Achieving Zero Energy Potential through Existing Building Retrofit

Case study: Center of Excellence for Research& Development of Biofuel Technology at the faculty of engineering, Mattaria branch, Helwan University

إمكانية الوصول إلى صفرية الطاقة من خلال تطوير المباني القائمة

دراسة حالة: مركز التميز لبحوث وتطوير تكنولوجيا الوقود الحيوي بكلية الهندسة بالمطرية، جامعة حلوان

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Abstract

This paper discusses the concept and significance of zero energy buildings and design considerations; then examines zero energy achieving possibility by retrofitting an existing building to maximize energy efficiency and utilize renewable energy sources. The existed Center of Excellence for Research & Development of Biofuel Technology is the selected case study to transform it to zero energy through calculating the building's real electricity consumption, simulating its performance using the design-builder program, applying environmental strategies to it, and simulating their role in improving the building energy efficiency and therefore reaching to a zero energy building.

Keywords: Zero energy buildings, Existing Buildings Retrofit, Energy Efficiency, Renewable sources

1. Introduction

Globally, the building and construction sector consumes about 40% of primary energy [1]. Most of this energy is produced from burning fossil fuels, which makes this sector the major contributor to increase global warming's negative impacts [2]. The building energy consumption depends on many factors such as the design efficiency, chosen materials, construction techniques, HVAC, lighting water heating system's efficiency, the devices and equipment's efficiency, and occupant's behavior [3]. Based on these facts; it is essential to improve the building's energy efficiency and use renewable energy technologies to meet energy consumption rates and environmental challenges, especially in the existing buildings because they represent the majority of the built environment and they use energy and produce greenhouse gases greater than the new ones [4]. So, this paper discusses the zero energy target as potential for the mentioned negative impacts of buildings and examines its achieving possibility on an existing building.

2. Study objective and Methodology: The objective of this study is the examination of achieving a zero energy building possibility by retrofitting an existing building as a case study. To achieve this objective; the study will include:

- **Theoretical study**

  This part of the study contains a literature review of zero energy buildings concept, design and construction consideration, and some environmental strategies and technologies that can be used to improve the building's energy efficiency or generate electricity from the available renewable sources.

- **Applied study**

  In this part, the study examines zero energy building achieving possibility on as existing building using the design-builder program after calibrating the building model to explain the actual performance of various strategies and their role in reaching a zero energy building.

3. Brief literature review

3.1 Zero Energy Buildings (ZEB) Concept

The ZEB concept is "a building with greatly reduced energy needs through efficiency gains such that the balance of the energy needs can be supplied by the renewable technologies". At the ideal conditions; ZEB generates on-site sufficient renewable energy to cover or surpass its annual energy needs. According to the national renewable energy laboratory (NREL), the zero-energy concept includes the following different definitions: "Net-Zero Site Energy, NetZero Source Energy, Net-Zero Energy Cost, and Net-Zero Energy Emissions" depending on project design targets [5].

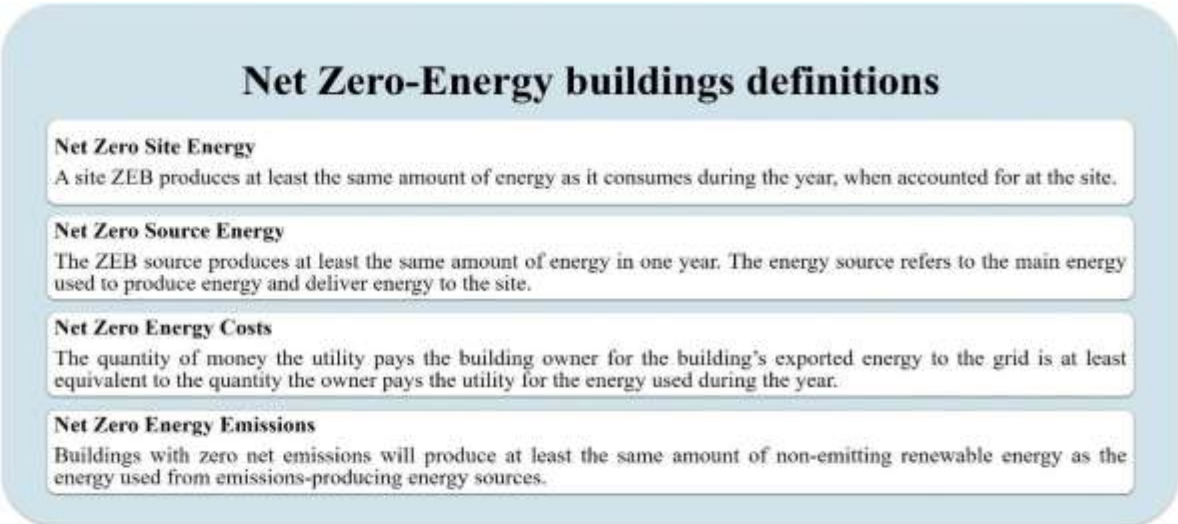


Figure 1: Net Zero Energy Definitions Based on NREL Definitions [6]

3.2 Design and Construction Considerations for ZEB

According to (Crawley, Pless, & Torcellini, 2009), the ideal process of achieving zeroenergy building contains two main levels. The first level is increasing the energy efficiency of the building envelope and systems to reduce the building's energy demands through employing environmental strategies and checking them frequently to ensure their energy efficiency such as natural day-lighting and ventilation, external shading for exposed windows, thermal insulation, high-efficient lighting, HVAC, water heating systems, energy-saving equipment, etc. The second level is generating electricity using the accessible renewable energy source to cover the remaining of the building's energy needs such as photovoltaic cells, wind turbines, biofuels, etc. [6]

On-site and off-site renewable energy generation are the two types of renewable energy generation. On-site energy generation incorporates renewable energy technologies into the building's footprint and site, such as using solar photovoltaic panels and solar heating systems on the building's roof. Off-site energygenerating purchases the required renewable energy from external renewable energy production sites [7]. The combination of these

