

The Role of Value Engineering in Improving Energy Efficiency through the Building Facades Case Study of Cairo International Airport- Terminal 3

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Abstract

Existing airport buildings need special requirements to increase their efficiency, as improving energy consumption is one of the most important aspects that can be achieved in the field of rationalizing energy consumption.

The outer envelope of the building plays a major role in improving energy efficiency and raising the building's performance, in order to provide thermal comfort throughout the life of the project, and this requires considering some environmental treatments to increase the efficiency of the outer envelope.

It is possible to move towards sustainability and high technology and improve technology materials in airport buildings through glass openings in the facades using high-performance technologies and using long-term cost.

Since openings are the main source of heat penetration to the interior and are usually through glass, it is necessary to study their effect and find several methods to treat them within the outer envelope of the building to rationalize energy consumption through them and reduce the thermal load penetrating into the building.

The importance of the study and experiment comes in developing a mechanism through which value engineering methods can be applied to the impact of choosing the most appropriate sustainable technologies used in facades; In an effort to achieve sustainable performance in airport buildings in Egypt, increase the economic advantages of the building and reduce energy costs in it

Keywords: Value Engineering (VE) - life cycle cost (LCC) - Sustainable Construction (SC) - Energy Consumption -Airport - Cairo International Airport.

1. Introduction

Airport terminal design is one of the most important types of specialized buildings, and it is no longer based on the ideas of meeting the functional performance or the theses of form as separate processes to produce this advanced style of high-performance and symbolic buildings, as modern technology has become the most important means to achieve the process of operational efficiency with a balanced environmental atmosphere for contemporary airport terminals.

Both Value Engineering (VE) and Sustainable Development (SD) help in the construction industry, achieving quality as well as improving performance throughout the life of the project, and achieving integration from life cycle cost (LCC) and quality to meeting user requirements. The integration of Value Engineering and Sustainable Construction concepts achieves the best value over the life of the project, using the tools and techniques of the International Standard VE Plan to better plan for construction sustainability (SC) during the early stages of the project. The strengths of Value Engineering help to increase sustainability in the construction industry, as it has its own benefits for projects in rationalizing energy consumption and reducing operating costs. Value Engineering and sustainability show the advantages of a strong positive relationship; hence, the two are linked in a search that results in sustainable value design increasing sustainability and value for money in all construction projects.

2. Objective

The research aims to develop a mechanism that can be applied through the application of value engineering methods in the impact of choosing the most appropriate sustainable technologies; In an effort to achieve sustainable performance in airports, this mechanism can be applied to airport facades in Egypt. To achieve the research objective, the theoretical approach was relied upon to study ways to improve energy consumption in existing buildings during the operation process and to present the stages of value engineering. The applied study in the research depends on applying the value engineering approach to the Cairo International Airport building, Terminal 3, with the aim of improving the energy efficiency required for operation during the development planning process.

3. Research Methodology

Applying the value engineering methodology during the development stages of the Cairo International Airport building to reach economic solutions that contribute to rationalizing energy consumption and achieving a balance between cost, quality and design objectives if value engineering is applied with a correct methodology that does not only depend on reducing cost but also takes into account the environmental and sustainable dimensions in the design

4. The Importance of Value Engineering in the Study:

Through the value engineering methodology, it is possible to add some modifications and think about different alternatives that differ in terms of specifications, cost and environmental impact on the building. The failure to conduct value engineering studies also results in a high initial cost for the building, which leads to investors not being interested in implementing these treatments in buildings without paying attention to the savings they achieve on the total cost throughout the life of the building.

Value engineering is considered one of the economic approaches that provides both cost and functional performance in the best possible way, which represents the highest value, and enables the detection of unnecessary costs and comparison between available alternatives without harming the quality required to achieve the function and emphasizes the possibility of achieving a balance between cost and quality. (D. Kazanc, 2000; Dell’Isolla P., 1982).

4-1 Value Engineering Objectives

This methodology has proven its high potential for solving problems and its ability to perform functional analysis and reduce costs without affecting the project’s objective and function, in addition to the speed of producing results and submitting proposals, innovating creative ideas and improving the project’s functional and aesthetic efficiency (Mohamed Moselhy, 2012).

Table 1 Value Engineering Axes Relationship Table (Mohamed Abu Al-Fotouh, 2021)

	Effectiveness of Value Engineering	Cost	Function Quality
1	Methodology Objectives	Decreased	Developed
2		Fixed	Developed

4.2 How to Measure Value:

Value and function are directly related, and value and cost are inversely related; the more efficient the function is and the lower the cost, the greater the value (Mohab Matar, 2008) .To obtain a true measure of value, all three elements must be considered, and the sustainability index must be included.

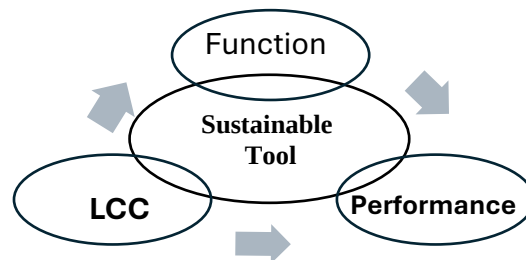


Figure 1 The three main elements of value are intertwined with sustainability (Al-Yami, A M; Price, A D F, 2005)

4.3 Value Engineering Action Plan

The value engineering workshop consists of five stages and is followed by many value experts (SAVE, 2005) It is as follows:

4.3.1 Information Phase:

Information about the building is collected that will help in analyzing the existing environmental performance and the performance that needs to be improved through the following:

1. Project location
2. General location
3. Analysis of the horizontal plan of the recurring role

4. Facades as a goal of the study
5. Use of energy modeling
6. Study of the building's structural determinants and requirements
7. Extracting the analysis results and collecting information.

4.3.2 Function Analysis Phase:

Functions are identified, classified, and linked to the FAST diagram, and the functions that can be improved are selected.

4.3.3 Creative Phase:

Focus on presenting ideas and innovating new ideas to achieve the required functions and technical specifications of the outer envelope; based on what has been done from:

- Determinants of the elements of the outer envelope under study with the requirements of the code.
- Properties and specifications of materials.
- Specifications that need to be achieved and studied.

4.3.4 Evaluation and Selection Phase:

All ideas and alternatives mentioned in the creativity and innovation phase are studied and analyzed. Serious ideas will be evaluated and selected, their quality and applicability tested, and ineffective ideas will be excluded.

4.3.5 Presentation Phase:

A presentation of ideas is presented to review the study and its results with the efforts made, and the methodology followed in the study to reach those results, where the study report is reviewed and what it contains of solutions, proposals, ideas and recommendations about the design work to decide on them and include them in the next phase through the architectural evaluation matrix of alternatives.

