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An Analytical Study on the Implementation of Energy-Efficient Design Strategies in Office Buildings in Khartoum, Sudan

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ABSTRACT

This study examines the implementation of energy-efficient design strategies in high-rise office buildings in Khartoum, Sudan, where energy demand is exceptionally high. Such buildings contribute significantly to global energy consumption and carbon dioxide emissions, intensifying environmental challenges such as global warming. Understanding and applying energy-efficient design principles is therefore crucial for energy conservation in the built environment.

Fifteen recently constructed office buildings were analyzed as case studies, supported by occupant interviews. Respondents were asked to indicate their awareness of selected energy-efficient strategies identified in previous research. Descriptive statistical analysis was used to evaluate the findings. Results indicate that the adoption of energy-efficient design strategies during the design stage is limited, leading to excessive energy consumption. The strategies most widely recognized by practitioners were site planning, natural ventilation, and building orientation, while other critical strategies, such as the building envelope, were largely neglected.

The study concludes that increasing the awareness and implementation of energy-efficient design strategies requires coordinated efforts from stakeholders in Sudan’s building industry. Professional associations and regulatory bodies should promote training programs and awareness initiatives to encourage the integration of sustainable design practices and reduce the environmental footprint of office buildings.

Keywords: Energy consumption, Energy-efficient design, Office buildings, Global warming, Sustainable architecture

INTRODUCTION AND BACKGROUND

Khartoum has recently experienced significant urban growth, particularly in the development of office buildings. These buildings have expanded in quantity, size, and height, and have also evolved in terms of finishing materials, design concepts, and architectural types. With this rapid transformation, energy efficiency has become an increasingly important consideration in modern building design. Energy-efficient buildings not only reduce negative environmental impacts but also contribute to economic sustainability and long-term resilience by conserving energy.

Globally, the building sector is one of the largest consumers of energy, accounting for nearly 36–40% of total energy use and responsible for about 33% of global greenhouse gas emissions (IEA, 2022; UN-Habitat, 2021). This makes buildings a critical focus area for addressing climate change and reducing environmental degradation. In addition, buildings have a direct influence on human well-being. Research indicates that energy-efficient buildings can improve indoor environmental quality, thereby supporting occupant health, comfort, and productivity.

Consequently, energy efficiency in the design and construction of office buildings is now recognized as a defining requirement of 21st-century architecture. Previous studies have provided valuable insights into strategies that enhance energy performance, including passive cooling, natural ventilation, shading systems, and optimized building orientation. However, the extent to which these strategies are understood and applied varies significantly across regions.

In Sudan, and particularly in Khartoum, the adoption of such strategies remains limited despite the hot-arid climate, which makes energy conservation a pressing necessity. A deeper understanding of energy-efficient design strategies is therefore essential for reducing energy demand and supporting sustainable urban growth. Against this backdrop, the present study evaluates the levels of implementation of energy-efficient design strategies in office buildings in Khartoum.

APPROACH AND METHODS

This study employed an analytical descriptive–quantitative approach to evaluate the implementation of energy-efficient design strategies in office buildings in Khartoum. The research combined a literature review with empirical investigation. Fifteen recently constructed office buildings were selected as case studies, representing the city's emerging generation of office developments. Each building was assessed through site observations focusing on orientation, shading, envelope design, and ventilation features.

In parallel, semi-structured interviews were conducted with architects, engineers, and occupants to gauge their awareness and application of energy-efficient design strategies. The collected data were analyzed using descriptive statistical methods to compare professional knowledge with actual implementation in practice. This integrated approach provided both physical evidence from buildings and perceptual insights from stakeholders, enabling a comprehensive evaluation of energy efficiency practices in the study area.

LITERATURE REVIEW

The principle of energy conservation in buildings is a fundamental concept that underpins sustainable design. It ensures the rational use of renewable energy resources while reducing the negative environmental impacts of buildings. In clarifying the meaning of energy use and efficiency in buildings, Griego, Krarti, and Hernandez-Guerrero (2015) defined it as the amount of energy consumed for heating, ventilation, and lighting, measured in accordance with standardized performance requirements applicable at any given time.

Further contributions by Baumert, Pershing, and Herzog (2005) and Trotta, Spangenberg, and Lorek (2018) emphasized that improvements in energy efficiency can support economic growth and social development, while simultaneously enhancing occupant health, well-being, and creating opportunities for competitiveness and investment. In the same context, Li and Colombier (2009) explained that the global community, in seeking solutions to mitigate climate change, has increasingly promoted standard design approaches that make energy efficiency in buildings a mandatory requirement. This is particularly significant since buildings are responsible for nearly one-third of global CO_2 emissions.

Moreover, Li, Yang, and Lam (2013) highlighted that energy-efficient design strategies in office buildings have become essential, as they not only reduce energy consumption but also improve user comfort and indoor environmental quality. Similarly, Fisk (2000) conducted a study in the United States on the relationship between energy efficiency, indoor environmental improvements, and workplace productivity. The study concluded that both theoretical evidence and limited empirical data confirm that existing technologies and design practices can significantly improve indoor environments, leading to measurable gains in worker performance within office settings.

Energy Efficiency Design Strategies

Energy-efficient buildings have become a key priority in the design and construction of office buildings in the 21st century. This growing interest arises from global concerns about the impact of buildings on the environment and on the comfort and well-being of their users (Kozusznik et al., 2019). Given the importance of conserving energy in contemporary office buildings, several studies have focused on promoting the development of energy-efficient buildings and identifying better ways to reduce energy use. For instance, a recent study on factors influencing the Integrated Design Process (IDP) in net-zero energy buildings highlighted the value of integrated approaches in achieving efficiency goals (Lu, Sood, Chang, & Liao, 2020). In Bangladesh, a subtropical monsoon climate, research recommended an optimum Window-to-Wall Ratio (WWR) of 30–40% for air-conditioned office buildings, as this range was found to reduce electricity consumption by up to 9.4% (Rana, Hasan, Sobuz, & Tam, 2020).

In recognition of this need, the present study focuses on ten energy efficiency design strategies identified in the literature. These strategies provide insight into practical approaches adopted in the design and construction of energy-efficient buildings. Beyond energy savings, such strategies have been shown to improve indoor environmental quality, supporting healthier, more comfortable, and more productive workplaces. Malin (2006) emphasized the role of integrated design in promoting energy efficiency, particularly through his contributions to the Canadian Government's Commercial Buildings Incentive Program.

Research also shows that most building energy consumption is linked to lighting, space heating, cooling, ventilation, and water heating. Energy performance is strongly influenced by climate, building form, envelope characteristics, occupant behavior, and system operation and maintenance (Day & Gunderson, 2015). As noted by Nwofe (2014), an energy-efficient building is one that reduces the energy required for essential functions, such as cooling and lighting, while still maintaining comfort and supporting user well-being. Collectively, these strategies ensure reduced energy use while delivering superior thermal and visual comfort for occupants. Previous studies further indicate that as many as 29 energy efficiency design strategies have been applied across different building types, providing a valuable foundation for advancing energy-efficient office building design.

Summary of the various strategies and the number of articles they were mentioned, is presented in Table 1.

