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MULTISTAGE OPTIMIZATION FOR SUSTAINABLE ZERO ENERGY RESIDENTIAL BUILDINGS ON THE HOT ARID CLIMATE

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Abstract. By decreasing the energy used, smart buildings can reduce their carbon footprint by incorporating sustainable energy sources into their energy mix. Building systems and energy sources are the most important factors in creating low-cost, high-energy-efficiency structures. Buildings that use the least amount of energy and have the lowest operating expenses are known as nearly zero-energy buildings (NZEBs). On the basis of a case study of residential building units located at the New Administrative Capital (NAC) in Egypt, the current paper introduces a general simulation methodology based on a multi-stage optimization process employing evolutionary algorithms to create virtually zero-energy buildings (ZEB). Additionally, this study simulates a workable energy plan to generate renewable building energy to reduce CO2 emissions, uphold sustainability, and combat climate change. As a result, the proposed methodology succeeded in minimizing CO_2 emissions at the residential building from approximately 100 kg to 30 kg daily. This means a 70% reduction in CO_2 emissions. The methodology of this research can be applied to both new residential construction and existing ones. Accordingly, an energy policy can be formulated based on the optimized results to execute the best building options to minimize CO_2 emissions.

Keywords: *Energy policy, optimization, renewable energy, sustainability, Zero Energy Building.*

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1. Introduction

Radiant energy is absorbed and reflected into the Earth's atmosphere by greenhouse gas (GHG), such as carbon dioxide (CO_2), ozone (O_3), methane (CH_4), nitrous oxide (N_2O), and water vapor (H_2O) (NASA GISS, 2016). Egypt's 2016 fossil CO_2 emissions were 219,377,350 tons. 4.72% more than the year before, or 9,879,440 tons more than 2015's CO_2 emissions of 209,497,910 tons (Emil & Diab, 2021). Egypt's Solar Atlas, on the other hand, is situated within the "sun belt" zone and receives between 2,000 and 3,000 kWh/m^2/year of direct solar radiation. From north to south, the sun shines for nine to eleven hours each day with little cloud cover (Fayad *et al*., 2020).

So, when the average temperature of the Earth's surface rises from 18°C (0 °F) to 15°C (59°F), the greenhouse effect occurs (Volkova *et al*., 2019). Human activities during the Industrial Revolution (about 1750), when the atmospheric CO_2 content

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increased by 45%, are the primary cause of this temperature increase (from 280 ppm in 1750 to 415 ppm in 2019). The primary source of CO_2 emissions in our facility is energy produced by the combustion of fossil fuels, including coal, oil, and natural gas (Jackson *et al.*, 2017; Elmousalami, 2021). Thus, unless GHG emissions are lowered during the next few years, humanity will suffer the disastrous effects of climate change (IPCC, 2018).

According to Egypt, extreme weather events and rising temperatures have caused devastating losses in nations throughout the Middle East and Central Asia. Egypt is extremely vulnerable to droughts, sea level rise, and other negative effects of climate change. Agriculture, tourism, and coastal towns will be particularly at risk if adaptation is not made (Omar *et al*., 2022). As a result, the Egyptian government's goal, as stated in its sustainable development strategy, is to reduce energy consumption and greenhouse gas emissions by 14% and 10%, respectively, by 2030. The goal of this phase is to minimize energy consumption in the building sector by implementing Net Zero Energy Building (NZEB) techniques for new construction and renovating existing buildings to lower demand and implement on-site generation to achieve NZEB goals (Emil & Diab, 2021).

Eliminating GHG emissions is just one aspect of mitigating climate change; adaptation is another (preparing for unavoidable consequences). Sustainable energy systems, zero-energy building techniques, and shifting land use all contribute to GHG mitigation (Rolnick *et al*., 2019). Crisis management, catastrophe preparedness, and understanding severe events all require adaptation. Therefore, it is necessary for public energy policies to support and supplement the management of energy use and generation in the building sector (Edenhofer, 2015). Best practices, initiatives, rules, and standards that are put into effect by governments, professional associations, international organizations, and standards committees are all examples of policy. Moreover, technology and artificial intelligence can play a significant role in fighting climate change and its related problems (Elmousalami, 2021; 2020).

Decision-makers frequently utilize quantitative techniques to investigate several policy options and choose the best one based on predetermined criteria (Elmousalami, 2020). Policymakers can analyze policy options and determine trade-offs based on many policy objectives with the aid of multi-criteria decision-making. However, it costs a lot of computation time to look for a Pareto-optimal answer. As a result, bio-inspired algorithms like particle swarms and evolutionary algorithms are frequently used to address this problem. 25% of worldwide greenhouse gas emissions each year are caused by electrical networks (IPCC, 2014). Furthermore, buildings consume 40% of all energy, and they are also responsible for 36% of CO_2 emissions (Liu *et al*., 2019; Hamdy *et al*., 2013).

As a result, the world community needs to act quickly to switch from carbon-emitting sources to low-carbon ones (such as solar, wind, and geothermal energy). Building efficiency improvements can successfully combat climate change by lowering greenhouse gas emissions, saving energy, and lowering operating costs (Wesselink & Deng, 2009; Boermans & Grözinger, 2011). Based on various energy policies, there is a global movement to minimize energy use and lower CO_2 emissions. For instance, China is the greatest emitter in our country and is first in line for responsibility for CO_2 emissions. The primary cause of CO_2 emissions in 2018 was the consumption of coal, which accounted for 59% of all energy consumption (Liu *et al*., 2019). As a result, as shown in Fig. 1, the Chinese government has implemented several regulations and policies based on green buildings, passive ultra-low energy green buildings, and nearly zero-energy buildings (NZEBs).

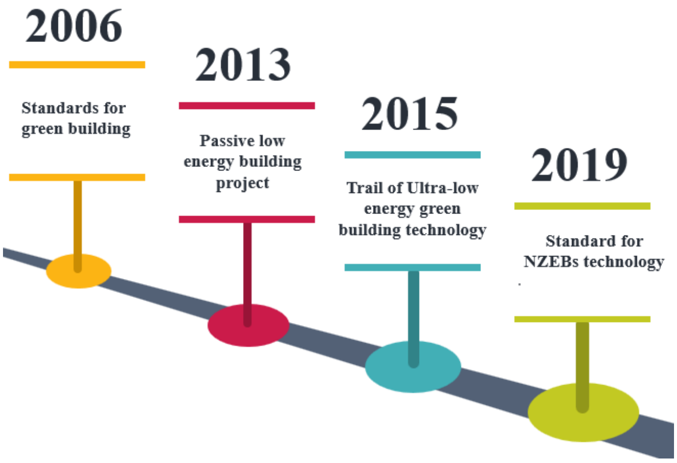

Figure 1. Development of building energy efficiency policies (Hamdy *et al.*, 2013)

Green buildings (sustainable construction buildings) are resource-efficient and environmentally responsible during the building lifecycle from the conceptual planning stage to all stages of the building lifecycle such as design, construction, maintenance, operation, renovation, and demolition (Zuo & Zhao, 2014). The key parameters for high-energy-efficiency and low-cost buildings are building systems and energy sources. Nearly zero energy buildings (NZEBs) are the concept of designing and operating buildings with the least energy consumption and least operational costs (D'Agostino & Parker, 2018) as shown in Fig.2. Designing NZEB is an exhausting job where the task requires searching and optimizing a huge number of building design combinations using energy supply systems and energy saving measures (D'Agostino & Mazzarella, 2019).