4.3.6 Initial Report Preparation Phase:

The initial report of the study is prepared so that it contains a comprehensive explanation of the project, the problem, the ideas and alternatives to solve it and choose the best alternative.

5. Building and energy:

Airport buildings are considered one of the sectors that consume the most energy after the industrial sector. In this part of the research, the importance of the feasibility of rationalizing energy consumption and the sustainability of the building will be studied (Ali Al-Alalfi, 2014). Through its facades to reach the system, the study's goal is to create a value system to evaluate sustainable performance in Cairo International Airport Building 3, and to expose the study to the energy consumed and consumption locations. We specialize in the study in the southern facade of the building. The rapid increase in global demand for energy and electricity consumption necessitates a shift towards sustainability and carbon neutrality, as the expansion of electricity use has led to the establishment of many substations with diverse energy consumption factors. Therefore, a passive innovation is proposed to save energy, by taking advantage of passive buildings that use effective insulation, low-heat transfer windows, and clean energy to control temperature, as passive design can significantly reduce energy consumption in different climates and building types (Charles J. Kibert, 2008).

5.1 Energy consumption rationalization:

Rationalization of energy consumption in Cairo Airport Building 3 through its facades is based on identifying the sites of waste and taking the necessary steps to reduce this loss to a minimum or prevent it. Energy consumption in the building can be rationalized using one of the following methods (Muhammad Abu al-Fath, 2021):

- A direct method that depends on rationalizing the current energy by reorganizing what is available to reduce loss and improve performance efficiency using energy-efficient systems, which will be applied in Cairo Airport Building 3.
- An indirect method that depends on replacing the current energy with another sustainable or more efficient one, by the building relying on its own energy generated within it from renewable energy sources such as solar energy and wind energy.

5.1.1 Energy Simulation Tools:

Energy simulation has become a matter of public interest with the rapid rise in population numbers, as the increase in production in all sectors leads to a significant increase in the demand for energy, as the consumption of nearly 40% of all resources today by the residential, commercial and public sectors, along with the industrial sector, makes it the main source of energy use (Alkali, M A; Jie, Liu; Dalibi, S G; Danja, I I; Nasir, M.H. ; Inuwa Labaran, Usman; Umar, Abdullahi M, 2021).

Until recently, typical energy control approaches, such as natural ventilation, solar orientation, and adaptation to different climate zones through local architecture, were the way society controlled basic energy efficiency, relying on non-renewable resources.

Therefore, it is possible to imagine a new, imaginary airport, which performs well both functionally and environmentally, by starting by thinking about the basic functions of the airport, then supporting these functions with buildings and technical systems. Then, it is possible to think about the causes of energy consumption in buildings and systems and the possibility of reducing this. After conducting this analysis, it is possible to start developing solutions that improve the airport's functional and energy performance.

5.2 The building's outer shell:

The climate inside the architectural spaces is considered part of the external climate and has undergone some changes from the external climate conditions as a result of the presence of a medium through which the external climate has moved into space. This medium is nothing but the external envelope of this space. Therefore, the external envelope of the building is considered the link between the interior and the exterior, whether the interior is connected to the exterior, such as vision or entering and exiting the building, or being affected by noise or heat or other external factors that affect internal space (Mohamed El-Eisawy, 2007).

Heat transfer between the interior and exterior is considered one of the most important elements of climate that has a strong impact on humans in terms of their feeling of comfort or not. Heat transfer between the external environment and the interior of the building takes place through its outer envelope of walls and ceilings as well as through external openings. Heat is transferred in the same way through ceilings and walls alike, but the amount of radiation falling on the surface is greater due to the long period of exposure to the sun. Therefore, the amount of heat leaking through it to the interior is greater than the vertical walls. As for the openings, they are considered the main source of heat penetration to the interior due to their thin thickness, as they are usually made of glass (Mohamed Abu Al-Fotouh, 2021).

5.2.1 The Effect of the Building's Outer Shell on Energy Consumption:

The outer envelope of the building plays a major role in reducing the loads on air conditioning devices, which increases the cost of operating the building throughout its lifespan. The outer envelope is the link between the internal space and the external space surrounding the building, as the design method and the materials from which it is made from a local climate. Accordingly, the basic concepts in climate design can be considered as follows:

- Reducing heat gain from surrounding heat sources.
- Conserving thermal energy in the interior space
- Disposing of thermal energy in the interior space.

There are several technical standards and determinants that, when available in the building's outer envelope, contribute to reducing air conditioning loads for air-conditioned buildings, which reduces the energy consumed in their operation, and thus reduces construction and operating costs over the entire life of the building.

The Egyptian Center for Housing and Building Research has issued the Egyptian Code for Improving Energy Efficiency in Buildings as a basic reference that the designer relies on in the building's outer envelope works. (Mohamed El-Eisawy, 2007)

This code aims to specify the mandatory requirements for the outer envelope of air-conditioned buildings, to improve energy efficiency and provide thermal comfort inside the space for users. Environmental architectural design methods as well as passive methods of cooling and heating contribute to rationalizing the consumption of electrical energy. These methods include controlling solar radiation falling on the external surfaces of the building, choosing the building's orientation and the optimal proportions of openings, choosing the thermal properties of building materials, and thermal insulation materials used to insulate the outer envelope of the building. (The Egyptian Code for Improving the Energy Efficiency of Buildings, 2005)

Self-design also calls for the phenomenon of using light-coloured materials through the colour of the building envelope (Ritchie, 2009), Especially the building's roof and facades, which gain high temperatures in the summer.

The formation of facades and their relationship with the surroundings on the vertical and horizontal levels with the external environment provides the best solutions for self-design, as these facades can be designed using special computational systems to determine their response to environmental influences. Materials are among the most important factors influencing self-design, in addition to the shading systems used to create good ventilation and prevent direct sunlight from entering the building. Proper design and continuous maintenance are essential to ensure the functionality of these features and their long-term sustainability. (Givoni, Baruch; John Wiley & Sons, 1994).

5.2.2 Treatments of the outer envelope elements:

There are several methods for treating the outer envelope elements, and they do not mean completely getting rid of the heat penetrating through it, but they are considered means of helping to reduce the heat penetrating into the space, and this is done through several factors in a way that prevents solar radiation from entering the building.