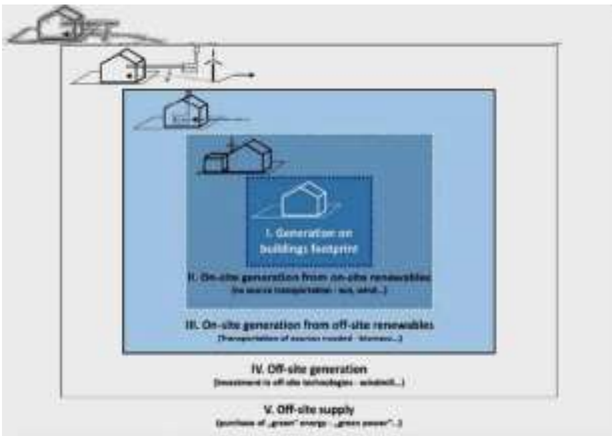
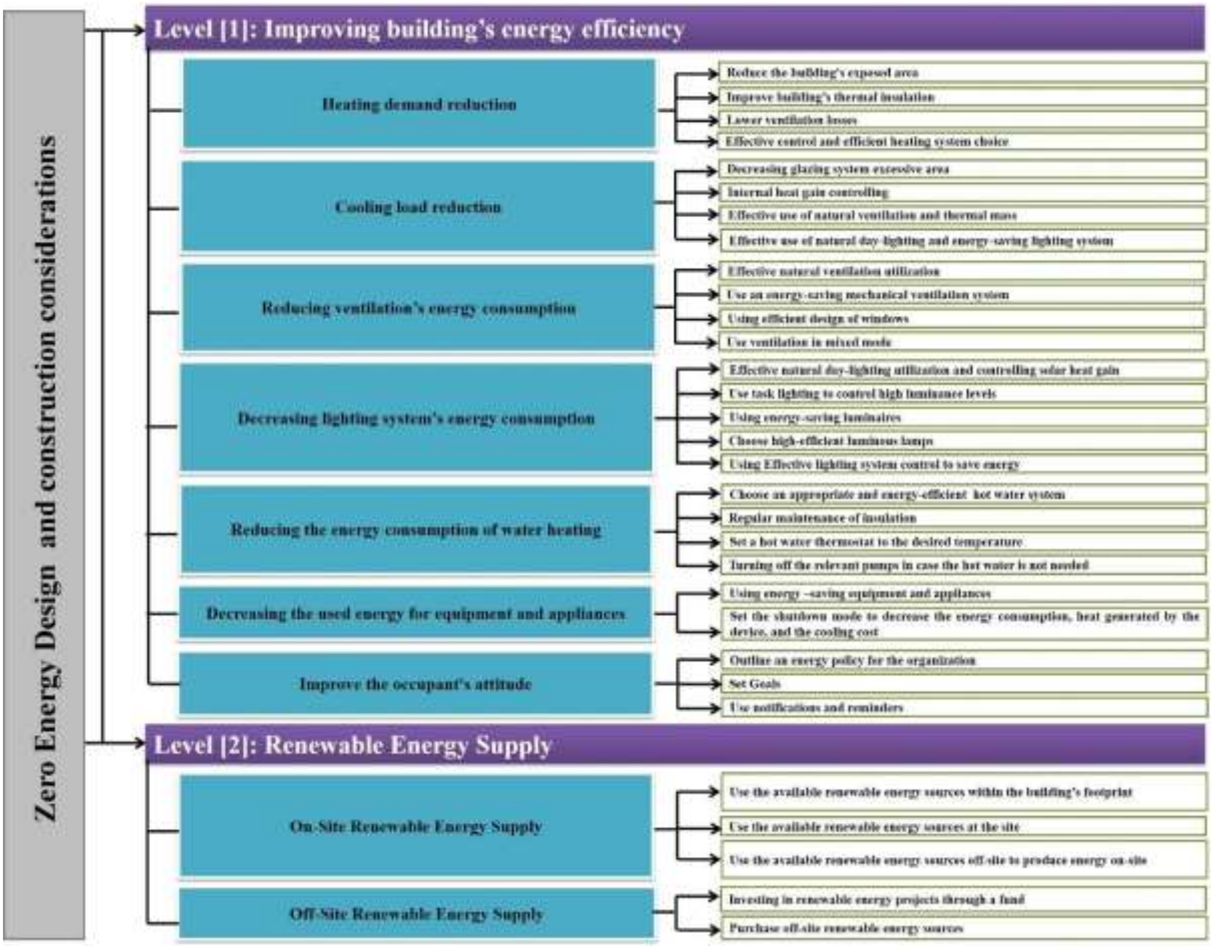


Figure 3: Overview of possible renewable energy supply options [8]



two levels is sufficient to achieve energy efficiency improvement and the zero-energy target.

Figure 2: Design and construction considerations for ZEB [6] [7] [9] [10]

3.3 Proposed methodology of applying zero energy on the existing buildings

Figure 4: Proposed methodology of applying zero energy on the existing buildings [4] [11] [12]

4. Case Study: Center of Excellence for Research &Developments of Biofuel Technology

Faculty of engineering, Helwan University, Mattaria Branch Buildings

Center of the Excellency for research & Development of biofuel technology site.

Figure5 : Site Location of Biofuel center, Google Earth

4.1 Biofuel Building Location

Center of Excellence for research & development of biofuel technology is located within the faculty of engineering, Mattaria branch, Helwan University. The center uses developing technologies to convert waste such as trees, grass, and other waste materials to fuels that can be used for electricity generation. Biofuels can reduce the dependence on fossil fuel, improve air quality, and support the economy [13].

Figure6 : Panorama view of the Existing buildings in the faculty of engineering, Mattaria branch [14].

4.2 Surrounding environment and existing buildings analysis

The biofuel center is independent of its surroundings except for the workshops. It is adjacent to the workshops and shares with them the back corridor. The site around the Biofuel center building is landscaped sufficiently of trees and shrubbery. The site has several building such as the automotive and tractors engineering building, architectural department building, Abd-Elrazek amphitheater, and credit hours building. There is a plaza in front of it and some sitting places. The sun’s rays can reach the building roof without being obstructed.

4.3 Climate Data Analysis

The building location is near Cairo Airport. So, it will use the weather data of the Cairo airport to determine the suitable environmental energy-efficient strategies and renewable energy generation systems. The Cairo airport location is at the north-east of Cairo with coordinates of 30° 6' 41" N, 31° 24' 50" E,75 m. According to [Köppen's climate classification], it has a hot desert climate [BWH] [15] [16]. Cairo climate data in [Figure 7] show hightemperature levels in the summer months; these indicate that the building in the summer months needs to control heat gain, and in the winter months, the sun is essential. The average length of daylight during the year allows access to take the most advantage of using natural day-lighting. Average sunshine hours through the year [Figure 7] and the average rates of global solar radiation [about 5.744kwh/m^2 per day] [17] [Figure 8] compared to the average lower wind speeds in Cairo [Figure 7] make the use of photovoltaic system is the most appropriate technology available to generate electricity.

