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A methodology towards delivery of net zero carbon building in hot arid climate with reference to low residential buildings — the western desert in Egypt

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Abstract

Net zero carbon building (NZCB) is considered an important approach for reducing carbon emissions (CE), which may be due to the exponential rise of energy use and greenhouse gas emissions in buildings industry. Delivery of NZCB on its life cycle is considered a challenge due to its complexity and research deficiency for examining CE life cycle assessment (LCA) to reach NZCB in early design phase, especially in hot arid climates. The present proposal aims to develop an experimental methodology for NZCB in hot arid climate, with reference to the western desert region in Egypt as an experimental location due to its hot climatic characteristic, which includes the most common climate in Africa. The study was held on three models for a single floor residential unit with fixed area 110 m^2, using DesignBuilder software for annual simulation and One-click LCA software for 50 years LC simulation. The effect of conventional construction materials replacement, as a passive technique, and application of solar panels, as an active technique, was examined. Simulation results indicated that there was a reduction in carbon emissions through LCA reached approximately 85% when applying both passive and active techniques on the experimental models, as well as a reduction of approximately 101% in energy consumption. Implementation and integration between passive and active systems in early design phase are evident for achieving net zero CE target in hot arid climate.

Keywords: Net zero carbon building (NZCB), Life cycle assessment (LCA), Carbon emissions (CE), Experimental CE simulation

Introduction

Among many construction activities in the construction industry, reinforced concrete embodied carbon is recognized as a significant source of the greenhouse gas (GHG) emissions [1], which is considered as a major potential for a large-scale reduction in CE [2]. Residential sector is ranked as the second-largest electricity consumer in the world, and very few studies were conducted to standardize an approach for estimating the CE of typically used residential reinforced concrete structures over their life cycle [3].

Carbon footprint can be calculated with unit CO_2eq/year; system boundary of a building's lifecycle CE consists of two main components: operational and embodied emissions [4]. Many researchers agreed that the operational emissions are much greater than the embodied emissions; however, other scientists revealed that the significance of embodied emissions in buildings is often underestimated in lifecycle emissions analysis [5]. The researchers applied estimation of carbon footprint per functional unit area (kg CO_2eq/m^2) and concluded that it can be the emissions factor.

The construction phase, in addition to the operation phase, contributes the most to global warming (that can reach to 91.4%) during the residential building's life cycle with reference to a case study in China [6]. As presented in Fig. 1, the researchers concluded that the case study emitted 42.1% of its CE during the construction phase, 49.3% during its operation and maintenance phase, and 8.56% only during the demolition phase.

Xikai et al. (2019) [7] also stated that annual CE per floor area averaged 30 to 60 kg CO_2/(m^2/year). In contradiction with Li et al. (2019) [6], Xikai et al. (2019) [7] indicated that the production phase CE ranged from 11 to 25%, and the operation phase ranged from 75 to 87% of the total CE along building's life cycle [7].

Mainly construction industry in the case study region (Egypt) relies on conventional building materials such as concrete (plain and reinforced) and mud fired bricks. The embodied CE for reinforced concrete buildings had a range between 505.7 kg CO_2e/m^2 and 1050 kg CO_2e/m^2, which confirms its higher global warming potential (GWP) impact in reference to all other structures (concrete, masonry, steel, and wood) [3], with reference to Van Den Heede et al. (2012) [8] and Zhang et al. (2014) [9], who concluded a general value of embodied CE for the production of plain concrete (without steel reinforcement) with the amount of 425 kg CO_2e/m^3 [8, 9]. Referring to mud-brick as a walling material has the highest embodied energy among all conventional walling materials [10], Henry et al. (2014) [11] conducted a study using BIM simulation and concluded that the mud-brick/m^2 embodied CE is 228.03 k gCO_2e/m^2, while cement-block/m^2 is 396.7 kg CO_2e/m^2, respectively [11]. That means the cement-block as walling material expends at least 1.5 times more embodied energy and emits at least 1.7 times more embodied CO2 than mud-brick. Also, Kulkarni et al. (2016) [4] concluded that the average carbon footprint of the bricks, produced in Karad clamps in India, is estimated between 162 g CO_2e/kg and 195 g CO_2e/kg of fired brick [5].

