able to control the building's internal temperature by blocking direct sunlight and heat from entering the façade. Therefore, they are an attempt to improve building's efficiency and lower air conditioning energy costs and lighting systems, particularly during the day.

2.2.4 Light control systems

2.2.4.1 Natural lighting and glazing

Using natural light may improve occupants' comfort and productivity while reducing the need for artificial lighting. In hot and dry climate, the intense sun, the excess amount of solar heat gains and the elevated outside temperatures, especially in summers, result in indoor discomfort. Thus, reducing glass surfaces is always suggested as a passive approach for these regions.

In 2017, a study was conducted in Alegria by Djamel and Noureddine where they examined the influence of window design on energy efficiency in several climate scenarios. Many window designs of various sizes were created on Google Sketchup and tested in a simulation program. The findings showed that in a desert climate, factors such as the number of windows opened and the type of glass (single, double, triple, … etc.) have a significant impact on the building's ability to regulate its temperature. Increased transparency leads to more energy consumption. The use of double and triple glazing improves energy efficiency (Djamel and Noureddine, 2017).

Another study in 2015, investigated the significance of solar reflectivity and the corresponding U-values of the windows' opaque and transparent surfaces. In the selection of windows, the importance of window materials and U-values in relation to the energy efficiency of the façade should be considered (Ihara, al., 2015).

The choice of glazing and its performance characteristics, include visible light transmission, solar heat gain coefficient and U-value can affect the amount and quality of daylight that enters the building through the façade. Using high-performance glazing, such as double or triple pane glass with low-E coatings can greatly enhance the façade's daylighting performance. The most challenging task for designers is creating an effective façade that maintain the balance between daylight harvesting and view-out optimization while reducing discomfort concerns and the building's energy consumption (Attia, al., 2020).

2.2.4.2 Smart windows

Windows are essential for regulating the light entering a building and the quality of energy used. The use of smart windows is not just limited to reducing energy loss. However, smart windows, with special qualities have the ability to maintain indoor temperatures, block sunlight during hot summer days and permit sunlight during winter by becoming transparent and conserving thermal energy.

2.2.5 Renewable energy control systems

High-rise buildings are exploring the generation of clean energy, combining architecture and technology to take advantage of both wind and solar radiation. The design of high-rise buildings can have the possibility to become an energy source and increase the output from the building's integrated renewable energies (integration of photovoltaic panels and wind turbines). They are considered as important factors in the achievement of the optimum level of a building's combined operational and embodied energy (Calves and Umakoshi, 2010).

Photovoltaic technology can be incorporated directly into the building façade. They can be integrated into facades to simultaneously generate power and shade to the building. For optimal efficiency and durability, the idea of building that produces its own electricity is a strong statement about the relationship between human activities that affect the environment. Building integrated photovoltaic (PV) systems that produce electricity has long been considered as a goal for future facades but the prototypes implemented to date are unlikely to find widespread application due to cost and other functional limitations (Selkowitz, 2001).

Briefly, this part was considered as the second part of the inductive phase in the research, which defined and explained the different design solutions and environmental control systems of high-performance facades for high-rise buildings in terms of solar, wind, light, thermal and energy control. Thus, Table (1) suggests these passive design strategies that can be applied in facades of high-rise buildings in order to achieve sustainability.

Table 1. Environmental control systems for high-performance facades

Solar Control	Wind and Air Flow Control	Thermal Control	Light Control	Renewable Energy Control
Façade location and orientation	Natural ventilation	Properties of façade materials	Natural lighting and glazing	Photovoltaic
Shading elements	Window-to-wall ratio	Color of envelope	Smart windows	Wind turbines
		Double-skin		Solar collectors

3. Methods: Analysis of High-Performance Facades in High-Rise Buildings in the Arab Region

This study adopted the building performance which is an integral part of the design process for energy efficient of high-rise buildings, since they contribute in investigating design alternatives and evaluate the energy and environmental effects of design decisions (Aksamija, 2009). There are essential parts in the design process for sustainable, high-performance building facades. Quantifiable predictions during the different stages of the design process can help to determine metrics which may be used to measure improvements by using different design techniques. It has become important that designers assess building energy performance before a detailed energy model is created. This prevents the project from major modifications due to misguided energy objectives. Nonetheless, building performance evaluations is a long process, and is often performed through several steps.