Table 1: Energy Efficient Design Strategies

Site	
1	Site Selection
2	Site Planning
Building Design	
1	Building Form
2	Building Shape
3	Building Orientation
4	Space organization
Building Envelope	
1	Specification of Energy Efficient Building Materials
2	Window Shape and Position
3	Exterior Shading Design
4	Effective Wall to Wall Ratio
5	Specification of Bright Colored Roofs
6	Specification of Bright Colored External Wall Paints

7	Green Roofs
8	Sky Garden
9	Double Skin Facades
Integrated Design Process	
1	Natural Ventilation
2	Making Provisions for Renewable Energy Sources in the Design (solar and photovoltaic cells)
3	Day Lighting Design
4	Mixed-mode Ventilation System (Natural and mechanical ventilation systems)
5	Solar Hot Water Heating Mechanisms
Energy Protection Considerations	
1	Occupancy and CO2 Sensors
2	Day Lighting Control Mechanisms
3	Integrated Design Process
4	Landscape Design
5	Service Core Placement
6	Night Ventilation (air flow patterns, user behavior, building characteristics, heat transfer, energy balance)
7	Eco Feedback System (Collection of energy-use data)
8	Occupancy Sensors
9	Biophilic Design
10	Bioclimatic Design

Source: Edited by the Author

Assessment Criteria

The study was designed to identify and categorize existing energy efficiency design strategies in office buildings based on literature. The assessment followed three main objectives:

Identification – determine the energy efficiency design strategies integrated into office buildings.

Categorization – group these strategies according to their design focus and application.

Evaluation – assess the extent to which these strategies have been implemented in practice.

Table 1 summarizes the identified strategies, some of which are difficult to measure directly.

Building Envelope

The building envelope acts as the physical separator between conditioned and unconditioned spaces. Key strategies include:

1. **Energy-efficient building materials** – selection of materials with high thermal performance.
2. **Window shape and position** – optimizing daylight access and heat control.
3. **Exterior shading devices** – using fixed or movable shading elements internally or externally.
4. **Effective window-to-wall ratio (WWR)** – maintaining an optimal balance of glazing to wall area.
5. **Bright-colored roofs** – reflecting solar radiation to reduce heat gain.
6. **Bright-colored external wall paints** – enhancing reflectivity and lowering thermal absorption.

7. **Green roofs** – integrating vegetation layers to improve insulation and microclimate.
8. **Sky gardens** – incorporating elevated green spaces in high-rise buildings.
9. **Double-skin façades** – using two façade layers to improve thermal and acoustic performance.

Integrated Design Process

Integrated design represents a holistic approach that unites different specialisms usually considered separately, with the aim of improving building performance and achieving energy efficiency. Key strategies within this process include:

Natural ventilation – using natural airflow to purge internal heat and cool the building fabric without mechanical systems.

Renewable energy sources – incorporating solar energy and photovoltaic cells as part of the building's energy supply.

Daylighting design – maximizing the controlled use of daylight, including direct sunlight and diffused skylight, to minimize dependence on artificial lighting and save energy.

Mixed-mode ventilation systems – combining natural ventilation with mechanical systems to achieve optimal indoor air quality and thermal comfort.

Solar cooling mechanisms – applying solar energy technologies, such as solar collectors and photovoltaic-driven systems, to generate cooling and reduce reliance on conventional air conditioning.

CASE STUDIES

To achieve the aim of this study, the case study method was applied as the primary research approach. Fifteen office buildings located in Khartoum city were selected. These buildings are among the most prominent in the city in terms of construction and operation costs, as well as their economic significance (Table 2).

The selected buildings were analyzed to identify the design techniques applied to reduce energy consumption. The criteria for case study assessment were based on findings from the literature review (Table 1), supported by direct observation and interviews.

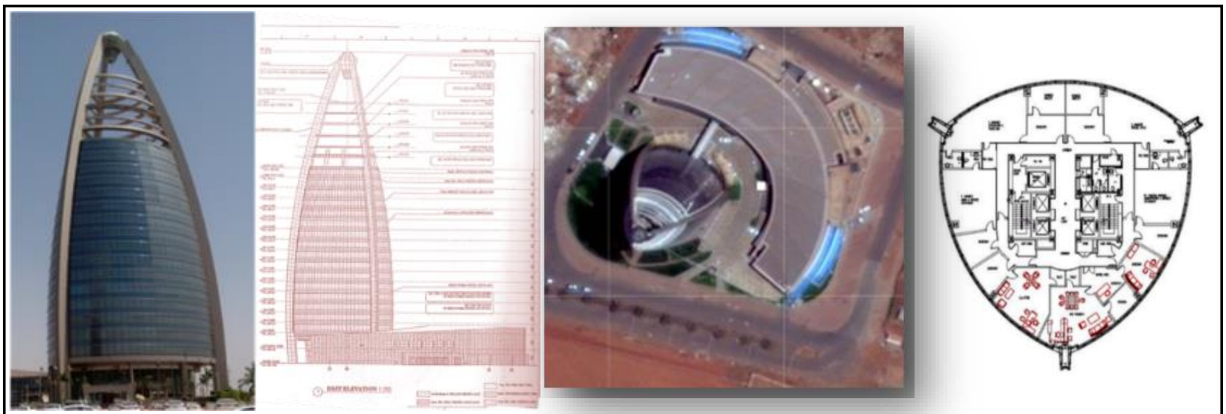
The buildings were constructed between 2003 and 2015, with heights ranging from 8 to 26 floors above ground level (excluding any underground levels). Their built-up areas vary between 2,800 m² and 5,500 m².

Figure 1

Table 2: Buildings as case study

No	Building Name	No	Building Name	No	Building Name
1	Greater Nile Petroleum Operating Company (GNPOC)	6	Al Neileen Tower	13	Higleig For petroleum Services Building
2	Petrodar tower (PDOC)	7	Byblos Bank Africa	14	Ministry of Energy & Oil
3	Central Bank of Sudan	8	Al Maleya Tower	15	Sudapet Company Ltd.
4	As Sahel & As Sahara Bank Tower	9	Al Moalim Tower		
5	At Tadamon Real Estate Tower	11	Sudan Airways Building		
6	Al Neileen Tower	13	Higleig For petroleum Services Building		

Greater Nile Petroleum Operating Company



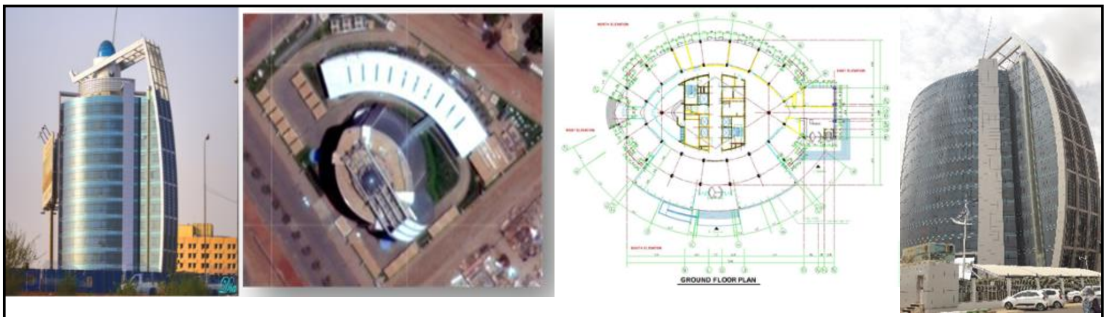
GNPOC- Tower GNPOC –Cross Section GNPOC- Site plan GNPOC- Typical Layout plan