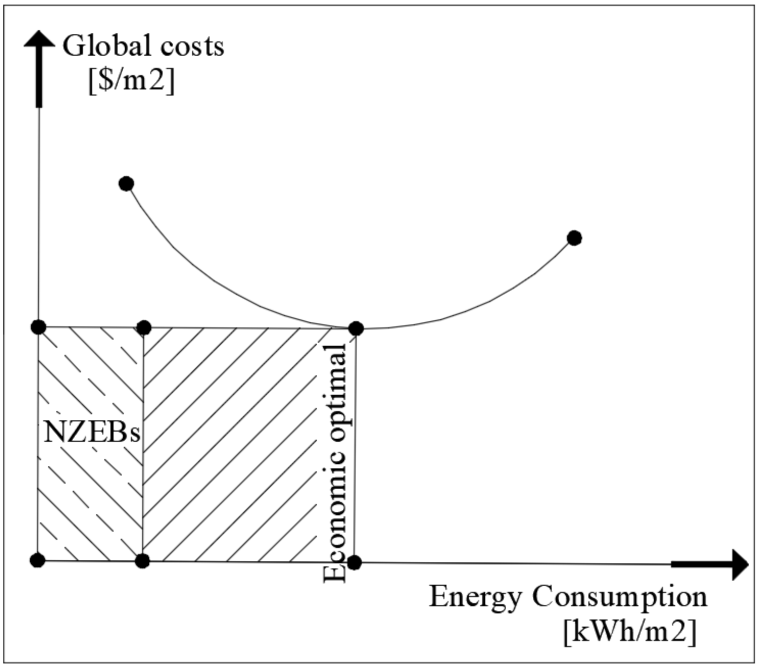

Figure 2. Cost optimal curve and NZEBs (Zuo & Zhao, 2014)

2. Relevant studies

In Egypt, three models for a residential unit with a fixed area of 110 m^2 were used for the study, which used Design Builder software for annual simulation and One-Click Life Cycle Assessment (LCA) software for 50 years of LC stimulation. The effects of replacing traditional building materials as a passive strategy and installing solar panels as an active technique were investigated. When both passive and active techniques were used on the experimental models, simulation results showed a reduction in carbon emissions through LCA of about 85% and a reduction in energy consumption of about 101%. To achieve the net zero carbon emissions (CE) target in a hot, arid climate, passive and active systems must be implemented and integrated into the early design phase (Fouly & Abdin, 2022).

In the case study region (Egypt), the construction sector mostly uses traditional building materials like concrete (plain and reinforced) and mud-fired bricks. Van Den Heede et al. (2012) and Zhang et al. (2014) came to the conclusion that a general value of embodied CE for the production of plain concrete (without steel reinforcement) had an amount of 425 kg CO_2 e/m^3 (Chastas, 2018), the embodied CE for reinforced concrete buildings had a range between 505.7 kg CO_2 e/m^3 and 1050 kg CO_2 e/m^2, which confirms its higher global warming potential (GWP).

The first home was built in Finland in the early 1990s with the goal of consuming the least amount of energy possible, and its energy use was tracked for three years. Energy efficiency's increased cost is recouped in five or six years (Hamdy *et al*., 2013). The use of NZEB performance in elements of appropriateness assessment, energy measures, and renewable energy application has been covered in numerous research studies. Georges et al. (2012) investigated a single-family residence in Belgium with sixteen heating systems and five building configurations. For multistory residential NZEB in Denmark, Marszal and Heiselberg (2011) optimized the life-cycle cost. As a result, policymakers and building managers can greatly benefit from the use of artificial intelligence and optimization approaches to control buildings.

For four building tightness levels, four-building insulation levels, nine heating systems, and three ventilation-heat recovery types, Pylsy and Kalema (2008) performed a life-cycle cost sensitivity study. The best solution for lowering the energy used to heat spaces is thermal insulation. To lower the life-cycle cost, Hasan et al. (2008) integrated optimization and simulation for a single-family home (LCC). The study investigated two different kinds of windows as well as the insulation levels of the roof, walls, and floors. An integrated, sustainable, and successful method has been created for improving energy efficiency in historic buildings using envelope insulation (Annibaldi *et al*., 2019). A fresh energy index is proposed, along with an outline of the definition of NZEBs, and a compressive comparison of NZEBs throughout Europe is discussed (D'Agostino & Mazzarella, 2019).

Heat-insulating solar glass, flat-plate solar collectors, and compound parabolic concentrator solar collectors have been reviewed and discussed for their energetic and financial performance in residential NZEBs (Li *et al*., 2019). To attain NZEB (2924 m^2) in Denmark, a convective building energy system with weather prediction control has been built. The effectiveness of power shifting, energy shifting, cost reduction, and comfort level in relation to weather predictive control systems is compared and evaluated (Liu & Heiselberg, 2019). For zero-energy office buildings in three different climate zones, a trigeneration system with hybrid photovoltaic-thermal (PVT) collectors has been created. Based on estimates of annual costs, the system is economically viable (Braun *et al.,* 2020).

To implement the NZEB design, distributed solar systems and air-source variable refrigerant flow have been created. Based on life-cycle cost analysis and energy efficiency standards in the USA, the system is dependable (Kim *et al*., 2020). Microclimate mitigation techniques in Italy can result in annual energy savings of up to 22%. (Cardinali *et al*., 2020). To assess the viability of constructing an integrated photovoltaic (PV) system with battery energy storage under the grid restrictions, economic analysis and correlation analysis have been carried out. The findings point to a workable solar power system with battery energy storage (Sharma *et al*., 2020).

For example, Barkokebas et al. (2019) have developed two methodologies to minimize the additional cost value of updated construction items on current houses in Canada based on the building specifications of the Alberta building code. However, based on the literature survey, the following points evolve:

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- Some research (Barkokebas *et al*., 2019; Pylsy & Kalema, 2008) concentrated primarily on planning and optimizing building envelopes, rejecting the idea that renewable energy is a viable and sustainable option for energy generation.
- While some techniques don't examine the cases of new construction structures, others simply focus on existing residential homes. Buildings vary based on their purpose, age, ownership, construction, climate zone, occupant behavior, and culture. As a result, depending on these variables, optimal tactics can differ greatly.
- According to its building code, some approaches are only applicable in regions with cold climates, such as Europe or Canada (Barkokebas *et al*., 2019).
- Some studies only offer a small number of possibilities for choosing the insulated envelope elements, resulting in limited solutions for envelope insulation systems. Some studies depend on only one objective function optimization, such as additional construction cost (Barkokebas *et al.,* 2019), where energy consumption and investment cost are ignored.