A literature review and analysis for international examples/applications associated with definitions, characteristics and control systems have set the foundation for this research. Based on the previous discussed theoretical study, there are several variables involved to select the appropriate façade design approach and the application of suitable modern technologies.

This evaluation is based on the analysis of the design approaches and environmental control systems for facades: solar, wind, lighting, thermal and energy efficiency. Additionally, it determines the most essential environmental methods required to reach the highest performance in every strategy associated with the design approach.

This part includes comparisons between relevant examples of high-performance facades in high-rise buildings in the Arab region. It starts with analytical studies, then sets some guidelines and environmental control systems for high-performance facades (Figure 3).

Therefore, the following section presents an analysis of building façade technologies and control systems in high-rise buildings to minimize the consumption of energy, eliminate greenhouse gases and promote indoor air quality. This part aims to provide design suggestions for façade treatments that take into account the intended energy performance of the façade system.

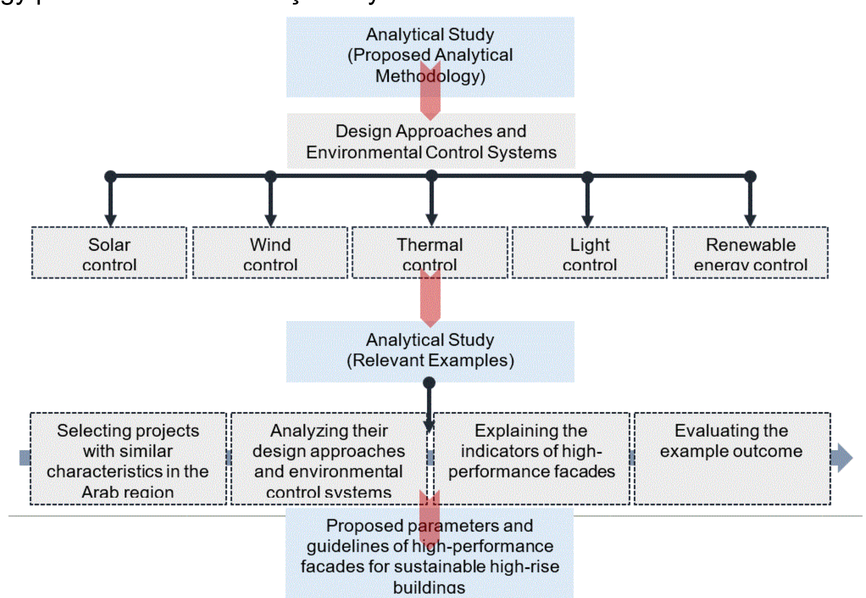

Figure 3. The methodology adopted in the study.

3.1 Al Bahr Towers (Abu Dhabi, U.A.E, 2012)

The building is situated on the north shore of Abu Dhabi where it experiences hot and humid climate and extremely sunny days with temperature reaching 49C^0 and humidity reaching 100% during summer. The project area is 56.000 square meters mostly used for bank offices. The tower floor is open plan office spaces with a service core. The façade system defines the typical typology of skyscrapers in the area, suggesting a more agile and dynamic solutions to the climate. Al Bahr Towers seek to provide contextual and culturally sensitive design while utilizing modern technology to meet the highest standards of efficiency.

3.1.1 Solar control

The façade is covered with a shading screen that is computer-controlled to adopt to optimal sun and light conditions. The shading system is a dynamic screen comprised of triangulate units. These units act as individual shading elements that unfold to various angles in response to the sun's movement in order to obstruct the direct solar radiation. When the shading element is closed, occupants can still see through from inside to outside (Figure 4).

3.1.2 Ventilation and air flow control

The buildings are fully air-conditioned with various back areas associated with storage and catering.

3.1.3 Thermal control

Al Bahr towers have double skin facades that consist of a dynamic mashrabiya shading system on the external skin, curtain wall on the internal glazing skin and a cavity between them spaced 2.0 meters from the surface of the glazing. The dynamic mashrabiya act as a shading system that filters light, reduces glare and heat gain.