Figure 2: Greater Nile building
Design consultant: KEO International Consultants

Table 3: Case 1: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: composite (Concrete and steel) structure ▪ Plan Depth:12 meters (from central core) ▪ Location of Plant Floors: Ground floor –out door area.	▪ Ventilation Type: ▪ Mixed-Mode, 90% mechanical 10% natural ventilation natural strategy ventilation ▪ Wind-Driven Single-Sided ventilation	▪ Double-skin façades (95% Glazing curtain wall) ▪ Double-Skin Façade Cavity: Depth: 500 mm ▪ Horizontal Continuity: 2 meters ▪ Vertical Continuity: 3.5 meters (floor-to-floor) ▪ Approximate Percentage of Year Natural Ventilation can be Utilized: 20% ▪ Percentage of Annual Energy Savings for Cooling: Unpublished ▪ Typical Annual Energy Consumption (Cooling): Unpublished	▪ The good natural lighting is provided by opening up the space that gives the 'atrium', with three floors, large porches and terraces.	▪ Widest possible point of view. ▪ Aerodynamic shape to allow wind flow around the building and its façade. ▪ Flexibly serviced, high specification 'user-friendly' column free office spaces. ▪ The smooth flow of wind around the building was one of the main considerations.

Petrodar Tower



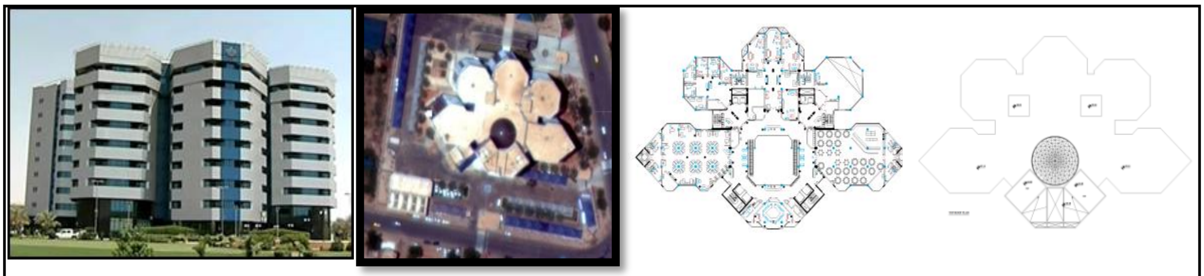
GNPOC - Tower | GNPOC Site plan | GNPOC- Typical Layout plan | Glazing-Curtain wall All-around

Figure 3: Petrodar tower (PDOC)
Design consultant: Engineering consulting group

Table 4: Case 2: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Composite (Concrete and steel) structure ▪ Plan Depth:8 meters (from central core) ▪ Location of Plant Floors: Ground floor –out door area.	▪ Ventilation Type Mixed-Mode: 85% mechanical 15% natural ventilation ▪ Natural Ventilation Strategy: ▪ Wind-Driven Single-Sided Ventilation	▪ Double-skin façades (98% Glazing curtain wall) ▪ Double-Skin Façade Cavity: Depth: 300 mm ▪ Horizontal Continuity: 2 meters ▪ Vertical Continuity: 3.2 meters (floor-to-floor) ▪ Approximate Percentage of Year Natural Ventilation can be Utilized: 25% Percentage of Annual Energy Savings for Cooling: Unpublished ▪ Typical Annual Energy Consumption (Cooling): Unpublished	▪ The good natural lighting is provided by opening up the space that gives the ‘atrium’, with three floors, large porches and terraces.	▪ Widest possible point of view. ▪ Aerodynamic shape to allow wind flow around the building and its façade. ▪ Flexibly serviced, high specification ‘user-friendly’ column free office spaces.

Central Bank of Sudan



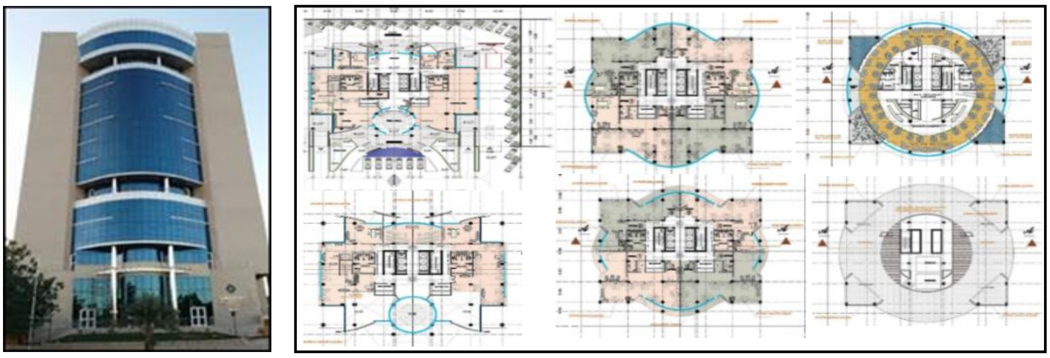
Central Bank of Sudan | Central Bank Site plan | Central Bank- Atrium, porches and balconies | Sky lighting- natural lighting

Figure 4: Central Bank of Sudan building
Design consultant: Hamdey consultant Group

Table 5: Case 3: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Concrete and steel structure ▪ Plan Depth:12-8 meters (from central core) ▪ Location of Plant Floors: Ground floor –out door area.	▪ Ventilation Type ▪ Mixed-Mode: 85% mechanical 15% natural ventilation ▪ Natural Ventilation Strategy ▪ Wind-Driven Single-Sided Ventilation	▪ Single-skin façades (40% Glazing curtain wall) ▪ Double-Skin Façade Cavity at South elevation: Depth: 350 mm Horizontal Continuity: 2 meters ▪ Vertical Continuity: 3.5 meters (floor-to-floor) Approximate Percentage of Year Natural Ventilation can be Utilized: 15% ▪ Percentage of Annual Energy Savings for Cooling: Unpublished ▪ Typical Annual Energy Consumption (Cooling): Unpublished	▪ The good natural lighting is provided by opening up the space that gives the 'atrium', with nine floors, porches and balconies.	▪ Good physical and visual interconnectivity between floors. ▪ Maximum use of public transport for the occupants of the building. ▪ Flexibly serviced, high specification 'user-friendly' column free office spaces with maximum primary space adjacent to natural light. ▪ Unique structural solution to an innovative form. ▪ A response to external and internal loading

Sahel & Sahara Bank Tower



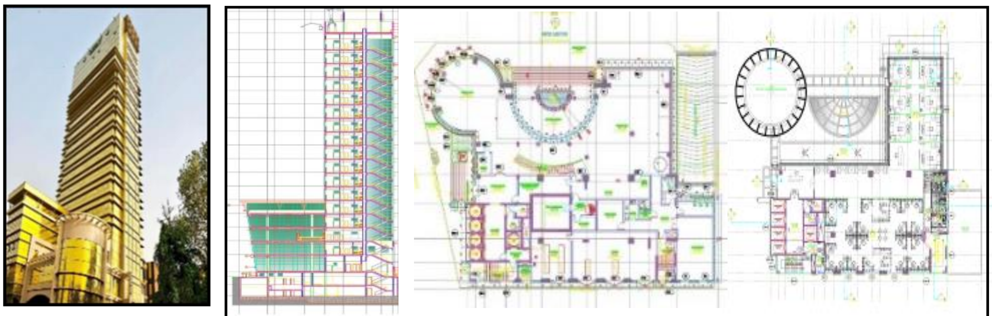
Sahel & Sahara Bank Tower — Different floors plans