3. Research objectives

The main factors influencing the development of green buildings are energy rules and policies, energy conservation, and building prices (Darko *et al*., 2017). Consequently, the main objective of this research is to create an integrated methodological framework that can support the following goals in Egypt:

1. Choosing the best insulation system for the building envelop, comprising insulation for the walls, floors, roofs, and windows, to achieve the lowest thermal conductivity.
2. Determining the lowest energy output percentage that can be produced in a green structure utilizing renewable technologies to meet NZEBs. Each building with the least amount of renewable energy output can be required to employ this percentage as part of its energy policy. Additionally, installing a renewable energy system will improve the structure's sustainability and environmental impact (Darko *et al*., 2017).
3. Establishing the annual costs (ACs) and total additional construction costs (TACC) for the building's additional insulation and renewable energy systems.

4. A small number of possible building designs might result in millions of design alternatives. As a result, this study creates an appropriate optimization strategy for effective exploration.

a. Research Methodology

By decreasing the energy used, sustainable buildings can reduce their carbon footprint by incorporating clean energy sources into their energy mix. As illustrated in Fig. 3, the recommended technique for achieving the study's purpose is composed of four parts: inputs, processing, criteria, and output. The methodology of this research can be applied to both new residential construction and existing ones.

Inputs:

1. Building a case: building a new one or remodeling an existing one
2. Characteristics of the building: its size, its construction, how much electricity it uses, and its requirements and building code.
3. Climate zone and meteorological information: temperature, wind speed, and solar irradiation.
4. Solar, wind, and geothermal energy are examples of renewable energy sources.
5. Information about building costs
6. Economic and microeconomic factors, including market prices and inflation.

Process:

1. Choosing the best improvements for the building based on minimizing energy loss and optimizing the production of renewable energy.
2. Reducing the building's thermal conductivity is the foundation for limiting energy loss (U-value).
3. Choosing appropriate renewable systems based on the climate zone and weather profile and adjusting the renewable energy parameters are necessary to maximize the output of renewable energy.
4. Reducing the total additional construction cost (TACC).

Criteria: Thermal conductivity insulation and renewable energy production are the two factors that affect energy efficiency. Economic factors: the overall increase in total additional construction costs (TACC).

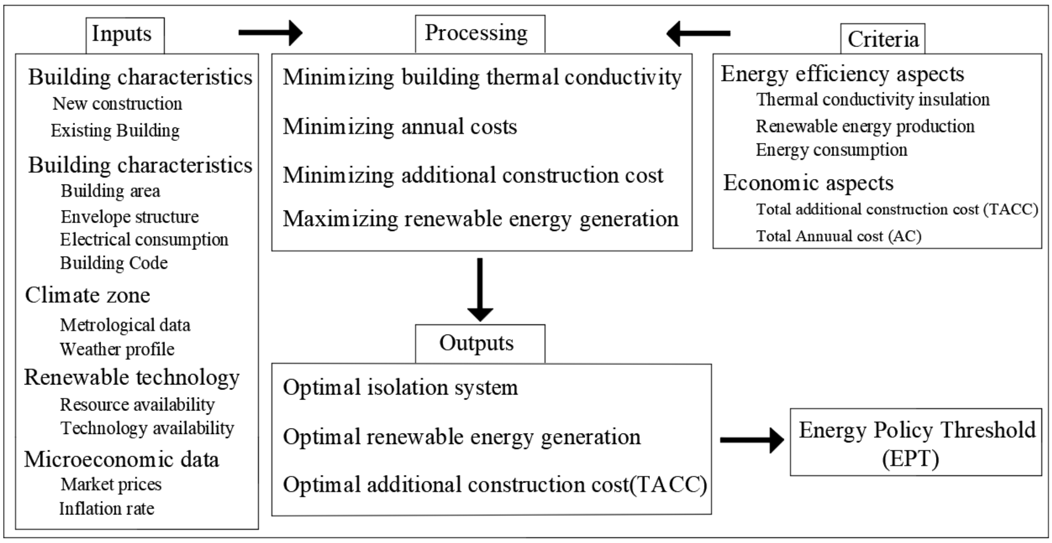

Figure 3. The NZEB methodology

Output

1. Choosing the best insulation method for the building's walls, roof, floor, and windows to achieve the lowest possible thermal conductivity
2. Outlining the building's use of renewable energy.
3. Establishing the least additional construction cost (LACC) for the inclusion of renewable energy systems and additional insulation to the structure
4. Establishing the energy policy threshold (EPT) that requires each building to produce renewable energy.

4. Case study

Residential buildings make about 60% of the building stock in Egypt (8 million structures and 78441 GWh/year) (Attia *et al*., 2012; Dabaieh *et al*., 2016; ElGohary & Khashaba, 2018). The residential building unit in the case study has a medium area of 135 m^2 and is located at New Administrative Capital (NAC) east of Cairo city in Egypt. According to Fig. 4, this construction unit is appropriate for a single family that, on average, has five members. Egypt receives more than 5 kwh/m^2/day of direct sun radiation on a yearly average (Aliyu *et al*., 2018). In areas with sunny climates, where each structure can produce some of its own electricity needs, solar energy has a promising future.