The relationship of the building with the surrounding environment and the way it is directed and shaped is important in keeping away solar radiation across different seasonal periods. The facades control it with shading methods and the type and size of openings used to control the amount of incoming solar radiation and reduce it, preserving the amount of incoming natural light. Smart glazing is one of the ecological systems that can be used in facades so that the temperature of the interior space does not increase and thus control solar radiation (Ritchie, Adam; Thomas, Randall, 2009).

Reducing the energy required to heat buildings by using the principle of orientation, and the shape of the windows to make the most of the latent solar energy, and at the same time reducing the energy required by having a good insulator with high performance glass. There are a number of different treatments depending on the element that can be summarized as follows (Mohamed Abu Al-Fotouh, 2021):

A- Roof Treatments: The heat transmitted to the roofs can be reduced through the following treatments:

- Using heat-insulating materials.
- Using materials that reflect sunlight.
- Leaving an insulating air space.
- Using curved roof shapes

B- Wall Treatments: Wall treatments are very similar to ceiling treatments. Examples of these treatments are as follows:

- Using heat insulation in the walls.
- Constructing walls from materials that are slow to gain and transfer heat.
- Constructing double walls that allow air to pass through and be renewed.
- Cladding the walls with heat-reflecting materials.
- Shading parts of the external walls with projections.

C- External Opening Treatments: External opening treatments play a fundamental role in reducing the thermal load penetrating into the building. The most famous examples of external opening treatments are the following:

- Using vertical and horizontal sun breakers for southern facades. Sun breakers differ according to the facade in which the opening is located. The design of the breaker also differs according to the designer's vision, provided that it achieves the primary goal of preventing sunlight from penetrating into space (National Center for Housing and Building Research-Cairo).
- Use high-quality glass to reduce the thermal loads transmitted through the openings.

5-3 Using the Egyptian Code to Improve Energy Efficiency in Buildings:

The Egyptian Code aims to specify the requirements for the outer envelope of air-conditioned buildings to improve energy efficiency and provide thermal comfort. Environmental architectural design methods and passive methods of cooling and heating contribute to rationalizing the consumption of electrical energy. These methods include controlling solar radiation falling on the external surfaces of the building, choosing the orientation of the building and the optimal proportions of openings, and choosing the thermal properties of building materials and thermal insulation materials used to insulate the outer envelope of the building. (Egyptian Code for Improving Energy Efficiency in Buildings; National Housing Research Center, 2005).

6. Practical Study

The study is based on analyzing a model to treat the facade most affected by the sun (the southern facades) of Terminal 3 at Cairo International Airport, as the study relies on using the value engineering methodology in analyzing the elements of the outer envelope of the southern facade as a model for choosing the most appropriate treatments for the sustainability of the building using the Egyptian code to improve the efficiency of energy use in buildings, finding

alternatives, evaluating those alternatives, and choosing the optimal alternative that achieves the highest value with appropriate quality and cost, depending on the project location, when developing the project in the future.



Figure 2 Cairo International Airport – Terminal-3 (google image.com)

6.1 Applying the Value Engineering Action Plan to the Case Study Cairo Airport -3:

6.1.1 Information Phase:

A- Project Location:

Cairo Airport is located in Cairo Governorate, 22 km southeast of the city center, in the Delta and Cairo regions according to the division of climatic regions in Egypt.

B- General Location:

The horizontal plane of the building is shaped like the letter U, with its sides pointing south and southeast, where the main entrance to the building is located on the northeastern facade. It is clear from studying the shape of the building and its general location that it does not receive any shadows due to the absence of any adjacent tall buildings according to the nature of airport locations. Due to the low height of the building and the small number of floors in it.



Figure 3 General location of Cairo Airport Building- 3(google.earth.com)

C- Horizontal analysis of typical floor:

The building consists of three main floors allocated:

- First floor: for passengers arriving on international flights.
- Second floor: for passengers departing on international flights.
- Third floor: for travel and arrival from domestic lines.

Two mezzanine floors: include administrative offices, airline offices and services necessary to serve and monitor air traffic.

D- Facades Objective of the study:

It is clear from the horizontal projections that all spaces on the facade Objective of the study are waiting halls and restaurants, and these spaces occupy %100of the facade Objective of the study.

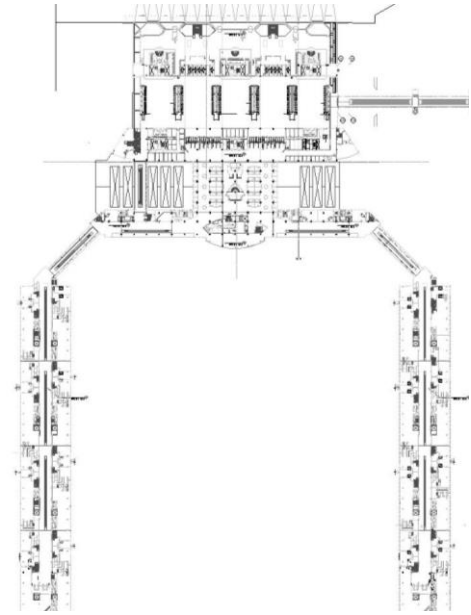


Figure 4 Horizontal plan of the ground floor - Cairo Airport-3 (Project Consultant ECG)



Figure 5 Aerial view of the southern facade - Cairo International Airport- 3 (AirportGuide.com)

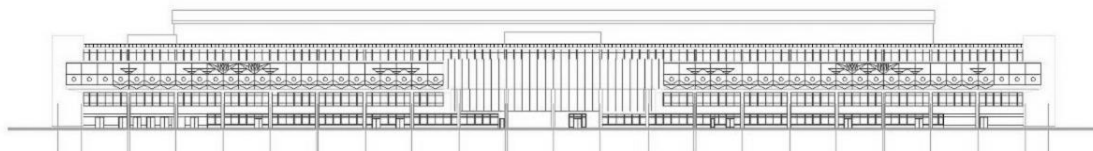


Figure 6 South Facade - CAD Program - Cairo International Airport- 3 (ECG Company, Cairo)

The facade elements under study are analyzed according to the Egyptian code for improving energy efficiency in buildings, to assess their compliance with the code standards, so that they are divided into solid areas and openings. The total thermal resistance of the wall is also calculated by the total sum of the resistances of the wall layers.