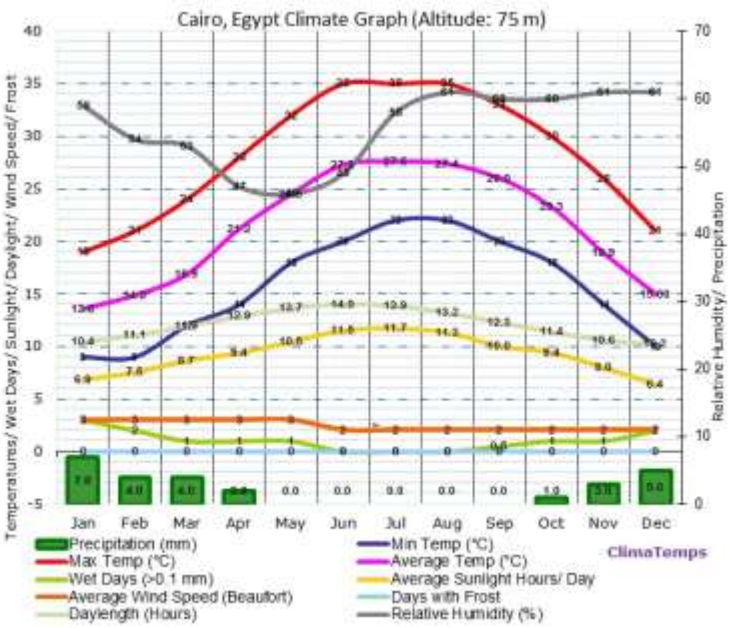


Figure 7: Cairo Climate data [16]

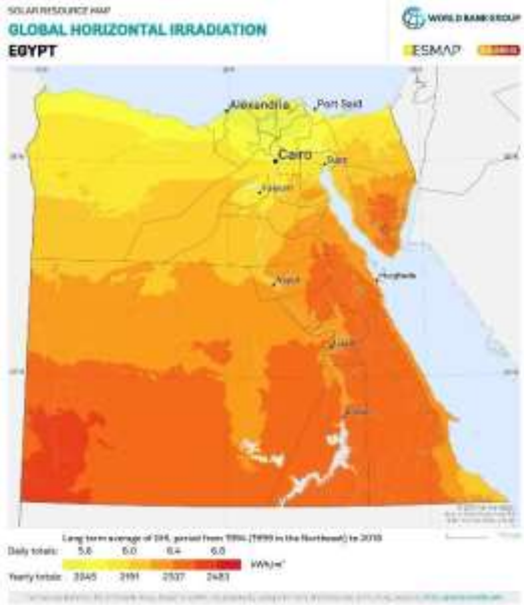


Figure 8: Global Solar Irradiation of Cairo [17]

4.4 Building Characteristics

The Center of Excellence for Research & Development of biofuel technology at the faculty of engineering, Mattaria branch is a renovated building that replaced an unused metal workshop. It consists of two floors; ground and mezzanine. The ground floor contains entrance hall, seminar hall, biofuel lab, laser lab, WC, and Two stairs. The mezzanine floor comprises offices, WC, and two stairs. The total area of the biofuel center is 370m^2.

Figure 9: The metal workshop before renovation

Figure 10: The building of metal workshop before Renovation and The metal workshop renovated proposal

Table 1: Biofuel center characteristics

Buiding Data	Characteristics
Renovation Date	2014 - 2017
Building Location	Faculty of engineering, Matteria branch, Helwan Univeristy
Design Form	The building has a rectangular plan shape

Area	$370\ m^2$	
Building Roof structure system	Vaults	
Building Envelope	The exterior walls is brick and stone Construction	
Interior building's Finish	Walls	White painted walls
	Floors	Porcelain
	Ceiling	White painted Vaults and false ceiling in the recption hall, seminar room, and the laser lab at the ground floor
	openings	Single and double glazing
Building Stairs numbers	The building has two steel stairs	

4.4.1 Biofuel center design

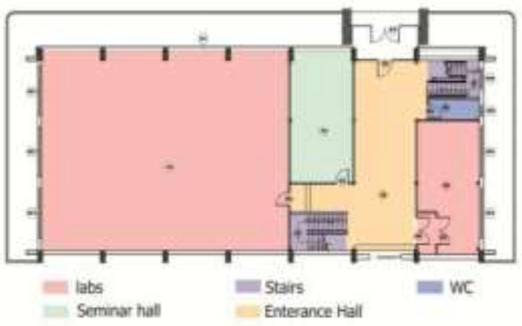


Figure22 : Shows Ground Floor Zones

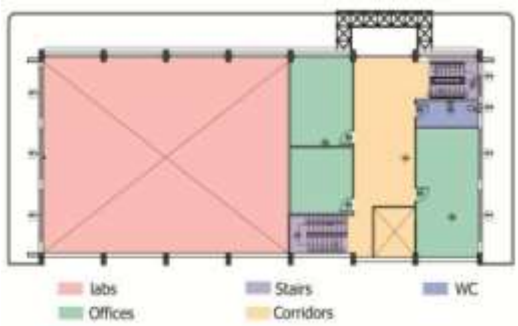


Figure21 : Shows First Floor Zones

4.4.2 Building Envelope

The main façade is a double-glazed curtain wall and a marble wall with 50 cm height from the ground surface. The East and West facades consist of brick, single glazed windows, and sandstone walls with 90 cm height from the ground surface. The south façade is white painted brick wall and it has an entrance opens to the workshops corridor. The cycloid vault's roof is made of concrete.

Figure 13: The Double glazed Curtain wall main north façade during renovation

Figure 14: Building east, west facades and the back entrance of the south facade

4.4.3 Interior building finish materials

All walls and vaulted roof are white painted. The ground floor rooms have false ceiling except biofuel lab, the building floors will be 40*40 cm porcelain tiles, and WCs have 30*30 cm ceramic tiles.

Figure 15: shows the interior biofuel building finish materials during renovation work

4.4.4 Building's Materials R-value

The biofuel building's component R-value is accessible in ECP306-2005 to use to make sure that the materials' R-value input of the design-builder virtual model is similar to the actual building's component R-value.