Figure 5: Sahel & Sahara Tower
Design consultant: S & S consultant group

Table 6: Case 4: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Concrete structure ▪ Plan Depth:10-14 meters (from central core) ▪ Location of Plant Floors: Ground floor –out door area	▪ Ventilation Type, Mixed-Mode: 80% mechanical20% natural ventilation ▪ Natural Ventilation Strategy, Wind-Driven Single-Sided Ventilation (20%)	• Double-skin façades (95% Glazing curtain wall) • Double-Skin Façade Cavity: Depth: 500 mm • Horizontal Continuity: 2 meters. • Vertical Continuity: 3.5 meters (floor-to-floor) • Approximate Percentage of Year Natural Ventilation can be Utilized: 75% • Percentage of Annual Energy Savings for Cooling: Unpublished • Typical Annual Energy Consumption (Cooling): Unpublished	▪ The good natural lighting is provided by opening up the space that gives the 'atrium', with three floors, large porches and terraces.	▪ Opening up new views across the site to the frontages of the adjacent buildings and allowing good access to and around the new development. ▪ Good physical and visual interconnectivity between floors.

Tadamon Real Estate Tower



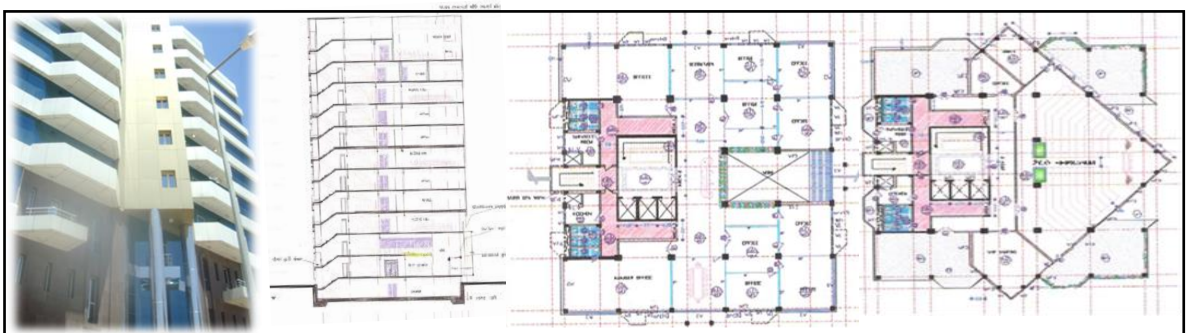
Tadamon Real Estate Cross sections Ground floor plan Typical floor plan

Figure 6: Tadamon Real Estate Tower
Design consultant: Murtada Maaz Consultancy

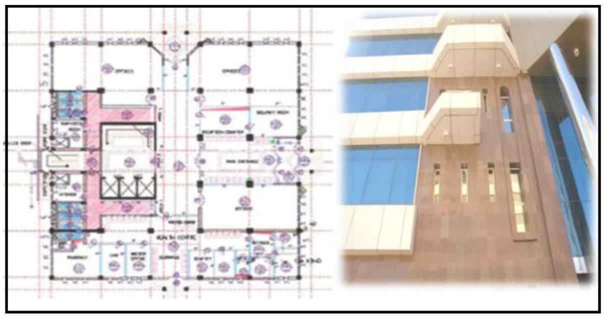
Table 7: Case 5: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Composite (Concrete and steel) structure ▪ Plan Depth:14 meters (from central core) ▪ Location of Plant Floors: Ground floor –out door area.	▪ Ventilation Type Mixed-Mode: 85% mechanical 15% natural ventilation ▪ Natural ventilation strategy: Wind-Driven single-sided ventilation	▪ Double-skin façades (85% Glazing curtain wall) ▪ Double-Skin Façade Cavity: Depth: 300 mm	▪ The good natural lighting is provided by opening at Curtin walls.	▪ No certain design technic to achieve energy saving. ▪ Good physical and visual interconnectivity between floors.

Almalyan Tower



Almalyan Tower Cross sections Ground floor plan 7th. floor plan



Typical floor plan Shading elements

Figure 7: Almalyan Tower
Design consultant: Al daar

Table 8: Case 6: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Concrete structure ▪ Plan Depth:10-8 meters (from central core) ▪ Location of Plant Floors: Ground floor – out door area.	▪ Ventilation type: Mixed-Mode: 85% mechanical 15% natural ventilation ▪ Natural Ventilation Strategy: Wind-Driven Single-Sided Ventilation	▪ Single-skin façades (75% Glazing curtain wall) ▪ Vertical Continuity: 3.5 meters (floor-to-floor) ▪ Approximate Percentage of Year Natural Ventilation can be Utilized: 10% ▪ Percentage of Annual Energy Savings for Cooling: Unpublished ▪ Typical annual energy consumption (Cooling): Unpublished	▪ The good natural lighting is provided by opening up the space that gives the 'atrium', with three floors, large porches and terraces.	▪ Simple design and shape to blend in with the surrounding urban design. ▪ Using the rectangular shape and simplicity in the formation of the facades, while reducing the materials used.

Byblos Bank Africa

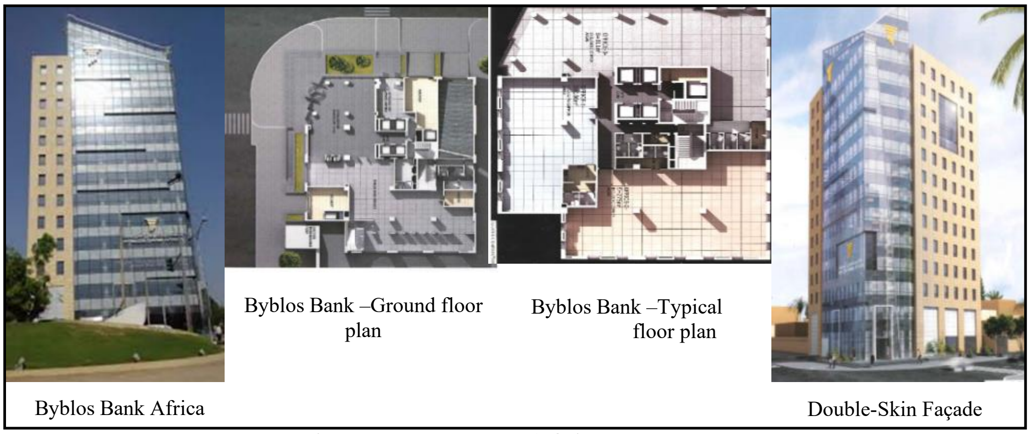


Figure 8: Byblos Africa Tower
Design consultant: A-CONSOL

Table 9: Case 7: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Concrete structure ▪ Plan Depth:12 meters (from central core) ▪ Location of Plant Floors: Ground floor –out door area.	▪ Ventilation Type: Mixed-Mode: 85% mechanical 15% natural ventilation ▪ Natural ventilation strategy: Single-Sided Ventilation	▪ Double-skin façades (65% Glazing curtain wall) ▪ Double-Skin Façade Cavity: Depth: 500 mm ▪ Horizontal Continuity: 2 meters ▪ Vertical Continuity: 3.5 meters (floor-to-floor) ▪ Approximate Percentage of Year Natural Ventilation can be Utilized: 25% ▪ Percentage of Annual Energy Savings for Cooling: Unpublished ▪ Typical Annual Energy Consumption (Cooling): Unpublished	▪ Natural lighting is provided by opening the space that gives the 'atrium', with all floors, large porches and terraces.	▪ Opening up new views across the site to the frontages of the adjacent buildings and allowing good access to and around the new development. ▪ Simple design and shape to blend in with the surrounding urban design