The main color of Al Bahr's envelope/façade is light beige stretched in polytetrafluoroethylene (PTFE) panels, which reduce the solar absorbance and the impact of solar radiation on heat gains resulting in comfort indoor temperatures.

3.1.4 Light control

By responding dynamically to the changing environmental context, the mashrabiya has a significant effect on the quantity of natural daylight allowed into the building. It minimizes the cooling loads required for air conditioning (Karanouh and Kerber, 2015). The towers are cladded with weather-tight glass curtain wall which is comprised of unitized panels from floor to ceiling. The curtain wall is separated from the kinetic shading system through a substructure by means of movement joints (Attia, 2017).

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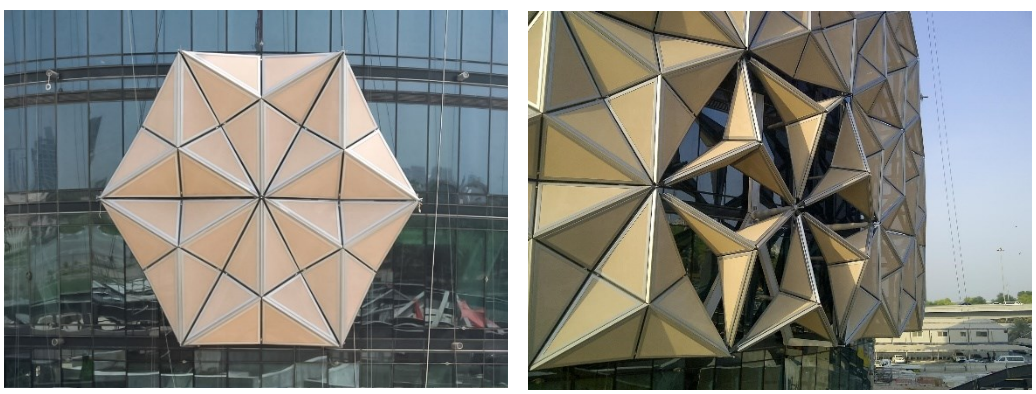


Figure 4. Computer-controlled shading elements - Nady, 2017

3.2 Al Hamra Firdous Tower (Kuwait, 2011)

The tower gets its design as per the climatic conditions of Kuwait. The geometry of the tower is based on a set of parameters that take into account the environmental conditions such as solar exposure and wind loads. The appearance of the building resembles a quiet sophisticated and contemporary structure. The resulting shape offers visibility into the Gulf and opacity to the severe desert.

3.2.1 Solar control

There is self-shading where the tower has two fins that protect the facade from solar exposure and desert sun minimizing heat absorption on the south façade (Figure 5).

3.2.2 Ventilation and air flow control

The Hamra Tower features three glass facades with 100% window-to-wall ratio (WWR) that allow inhabitants to enjoy views of the Gulf to the north, east and west while minimizing solar heat gain for internal areas (offices). Further, the performance objective in glass selection is to optimize the visible light transmittance.

However, according to the sun orientation, the southern façade has adhered limestone cladding with minimal window openings to control heat gain and allow natural ventilation. Lastly, the contrast between transparent elevations and the monolithic stone with minimal openings on the south façade is an environmental strategy to control solar heat gain and achieve energy efficiency.

3.2.3 Thermal control

The purpose of the south solid façade is to reduce the absorption of solar radiation that serves as the building structural spine in addition to protecting it from harmful environmental conditions. Additionally, the adhered limestone cladding on the south façade shield the tower from intense solar exposure.

The environmental objective in Al Hamra tower is to visually create a façade as light in color as possible to reduce solar absorption and heat gain. As a result, the color of the envelope of Al Hamra tower is generally silver/white in appearance (Sarkisian, 2011).

3.2.4 Light control

The southern façade has multiple deep openings on it. This is exactly how the sun responds to the different angles of sunlight over the day. The windows are set in angles precisely in the iconic solid façade to shade the façade and the building from the severe solar radiations of the desert and to minimize heat absorption. Al Hamra tower has minimum openings on the south façade to reduce solar heat gain and allow natural daylight into the inner spaces. These openings are deep recessed angled windows based on the ratio of the envelope and its position relative to the sun, creating a staggered pattern of punched windows at the south façade.