Table 2: Building envelope materials R-value [18]

Panels	Layers	Material	R-value
North exterior wall	2	Glass	0.3
East wall	3	Brick 25cm, two layer Plaster	0.6
West wall	4	Brick 25cm, two layer Plaster	0.6
		Sand stone	0.32
South wall	3	Brick 25cm, two layer Plaster	0.6
Ceiling	5	Concrete	0.3
		Gypsum Board	0.22
Roof	5	Concrete vaults	0.4
Floors	5	Concrete –sand- cement plaster, tiles	0.3

4.4.5 Openings' Characteristics

On the building's envelope, windows are sliding single glazed with aluminum frames. There is an iron Creteil on the outer window side. The used glazing properties and characteristics are shown in the following table:

Table 3: Biofuel Windows's characteristics[18]

Window	Glass type	NO.	size	Iron Creteil	U-value	SHGC
Sliding window	Single glazed	7	3 × 1.3	√	5.7	0.8
Hinged window	Single glazed	3	1.2 × 1.3	√	5.7	0.8
Pivotal window	Single glazed	3	3 × 0.5	-	5.7	0.8
Fixed window	Single glazed	1	1.2 × 2.3	√	6.42	0.78

There are two doors for the biofuel center entrances. They are the VIP door and the researchers' door. The VIP entrance has a vitreous door, while the researchers' door has a metal door. Doors characteristics are shown in the following table:

Table 4: The characteristics of biofuel building doors [18]

		Size			
VIP Door	Vitreous	2 × 2.3	-	2.59	0.66
Researchers door	Metal	2 × 2.3	√	0.35	-

4.4.6 Building's occupancy data

The occupancy data determine the user's number and their occupancy time in the building.

These data are utilized in the virtual model in the cooling design estimations, users' metabolic heat output, and holidays to estimate the building's heat input [19].

Table 5: Biofuel center spaces' occupancy

Space	Days number	Area (m^2)	people /week	Occupancy hours	Occupancy time	Occupancy Density (people/m^2)
Reception	6	49	1	6	9 am : 3 pm	0.02
Seminar hall	1	32	15	6	9 am : 3 pm	0.66
Laser lab	6	30	3	13	9 am : 10 pm	0.1
Bio-fuel lab	6	192	6	13	9 am : 10 pm	0.03
Offices	6	36	6	6	9 am : 3 pm	0.16
Corridors	6	40	0	0	0	0
meeting room	1	36	25	6	9 am : 3 pm	0.3
WCs	6	4	0	0	0	0
Holidays	From 1 July to 15 September From 30 Jan to 15 Feb Formal vacations					

4.5 Calculating electricity consumption of biofuel center

"The energy E in kilowatt-hours (kWh) per day is equal to the power P in watts (W) times number of usage hours per day t divided by 1000 watts per kilowatt":

- "E (kWh/day) = P (W) × t (h/day) / 1000(W/kW)"
- "E (kWh/year) = E (kWh/day) × Building work days" [20]

4.5.1 Electricity consumption from lighting system

The calculations of the biofuel center electricity consumption from lighting system are explained in the following table:

Table 6: Biofuel center lighting electricity consumption

space	Light type	*Light units*	*power* (W)	Σ power/h	Work hours	Work days	*E*(kWh/year)
Reception	Fluorescent Lamps	4	72	288	6	228	393.98
Seminar hall	Fluorescent Lamps	8	72	576	2	228	262.66
Laser lab	Fluorescent Lamps	8	72	576	6	228	787.97
Bio-fuel lab	Incandescent lamps	16	250	4000	6	228	5472
Offices	Fluorescent Lamps	4	80	320	3	228	218.88
Corridors	Fluorescent Lamps	5	80	400	3	228	273.6
meeting rooms	Fluorescent Lamps	5	80	400	3	228	273.6
WCs	Fluorescent Lamps	2	72	144	2	228	65.66
Stairs	Fluorescent Lamps	2	80	160	6	228	218.88
***E*(kWh/year)**							**7967.23**

4.5.2 Electricity consumption from building equipment

The biofuel center electricity consumption calculations from equipment are as follow:

Table 7: Energy Consumption from Equipment

space	Equipment	Power (w)	Work hours	Work days	*E*(kWh/yea)
Reception	Computer	500	6	228	684
	printer				
Seminar hall	Projector – Standby Mode	17	6	228	23.256
	Projector – Working Mode	315	3	228	215.46
	Computer	500	3	228	342
	Wall fan	180	3	87	46.98
Laser lab	Infrared Spectrometer With Hyper IR Software	150	8	228	273.6
	Wall fan	180	6	87	125.28
Bio-fuel lab	High performance liquid chromatograph (HPLC). Apparatus	600	8	228	1094.4

	Pensky- Matyens Flash Point Apparatus	720	8	228	1313.28
	Vacuum Distillation Apparatus	2500	8	228	4560
	Pour / Cloud Point Apparatus	3700	8	228	6748.8
	Cetane test engine combustion chamber	3500	8	228	6384
	Ceiling Fan	450	6	87	234.9
Offices	Computer	2000	6	228	2736
	printer				
	Airconditioning Unit (1.25 HP)	1862.5	4	87	648.15
Meeting rooms	Computer	500	6	228	684
	printer				
	Projector – Standby Mode	17	6	228	23.256
	Projector – Working Mode	315	3	228	215.46
	Wall fan	180	3	86	46.44
E **(kWh/year)**					**26399.26**

Total energy consumption = 7967.23 + 26399.262= 34366.492 kW/year

The monthly energy consumption calculations of the biofuel center are as follow:

Table 8: Total biofuel center monthly consumption

Month	Work days	lighting	Equip	Cooling	Fans	process	Total monthly consumption
Jan	25	873.6	554.85	0	0	2234	3662.45
Feb	11	384.4	252.5	0	0	983	1620.7
March	27	943.5	583.03	0	0	2412.7	3939.23
April	24	838.7	518.3	178.8	116.64	2144.64	3797.08
May	26	908.5	561.4	193.7	126.4	2323.4	4113.4
June	22	768.8	475.1	163.9	106.9	1965.9	3480.6
July	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0
September	15	524.2	323.91	111.6	72.9	1340.4	2373.01
October	26	908.54	561.4	0	0	2323.4	3793.34
November	26	908.54	561.4	0	0	2323.4	3793.34
December	26	908.54	561.4	0	0	2323.4	3793.34
Total	228	7967.32	4923.29	648	422.84	20374.24	34366.49

4.6 Simulation software selection and biofuel center virtual model

4.6.1 Simulation software selection

For the biofuel building simulation; the design-builder is the selected program because:

- The virtual created models in design-builder use ASHRAE standards, which make the generated results more precise.
- Design-builder provides various controlling possibilities for the data generated from the simulation process [21] [22] [23] [4].