Using alternative low-emission construction materials like eco-cement can reduce the reinforced concrete embodied CE in buildings up to 31%, by using supplementary cementitious materials (SCMs) in concrete mixture [1]. On the other hand, the previous study indicated that using 100% recycled steel scrap in reinforcement reduces the total building embodied CE by 39%, and therefore, it should be encouraged. Fernandes et al. (2019) [12] concluded that the compacted earth blocks (CEB) had total embodied CE of about 47.5 kg CO2eq./m^3 which included cradle-to-gate LCA for different walls [12]; this indicates that using CEB can contribute in a considerable reduction of potential embodied CE of 50% or more in comparison with conventional walling materials in a cradle-to-gate analysis.

Previous researchers indicated that there was no distinctive definition for NZCB. To et al. (2017) [13] aimed to achieve zero CE through balancing the energy consumed with the energy generated through renewable energy (RE) resources over its life cycle. There

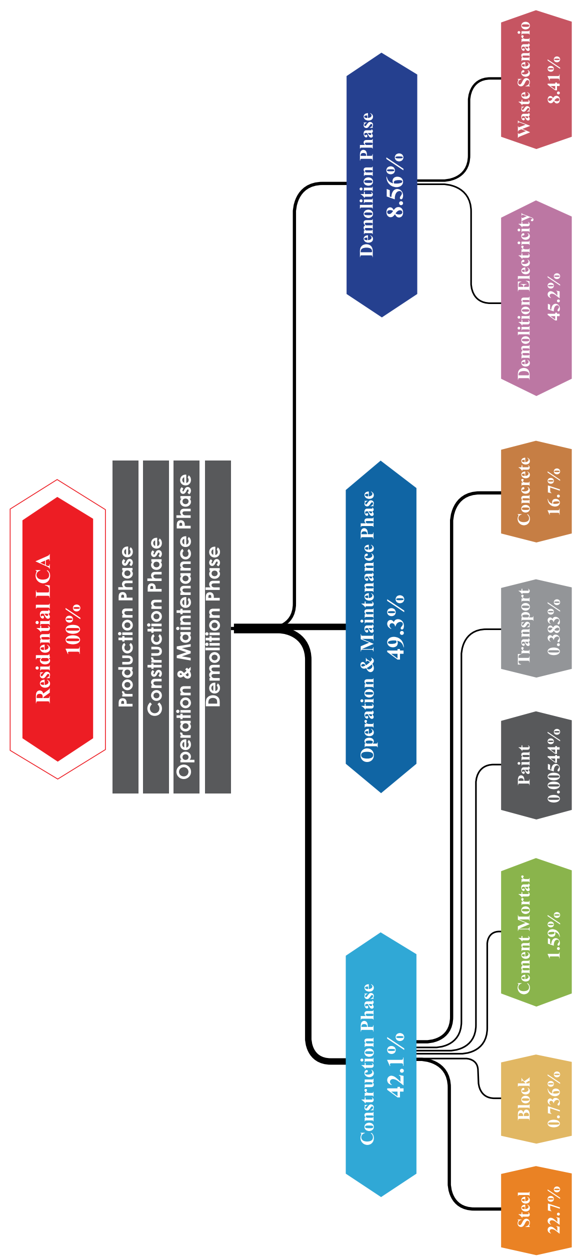

Fig. 1 Network structure of the environmental emissions of the residential building life cycle with construction materials conclusion [6]

are few case studies for NZCBs; however, there is a growing number of NZCBs in relatively hot and humid subtropical climates [13] but, unfortunately, very limited attempts to deliver NZCB in arid regions like Egypt.