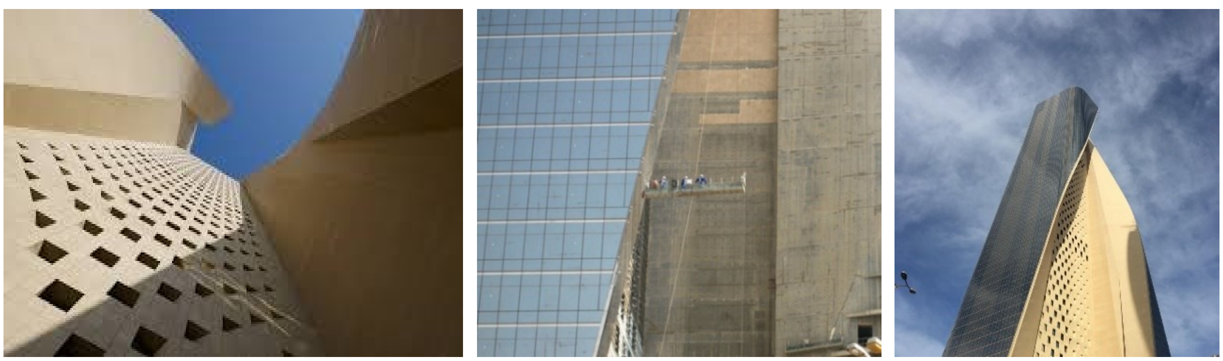


Figure 5. The self-shading fin - Asci and Sarkisian, 2011

3.3 Bahrain World Trade Center (Manama, Bahrain, 2008)

The Bahrain World Trade Center stands as an icon for sustainable design and engineering. It is inspired from the traditional Arabian wind towers.

3.3.1 Solar control

There are fixed shading systems as part of the building architecture (mashrabiya). The innovative usage of shading elements across the external glass façade minimizes solar gains and reduces energy measures which consequently provide interior quality of spaces.

3.3.2 Thermal control

Concerning the external walls, there is a sufficient buffer zone that has been included between the air-conditioned spaces and the outside environment to reduce the effect of sunlight on the façade.

3.3.3 Light control

The facades are designed with double paned windows (double glazed) that consist of two facing glass panels in a frame divided by a small space filled with non-toxic gas to enhance insulation. The glass is high-quality solar glass with low shading co-efficient to reduce solar gains (Killa and Smith, 2008).

3.3.4 Energy control

The façade incorporates renewable energy solutions. The design provides 29 meters diameter wind turbines to be horizontally supported between the facades of the two towers. The two facades are connected by three bridges that support each of the three wind turbines. The facades are designed to maximize the flow of wind through the space where the turbines are placed increasing its natural rate by up to 30% (Figure 6).

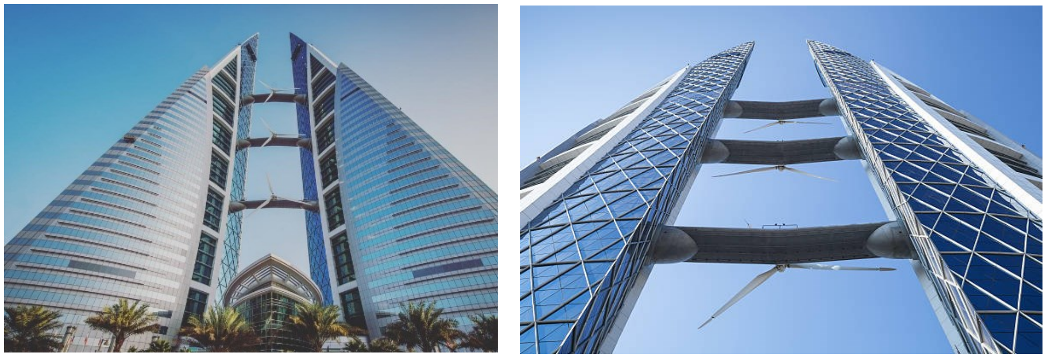


Figure 6. Horizontal wind turbines - Killa and Smith, 2008

3.4 Doha Tower (Doha, Qatar, 2012)

It is situated in the West bay in Doha. The climate in Qatar is hot dry with long summers and mild winters. The tower has 46 floors of office use above ground and three floors below ground.