4.6.2 Creating virtual model

All design-builder virtual model input are similar to the actual biofuel building's data.

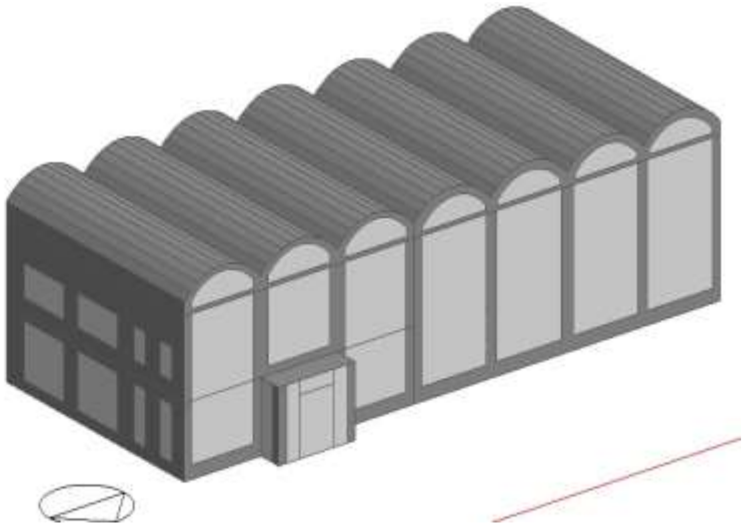


Figure 16: Biofuel building's 3d design builder virtual model

4.6.3 Calibrating the virtual model upon manual calculations

Calibrating the Virtual model created by the design-builder program by making a comparison between the manual calculations of building's electricity consumption and the virtual design-builder model's results until its reach so close to the manual calculations has a very effective role in achieving the zero-energy target. In most cases, un-calibrated models give misleading results and significant differences from the actual performance of the building that affect energy and financial saving rates. Calibrated models help in accurately evaluating energy-saving strategies. The calibrated model's results are within the acceptable accuracy ranges of the international simulation calibration standards and guidelines [4] [11] [12] [24].

In the biofuel center, the comparison between the electricity consumption's manual calculations and the design-builder results shows that:

- ➢ The cooling capacity has been considered "zero", but offices have a 1.25 HP air conditioning unit.
- ➢ The schedules input of the building's occupancy have wrong values.
- ➢ The process gain was 2.0 w/m^2 by default, so the process weight in the simulation results is incorrect. ➢ The luminaire type of biofuel center input is a recessed but it is suspended in the actual building.

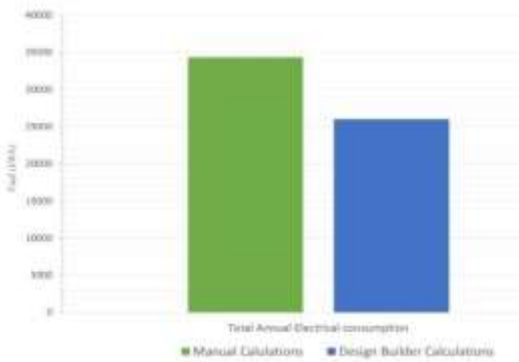


Figure 17: Total Annual Electrical Consumption comparison between Manual and Design builder calculations.

After the model's mistakes corrections, the design-builder results are very close to the actual building consumption, and the model has become calibrated according to ASHRAE-14 acceptable 15% monthly tolerance [24].

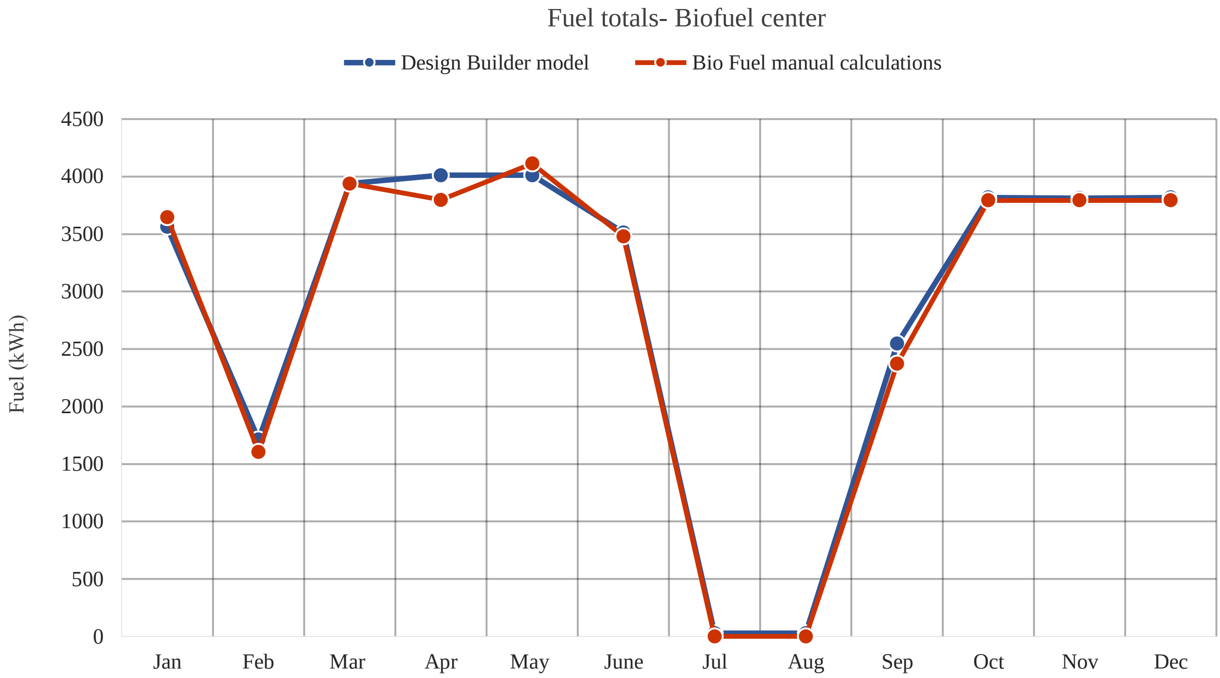


Figure 19: The comparison between the design-builder result and biofuel lab manual calculations shows that the perfected results is very close to the actual performance of the building