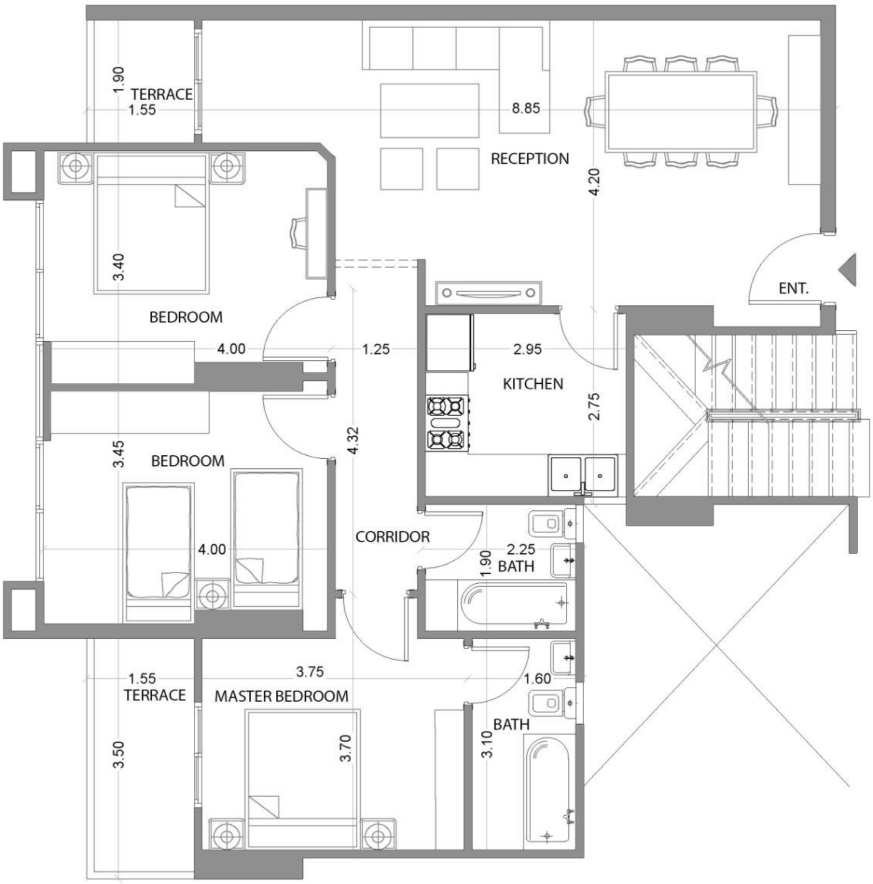

Figure 4. The residential building unit in Egypt (135 m^2)

4.1. Defining the design variables

The variables are classified into three main categories:

1. Passive energy variables, including all thermal resistance options for the roof, walls, floors, and windows as displayed in Table 1, where the thermal transmittance U-value (W/m^{2}K) and additional construction cost (ACC) for each option have been displayed. Table.1 includes 14 options for floor insulation, 25 options for wall insulation and construction, 12 options for roof insulation, 7 options for window types and 5 options (10%, 20%, 25%, 30%, and 40%) for window to wall ratio (WWR). The U-values and initial cost for WWR are calculated based on the following equations: Equation (1) and Equation (2):

$$U_{values\ WWR} = WWR(\%) * U_{value\ of\ window} + \big(1 - WWR(\%)\big) * U_{value\ of\ wall} \quad (1)$$

$$IC_{WWR} = WWR(\%) * cost\ of\ window + \big(1 - WWR(\%)\big) * cost\ of\ wall \quad (2)$$

where U-values WWR is the WWR's final U-value (W/m^{2}K), and ICWWR is the WWR's initial cost ($). The data for the U-value of window (W/m^2 K), U-value of wall (W/m^2 K), cost of window ($), and cost of wall ($) are available in Table.1 in sections of wall insulation (WI) and window types (WT).

Table 1. Building envelop insulation systems data

Floor insulation (FI)	**Specifications**	**U-value (W/m^2 K)**	**ACC ($/m^2)**
FI 1	No insulation (12 cm concrete)	1.14	0.00
FI 2	Polyure-thane from 0.2 m to 0.44 m. The number of options is 13 using a uniform step (0.02 m)	From 0.17 to 0.080	Thickness(m) * 112 ($/m^3)
Wall insulation (WI)			
	External Solid brick wall No insulation 25 cm		10 ($/m^2)
WI 1	Internal cavity brick wall/partitions 12 cm	1.58	5 ($/m^2)
WI 2	External wall Insulation; Mineral wool from	1.14	Thickness(m)
WI 3	0.185 m to 0.48 m. The number of options is	From 0.17 to 0.07	*62.72 ($/m^3)
WI 4	16 using a uniform step (0.02 m)	1.64	5 ($/m^2)
WI 5	Internal Solid brick wall/partitions 12 cm	1.08	10 ($/m^2)
WI 6	External cavity brick wall No insulation 25 cm	0.34	17 ($/m^2)
WI 7	Concrete block 22 cm + Polystyrene 10 cm	0.36	12 ($/m^2)
WI 8	Concrete block 10 cm + Polystyrene 10 cm	0.24	45 ($/m^2)
WI 10	Cellular (foam) concrete 37 cm	0.22	14 ($/m^2)
WI 11	Hemp concrete 30 cm	0.29	11 ($/m^2)
	Monomur brick 38 cm		
Roof insulation (RI)			
	Roof No insulation 12 cm concrete		22 ($/m^2)
RI 1	Insulation of Roof; Blow-in wool from 0.41 to	1.92	Thickness(m)
RI 2	0.55. The number of options is 8 using a	From 0.09 to 0.07	*36.2 ($/m^3)
RI 3	uniform step (0.02 m)	1.488	2 ($/m^2)
RI 4	Polystyrene (2 cm thickness)	0.744	3 ($/m^2)
RI 5	Polystyrene (4 cm thickness)	0.5208	4 ($/m^3)
	Polystyrene (6 cm thickness)		

Window types (WT)			
WT 1	Triple Laminated glass Wood aluminum frame (Argon gas)	1	228.4 ($/m^2)
WT 2	Triple Laminated glass Wood aluminum Frame (Argon gas)	0.85	267.4 ($/m^2)
WT 3	Quadruple Laminated Wood aluminum frame (Argon gas)	1.1	234 ($/m^2)
WT 4	Single glass windows price Aluminum frame	5.76	75 ($/m^2)
WT 5	Single reflective glass windows price Aluminum frame	5.36	76 ($/m^2)
WT 6	Double glass windows price Aluminum frame	3.71	90 ($/m^2)
WT 7	Double reflective glass windows price Aluminum frame	2.66	92 ($/m^2)
Window to Wall Ratio (WWR)			
	WWR (%)	Equation.1	Equation.2
WWR 1	10%	Equation.1	Equation.2
WWR 2	20%	Equation.1	Equation.2
WWR 3	25%	Equation.1	Equation.2
WWR 4	30%	Equation.1	Equation.2
WWR 5	40%	Equation.1	Equation.2

2. Sustainable energy variables include all clean energy options such as solar energy as displayed in Table 2 and solar heat collectors as displayed in Table 7 (WH6 and WH7). The type of solar heater was V-Guard 200-Watt Silicone Solar Water Heater. Table 2 shows the options for application of renewable supply systems. Table 2 displays the initial cost ($), electricity production (KWh/day/m^2), and annual electricity income ($/m^2/year). The PV panels are sloped by 30 degrees from south orientation to maximize solar energy harvesting (Hafez *et al.*, 2017; Aliyu *et al.*, 2018). PV type was Monocrystalline Solar Panels (Mono-SI). Moreover, the cost percentage of the solar system has been displayed in Fig.5, where the cost of photovoltaic (PV) panels represents 58.6% of the initial cost of the system. The initial additional construction cost of the PV system (ACCPVS) is shown in Equation (3).

$$AAC_{PVS}(\$) = 6000\$ + 83 * +A_{PVS}(\mathrm{m}^2) \tag{3}$$

where A_{PV}: Surface area of PV panels (m^2).