As per study for evaluation of existing NZCBs, integration of three main strategies to achieve net zero is as follows: (1) reducing energy demand through the use of low-energy passive design measures; (2) increasing efficiency through using energy-efficient building systems and technologies; and (3) using RE sources like photovoltaic (PV) panels to supply the remaining energy demand and mitigate CE target [13, 14]. Integration of systems and technologies, which are based on principles of sustainable site planning, energy use reduction, low-carbon construction and material selection, water use minimization, building flexibility and adaptability, had been integrated into NZCB [15]. There is limitation in previous research for addressing NZCB outlines and challenges that face delivering NZCB which fracture our NZCBs understanding, therefore, more researches on NZCB outlines and challenges are needed.

NZCB delivery system is based on eight boundaries, which include a detailed description and role for each NZCB boundary (e.g., geographic, climatic, density, building life cycle, etc.) [16]. These boundaries are considered as an innovative approach for examining NZCBs in terms of system integration for future research and practice. Noticing that the early design phase parameters connect and integrate all NZCB boundaries, the criteria for each outline can be analyzed in the early design phase with respect for project's circumstances.

The challenges that face NZCB delivery can be summarized in lack of understanding NZCB principles, unclear NZCB policies with conflict in NZCB management and priorities, and with underlying lack of theoretical grounds knowledge as well as NZCB boundaries. These main challenges are (1) designed target vs. operating target, (2) testing and commissioning, and (3) occupant behavior, comfort, and satisfaction. The designed target vs. operating target can exceed 3.5–5 times initial design estimations in examined case studies which make early design phase simulation for each design parameter a necessary process [13]. Reliability of RE generation is an essential factor for achieving net zero carbon objective and to be effective for a specific context. Finding the best combination between passive and active RE systems design strategies is also essential for achieving best CE target [14, 15].

By reflecting previous literature on the case study location, the western desert in Egypt is rich with climate-responsive vernacular architecture. Settlements in the Dakhlah Oasis are collected structures with a strong defensive character; constructions are bound to each other to cope with the hot arid environment. These settlements are characterized by traditional mud-brick Islamic architecture with wind catchers for natural ventilation enhancement (Fig. 2) [17]. On the other hand, the Egyptian government was building housing projects in Al-Wadi Al-Jadid governorate with the same conventional construction materials (concrete and fired bricks) with no consideration to climatic conditions (Fig. 3).

Summarizing the research's knowledge gaps for this research, limitation in conducted studies for standardizing an approach of residential structures CE estimation over their life cycle stages in hot arid climates, with no distinctive definition for NZCB in such climatic region. In addition, there is deficiency in embodied CE data for conventional and

Fig. 2 Al Qasr, vernacular architecture in Dakhla Oasis, the western desert [17]

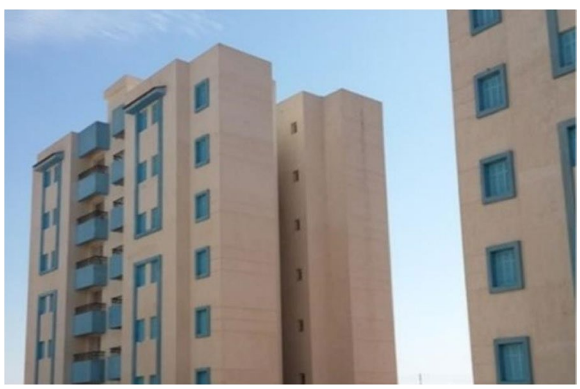

Fig. 3 Governmental housing typologies in Al-Wadi Al-Jadid, the western desert [18]

alternative construction materials in the case study region. Additionally, the absence of understanding among designers and developers results in climatic responsive design application limitations in Egypt. Addressing LCA as a tool for CE reduction in buildings in early design phase can be a valuable tool in CE mitigation [6]. Moreover, the raise of awareness to nonprofessional users and designers to such problem has a great role in due course.