Table 2 Analysis of the facade elements under study in terms of solid spaces and openings

Total Area of the Southern Facade 4139.4m²		
Element	Area	Percentage of facade area
Solid walls	2019.5	48% of facade area
Openings	2119.9	52% of facade area

First: Analysis of solid walls:

Table 3 Analysis of thermal resistance to the required value according to the requirements of the code

South facade wall ratio %48 - Thermal resistance required			
Properties	Specifications	Resistance	Notes
Color	Dark red	0.9	Surface absorption is more than 50%
Construction weight	Light	1.8	Material density is more than 450 kg/m ³
Required thermal resistance	2.7 Required to be achieved		

Table 4 Analysis of thermal resistances by basic design

Thermal resistance of the southern facade walls in the basic design	
Layers	Resistance
Internal surface resistance	0.17
(Marble cladding 4cm)	0.068
Iron frame× 2	0.003
Rock wool insulation 7cm	0.62
GRC 10cm	0.116
External surface resistance	0.18
Total current thermal resistance of the wall	1.15

If thermal insulation is placed inside the walls, the thermal resistance decreases by %30, and thus the resistance value for thermal insulation with a thickness of 7 cm becomes $2.05 \times \%30 = 0.62 \text{ m}^2 \cdot \text{C/W}$ (Egyptian Code, 2005). The resistance of any component of the wall or ceiling varies depending on the type and thickness of the material and can be calculated from the following relationship:

$R = L / K$, $K = L / R$, $U = K / L$ where:

R = thermal resistance of the material ($\text{m}^2 \cdot \text{C} / \text{Watt}$)

L = thickness of the material (meter)

K = thermal conductivity of the material ($\text{W} / \text{m} \cdot \text{C}$)

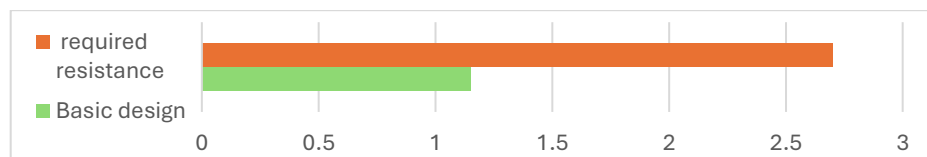


Figure 7 Comparison between basic thermal resistance and required thermal resistance.

Second: Analysis of the Openings:

A 12cm thick blue-green double-glazed glass with an air gap was used in the openings with a layer with an emissive coefficient of 0.2 mm on both sides, fixed type without thermal bridges (Films).

The thermal resistance value R was calculated using the equation: $U \text{ Value} = 1 / R$

The (U-value) refers to a measure of the efficiency of thermal insulation of glass facades, in terms of the amount of heat transmitted through the square meter of glass for each degree Celsius of the difference in temperature between the inside and outside. The lower the U value,

the better the thermal insulation, which means that the glass is more efficient in maintaining heat inside or outside the building.

The thermal gain coefficient SHGC, the thermal transmission U Value were calculated according to the code for the southern façade.

Table 5 Analysis of openings in the basic design and the required value

The percentage of the openings area on the southern facade is %52		
Properties	Basic design	Required value- Delta and Cairo region
Heat Gain Coefficient SHGC	0.43	0.3
Thermal Resistance R	0.334	0.82
Thermal Transmissivity U Value	2.99	1.2

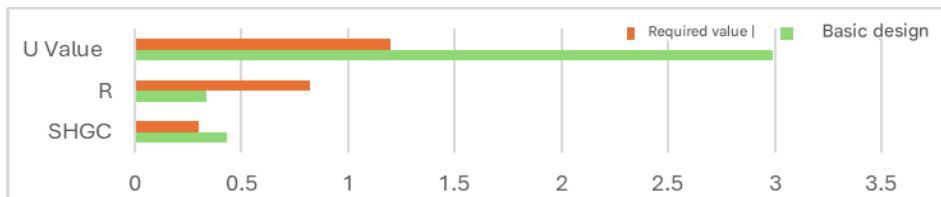


Figure 8 U-Value-SHGC-R ratio between basic design and required value for Delta and Cairo region.

E - Using energy modeling:

A three D -model of the building was built on the REVIT program with the internal spaces to be used with simulation programs to analyze and simulate the current situation correctly, as the Design Builder program was used to calculate the cooling loads required for the spaces connected to the facade under study.

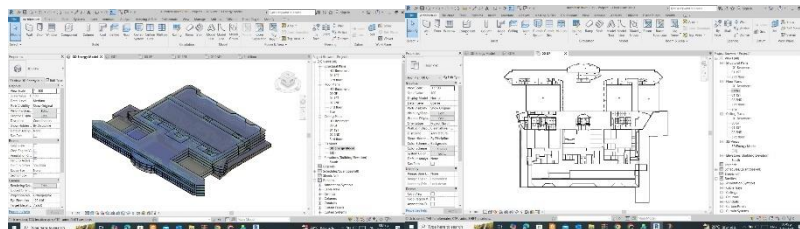


Figure 9 Building model on REVIT program

A few data required to be used in the program were identified, and through them the outputs of the existing design and the most environmentally appropriate design will be obtained, as follows:

- Building location: The building is located at latitude 30.12 and longitude 31.40.
- Orientation: South facade.
- Building activity: International airport - spaces on the facade are waiting halls and restaurants.
- Total area of spaces connected to the facade under study: 14741.34 m².
- Net height of one floor below the false ceiling: 3.5 m net.
- Number of floors: 3 floors and a basement
- Cooling degree inside the building: 24 °

- Control systems: There is an automatic main control system for the hall, and it has more than 18,000 control points.
- Operating schedule: 24 hours
- Air conditioning system in the building: 5 chillers in summer, 2 chillers in winter, 153 main air handling units with different capacities.
- Altitude above sea level: 122.6 m.
- Average annual temperature: °27^C. (World Meteorological Organization).
- Annual passenger capacity: 11million passengers at the start of construction and 20million passengers in 2020.
- Cooling loads for the building: tons of refrigeration, as in the table (Director of Power Plant station, Cairo Airport -3, 2024)

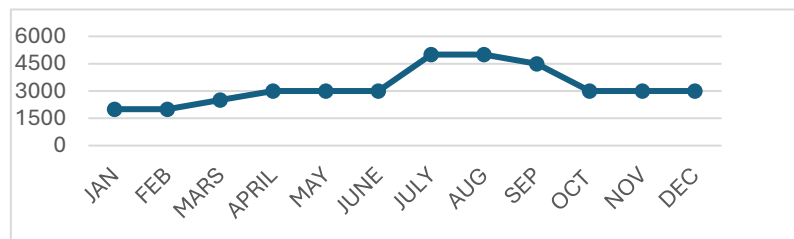


Figure 10 Year-round cooling loads for basic design (Cairo Airport Company, 2024)
Since 1000tons of refrigeration = 3.51kilowatts, the annual cooling loads = 137157.15 kilowatts/year.