Alneline Tower

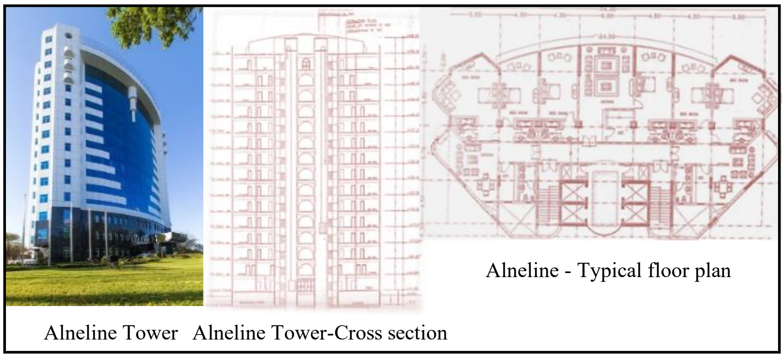


Figure 9: Alneline Tower
Design consultant: Al daar consultant

Table 10: Case 8: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Date:2003 ▪ Structural Material: Concrete structure ▪ Plan Depth:8-12 meters (from central core) ▪ Location of Plant Floors: Nun	▪ Ventilation Type ▪ Mixed-Mode: 90% mechanical 10% natural ventilation	▪ Double-skin façades (70% Glazing curtain wall) ▪ Single-skin aluminum cladding façade and granite tiles ▪ Vertical Continuity: 3.5 meters (floor-to-floor)	▪ Natural light Strategy: Nun	▪ Widest possible point of view (Nile view). ▪ No certain design technic to achieve energy saving. ▪ Flexibly serviced, high specification 'user-friendly' column free office spaces.

Almoalem Tower

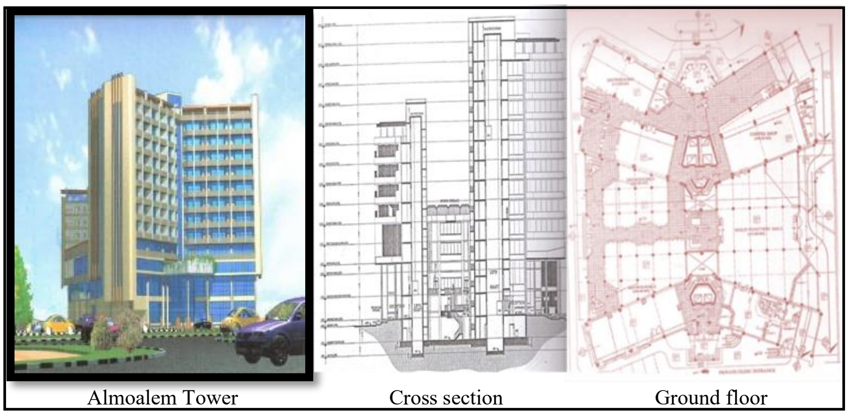


Figure 10: Alneline Tower

Table 11: Case 9: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Concrete structure ▪ Plan Depth:8 meters (from central core) ▪ Location of Plant Floors: Nun.	▪ Ventilation Type: Mixed-Mode, 80% mechanical 20% natural ventilation ▪ Natural Ventilation Strategy: Nun	▪ Double-skin façades (80% Glazing wall) ▪ Single-Skin Aluminum Cladding Façade ▪ Vertical Continuity: 3.5 meters (floor-to-floor)	▪ The good natural lighting is provided by opening at Curtin walls.	▪ Simple design and shape (Fan shape) to blend in with the surrounding urban design and provide widest possible point of view.

Sudanese Standard Measurement Organization (SSMO)

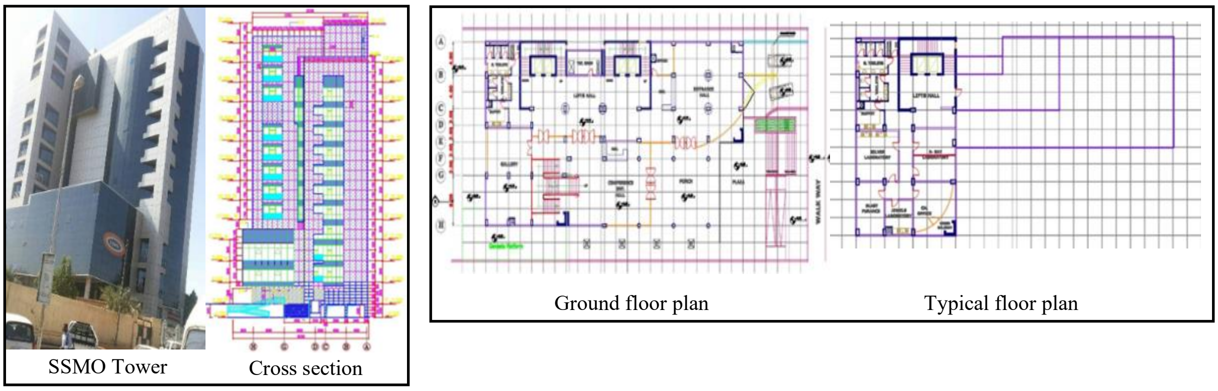


Figure 11: SSMO. Tower
Design consultant: Perfection Engineering

Table 12: Case 10: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Concrete structure ▪ Plan Depth:8 meters (from central core) ▪ Location of Plant Floors: Nun.	▪ Ventilation Type: Mixed-Mode, 85% mechanical 15% natural ventilation ▪ Natural Ventilation Strategy: Nun	▪ Double-skin façades (80% Glazing wall) ▪ Single-Skin Aluminum Cladding Façade ▪ Vertical Continuity: 3.5 meters (floor-to-floor)	▪ The good natural lighting is provided by opening at Curtin walls at east and west side.	▪ Simple design and shape. ▪ Unique structural solution to an innovative form

National Telecom Corporation Tower (NTC)