The next part of this research investigated the building's life cycle assessment based on carbon emissions ($LCCO_2$), embodied CE for applying conventional and alternative construction materials. It was felt necessary to define the methodology towards delivery of NZCB in the western desert in Egypt through design strategies and techniques

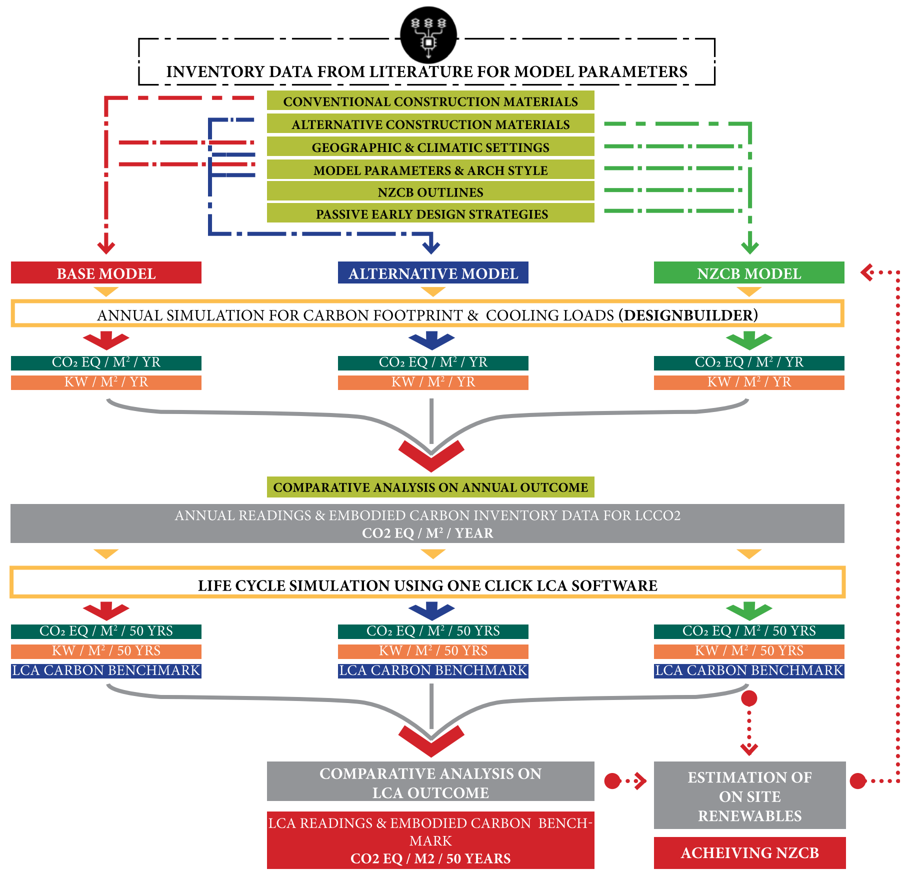

Fig. 4 Experimental methodology for achieving NZCB

integration, which may be applicable for a governmental typology of low-rise residential buildings in a hot arid climate. The experimental yearly and LCA simulations were conducted by using DesignBuilder and One-click LCA software.

Methodology

Implementing inventory from literature review to be an input data for experimental/simulation part, Fig. 4 illustrates three experimental models with fixed area (110 m^2) with reference to the Egyptian governmental prototype in the western desert. Base model is the typical prototype that was constructed by the Ministry of Housing. Alternative model is the same design of base model but with alternative construction materials. NZCB model had the same area with the implementation of passive and active techniques. Simulation process consisted of two main parts: modeling and simulation on DesignBuilder software for annual readings and then implementation of data on One-click LCA for LCA readings. Optimization process in simulation of NZCB model was applied for achieving zero LCA CE target. In order to achieve precise experimental results, system boundaries were investigated as follows:

Methodology of system boundaries

The functional unit for this research is kg CO2e/m^2/50 years for a residential building, and the target is to reach net zero carbon target on its LCA. There were assumptions for simulation process, which were constants for the three models, such as the service life of construction materials that were estimated with the same life span of the building (50 years). Traveling distances for the site transportation were assumed with 60 km per truck which is adequate for average transportation distance in conventional construction site in Egypt. The end of life scenarios was neglected in simulations due to its minor impact on the whole LCA [6]; at last, the main aim to use passive techniques was for overcoming mechanical HVAC and reducing the operational CE without testing indoor thermal comfort in detail, as it has several considerations that need to be carefully studied in further research.