Table 6 Cooling loads in kilowatts throughout the year for the basic design required to be entered into the simulation program (Cairo Airport company, 2024)

Month	Cooling load in tons of cooling	Cooling load in kW
January	2000	7033.7
February	2000	7033.7
March	2500	8792.1
April	3000	10550.55
May	3000	10550.55
June	3000	10550.55
July	5000	17584.26
August	5000	17584.26
September	4500	15825.8
October	3000	10550.55
November	3000	10550.55
December	3000	10550.55
Total Annual	39000 tons of cooling/year	137157.26 kWh/year

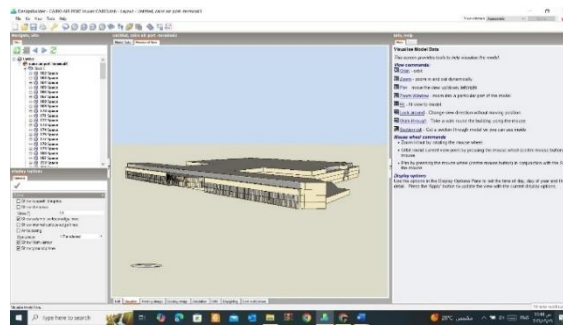


Figure 11 Building model on the simulation program Design Builder

F - Studying the building's construction requirements:

The following becomes clear through studying the building's special conditions and civil aviation requirements to identify the limits of permissible intervention in terms of the possibilities of modification in the formation or addition: (Cairo International Port Company, 2023)

- The necessity of maintaining the airport's operation without stopping work inside it.
- Maintaining the architectural formation of the facades.
- Not allowing any concrete protrusions in any direction for security reasons.
- Maintaining the floor areas as much as possible and the areas of the internal branches of the waiting halls and restaurants connected to the facade under study.
- The possibility of changing the glass openings with the addition of elements to prevent the leakage of heat and air.

G- Study Specifications (Mohamed El-Eisawy, 2007):

- Neutralizing the maintenance cost item for all alternatives and focusing on the initial cost and the cost of energy consumption over the life of the project.
- Neutralizing the impact of the thermal load of the basement floor on the level of alternatives in the study.
- Determining the average energy price in airport buildings according to the medium voltage electricity tariff for the year 2024, estimated at 1.389 pounds/kilowatt, and in peak months, 7-8-9, it reaches: 1.923 pounds/kilowatt (Electricity Regulatory Authority, www.egyptera.org)
- Criteria for evaluating glass in openings as will be used later in the standard evaluation matrix:
 - ☐ Reducing cooling loads.
 - ☐ Impact on thermal comfort.
 - ☐ Reducing the heat transfer of the glass U value.
 - ☐ Increasing the thermal resistance of glass type R.
 - ☐ Reducing the thermal conductivity K.
 - ☐ Impact on space.
 - ☐ Possibility of recycling and reusing.
 - ☐ Availability in the local market.
- Solid wall evaluation criteria as will be used later in the .
- standard evaluation matrix:
 - ☐ Consideration of architectural formation
 - ☐ Impact on thermal comfort

- Achieving the required thermal resistance R.
- Low thermal conductivity K.
- Impact on area
- Speed of implementation.
- Availability in the local market.

H-- Extracting the results of the analysis and collecting information:

The following is clear from the previous analysis of the different values of the facade elements:

- The percentage of walls on the southern facade is 48%
- The percentage of the openings on the southern facade is 52%
- The current total thermal resistance of the wall is 1.15 and the required is 2.7
- The heat gain coefficient SHGC is the basic value 0.43 and the required is 0.3
- The current thermal resistance R is 0.334 and the required is 0.82
- The current thermal transfer U Value is 2.99 and the required is 1.2
- A central air conditioning system is used, chillers (5 chillers in summer, 2 chillers in winter) containing 153 main air handling units of different capacities, with the temperature set at 24° in the presence of an automatic main control system for the hall, and it has more than 18,000 control points, and the system operating hours are 24 hours a day.
- The solid parts of the southern facade achieve 42.6% of the required thermal resistance, which will be worked on in the phase of finding suitable alternatives to increase the efficiency of the facade.
- The heat gain coefficient of the facade openings is high by a large percentage exceeding the required percentage by 143.3%.
- The thermal resistance of the openings achieves only 83.5% of the required value.
- The most energy consumed in the building is the energy resulting from cooling loads, equivalent to 10.12 gigawatts, followed by loads resulting from lighting, equivalent to 5.63 gigawatts, then electricity loads, equivalent to 5.12, and finally heating energy, equivalent to 0.37 gigawatts.

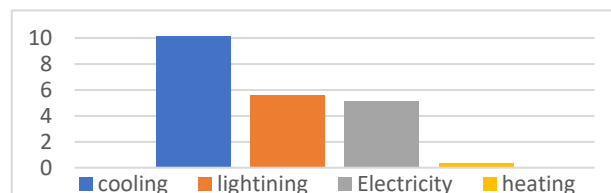


Figure 12 The most consumed energy in Cairo Airport Building- 3

- The cost of energy consumption in the building is estimated = (cooling energy in kilowatts × energy price), where each gigawatt = 1,000,000kilowatts, and thus the cost of energy consumption in the building becomes.

Table 7 Building Energy Cost - Basic Design

Energy Type	Energy consumption in kWh	Energy consumption cost in pounds
Cooling Energy	10120000	14.056680 million pounds
Lightning Energy	5630000	7.769400 million pounds
Electricity Energy	5120000	7.065600 million pounds
Heating Energy	370000	510600 pounds

Building Energy Consumption Cost for Basic Design	21720000 kWh	30.169080 million pounds
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6.1.2 Function Analysis Phase:

The functions are identified, classified, and linked to the FAST chart, and the functions that can be improved are selected.

6.1.3 Creative Phase:

The focus is on brainstorming and creating new ideas to achieve the required functions and technical specifications of the outer shell; Based on what was done:

- Specifications of the elements of the outer shell under study, along with code requirements.
- Properties and specifications of materials.
- Properties and specifications of materials.
- Specifications that need to be achieved and studied.