4.6.4 The Calibrated virtual model results

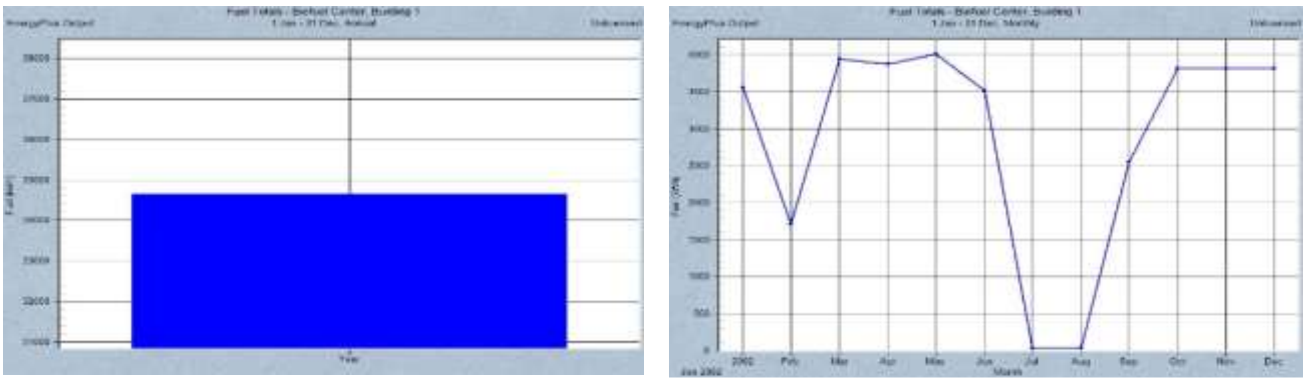
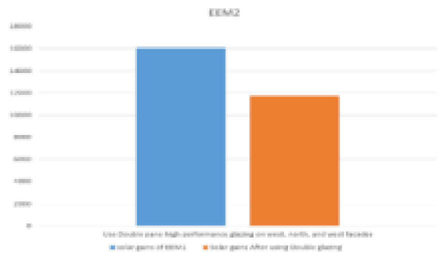
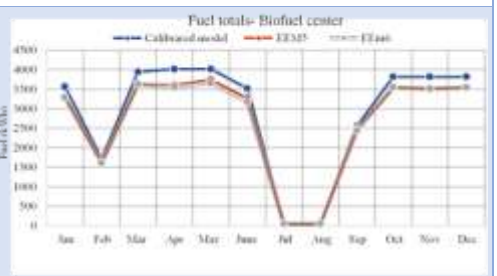


Figure 18: Biofuel building' annual and monthly energy consumption of the calibrated Design-Builder virtual model

4.7 Examining the achieving possibility of zero-energy target

4.7.1 Level one: Improving biofuel center energy efficiency

Energy – efficient strategies	The effect of applying the different environmental energy-efficient strategies

Adding shading devices	- Adding shading devices protect windows from heat gain, provide day-lighting, reduce glare, and keep outdoor air temperature low[25]. So window overhangs and side fins are used in east and west facades to examine the impact on building's energy consumption. - The simulation result shows that window overhangs and side fins lower the annual consumption by 0.4% and windows solar gains by 23.3%.	
Using double pane glazing on west, north, and west facades	- Using high performance glazing lower Ufactor, therefore reduce the windows solar gain [26]. - The simulation result shows that there is another annual solar gains reduction form exterior windows about 7% and no annual electrical consumption reduction.	
Using efficient light sources	- Replacing all lighting fixtures in the biofuel center with LED fixtures to improve the energy efficiency of the building's lighting system [27]. - The simulation result shows that using efficient LED fixtures lower the annual electrical consumption by 6.7% and cooling loads by 5.5%.	
Adding Roof Insulation	- To reduce the space-conditioning loads, installing 5cm glass fiber insulation to the roof lowering U-Value to 0.593(w/m2-k). - The simulation result shows that heat loss from the roof lowered by 54.6%, no annual electrical consumption reduction, and a little cooling loads reduction.	
Using Lighting controls	- Linear lighting controls are the selected type to improve energy efficiency in the building. The lighting controls lower the annual electrical consumption by 0.9% and a little reduction from cooling loads.	

Automation equipment, sensors and controls	- Sensors are utilized to make the equipment in response to occupant's attendance changes. - The simulation result shows that annual reduction reaches to 26.7% for electrical consumption. Process load reduces by 25.9%, equipment by 23.9%, and cooling loads by 2.9%.	
Operations and maintenance	- Checking and maintaining Regularly all building systems, components, and equipment guarantee that they are work efficiently.	

The using of the environmental strategies on the "Center of Excellence for Research & Development of Biofuel Technology" reduce the biofuel building electrical consumption by 26.7%.

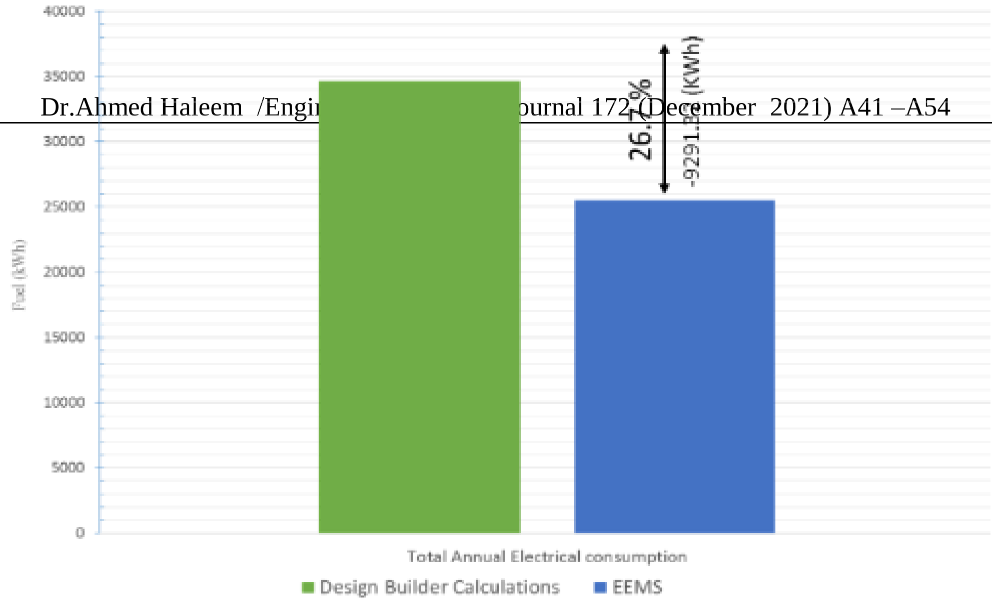


Figure 20: The energy reduction using Energy efficient strategies

4.7.2 Level two: On-site Renewable Energy Generation Potential

The biofuel center has an opportunity to produce electricity from two different renewable sources: solar energy and biofuel energy. The main source of energy production is the solar system on the building's rooftop supplemented by using a biofuel system that generates power from waste utilization if the solar production don't sufficient for the building's need.