Table 2. Renewable energy system

System	PV panels cost ($ / m^2)	ACC ($)	Electricity production (KWh /day/ m^2)	Feed-in Tariff Returns $/KWh	Annual electricity income $/ m^2 /year
No PV system	0	0		0	0
With PV system	83	ACC_{PVS} Equation.3	1.692	0.06375	39.370725

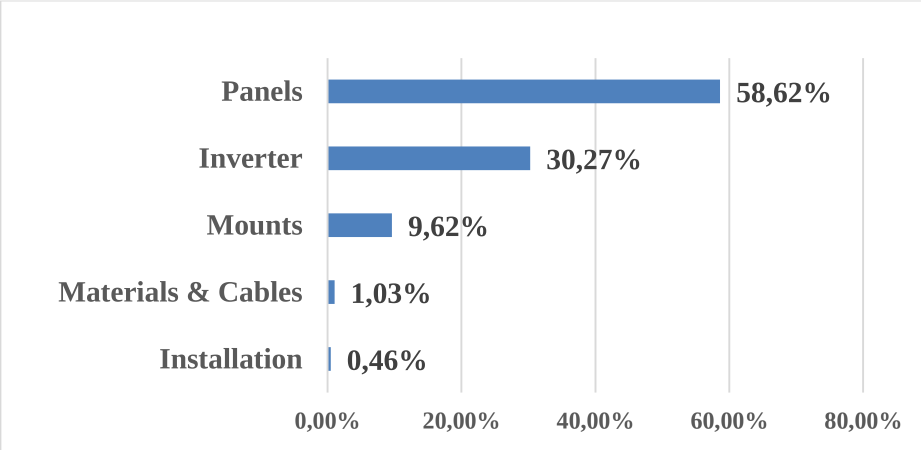

Figure 5. The cost of the electrical supply solar system

Table 3. Air conditioning units (ACUs) for first bedroom (13.2 m^2)

Notations	Cooling options	ACC ($)	Annual Electricity consumption (KWh/ Year)	Annual electricity cost ($/year)
C1.1	No cooling device	0	0.0	0.0
C1.2	(power 1.5 HP) (non-inverter) (CP = 18 C)	625	3613.5	327.5
C1.3	(power 2.25 HP)(non-inverter)(CP = 18 C)	687.5	5420.3	491.2
C1.4	(power 1.5 HP) (inverter)(CP = 18 C)	725	3131.7	283.8
C1.5	(power 2.25 HP)(inverter)(CP = 18 C)	787.5	4697.6	425.7
C1.6	(power 1.5 HP)(non inverter)(CP = 20 C)	625	3285.0	297.7
C1.7	(power 2.25 HP)(non-inverter)(CP = 20 C)	687.5	4927.5	446.6
C1.8	(power 1.5 HP)(inverter)(CP = 20 C)	725	2847.0	258.0
C1.9	(power 2.25 HP)(inverter)(CP = 20 C)	787.5	4270.5	387.0
C1.10	(power 1.5 HP)(non inverter)(CP =22 C)	625	2956.5	267.9
C1.11	(power 2.25 HP)(non inverter)(CP = 22 C)	687.5	4434.8	401.9
C1.12	(power 1.5 HP)(inverter)(CP = 22 C)	725	2562.3	232.2
C1.13	(power 2.25 HP)(inverter)(CP = 22 C)	787.5	3843.5	348.3
C1.14	(power 1.5 HP)(non inverter)(CP =24 C)	625	2660.9	241.1
C1.15	(power 2.25 HP)(non inverter)(CP = 24 C)	687.5	3991.3	361.7
C1.16	(power 1.5 HP)(inverter)(CP = 24 C)	725	2306.1	209.0
C1.17	(power 2.25 HP)(inverter)(CP = 24 C)	787.5	3459.1	313.5
C1.18	(power 1.5 HP)(non inverter)(CP =26 C)	625	2394.8	217.0
C1.19	(power 2.25 HP)(non inverter)(CP = 26 C)	687.5	3592.1	325.5
C1.20	(power 1.5 HP)(inverter)(CP = 26 C)	725	2075.5	188.1
C1.21	(power 2.25 HP)(inverter)(CP = 26 C)	787.5	3113.2	282.1

3. Energy consumption factors, such as all domestic appliances like air conditioners and kitchen appliances that use residential energy. As shown in Tables 3 to 9, lighting systems and water heaters absorb more than 75% of the annual energy used in homes in hot climates (Attia *et al*., 2012; Dabaieh *et al*., 2016). As a result, Table.3 shows the air conditioners for the first bedroom (13.2 m^2). Based on the cooling units' horsepower (1.5 HP, 2.25 HP, 3 HP, and 4 HP), unit type (inverter or non-inverter), and cooling point (CP), a total of 21 cooling possibilities have been found (18°C, 20°C, 22°C, 24°C, and 26°C).

Table 4. Air conditioning units for second bedroom (13.2 m^2)

Notations	Cooling options	ACC ($)	Annual Electricity consumption (KWh/ Year)	Annual electricity cost ($/year)
C2.1	No cooling device	0	0.0	0.0
C2.2	(power 1.5 HP)(non inverter)(CP = 18 C)	625	3613.5	327.5
C2.3	(power 2.25 HP)(non inverter)(CP = 18 C)	687.5	5420.3	491.2
C2.4	(power 1.5 HP)(inverter)(CP = 18 C)	725	3131.7	283.8
C2.5	(power 2.25 HP)(inverter)(CP = 18 C)	787.5	4697.6	425.7
C2.6	(power 1.5 HP)(non inverter)(CP = 20 C)	625	3285.0	297.7
C2.7	(power 2.25 HP)(non inverter)(CP = 20 C)	687.5	4927.5	446.6
C2.8	(power 1.5 HP)(inverter)(CP = 20 C)	725	2847.0	258.0
C2.9	(power 2.25 HP)(inverter)(CP = 20 C)	787.5	4270.5	387.0
C2.10	(power 1.5 HP)(non inverter)(CP =22 C)	625	2956.5	267.9
C2.11	(power 2.25 HP)(non inverter)(CP = 22 C)	687.5	4434.8	401.9
C2.12	(power 1.5 HP)(inverter)(CP = 22 C)	725	2562.3	232.2
C2.13	(power 2.25 HP)(inverter)(CP = 22 C)	787.5	3843.5	348.3
C2.14	(power 1.5 HP)(non inverter)(CP =24 C)	625	2660.9	241.1
C2.15	(power 2.25 HP)(non inverter)(CP = 24 C)	687.5	3991.3	361.7
C2.16	(power 1.5 HP)(inverter)(CP = 24 C)	725	2306.1	209.0
C2.17	(power 2.25 HP)(inverter)(CP = 24 C)	787.5	3459.1	313.5
C2.18	(power 1.5 HP)(non inverter)(CP =26 C)	625	2394.8	217.0
C2.19	(power 2.25 HP)(non inverter)(CP = 26 C)	687.5	3592.1	325.5
C2.20	(power 1.5 HP)(inverter)(CP = 26 C)	725	2075.5	188.1
C2.21	(power 2.25 HP)(inverter)(CP = 26 C)	787.5	3113.2	282.1