3.4.1 Solar control

The cladding system is a reference to the traditional Islamic mashrabiya with linear patterns of butter-shaped aluminum to refract light (Figure 7). Moreover, the mashrabiya sunscreens are used to protect the building from high temperature, solar glare and heat gain. The face of Doha Tower is comprised of a delicate lace-like layered façade.

3.4.2 Thermal control

The façade of Doha Tower uses a double-skin system with unique aluminum mashrabiya sunscreens and a glass curtain wall. The external layer is composed of butterfly elements while the internal layer is curtain wall that is slightly reflective to reduce solar heat gain. The walkway between the two layers provide maintenance access and ventilation creating a “chimney effect” between the two layers.

Regarding the color of envelope of Doha Tower, the materials are glass, steel, aluminum and concrete. The exterior envelope is silver-laced aluminum screen (Al-Kodmany, 2014).

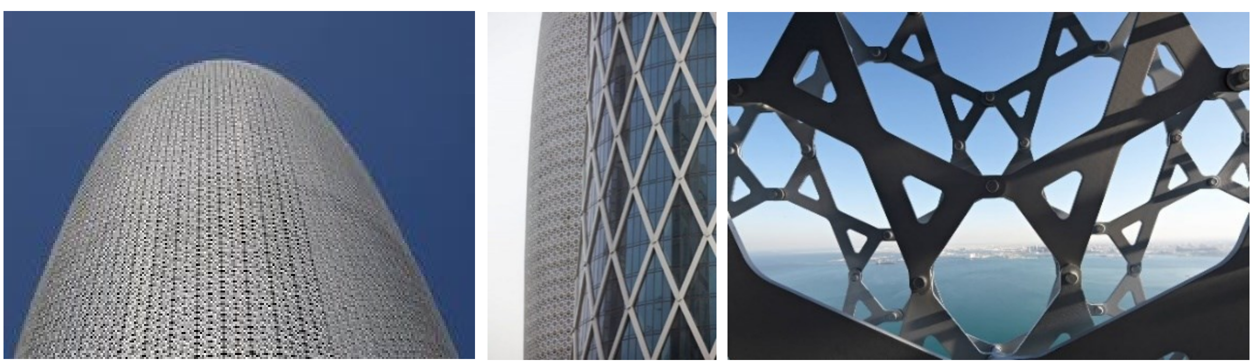


Figure 7. Aluminum mashrabiya patterns to refract light - Al-Kodmany, 2014

3.5 O-14 Green Dubai Tower (Dubai, U.A.E, 2011)

The O-14 office tower is a 22 story high-rise building with distinctive façade composed of concrete that is 40cm thick and has over 1000 circular openings.

3.5.1 Solar control

The openings in the building's façade act as a solar screen to reduce direct sunlight into the spaces (Figure 8).

3.5.2 Thermal control

The one-meter gap between the façade and the building's glass surface act as a chimney effect that causes hot air to rise and creates an effective passive cooling system (Al-Kodmany, 2014).

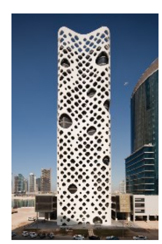
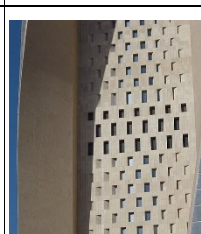
3.5.3 Light control

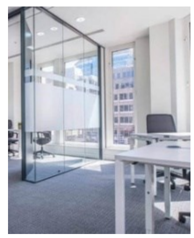
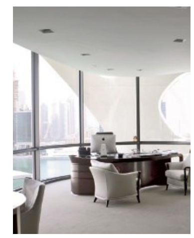
The openings of the building's façade allow light and air and provide users with better views.

Figure 8. Façade perforations that act as solar screens - Al-Kodmany, 2014

In this section, different cases of relevant examples are analyzed by selecting applications of high-performance facades for different high-rise buildings in the Arab region. Table (2) represents an analytical review of the environmental control systems and design parameters in each building.