The most common, most used and most sustainable types of glass were chosen in international airport buildings, including Kansai Airport Japan, Ancon Airport Korea, Gatwick Building London, and finally Zayed International Airport UAE, which reduce the thermal load in the building to be simulated in Cairo Airport Building-3 in the Delta region and Cairo, and energy modeling in it, and these types will serve as alternatives to the outer shell as follows:

First: Proposing Ideas for Glass Alternatives:

Table 8 Types of glass alternatives based on theoretical study (Aviation Symposium, 2009; Buchanan, 1997)

Types of Glass	High-Performance Insulating Glass	Triple-Glazed Glass	Reflective Glass	Low e-glass
	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Airport	Zayed International UAE	Planned for Gatwick Building London	Angon Airport Korea	Kansai Airport Japan
Cost Pound	2000 - 3500	2500 - 1500	1200-2000	1500- 2500
Transparency	%34 Opaque Sun Blocking Glazing %50 Top Clear Bottom	Blue exterior and clear interior	Low Due to the metal coating, it blocks the view from the outside due to the reflection of the sun's rays	Large
Thickness	24mm	44mm	6mm	24mm
Layers	High performance selective laminated glass to filter out unwanted daylight waves	Two layers of 4mm glass with a 4mm heat mirror film between them	Clear Stainless Steel Coated 14%	Two layers of 6mm thick infrared absorbing glass with a 12mm air gap between them

	External face Bi-colored glass with solar coating Laminated glass with bi-colored frit + solar coating Air vacuum Internal face Clear glass with low-emissivity coating	Two 16mm air or argon spaces		
Type of Insulator in Outer Frame	Ammonium frame Rubber strips for protection and heat reduction on the facade	Rubber sealing frame for protection and reducing heat generated on the facade	Rubber frame for protection and reducing the heat generated on the facade	Silicone rubber frame for protection and reducing heat generated on the facade
Resistance R	5.2	1.6-0.8	0.19	2
Thermal Transmission	Less than 0.5	1.2- 0.6	5.11	0.5
U Value	0.005	0.025-0.05	0.031	0.12
Thermal Conductivity K	Includes double or triple glazing with additional insulation improvements such as low radiation coatings and improvements in the type of insulating gas	It consists of three layers of glass with two air or insulating gas gaps between them, providing the best thermal insulation performance.	Covered with a thin layer of metals to reduce the effect of penetrating sunlight by reflecting some of its rays	Low-E coatings help improve the thermal performance of the glass.
Specifications	Insulation with high selectivity layers to filter sunlight through the clear glass	No impact on architectural formation	Glass reflectivity for infrared rays 30-60%	A thin layer of material is applied that reflects heat and reduces its transmission, improving its thermal insulation efficiency

Second: Proposing Ideas for Alternatives to Insulating Solid Walls:

Using thermal insulation to improve the building's outer envelope through insulation to reduce heat gain and reduce heat transfer.

Table 9 View specifications for each solid wall alternative, (TPM Industrial Insulation & others; Warmcel and others)

	Solid wall insulation		
	Foam insulation - polyurethane	cellulose foam	Reflective coatings for surfaces
Alternative	Alternative 1	Alternative 2	Alternative 3
Cost	1,200 - 600	400 - 200	120 - 50
Thickness	20-40 mm	40-50 mm	0.3-1 mm
Resistance R	3.15	2.2-1.8	1-3
Thermal conductivity K W/m·K	0.026 -0.023	0.04-0.038	1.0-0.3
Specifications	Excellent for thermal insulation due to low thermal conductivity and high insulation efficiency	Environmentally friendly insulation as it is made from recycled materials	Reflective coatings can be used on building facades to improve heat gain control

Table 10 Analysis of thermal resistance after adding and replacing solid wall insulation

Thermal resistance of the southern facade walls in the basic design		When replaced with polyurethane foam	When replacing cellulose foam	Exterior paint reflective paint
Layers	Resistance	Alternative resistance 1	Alternative resistance 2	Alternative resistance 3
Internal surface resistance	0.17	0.17	0.17	0.17
(4cm marble cladding)	0.068	0.068	0.068	0.068
Iron frame *2	0.003	0.003	0.003	0.003
Rock wool insulation 7cm	0.62	3.15	2.2	0.62
GRC 10cm	0.116	0.116	0.116	0.116
External surface resistance	0.18	0.18	0.18	0.18
External paint	-	-	-	1
Total current thermal resistance of the wall	1.15	3.68	2.74	2.15
Required thermal resistance	2.7 Required to be achieved			

6.1.4 Evaluation and Selection Phase:

All ideas and alternatives mentioned in the creativity and innovation stage will be studied and analyzed. Serious ideas will be evaluated and selected, their quality and applicability will be tested, and ineffective ideas will be excluded, through the following:

First: Solid walls:

A- Choosing ineffective ideas:

It is clear from the previous table when using different alternatives for insulating materials, and through evaluating the resistance of the wall, we find that alternative No. 3, which is painting the external facade with reflective paint, did not achieve the required resistance when used, and its effect on changing the thermal properties of the wall is small, and therefore it was excluded.

B- Choosing the most suitable alternative:

Through simulation programs, the alternatives of solid walls in the southern facade in the Delta region and Cairo were evaluated, and their quality and energy consumption were selected. All effective treatment alternatives are compared, and to choose the most suitable alternative, a trade-off is made between them by calculating the costs of treatment alternatives and the standard evaluation matrix later.

C- Calculating the energy savings:

The energy savings are calculated for each alternative for 20 years using the Design Builder program; in order to simulate the proposed alternatives for the building and calculate the cooling loads required for the spaces connected to the facade under study (the outer shell of the southern facade). As follows:

- Cooling loads for the spaces connected to the outer shell = 10120000 kilowatts / year
- Cooling loads for alternative cases
- Energy price / kilowatt in pounds: 1.389 pounds
- Energy consumption cost in pounds / year = Cooling load x Official price per kilowatt / hour = 10120000 * 1.389 = 14.056680 million pounds
- Energy consumption cost in pounds for 20 years = Consumption value in pounds / year x 20
- = 14.056680 million * 20 = 281.133600 million pounds
- Savings in consumption = $\frac{\text{consumption for the basic design} - \text{consumption for the alternative case}}{\text{Consumption for the basic design}}$

Table 11 Energy consumption cost of solid wall alternatives

Alternatives	Annual cooling loads kW/year	Energy consumption costs in pounds	Energy consumption costs in pounds for 20 years	Savings value in pounds	Savings ratio
Basic Design	10120000	14.056680 million	281.133600 million	0	0
1 Polyurethane foam	9930000	12.909000 million	258.180000 million	22.953600 million	%8.1
2 Cellulose foam	9920000	12.896000 million	257.920000 million	23.213600 million	%8.3

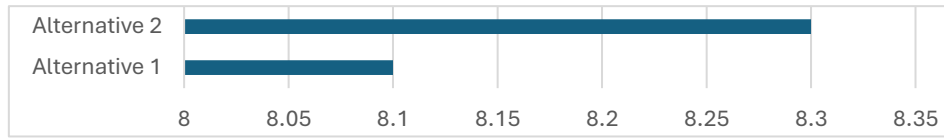


Figure 13 Energy saving ratio for solid wall alternatives

D - Calculating the cost of alternatives:

- At this stage, the following is calculated:
- The initial cost** required for treatment alternatives, which includes (supply and installation of raw materials - transportation and equipment costs, and operating and maintenance costs have been neutralized) * the area of solid walls
- The total cost**, which includes the initial cost + the cost of energy consumption during the project's lifespan of 20 years (from the previous table).