Table 5. Air conditioning units for master bedroom (13.7 m^2)

Notations	Cooling options	ACC ($)	Annual Electricity consumption (KWh/ Year)	Annual electricity cost ($/year)
C3.1	No cooling device	0	0	0
C3.2	(power 2.25 HP)(non inventer)(CP = 18 C)	625	5420.3	491.2
C3.3	(power 3 HP)(non inventer)(CP = 18 C)	687.5	7227.0	654.9
C3.4	(power 2.25 HP)(inventer)(CP = 18 C)	725	4697.6	425.7
C3.5	(power 3 HP)(inventer)(CP = 18 C)	787.5	6263.4	567.6
C3.6	(power 2.25 HP)(non inventer)(CP = 20 C)	625	4927.5	446.6
C3.7	(power 3 HP)(non inventer)(CP = 20 C)	687.5	6570.0	595.4
C3.8	(power 2.25 HP)(inventer)(CP = 20 C)	725	4270.5	387.0
C3.9	(power 3 HP)(inventer)(CP = 20 C)	787.5	5694.0	516.0
C3.10	(power 2.25 HP)(non inventer)(CP =22 C)	625	4434.8	401.9
C3.11	(power 3 HP)(non inventor)(CP = 22 C)	687.5	5913.0	535.9
C3.12	(power 2.25 HP)(inventor)(CP = 22 C)	725	3843.5	348.3
C3.13	(power 3 HP)(inventor)(CP = 22 C)	787.5	5124.6	464.4
C3.14	(power 2.25 HP)(non inventor)(CP =24 C)	625	3991.3	361.7
C3.15	(power 3 HP)(non inventor)(CP = 24 C)	687.5	5321.7	482.3
C3.16	(power 2.25 HP)(invinventorP = 24 C)	725	3459.1	313.5
C3.17	(power 3 HP)(inventor)(CP = 24 C)	787.5	4612.1	418.0

C3.18	(power 2.25 HP)(non inventor)(CP =26 C)	625	3592.1	325.5
C3.19	(power 3 HP)(non inventor)(CP = 26 C)	687.5	4789.5	434.1
C3.20	(power 2.25 HP)(inventor)(CP = 26 C)	725	3113.2	282.1
C3.21	(power 3 HP)(inventor)(CP = 26 C)	787.5	4150.9	376.2

Table 6. Air conditioning units for reception area (32 m^2)

Notations	Cooling options	ACC ($)	Annual Electricity consumption (KWh/ Year)	Annual electricity cost ($/year)
C4.1	No cooling device	0	0	0
C4.2	(power 3 HP)(non inventer)(CP = 18 C)	625	7227.0	654.9
C4.3	(power 4 HP)(non inventer)(CP = 18 C)	687.5	9636.0	873.3
C4.4	(power 3 HP)(inventer)(CP = 18 C)	725	6263.4	567.6
C4.5	(power 4 HP)(inventer)(CP = 18 C)	787.5	8351.2	756.8
C4.6	(power 3 HP)(non inventer)(CP = 20 C)	625	6570.0	595.4
C4.7	(power 4 HP)(non inventer)(CP = 20 C)	687.5	8760.0	793.9
C4.8	(power 3 HP)(inventer)(CP = 20 C)	725	5694.0	516.0
C4.9	(power 4 HP)(inventer)(CP = 20 C)	787.5	7592.0	688.0
C4.10	(power 3 HP)(non inventer)(CP =22 C)	625	5913.0	535.9
C4.11	(power 4 HP)(non inventer)(CP = 22 C)	687.5	7884.0	714.5
C4.12	(power 3 HP)(inventer)(CP = 22 C)	725	5124.6	464.4
C4.13	(power 4 HP)(inventer)(CP = 22 C)	787.5	6832.8	619.2
C4.14	(power 3 HP)(non inventer)(CP =24 C)	625	5321.7	482.3
C4.15	(power 4 HP)(non inventer)(CP = 24 C)	687.5	7095.6	643.0
C4.16	(power 3 HP)(inventer)(CP = 24 C)	725	4612.1	418.0
C4.17	(power 4 HP)(inventer)(CP = 24 C)	787.5	6149.5	557.3
C4.18	(power 3 HP)(non inventer)(CP =26 C)	625	4789.5	434.1
C4.19	(power 4 HP)(non inventer)(CP = 26 C)	687.5	6386.0	578.7
C4.20	(power 3 HP)(inventer)(CP = 26 C)	725	4150.9	376.2
C4.21	(power 4 HP)(inventer)(CP = 26 C)	787.5	5534.6	501.6

Table 7. Water heating options (WH)

Notations	water heating options	ACC ($)	Annual energy consumption (KWh/ year)	Annual cost ($/ year)
WH1	No water heating	0	0	0
WH2	Electrical water heater (50 Liter)	87.5	657	59.5
WH3	Electrical water heater (60 Liter)	100	821.25	74.4
WH4	Gas water heater (6 Liter)	80	711	13.7
WH5	Gas water heater (10 Liter)	93.75	1365	26.5
WH6	Solar water heater (100 Liter)	625	0	0
WH7	Solar water heater (250 Liter)	1125	0	0

Table 8. Cooking appliances

Notations	Cooking appliances	ACC ($)	Annual energy consumption (KWh/ year)	Annual cost ($/ year)
CA1	Only gas oven	0	3326.4	80
CA2	Microwave 20 Liters	125	365	33.078125
CA3	Kettle (1.7 Liter)	28	292	26.4625
CA4	Electric Oven (55 Liter)	87.5	803	72.771875

Table 9. Lighting device

Notations	Lighting device	Number of lamps	lightening density W/m^2	ACC ($)	Annual energy consumption (KWH/ year)	Annual cost ($/ year)
LD1	LED	21	4.2	94.5	1533	138.928125
LD2	Fluorescent	21	4.83	46.83	1762.95	159.7673438
LD3	Halogen	21	16.17	33.6	5902.05	534.8732813
LD4	Incandescent	21	21	7.77	7665	694.640625

Tables 4, 5, and 6 show the options for the second, master, and reception areas, respectively. The tables show the data for the initial cost ($) of the units, annual energy consumption (KWh/year) and annual cost ($/year). Table.8 shows the 4 options for cooking appliances, and Table.9 shows the 4 options for lighting devices.

5. Optimization formulation

The optimization model consists of two separate optimization modules. The first optimization module has two objective functions. The objectives are to minimize the thermal conductivity (U-value) and its additional construction cost (ACCT), as in the following equations: Equation (4) and Equation (5).

$$Min: AAC_T = \sum CC_T = CC_{FI} + CC_{WI} + CC_{RI} + CC_{WT} + CC_{WWR} \quad (4)$$

$$Min: TU_{value} = \sum U_{value} = U_{FI} + U_{WI} + U_{RI} + U_{WT} + U_{WWR} \quad (5)$$

where:
ACC_T : Additional construction costs due to thermal insulation in the building.
CCT: The cost of construction for each additional item of thermal insulation.