Table 2. Analysis of environmental control systems applied in high-rise buildings in the Arab region

Environmental Control Systems applied in the Facades of High-Rise Buildings		**El Bahr Towers**	**Al Hamra Firdous Tower**	**Bahrain World Trade Center**	**Doha Tower**	**O-14 Green Dubai Tower**
		Abu Dhabi	Kuwait	Bahrain	Doha	Dubai
		Bank	Offices	Commercial	Offices	Offices
						
Solar Control	Shading elements	Computer-controlled screens	Self-shading through two fins	Fixed shading systems	Aluminum mashrabiya	Fixed solar screens
						

Air Flow Control	Natural ventilation	Does not exist	Not applicable	Not applicable	Not applicable	Not applicable
	WWR	50%	100%	---	---	---
Thermal Control	Properties of materials	PTFE	Lime stone cladding	Glass	Glass, steel, concrete and aluminum	Concrete
	Color	Light beige	Silver white	Cool blue	Silver	White
Light Control	Glazing	Exterior dynamic mashrabiya and interior curtain wall	Not applicable	Buffer	Exterior sunscreen and Interior curtain wall	Double skin
						
	Smart windows	Curtain wall of unitized panels	Deep recessed angled windows	Double glazed	Not applicable	Façade partitions
Energy Control	PV	On the roof	Not applicable	Not applicable	Not applicable	Not applicable
	Wind turbines	Not applicable	Not applicable	Horizontal wind turbines	Not applicable	Not applicable

4. Analysis

4.1 Proposed Parameters of High-Performance Facades for Sustainable High-Rise Buildings in Egypt

The issues discussed previously are the critical need for the integration of control systems of facades in all aspects of design, construction and operation. Although the idea is simple, the actual implementation may be more challenging. The integration problem is further complicated because it addresses a complex building system that is dynamic and responsive to changing occupant demands and the surrounding environment. High-performance facades in high-rise buildings should be designed and operated as an integrated whole rather than as a loose collection of parts. Consequently, the integration of all these systems will lead to the reduction of operating costs by minimizing artificial lighting, cooling and heating energy use and the improvement of indoor environments leading to improved occupant performance, comfort and health (Table 3).

Table 3. Proposed environmental parameters of high-performance facades for high-rise buildings

Different environmental parameters for façade performance	Optimization approaches for high-performance façade design
Location and orientation	The façade should modulate dynamically to climatic extremes. It should operate as an integrated element in the overall building system.
Shading elements	They should enhance sun protection and control cooling loads while improving thermal comfort and providing the most of the light needed.
Ventilation and air flow	It should enhance air quality and reduce cooling loads using natural ventilation schemes employing the façade as an active air control element.
Window-to-wall ratio (WWR)	The size of windows is necessary for optimal daylight and it significantly impacts energy saving in terms of heating and cooling.
Glazing	It affects the energy efficiency of the building and at the same time influences its aesthetics.
Smart windows	They play an important dual role in reducing energy consumption and providing light transmission for visual comfort and electric energy savings.
Double skin	It is a passive façade system that provides energy conservation, controls daylight, reduces interior heating demands and provides ventilation and appropriate acoustic comfort.
Thermal properties of building materials	Taking into consideration, the thermal properties of materials have some benefits for the building's sustainability in terms of its energy and increase thermal comfort.
Photovoltaic	This leads to energy balance of the building when using integrated PV systems.

4.2 Results and Discussion

The literature review presented the thermal and the energy performance as some important factors in selecting and designing high-performance façade systems to face global climate problems to achieve the energy saving objectives.

It is possible to classify an area in hot climate zone if the high summer day time temperature is (32-36C^0) with high sun radiation. In this climate zone, most of the year, the weather is hot and dry. The primary concern in such climate is the user thermal comfort. A building may be considered sustainable if it is thermal resistance and can protect users from high temperature difference between outside and inside the building. Based on the literature review, the analysis and the assessment of applications, it is found that the main challenge for designing a high-performance façade in such climatic zone requires studies related to the factors influencing the façade energy performance as well as using the appropriate environmental approach to overcome the problems that challenge designing facades particularly in hot climates.