Table 12 Total cost of solid wall alternatives and percentage of savings

Alternatives	Initial cost: (million pounds)	Energy consumption costs in pounds for 20 years	Total cost: (million pounds)	Savings ratio
Basic Design	0	281.133600	281.133600	-
1 Polyurethane foam	1200*2019.5	258.180000	260.603400	%7.3
2 Cellulose foam	400*2019.5	257.920000	258.727800	%8

E- Standard Evaluation Matrix:

Weighted Evaluation Matrix (WEM)										
Standardized Evaluation System										
project Terminal 3 - Cairo International Airport										
insulation in solid walls - South façade										
Non-Monetary Criteria										
A. Achieving thermal insulation and thermal conductivity K	A									
B. Low thermal conductivity K	AB	B								
C. Possibility of recycling and reuse	AC	B1	C							
D. Availability in the local market	AD	B2	C1	D						
E. Cost	AE	B1	C2	DE	E	P	C	V		
the weight	4	5	4	2	2	Performance Points	LCC	(P / C)*100		
Relative weight %	24	29	24	12	12					
The basic design	1	3	3	5	3					
glass wool	23.5	88.2	70.6	58.8	35.3	276.5	281	98.343		
1st alternative	5	4	3	5	3					
polyurethane foam	117.6	117.6	70.6	58.8	35.3	400.0	260	153.846		
2nd Alternative	3	5	5	5	5					
cellulose foam	70.6	147.1	117.6	58.8	58.8	452.9	258	175.559		
Rating: 5 Excellent - 4 Very Good - 3 Good - 2 Acceptable - 1 Poor										
Non-Monetary Criteria Scoring References										
Value Index = Performance Points	2 Points for Major Preference									
Estimated Cost	1 Point for Minor Preference									

Figure 14 Standard evaluation matrix for solid walls in the southern façade

It is clear from the standard evaluation matrix of solid walls that the **second alternative** for treatments, which is replacing the internal thermal insulation with **cellulose insulation**, is the highest value and is the best option for treating the rationalization of energy consumption in the building under study in solid walls.

It is also clear that:

- The value of energy savings is 200,000 kilowatts, equivalent to 8.3% energy savings.

- The percentage of cost savings achieved by the second alternative is 8% cost savings.

Second: Glass Openings:

Through simulation programs, the alternatives of glass openings in the southern facade in the Delta region and Cairo were evaluated, and their quality and energy consumption were selected.

All effective treatment alternatives are compared, and to choose the most appropriate alternative, a trade-off is made between them by calculating the costs of the treatment alternatives and the standard evaluation matrix later.

A-Calculating the Energy Consumption Savings:

The energy consumption savings are calculated for each alternative for 20 years using the Design Builder program; in order to simulate the proposed alternatives for the building and calculate the cooling loads required for the spaces connected to the facade under study (the outer shell of the southern facade).

It is clear from calculating the cooling energy consumption for the basic design and the energy required for cooling loads, which is shown in the table as follows:

- Cooling loads for spaces connected to the outer envelope = 10120000kW/year
- Cooling loads for alternative cases
- Energy price/kW in pounds: 1.389pounds
- Energy consumption cost in pounds/year = Cooling load x Official price per kilowatt/hour = 10120000* 1.389= 14.056680million pounds
- Energy consumption cost in pounds for 20years = Consumption value in pounds/year x 20
- 14.056680 =million * 20= 281.133600million pounds

$$\text{Savings in consumption} = \frac{\text{consumption for the basic design} - \text{consumption for the alternative case}}{\text{Consumption for the basic design}}$$

Table 13 Energy consumption cost of glass louver alternatives

Alternatives	Annual cooling loads kWh/year	Energy consumption costs in pounds	Energy consumption costs in pounds for 20years	Savings value in pounds	Savings ratio
The basic design	10120000	14.056680 million	281.133600 million	0	0
1 High-Performance glass	9990000	12.987000 million	259.740000 million	21.393600 million	%7.6
2 Triple-Glazed Glass	10080000	13.104000 million	262.080000 million	19.053600 million	%6.7
3 Reflective Glass	10270000	13.351000 million	267.020000 million	14.113600 million	%5
4 Low e glass	9990000	12.987000 million	259.740000 million	21.393600 million	%7.6

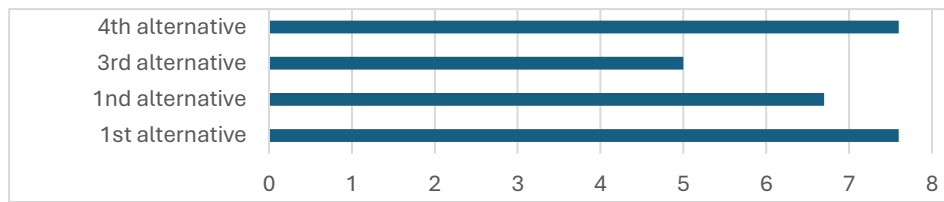


Figure 15 Energy saving percentage for glass opening alternatives.

B - Calculating the cost of alternatives:

At this stage, the following is calculated:

- **The initial cost** required for the alternative treatments, which includes (supply and installation of raw materials - transportation and equipment costs, operating and maintenance costs have been neutralized) * glass area.
- **The total cost**, which includes the initial cost + the cost of energy consumption during the project's lifespan of 20years (from the previous table).