Case study investigation

Geographic and climatic outlines

The experimental study was located in Al-Kharj, Al-Wadi Al-Jadid, the western desert in Egypt, with climatic classification of hyper-arid climate. Table 1 showed values for climatic characteristics with reference to Bahariya Oasis weather station in the western desert, as presented for warmest and coldest months and their temperature values, relative humidity ranges, global radiation, and average annual rainfall. Almost 73% of the year is outside the human comfort range, with average cooling hours needed were 2795 out of 8760 yearly hours [19]. These climatic data were implemented in simulation software as a part of CE simulation.

Model parameters and architectural style

The Egyptian government attempted to follow vernacular architecture typology to harmonize with the geographic nature in new housing projects in the western desert (Figs. 5 and 6). This residential prototype had an area of 110 m^2 on footprint, 5% of total land plot [20–22]. The architectural style is characterized with domes and vaults on the roof formation; however, it was built with the conventional construction materials used in construction industry in Egypt (masonry blocks and reinforced concrete), without taking into consideration applying any vernacular passive techniques for natural ventilation like wind catchers. The prototype floor plan had living spaces for a family of four individuals as illustrated in Fig. 7.

Data analysis from literature review

Conventional and alternate construction material properties

Experimental models followed literature data gathering for their construction materials, base model was built with conventional construction materials (concrete and masonry blocks), while alternative model and NZCB were built with alternative construction materials for better environmental and carbon emissions performance (CEB and low-E concrete). Table 2 described the general information for the experimental three models. Also Tables 3 and 4 illustrated the conventional and the alternative construction materials specification which were used as an input data for annual simulation study.

Table 1 Experimental models geographic and climatic boundaries from Bahariya Oasis weather station

Geographic & Climatic Outlines	
Geographic Location	Al Kharga Oasis - Al Wadi Al Jadeed Governorate - Western Desert - Egypt
Height above sea level	100 to 500 m
Climatic Classification	Hyper Arid
Warmest Months	July + August
Maximum Mean Temperature	38°C
Maximum Operative Temperature	42°C - 48°C
Minimum Operative Temperature	19°C - 22°C
Coldest Months	January + February
Minimum Mean Temperature	8°C
Maximum Operative Temperature	28°C - 31°C
Minimum Operative Temperature	3°C - 10°C
Relative Humidity	30% to 60%
Global Radiation	870 W/m^2 and 540 W/m^2 in July and January
annual rainfall	2 mm

Ventilation methods and vernacular passive solutions application

The base model followed the governmental typology with partially mechanical conditioned with split units without taking into consideration any passive techniques application for natural ventilation enhancement (Fig. 8). However, the western desert accommodates buildings with vernacular architectural style, which is responsive to hot arid climate in terms of indoor thermal environment and human comfort, using passive techniques in construction materials selection and natural ventilation enhancement (Fig. 9). The alternative model and NZCB model used natural ventilation techniques as presented in Fig. 10 without adding new masses for wind catchers for maintaining the same construction materials volume.

Simulation process

Three models were modeled on DesignBuilder using building block technique, and then comparable simulation for annual performance and carbon emissions took place. The first model is the base model (BM), which mimics the governmental typology for low-rise houses in western desert with its conventional construction materials and with partially air-conditioned split system. The second model is the alternative model (AM) with application of passive techniques, which are replacing conventional construction materials with alternative materials with lower embodied carbon, and natural ventilation enhancement for overcoming the AC usage. The third model is testing the selective active systems on the alternative model which is the implementation of onsite PV panels to reach net zero carbon building (NZCB).