When designing a high-performance façade in a hot climate, the first step is determining the best site location, which is achieved by taking into account the direction of the prevailing winds and the possibility of shading the façade through shading elements with light paint colors to reduce solar radiation.

The most important objective in high-performance facades in hot climates, is to eliminate the solar heat gain. This is because direct sunlight can present challenges and can increase cooling costs for users and make the building far from sustainability. Another important consideration is providing natural ventilation which can help to enhance the cooling of the building. At the same time, it is important to provide natural lighting as it is a significant fact for users.

In general, it should be mentioned that, double skin façade approach is highly effective for hot and dry climate zones particularly the ones that increase natural ventilation. Also, the thermal properties of building materials are an important element in the design of high-performance façade. Local available materials are very useful for hot climate and can adapt themselves with climate-related problems and help the façade in reducing energy consumption.

For window and glazing, it is recommended to use double or triple glazing due to the gas between the layers. They are more thermal resistant and can improve the sustainability of the building. In addition, the incorporation of advanced technologies in building envelopes provides environmentally high-performance facades that can control energy consumption through the use of energy-efficient performance strategies

such as using operable windows with integrated smart glass which allow personal control over ventilation and provide visual transmission, enhancing daylight and reducing artificial lighting. To maximize the façade energy performance, it is recommended to generate electricity based on renewable sources such as using photovoltaic on the façade which sometimes work as sun shading for the building.
Thus, this analysis can support designers and architects in their decision-making process by selecting the appropriate system with optimized and efficient thermal performance.
The following diagram considers all design parameters of high-performance facades and works as guidelines for any architect who wants to design a high-performance façade in hot and dry climate zone (Figure 9).

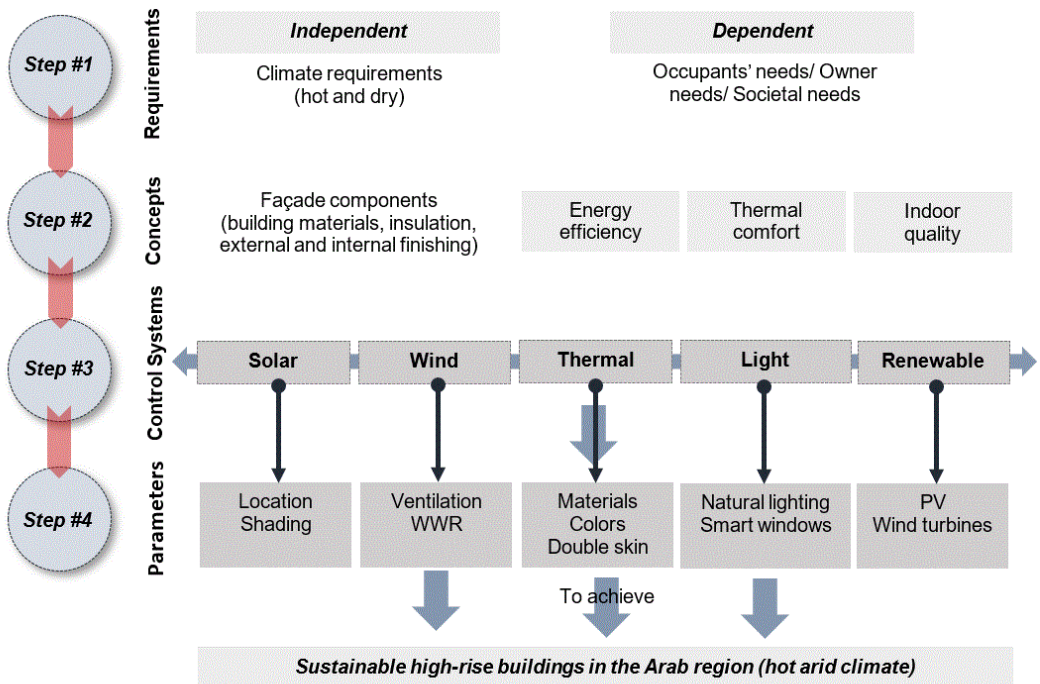


Figure 9. Steps which should be taken into consideration when designing high-performance facades in sustainable high-rise buildings