Table 14 Total cost of alternatives and percentage of savings

Alternatives	Initial cost million pounds	Energy consumption costs in pounds for 20 years	Total cost million pounds	Savings percentage
The basic desig C- n	0	281.133600	281.133600	-
1 High-Performance glass	2119.9×3500 $7.419650 =$	259.740000	267.159650	%5
2 Triple-Glazed Glass	2119.9×2500 $4.239800 =$	262.080000	267.379750	%4.8
3 Reflective Glass	2119.9×2000 $4.239800 =$	267.020000	271.259800	%3.5
4 Low e glass	2119.9×2500 $5.299750 =$	259.740000	265.039750	%5.7

Standard Evaluation Matrix:

Weighted Evaluation Matrix (WEM)												
Standardized Evaluation System												
project Terminal 3 - Cairo International Airport												
Glass openings - South façade												
Non-Monetary Criteria												
A. reduce cooling load	A											
B. Effect on Thermal Comfort U-R-K	AB	B										
C. Impact on space	AC	B1	C									
D. Recyclable and reusable	AD	D1	D1									
E. Its availability in the local market	AE	B1	C1	E2	E		P	C	V			
	the weight	4	3	2	3	3	Performance Points	LCC	P / C*100			
	Relative weight %	27	20	13	20	20						
alternatives	basic design	3	3	3	1	5						
	double tinted Glass	80.0	60.0	40.0	20.0	100.0	390.0	281	106.712			
	1st alternative	5	4	3	3	3						
	High-Performance Insulating Glass	133.3	80.0	40.0	60.0	60.0	373.3	267	139.721			
	2nd alternative	5	5	1	3	4						
	Triple-Glazed Glass	133.3	100.0	13.3	60.0	80.0	386.7	267	144.656			
	3rd alternative	2	3	5	3	5						
	Reflective Glass	53.3	60.0	66.7	60.0	100.0	340.0	271	125.461			
	4 th alternative	5	5	3	3	4						
	Low-E glass	133.3	100.0	40.0	60.0	80.0	413.3	265	155.975			
Rating: 5,Excellent - 4 Very Good - 3 Good - 2 Acceptable - 1 Poor												

Figure 16 Standard evaluation matrix for glass openings in the southern façade

- It is clear from the standard evaluation matrix of glass openings that the fourth alternative for treatments, which is replacing the glass with low emissivity treated glass, is the highest value among the alternatives and is the best option for treating the rationalization of energy consumption in the building under study.

It is also clear that:

- The percentage of cost savings achieved by the fourth alternative is %5.7cost savings.
- The value of energy savings is 130,000kilowatts, equivalent to %7.6energy savings.

6.1.5 Presentation Phase:

A presentation of ideas is presented to review the study and its results with the efforts made, and the methodology followed in the study to reach those results, where the study report is reviewed and what it contains of solutions, proposals, ideas and recommendations about the design work to decide on them and include them in the next phase through the architectural evaluation matrix for alternatives

A presentation of ideas is presented to review the study and its results with the efforts made, and the methodology followed in the study to reach those results, where the study report is reviewed and what it contains of solutions, proposals, ideas and recommendations about the design work to decide on them and include them in the next phase through the architectural evaluation matrix for alternatives.

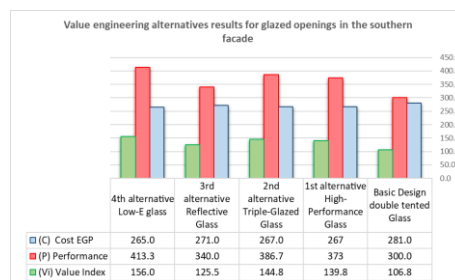


Figure 17 Value engineering alternatives results for glazed openings in the southern façade

The previous table shows that the fourth alternative (low-emissivity glass) is the best and highest performing for the building and gives the highest value despite its average cost, but the glass specifications achieve the thermal comfort required for the façade.

The following table also shows that the second alternative (cellulose foam insulation) is the best and highest performing for the building and gives the highest value despite its low cost, but it provides good value in terms of performance and economy.

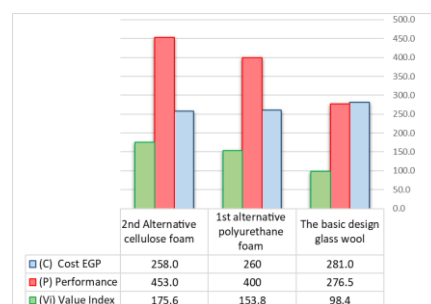


Figure 18 Results of value engineering alternatives for insulation in solid walls on the southern façade

6.1.6 Report Phase:

The preliminary report of the study is prepared to include a comprehensive explanation of the project, the problem, ideas, and alternatives to solve it and choose the best alternative.

7. Study Conclusion

- This study was conducted to inform effective long-term decisions on both design and construction in order to increase efficiency through project facades throughout the project life cycle.
- The research concluded the importance of applying the value engineering methodology during the planning phase for the development of existing airports and its impact on making design decisions for external envelope treatments, and how to apply this approach correctly to improve the building's performance at an appropriate cost, in addition to emphasizing the ability of value engineering to choose between alternatives based on a comparative analysis of the value level of the design elements that make up each alternative.
- The study resulted in evaluating the envelope of Terminal 3 with an area of 4139.4m², represented by the southern facade including passive design strategies, as the external envelope represents the largest share of the thermal comfort system for the building as a whole when replacing glass facades, which confirms the possibility of reducing the cost without compromising quality standards with the help of studies during the design phase, which will lead to:
 - Energy savings: 130,000kWh/year.
 - Total cost saved: 160.93850million pounds, when changing the glass areas of the facade.
- It will also lead to saving energy consumption of 200,000kilowatts, equivalent to %8.3 energy savings when replacing the internal thermal insulation and achieving a percentage of cost savings in solid walls achieved by the second alternative, which is %8cost savings.
- Studies have shown the weakness of environmental standards at Cairo Airport- 3and the extent of interest in taking the required measurements, hence the importance of developing a sustainable environmental strategy to be an approach when establishing and developing Egyptian airports and improving energy efficiency using the value engineering approach due to its role in improving building performance.

8. Recommendations

- The necessity of developing a proposed environmental strategy for future Egyptian airports and creating a vision for an environmental airport through the outer shell of its facades, as achieving sustainability is not limited to new buildings only, but also includes existing buildings.
- When attention is paid to the economic and functional performance of the project, as well as its impacts on the environment and society in the long term, in addition to the economic aspects, airports can enhance their efforts towards sustainability in an effective and organized manner, which helps them achieve a balance between the environmental, social and economic dimensions in their operations.
- Directing design teams towards finding new solutions using value engineering methodology, which will meet the minimum environmental impact of future requirements.
- Prioritizing passive design strategies as these are the most effective solutions to reduce the demand for cooling the building.

- Modeling passive design strategies separately and identifying the resulting cost savings using value engineering as these savings will be continuous and stable throughout the life cycle of the building.
- Using sustainable, recyclable materials for facades can reduce the environmental impact of the airport.
- It is important that future airport strategies place more emphasis on environmental strategies and increase the relationship between the economy and the environment with airports and the civil aviation industry.
- Using these strategies, the sustainability of Cairo Airport 3 can be significantly improved by designing built facades to maximize resource efficiency and minimize environmental impact.

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