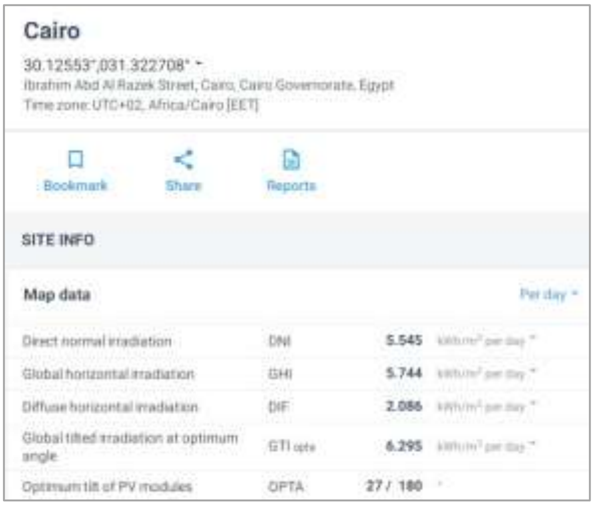


Figure 21: shows the solar radiation and optimum tilt angle for the building's location [28]

According to (the Global Solar Atlas), the most suitable type of PV module for Egypt is the crystalline-silicon PV, The ideal angle of inclination is between 20° and 33° oriented to the equator [17], and for the biofuel center location, The optimum inclination angle is [27°] towards south direction [figure 21] [28].

After adding a solar collector - Photovoltaic on the building rooftop and back corridor as shown in [figure 22] with a [27°] facing the south orientation to the biofuel center model, the designbuilder predicts a potential electricity generation of 24137.74 kWh/year that accounts for 94.7% of the building's electricity needs.

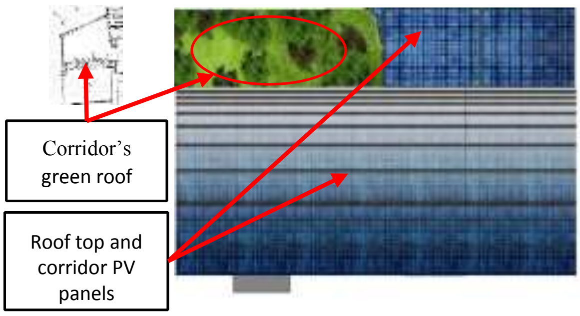


Figure 22: Layout of biofuel center shows the corridor's green roof and PV panels on both building's roof and corridor

As the Biofuel center has instituted to get the best benefits from waste by burning municipal waste using an air pollution control system to produce high-pressure steam in a boiler to drive a turbine to generate electricity [29]. So the produced biofuels can cover the remaining 5.3% of the building energy needs. Adding a green roof to the site green areas on the back corridor rooftop can provide solar gain reduction and improve air quality by reabsorption of the released carbon dioxide.

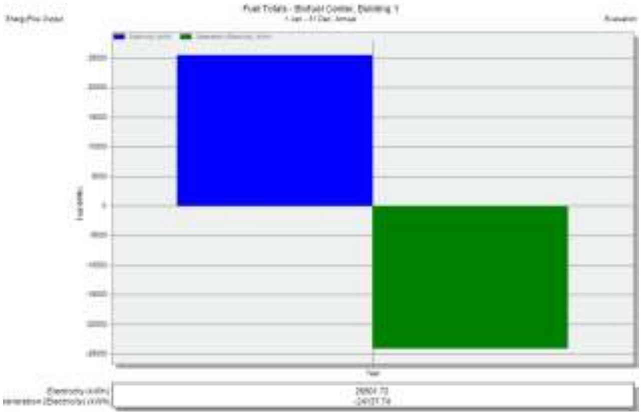


Figure 23: The on-site energy generation potential using roof PV panels

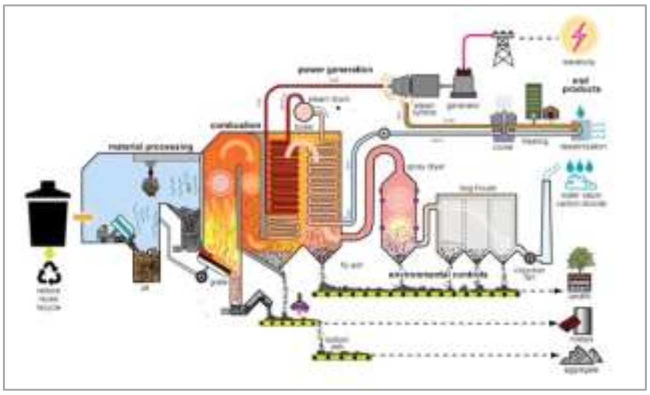


Figure 24: The process of using waste to generate electricity [29]

To calculate panels' number of the design builder predicted result; (Egypt-PV) stated that:

- The number of panels =”overall capacity / (sun peak hours*capacity per panel)”.
- Overall capacity= (the daily consumption of the building + power loss).
- The loss factor varies between 20 and 30 percent [30].

As the design builder predicts a potential PV output electricity generation of 24137.74 kWh/year, so the daily generation could be considered as the annual building generated electricity/ 365.