5. Conclusion

The world is facing a significant challenge represented in the shortage of conventional energy and spread of pollution due to the increase in energy consumption. High-rise buildings contribute to these problems as they are considered the main consumers of energy. Thus, architecture faces unprecedented demands to minimize the environmental damage of buildings and to establish reliable and accurate performance analysis methods for buildings. The façade which functions as a barrier between interior and exterior environments, is a main building component that has a significant impact on indoor climate, energy consumption and occupants' comfort levels. Designing facades to achieve thermal comfort is associated with studying the mechanisms of heat transfer between the building and the outdoor environment.
Recently, high-performance façade concepts have gained attention as an important study issue in the field of sustainable design, given their potential to reduce a building's energy demand while providing new design opportunities. However, the subject does not receive enough attention.
The paper has presented the role of high-performance facades in energy conservation and improving the internal environment. The study has posed several questions which have been answered through the study concerning the design approaches and the environmental solutions which positively impact the overall energy demand of the building and its interior comfort. Also, the study suggested a hypothesis which is based on the idea is that by balancing thermal comfort and energy consumption through the use of environmental passive building façade parameters can improve occupants' productivity and promote the indoor environmental quality (IEQ).
In order to fill the theoretical gap and answer the questions of the study, the research has examined the passive design approaches and control systems used in the design of high-performance facades in high-rise buildings. Furthermore, this study analyzed and evaluated different applications which have utilized different environmental approaches of high-performance façades in high-rise buildings. The analysis

resulted in proposing and considering the significance of passive design parameters through orientation and location of buildings, natural ventilation, shading and lighting strategies along with the integration of modern technologies such as smart glass, the use of PV, … etc. to achieve high performance facades.

Based on employing passive design parameters and integrating energy-efficient technologies, the analyzed high-performance façades were successful in minimizing energy consumption for occupants in hot arid climate.

The main findings of the study are that high-performance systems concepts are designed to solve and preserve a suitable balance between optimum interior conditions, environmental and thermal performance. High-performance facades can adapt to the surrounding through solar, wind, light and thermal control systems.

Afterwards, from the outcomes of the analysis of examples, the main result is concluding guidelines for designing high-performance facades for high-rise buildings that are suitable for hot and dry climate in the Arab region through the development of a proposed methodology and an optimization approach of comparison between relevant examples. By doing this, the research knowledge gap is filled. As the environmental control systems that were highlighted from the literature review were incorporated in the design parameters and a recommendation for the energy efficiency of buildings.

In addition, the study results agreed with the existing theories of literature review on how to achieve energy efficiency and interior thermal comfort of occupants in high-rise buildings through environmental design parameters.

However, although these high-performance facades are based on precise planning and design, they also require careful operation, management and continuous maintenance strategies to sustain their indoor and built environment. Furthermore, the main motivation for occupant engagement with high-performance facades is to satisfy the individual environmental needs including increasing daylight, privacy, access to views and avoiding glare discomfort. Although high-performance facades can provide comfortable indoor environmental conditions, it does not properly ensure the achievement of individual environmental requirements and preferences.

In conclusion, this study helps architects to think about sustainability during the first phases of design as they are the ones who can control the energy consumption of buildings by their decisions. This research contributes to the existing theories of literature in achieving energy efficiency and indoor comfort in high-rise buildings through high-performance facades. Careful planning and integration of design parameters during the early design process of high-performance facades is the key to produce energy efficient high-rise buildings.

Nevertheless, most studies about high-rise buildings in the Arab region focused on the overall building envelope parameters rather than the integration of high-performance façade design parameters within the design process. Further research is required to show the advantages of sustainable façade control strategies and whether customized measures are required to increase occupants' satisfaction whilst reducing the energy demand.

Also, this research contributes to the practical application as the research's results should be taken into consideration and involvement in the early stages of the design process of high-rise buildings (particularly the façade phase) in the hot arid context or similar environments in order to achieve energy efficiency and thermal comfort inside these buildings. This study is focused on investigating the possibilities of optimizing the building façade design to improve building energy efficiency and thermal comfort. It is limited to multi-functional high-rise buildings in the Arab region (hot and dry climate). Although some of the findings may be broadly applicable, the multi-objective optimization approach can be applied in different contexts.

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Conflict of Interest

There is no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors/s.

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