CC_{FI}, CC_{WI}, CC_{RI}, CC_{WT}, CC_{WWR} are the construction costs for floor insulation, wall insulation, roof insulation, window type, and widow to wall ration, respectively, as shown in Table.1.
TU_{value} : Total U-values for the thermal insulation elements in the building.
U_{value} : U-value for each thermal insulation element in the building as displayed in Table 1.
U_{FI}, U_{WI}, U_{RI}, U_{WT}, U_{WWR}: U-values for floor insulation, wall insulation, roof insulation, window type and widow to wall ration, respectively, as shown in Table.1.

The second optimization module consists of three objective optimization formulations. The objectives are to minimize annual energy consumption (AEC) and the home appliances' additional construction costs (ACC_A) and minimize the running annual costs (AC) as illustrated in the following equations.

$$Min: ACC_A = \sum ACC_A = ACC_{PVS} + \sum ACC_{CU} + \sum ACC_{CA} + ACC_{LD} + ACC_{WH} \quad (6)$$

where:

ACC_a: Additional construction costs incurred because of home appliances such as renewable energy systems, air conditioning units, cooking appliances, and lighting systems ($). The additional construction costs for photovoltaic systems (PVS), cooling units (CU), cooking appliances (CA), and lighting devices (LD), respectively.

$$Min: AC = a_e * \sum AC$$
$$\sum AC = AC_{CU} + \sum AC_{CA} + AC_{LD} - AC_{PVS} + AC_{WH} \quad (7)$$

$$a_e = \frac{1-(1+r_e)^{-n}}{r_e}$$

$$r_e = \frac{r-e}{1+e}$$

where:

AC: Annual cost of the home appliances ($/m^2/ year).

AC_{PVS}, $\sum AC_{CU}$, $\sum AC_{CA}$, AC_{LD}**:** running annual cost (AC) for photovoltaic system (PVS), cooling units (CU), cooking appliances (CA) and lightening devices (LD), respectively.

a_e: discount factor (a) for the energy price escalation rate.

r_e: real interest rate (r) for the energy price escalation rate.

r: real interest rate (7%).

e: energy price escalation rate (5%).

n: the lifetime period in years where the study assumes that no change exists in the building energy demand during the lifetime period (25 years).

$$Min: AEC = \sum AEC_{CU} + \sum AEC_{CA} + AEC_{LD} - REP + AEC_{WH} \quad (8)$$
$$REP = \sum REP_P$$

Constrains:

Total area of solar panels system ≤ 0.7 * Building roof area (135 m^2)

Total area of solar panels system = Number of Panels * Area of one PV panel (1.63m^2)

where:

AEC: Annual energy consumption (KWh / year).

$\sum ACC_{CU}$, $\sum AEC_{CA}$, AEC_{LD}, REP: Annual energy consumption (AEC) for cooling units (CU), cooking appliances (CA), lightening devices (LD), and renewable energy production (REP), respectively.

REP_P: renewable energy production for each PV panel.

The whole optimization model can be summarized in the Fig.6. The output of this optimization model are as follows:

1. Optimal thermal conductivity (U_{value})
2. Optimal ACC_T
3. Optimal combinations of home electrical appliance to minimize the AEC.
4. Optimal initial cost of these appliances (ACC_A).
5. Optimal running annal costs (AC).

6. Optimal life cycle cost (LCC) as the following equation.

$$LCC = TACC + Min\ (AC)$$

$$TACC = \sum ACC = Min\ (ACC_T) + Min\ (ACC_A)$$

where:
LCC: Life-cycle cost for the optimal options ($).
TACC: Total additional construction cost for the optimal options ($).
ACC: Additional construction cost ($).

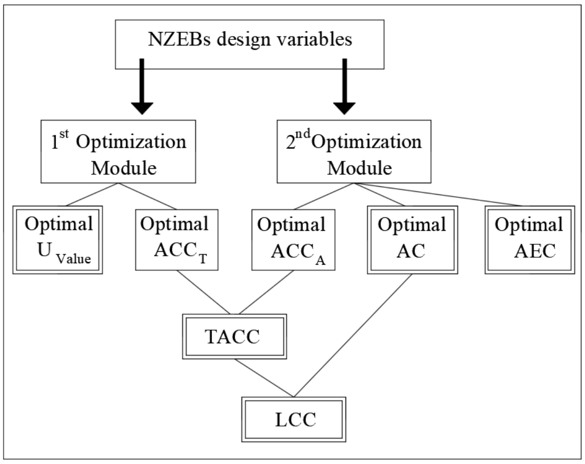

Figure 6. The optimization model

5.1. Genetic algorithm optimization

Natural selection and the Darwinian evolutionary theory serve as the foundation for the optimization strategy known as evolutionary computing (EC) (Darwin, 1859). An evolutionary algorithm (EA) used for searching and optimization based on a specified fitness function is known as a genetic algorithm (GA) (Siddique & Adeli 2013; Elmousalami & Elaskary 2020). The problem variable number is equal to the bit number in the chromosome string, which is how the chromosome is encoded as a binary digit (Kohavi & John, 1997; Beykal *et al*., 2018).

The functional unit of the inheritance process is the chromosomal gene, where each chromosome is represented by a collection of genes. Floor insulation (FI), wall insulation (WI), roof insulation (RI), window types (WT), and window to wall ratio (WWR) make up the chromosome for the first optimization module. As shown in Fig. 7, the two associated output genes are the additional construction cost due to thermal insulation in the building (ACCT) and the total U-values for the thermal insulation elements in the building (TU value). Equations (4) and will serve as the goal functions for the initial optimization module (5). The chromosomal digits are depicted coding and decoding in Fig. 7. For instance, for floor insulation (FI), there are only two options: FI1 and FI2, which will be coded as 0 and 1, respectively.

The chromosome for the second optimization module can be represented similarly, with the input vector consisting of the surface area of PV panels (APV), air conditioning units (ACUs), water heating options (WH), cooking appliances (CA), and lighting devices (LD), and the three associated output genes being the additional construction cost due to home appliances like the renewable energy system, air conditioning units, cooking appliances, and lighting systems (ACCa), the additional construction cost due to the water heating options (WH), and the additional construction cost due to the (AEC). Equations will serve as the second optimization module's goal function (6, 7, and 8). With 5000 iterations, the GA optimization settings were set to 0.7 for crossover and 0.03 for mutation.