Building daily generation	24137.74/365= 66.13 kWh/day
Power loss (consider it as 30%)	66.13*30%= 19.839 kWh/day
Overall capacity	66.13+19.839=85.97 kWh/day
Sun peak hours	Consider it (5)
Panel's capacity	100 watt
panels number	85970/(5*100)= 171.94 ≈ 172 Solar panel
The required area of 4 panels	Consider it (10m^2)
The system required area	(172/ 4) *10 = 430m^2
Installation Placement	On the rooftop of biofuel building and back corridor
The mounting solar structure	For the biofuel building's roof: An elevated structure For back corridor's roof: Railed Mounting Structure

As illustrated in the previous proposal, the building requires a significant number of solar panels (about 172). So, the utilization of high-capacity panels lowers this amount. Regarding 25501.72 KWh building energy consumption; using a 250-watt capacity per panel minimize the panel's number to (73) solar panel as shown in the following table:

Building daily consumption	25501.72 /365= 69.87kWh/day
Power loss (consider it as 30%)	69.87*30%= 20.96kWh/day
Overall capacity	69.87+20.96=90.83kWh/day
Sun peak hours	Consider it (5)
Panel's capacity	250 watt
panels number	90830/(5*250)= 72.664 ≈ 73 Solar panel
The required area of 4 panels	Consider it (10m^2)

The system required area	(73/ 4) *10 = 182.5 m^2
Installation Placement	On the rooftop of biofuel building only
The mounting solar structure	For the biofuel building's roof: An elevated structure An elevated structure

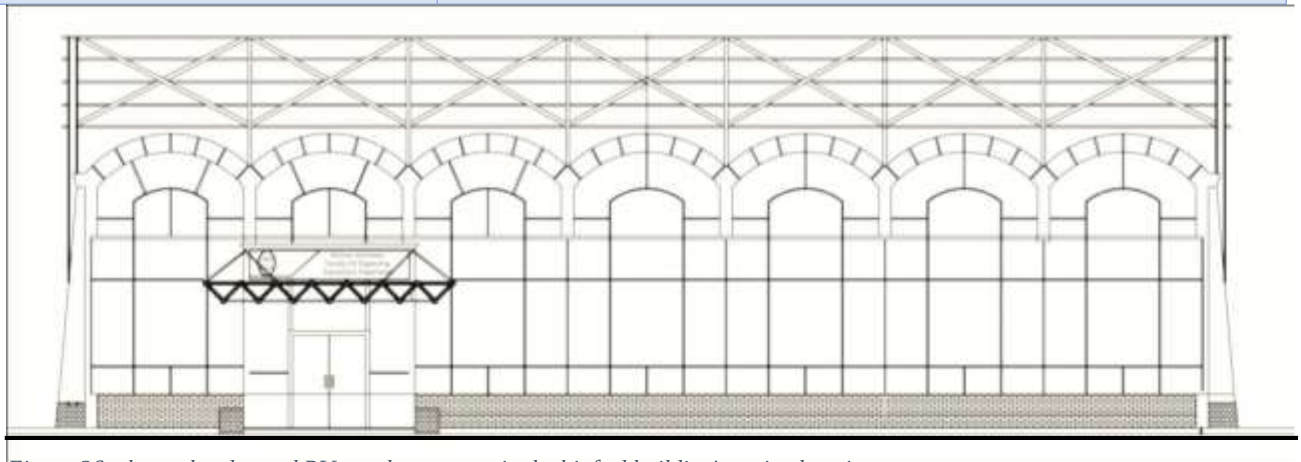


Figure 26: shows the elevated PV panels structure in the biofuel building's main elevation

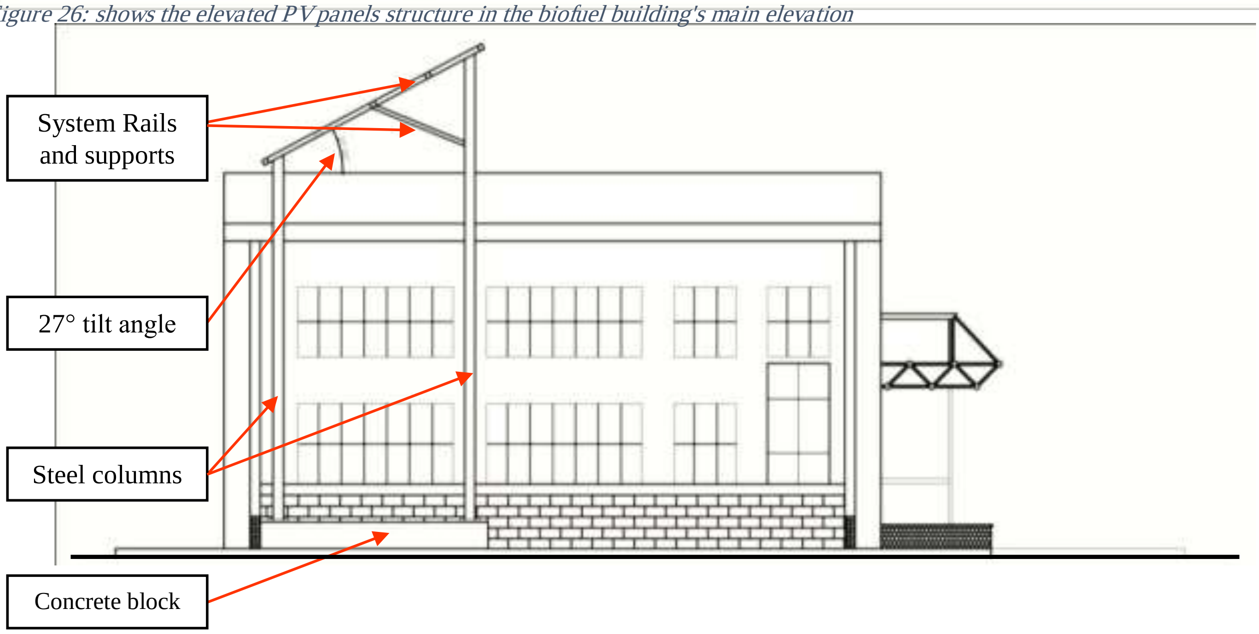


Figure 25: The elevated structure details from the side elevation

5. Conclusion

It is possible to reduce the high energy consumption rates (about 40% of the global total energy consumption) resulting from the building sector and the related environmental impacts by achieving zero-energy buildings, especially the existing buildings.

Achieving zero-energy target contains two main levels; improving the building energy efficiency and utilizing the available renewable energy sources. Using this method and following the proposed methodology steps, the biofuel center has reached the zero energy target. It achieves a 26.7% energy consumption reduction by utilizing environmental energyefficient strategies included shading devices, natural daylight, natural ventilation, efficient glazing type, energy efficient lighting sources, and equipment sensors installation. The potential of generating electricity using renewable sources depends on the project site's capabilities. In the biofuel center, there are two renewable sources available to produce electricity. The chosen main source of energy production is the solar system on the building's rooftop supplemented by using the biofuel energy if the solar production isn't sufficient for the building's needs. By using high-capacity solar panels; the PV system above the building rooftop can meet all the required energy and provide savings in solar system's panels number and the required area.

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