Design builder models input data

Design Settings & Activity The experimental models were built on DesignBuilder interface, with orientation of western entrance façade as presented in Fig. 11. Unit floor plan, as presented in Fig. 7, is a typical one floor home with entrance lobby, reception,

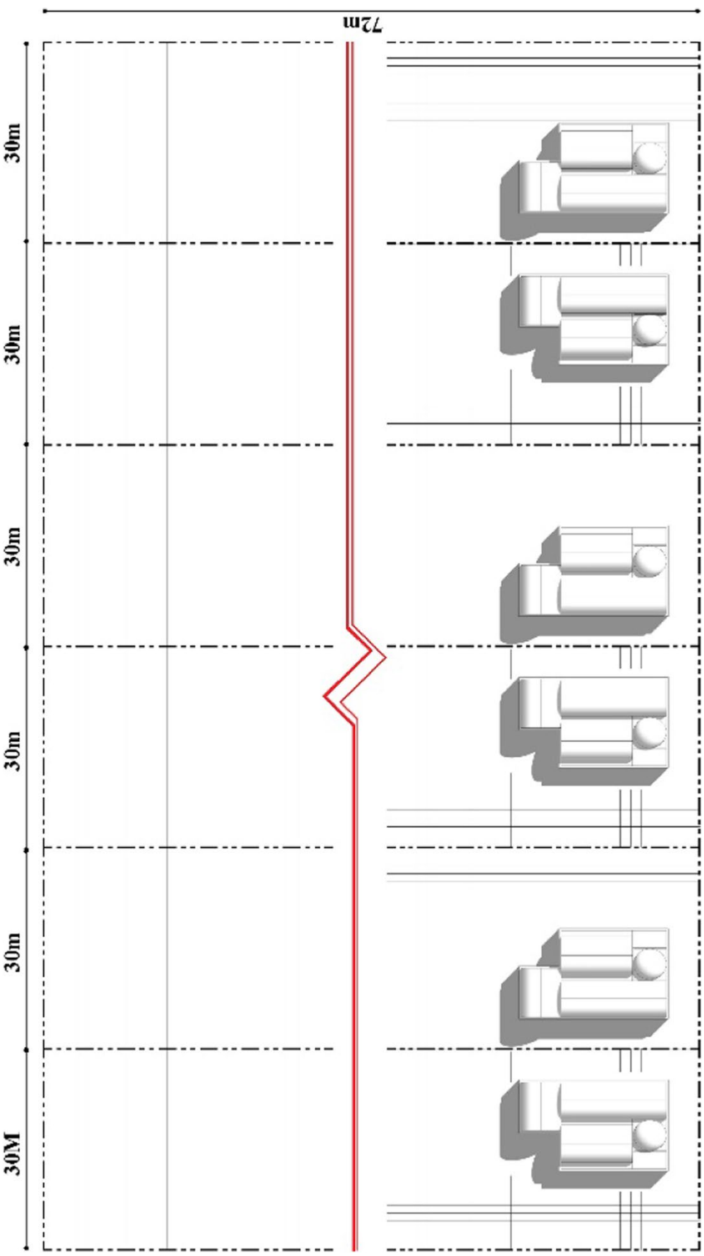

Fig. 5 Governmental housing prototype in western desert illustrative layout, Egypt

Fig. 6 Governmental housing prototype in western desert, Egypt [20]