First Optimization module

	FI	WI	RI	WT	WWR	*Output* ACC$_T$	*Output* TU value
Chromosome 1	FI 1	WI 1	RI 1	WT 1	WWR 1	$15,054.00	0.07
Chromosome 2	FI 2	WI 2	RI 3	WT2	WWR 2	$17,560.00	0.03
…….	…….	…….	…….	…….	…….	…….	…….
Chromosome _N	FI 2	WI 3	RI 3	WT 3	WWR 3	$13,250.00	0.05

Second Optimization module

	A$_{PV}$	ACUs	WH	CA	LD	*Output* ACC$_A$	*Output* AC	*Output* AEC
Chromosome 1								
Chromosome 2								
…….								
Chromosome _N								

Figure 7. The chromosome representation

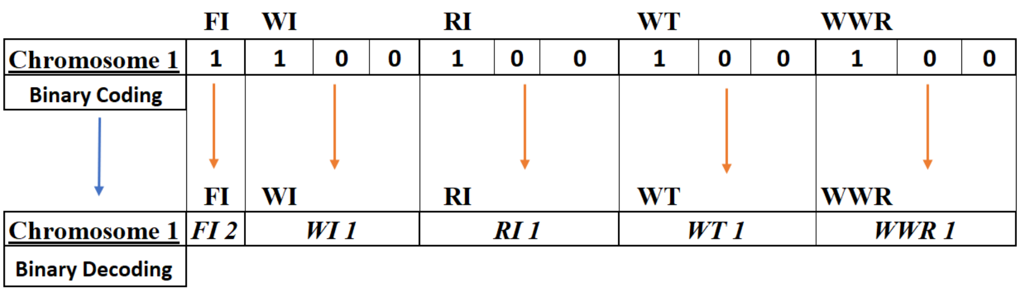

Figure 7. The chromosome digits coding and decoding

6. Results and discussion

Egypt's Solar Atlas is situated within the "sun belt," where direct solar radiation levels range from 2,000 to 3,000 kWh/m^2/year. From north to south, the sun shines for nine to eleven hours each day with little cloud cover (Fayad *et al.*, 2020). Traditional household appliances include two cooling units with 3 HP and 4 HP each for the master bedroom and reception area, respectively, but no PV system. The structure also makes use of fluorescent lighting fixtures, a microwave (20 liters), a kettle (1.7 liters), an electric oven (55 liters), and a 50-litre electric water heater. The conversion factor of CO_2 emission units is the electrical energy consumption E [kWh], which is 690 g/kWh (Ooka & Komamura, 2009). However, the used solar energy doesn't produce any CO_2 emissions. Therefore, Fig. 8 represents the approximate amount of CO_2 reduction due to the optimization technique and solar energy application.

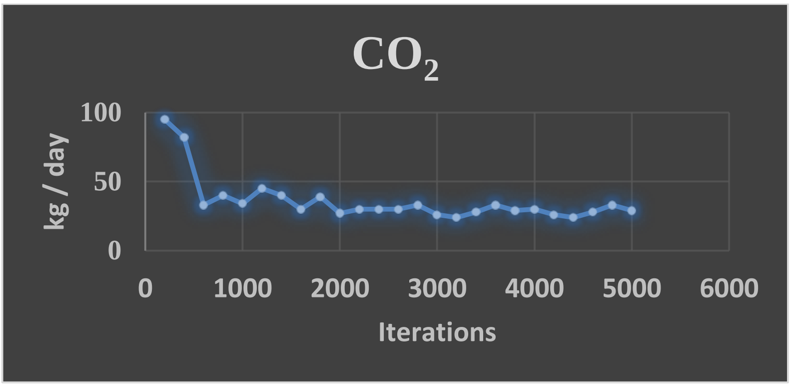

Figure 8. Effect of the number of generations on the optimal solution without solar energy solution

These, however, are optimum choices. The initial optimization module seeks to maintain two goals: the building's thermal insulation (ACCT) and the sum of the U-values for its thermal insulation components (TU value). Based on 5000 GA iterations, the winning candidate was represented as a vector with the following components: window types (WT: WT 7), wall insulation (WI: WI 6), roof insulation (RI: RI 4), floor insulation (FI: FI 2 with 0.1 mm thickness), and window to wall ratio (WWR: WWR 2). To maximize thermal insulation at a reasonable price, this optimization module advises utilizing the following materials: 0.1 mm thick wall insulation and floor insulation polystyrene roof insulation, polystyrene block, and 22 cm of concrete (4 cm thickness), Double reflective glass windows price aluminum frame window type, 20% as window to wall ration. As a result, the proposed methodology succeeded to minimize CO_2 emission at residential building from approximately 100 kg to 30kg daily. This means 70% reduction of CO_2 emissions.

The first optimization module seeks to maintain three goals: reducing the annual cost of the house appliances (AC), the additional construction cost caused by the appliances (ACCa), and the annual energy consumption (AEC). The winning candidate was shown as a vector with the following components: the surface area of PV panels (APV: 110 m^2), air conditioning units (ACUs: C1.21, C2.21, C3.21, C4.21), water heating options (WH: WH7), cooking appliances (CA: CA1, CA2), and lighting devices (LD: LD1); where the three associated output genes will be the additional construction cost due to home appliances such as the renewable energy system, cooking appliances, air conditioning units, and lighting devices (ACCa).

The overall average annual electrical consumption is calculated at 165.5 kWh/m^2, with an initial cost of $ 3279.83 and a running yearly cost of $ 2024.6, as shown in Fig.9 using the data of design factors that have been gathered. Based on resident usage and design options, the power consumption, operational costs, startup expenditures, and CO_2 emissions may increase or decrease. As a result, the following can be formulated as an energy policy:

$$REP \geq EPT * BEC$$

where:
REP: Renewable energy production for the building unit.
EPT: Energy policy threshold.
BEC: Building unit energy consumption.
IF: Energy policy threshold (EPT) = 75%.

Then the expected energy policy will be: “In such climate zone, each building unit must produce at least 75% renewable energy of its energy consumption”.

Figure 9. The optimal residential net-zero energy building

7. Conclusion

The paper's main goals are to reduce CO_2 emissions, uphold sustainability, combat climate change, and discover ways to lower energy costs and usage. Initial essential zero-carbon building heating and cooling technologies include renewable energy and wall/floor insulation. In order to attain nearly Zero Energy Buildings, the current study introduces a general methodology based on a multi-stage optimization methodology (NZEB). In this study, the best insulation material and wall, floor, and ceiling thicknesses were used to examine the best solutions for nearly Zero Energy Buildings (NZEB). Additionally, the form, ratio, and materials of the windows are crucial in preserving building insulation. the proposed methodology succeeded to minimize CO_2 emission at residential building from approximately 100kg to 30kg daily. This means 70% reduction of CO_2 emissions.

The main goals to maximize electrical generation and consumption are to balance electrical supply and demand for the analyzed building. As a result, choosing the right HVAC and electrical equipment significantly lowers electricity use. On the other hand, the main electrical generation alternative to the conventional on-grid supply is solar energy and PV panels. Therefore, applying clean energy generation to require zero energy buildings is the main idea of the renewable strategy. Additionally, this study develops a workable energy plan to generate renewable building energy to reduce CO_2 emissions, uphold sustainability, and combat climate change. Additionally, machine learning and the internet of things (IOTs) can efficiently improve the building's energy use.

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