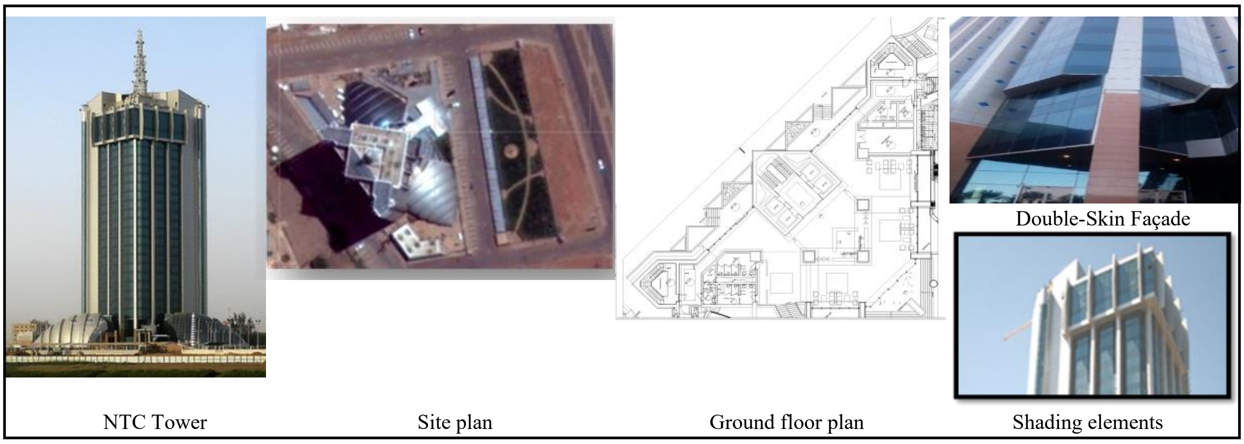


Figure 12: NTC. Tower
Design consultant: Centecs for Engineering Consultation & Studies Co. Ltd

Table 13: Case 11: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: composite (Concrete and steel) structure ▪ Plan Depth:10 meters (from central core) ▪ Location of Plant Floors: Ground floor –out door area	▪ Ventilation Type: Mixed-Mode, 90% mechanical 10% natural ventilation ▪ Natural Ventilation Strategy: Wind-Driven single-sided ventilation.	▪ Double-skin façades (96% Glazing curtain wall) ▪ Double-Skin Façade Cavity: Depth: 200 mm ▪ Horizontal Continuity: 2 meters ▪ Vertical Continuity: 3.5 meters (floor-to-floor) ▪ Approximate Percentage of Year Natural Ventilation can be Utilized: 25% ▪ Percentage of Annual Energy Savings for Cooling: Unpublished ▪ Typical Annual Energy Consumption (Cooling): Unpublished	▪ Natural lighting is provided by opening up the space	▪ Reduced energy consumption by use of natural ventilation whenever suitable, low façade heat gain and smart building control systems. ▪ Maximum use of public transport for the occupants of the building. ▪ Flexibly serviced, high specification 'user-friendly' column free office spaces with maximum primary space adjacent to natural light.

Sudan Airways

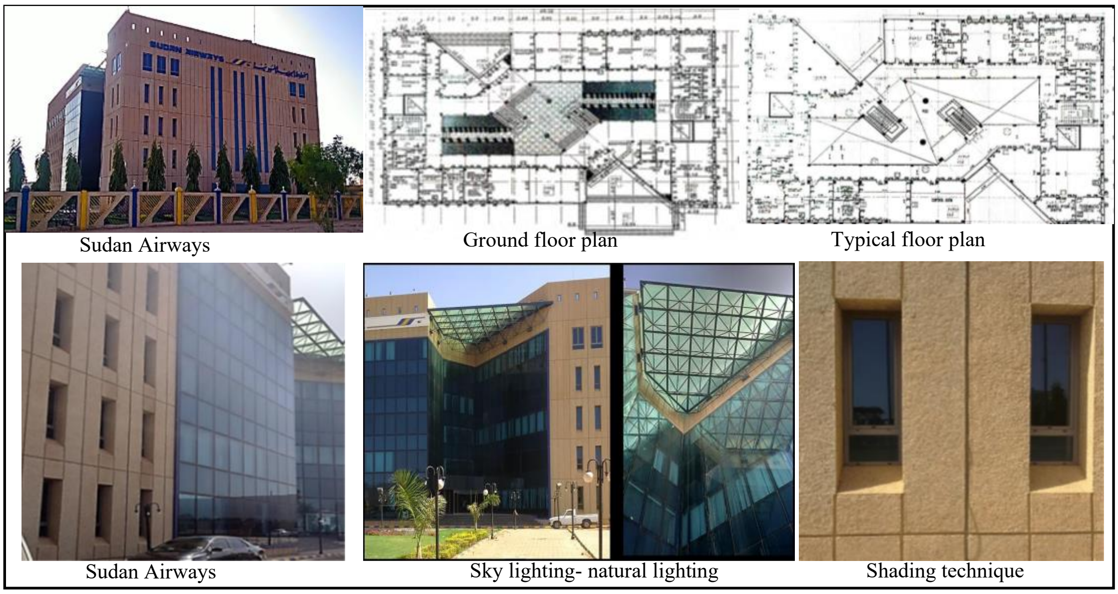


Figure 13: Sudan Airways building
Design consultant: Centecs for Engineering

Table 14: Case 12: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: Concrete structure ▪ Plan Depth:6 meters (from central core) ▪ Location of Plant Floors: Ground floor in and out door area	▪ Ventilation Type: Mixed-Mode: 85% mechanical 15% natural ventilation ▪ Natural Ventilation Strategy: Wind-Driven Single-Sided Ventilation	▪ Double-skin façades (60% Glazing curtain wall) ▪ Double-Skin Façade Cavity. ▪ Vertical Continuity: 3.5 meters (floor-to-floor) Approximate Percentage of year natural ventilation can be utilized 15%	▪ The good natural lighting is provided by opening up the space that gives the 'atrium', with three floors, large porches and terraces.	▪ Good physical and visual interconnectivity between floors. ▪ Flexibly serviced, high specification 'user-friendly' column free office spaces with maximum primary space adjacent to natural light.

Higleig For petroleum Services

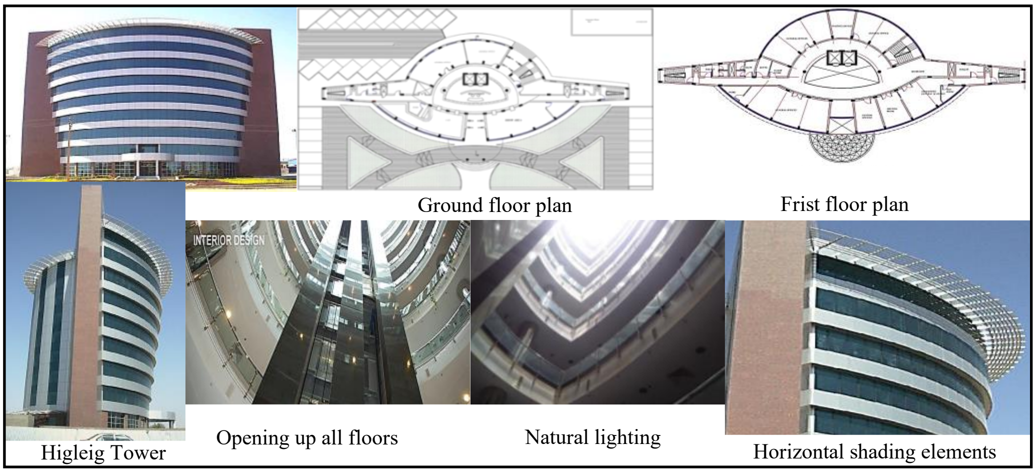


Figure 14: Higleig Tower
Design consultant: Murtada Maaz Consultancy

Table 15: Case 13: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Date: 2003 Structural Material: Concrete structure ▪ Plan Depth:8 meters (from central core) ▪ Location of Plant Floors: Nun.	▪ Approximate Percentage of Year Natural Ventilation can be Utilized: 0% ▪ Percentage of Annual Energy Savings for Cooling: Unpublished ▪ Typical Annual Energy ▪ Consumption (Cooling): Unpublished	▪ Single-Skin Aluminum Cladding Façade ▪ Vertical Continuity: 3.5 meters (floor-to-floor)	▪ The good natural lighting is provided by opening up the space that gives the ‘atrium’, with all floors. Ventilation Type: Mode: 85% mechanical 15% natural ventilation ▪ Natural Ventilation Strategy: Nun	▪ Good physical and visual interconnectivity between floors. Flexibly serviced, high specification ‘user-friendly’ column free office spaces with maximum primary space adjacent to natural light. ▪ Maximum transparency of facades.

Ministry of Energy & Oil

Figure 15: Ministry of Energy & Oil building

Table 16: Case 14: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Plan Depth: 10 meters (from central core) ▪ Location of Plant Floors: Ground floor –out door area Structural Material: Concrete structure door area.	▪ Ventilation Type: Mixed-Mode, 85% mechanical 15% natural ventilation ▪ Natural ventilation strategy Wind-Driven Single-Sided Ventilation	▪ Daylight Strategies ▪ Double-skin façades (60% Glazing curtain wall) ▪ Double-Skin Façade Cavity: Depth: 600 mm ▪ Horizontal Continuity: 2 meters ▪ Vertical Continuity: 3.5 meters (floor-to-floor) ▪ Approximate Percentage of Year Natural Ventilation can be Utilized: 15% ▪ Percentage of Annual Energy Savings for Cooling: Unpublished Typical Annual Energy Consumption (Cooling): Unpublished	▪ The good natural lighting is provided by opening up the space that gives the 'atrium', with three floors, large porches and terraces.	▪ Flexibly serviced, high specification 'user-friendly' column free office spaces with maximum primary space adjacent to natural light

Sudapet Co. Ltd Company

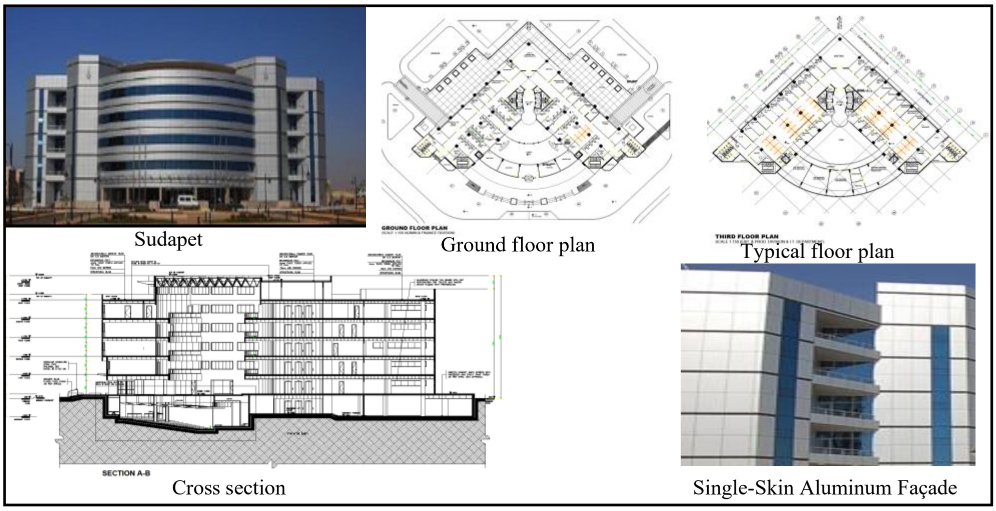


Figure 16: Sudapet building
Design consultant: PARC international

Table 17: Case 15: General description

Project Data	Ventilation Overview	Design Strategies	Daylight Overview	Mass design Strategy
▪ Structural Material: ▪ Date: June 2005 ▪ Composite (Concrete and steel) structure ▪ Plan Depth: 8 meters (from central core) ▪ Location of Plant Floors: Ground floor – out door area.	▪ Ventilation Type: Mixed-Mode, 85% mechanical 15% natural ventilation Single-Skin Aluminum Façade. ▪ Natural Ventilation Strategy ▪ Wind-Driven Single-Sided Ventilation	▪ Double-skin façades (60% Glazing curtain wall) ▪ Single-Skin Aluminum Cladding Façade ▪ Vertical Continuity: 3.20 meters (floor-to-floor) ▪ Approximate Percentage of Year Natural Ventilation can be Utilized: Zero% ▪ Percentage of Annual Energy Savings for Cooling: Unpublished ▪ Typical Annual Energy Consumption (Cooling): Unpublished	▪ Little natural lighting is provided by opening up the space that gives the 'atrium', with three floors, large porches and terraces.	▪ Good physical and visual interconnectivity between floors. ▪ Flexible interior design for easy circulation between spaces. ▪ Extensible block formation horizontally and vertically. ▪ Optimal spaces use.

RESULTS AND DISCUSSION

A quantitative research approach was adopted in this study, integrating multiple analytical tools to ensure the reliability and validity of findings. The results revealed that a range of energy efficiency design strategies have been identified, categorized, and assessed in terms of their application in office buildings within Khartoum.

The findings showed that the implementation of these strategies varies across buildings. However, there was a clear consensus among specialists that two categories are the most influential in reducing energy consumption: building envelope design techniques (see Table 18) and the integrated design process (see Table 20). These categories were identified as the key determinants significantly shaping the rate of energy consumption in office buildings in Khartoum, consistent with previous studies highlighting the dominant impact of passive envelope optimization and integrated design methodologies on energy performance (e.g., Li et al., 2013; Lu et al., 2020; Nwofe, 2014).

Building Envelope Design Techniques

The detailed analysis of the fifteen case- office buildings indicated varied levels of adoption of the nine identified building envelope strategies. Notably, four techniques—energy-efficient building materials, optimized window shape and position, green roofs, and sky gardens—were not implemented in any of the surveyed buildings.

A small number of buildings integrated specific measures: only two incorporated bright-colored roofs, three applied shading devices for thermal protection, and four utilized bright-colored external wall paints to reduce heat gain. Six buildings achieved an effective window-to-wall ratio within recommended limits.

The most widely adopted measure was the double-skin façade, applied in eleven of the studied buildings, confirming its perceived effectiveness in mitigating heat gain and improving thermal comfort (see Table 19). This outcome aligns with international research that underscores the importance of façade systems and envelope optimization in enhancing building energy performance in hot, arid climates (Day & Gunderson, 2015; Kozusznik et al., 2019).

Table 18: Buildings Envelope Design Techniques

No	Design Techniques
a	Specification of Energy Efficient Building materials
b	Window Shape and Position
c	Exterior Shading Design
d	Effective Wall to Wall Ratio
e	Specification of Bright Colored Roofs
f	Specification of Bright Colored External Wall Paints
g	Green Roofs
h	Sky Garden
i	Double Skin Facades

Table 19: Energy Efficient Design Strategies Implementation level
Building Envelope Design Strategies

No	Buildings	Factors of Assessment									Total 135	Total 135
		a	b	c	d	e	f	g	h	i	√	×
1	Greeter Nile petroleum	×	×	×	×	×	×	×	×	√	1	8
2	Petrodar tower (PDOC)	×	×	×	×	×	×	×	×	√	1	8
3	Central Bank of Sudan building	×	×	×	×	√	√	×	×	√	3	9
4	Sahel & Sahara Bank Tower	×	×	√	×	×	×	×	×	√	2	7
5	Altdamon Real Estate Tower	×	×	×	×	×	×	×	×	√	1	8
6	Alneileen Tower	×	×	×	×	×	×	×	×	×	0	9
7	Byblos Bank Africa	×	×	×	√	√	√	×	×	√	4	5
8	Al malya Tower	×	×	×	×	×	×	×	×	√	1	8
9	Almoalem Tower	×	×	×	√	×	×	×	×	×	1	8
10	Sudanese Standard Measurement Organization	×	×	×	√	×	×	×	×	×	1	8
11	National Telecom Corporation Tower (NTC)	×	×	√	×	×	×	×	×	√	2	7
12	Sudan Airways Building	×	×	×	√	×	√	×	×	√	3	6
13	Higleig for petroleum Services	×	×	×	×	×	×	×	×	√	1	8
14	Ministry of Energy & Oil	×	×	√	√	×	√	×	×	√	4	5
15	Sudapet co. Ltd company	×	×	×	√	×	×	×	×	×	1	8
Total		**0**	**0**	**3**	**6**	**2**	**4**	**0**	**0**	**11**	**26**	**109**

√ Implemented (26 0f 135*)

× Un implemented (109 of 135*)

***135: Total of building envelope design strategies = 15x9**
9: Envelope efficient design strategies
15: Total number of the buildings.

The study examined nine building envelope techniques across the fifteen office buildings, representing a total of 135 possible applications. Out of these, only 29 techniques were implemented (19%), while 106 were not implemented (81%), as shown in Figure 17 and Table 19.

Table 20

No	Design Techniques
j	Natural Ventilation
k	Renewable Energy Sources
l	Day Lighting Design
m	Mixed-mode Ventilation System
n	Solar Cooling Mechanisms

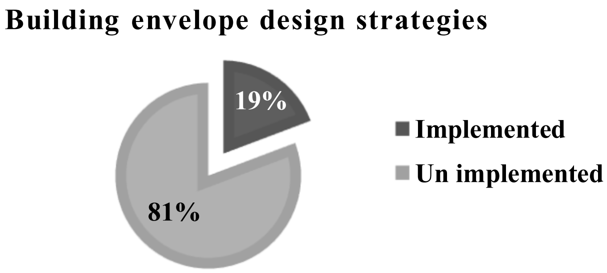


Figure 17: Implementation level of buildings envelope design strategies

Integrated Design Process

The fifteen buildings were analyzed in relation to the five integrated design process techniques. The results show that none of the buildings employed natural ventilation as a means of reducing energy consumption. Only one building (NTC Building) incorporated renewable energy sources. Daylighting design emerged as the most widely adopted strategy, implemented in six buildings. In contrast, both the mixed-mode ventilation system and solar cooling mechanisms were applied only once across the entire sample. These findings are summarized in Table 20.

Table 21: Integrated Design Process Techniques Implementation level

No	Buildings (15)	Factors of Assessment					Total	Total
		j	k	l	m	n	× 75	√ 75
1	Gretel Nile petroleum Tower	×	×	×	×	×	**5**	**0**
2	Petrodar tower	×	×	×	×	×	**5**	**0**
3	Central Bank of Sudan building	×	×	√	×	×	**4**	**1**
4	Sahel & Sahara Bank Tower	×	×	×	×	×	**5**	**0**
5	Altdamon Real Estate Tower	×	×	×	×	×	**5**	**0**
6	Alneileen Tower	×	×	√	×	×	**4**	**1**
7	Byblos Bank Africa building	×	×	×	×	×	**5**	**0**
8	Al malya Tower	×	×	×	×	×	**5**	**0**
9	Almoalem Tower	×	×	√	×	×	**4**	**1**
10	Sudanese Standard Measurement Organization building	×	×	×	×	×	**5**	**0**
11	National Telecom Corporation Tower	×	√	×	×	√	**3**	**2**
12	Sudan Airways Building	√	×	√	×	×	**3**	**2**
13	Higleig For petroleum Services	×	×	×	×	×	**5**	**0**
14	Ministry of Energy & Oil building	×	×	√	×	×	**4**	**1**
15	Sudapet co. Ltd company	×	×	√	×	×	**4**	**1**
Total		**1**	**1**	**6**	**0**	**1**	**66**	**9**

√ Implemented (9 0f 75*)

× Un implemented (66 of 75*)

***75: Total of energy efficient design strategies at all buildings =15x5**
5: Energy efficient design strategies
15: Total number of the buildings

The study examined five techniques related to the integrated design process across the fifteen buildings, resulting in seventy-five possible applications of these techniques. Out of this total, only nine instances were implemented, representing 12%, while sixty-six instances were not implemented, accounting for 88%. These results are illustrated in Figure 18.

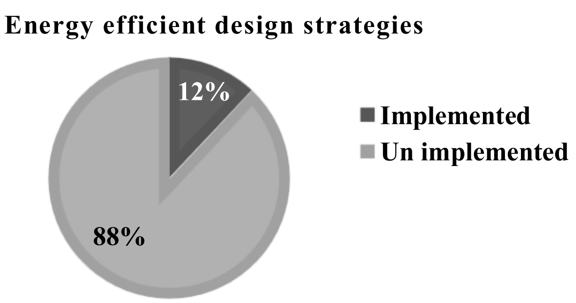


Figure 18: Implementation level of energy efficient design Strategies

Disruption of the Results

The study investigated the level of implementation of energy-efficient design strategies in fifteen major office buildings in Khartoum. The assessment focused on two of the most influential strategies identified in the literature: building envelope design techniques and the integrated design process, both of which significantly affect energy consumption (Griego, Krarti, & Hernandez-Guerrero, 2015; Lu, Sood, Chang, & Liao, 2020).

Findings indicated that only 29% of the building envelope design techniques were applied, while 71% were not implemented. Similarly, for the integrated design process, only 12% of strategies were adopted, whereas 88% were not utilized. Overall, these results suggest that most critical energy-saving strategies have not been incorporated into the studied buildings. The analysis further highlighted that a few technologies were relatively more common, while many others were implemented in only a limited number of cases (Day & Gunderson, 2015; Li, Yang, & Lam, 2013).

CONCLUSIONS

This study examined the adoption of energy-efficient design strategies in fifteen office buildings in Khartoum, focusing on building envelope techniques and the integrated design process. The results revealed a very low level of implementation compared to their potential effectiveness in reducing energy demand (Li & Colombier, 2009; Rana, Hasan, Sobuz, & Tam, 2020).

Building Envelope Design Techniques

Only 29% of the studied applications were implemented, while 71% were absent. High-impact techniques, such as green roofs and sky gardens, were not applied in any of the buildings. The double-skin façade was the most frequently used strategy, applied in eleven buildings, whereas shading devices, bright roof colors, and reflective wall paints were adopted in only a few cases. These results indicate a narrow and selective application of envelope solutions (Fisk, 2000; Trotta, Spangenberg, & Lorek, 2018).

Integrated Design Process

Implementation of integrated design strategies was even lower, with only 12% adoption and 88% absence. No building employed natural ventilation, and only one incorporated integrated renewable energy sources. Daylighting design was the most frequently applied strategy, present in six buildings. This demonstrates a reliance on mechanical systems with minimal integration of holistic, passive solutions (Kozusznik et al., 2019; Lu et al., 2020).

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