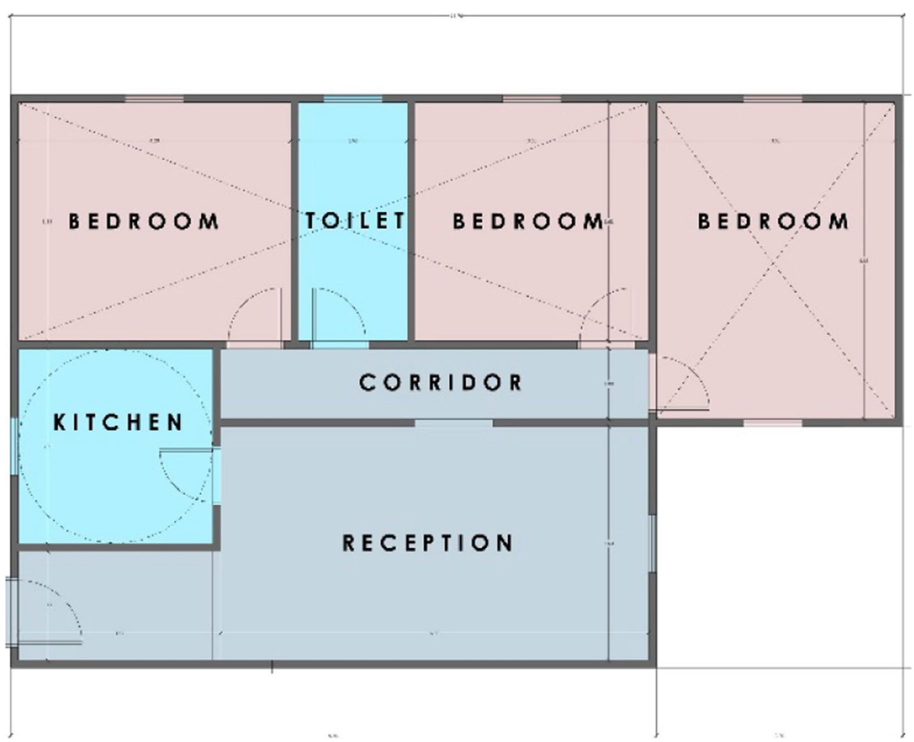

Fig. 7 Base model floor plan

kitchen, three bedrooms, and bathroom. Implementation of activity template of residential dwelling occupied with four persons and standard metabolic rate (0.5) and activity of seated quiet template; natural ventilation technique was introduced in the activity settings. Occupancy of home appliances was introduced as well with power intensity of 13 W/m^2.

Table 2 Experimental models information card

Pysical Parameters	Base Model (BM)	Alternative Model (AM)	NZCB Model (NZCB)
Location	Al Kharj - Al Wadi Al Jadeed - Western Desert - Egypt		
Area	110 sqm		
Type	Residential Dwelling		
Structure Type	Reinforced Concrete & Fired Clay Bricks	Low-E reinforced Concrete & Compacted Earth Blocks CEB	Low-E reinforced Concrete & Compacted Earth Blocks CEB
Building Finishing	Semi finished		
Occupation	Family of Four Members (Husband, Wife, Two Kids)		
HVAC Type	Partially HVAC with Split units	Naturally ventilated	Naturally ventilated
Passive cooling systems	NA	Alternative construction materials (insulation following EEEBC Code)	
	120 mm	380 mm	380 mm insulated
Active Systems		NA	
Life Cycle Span	50 Years		

Construction materials input Implementation of construction materials specifications for three models, as concluded from the literature review, into DesignBuilder interface took place. The conventional materials were applied as presented in Table 3 for base model (BM); walling material is fired bricks of 120 mm thickness with outer/inner cement plastering with thickness 20 mm without insulation, and the roofing system is reinforced concrete 200 mm thick with outer/inner 20 mm plastering without insulation. The openings of base model were introduced as uninsulated with single glazed of 6-mm clear glass with R-value 0.15 m^2 K/W [25].

As for the alternative and NZCB models, alternative materials were applied as presented in Table 4 with their heat specification and embodied CE data as a passive technique. Walling and roofing materials are CEB 380 mm thick with inner/outer cement mortar for plastering with wall insulation for better thermal performance; openings were introduced as insulated 6mm double-glazed glass complied with Egyptian energy-efficient building code with R-value 0.58 m^2 K/W [14]; both models had the same wall/window ratio (opening dimensions 900 mm × 900 mm in each space). Figures 12 and 13 illustrated the construction materials in wall sections for BM, AM, and NZCB with their thermal specifications and embodied CE, which were implemented into DesignBuilder interface.

One-click LCA platform input data for LCA simulation

One-click LCA platform is an automated whole life cycle assessment online database software that helps in calculation and reduction of the environmental impacts of certain building or product as well as its embodied CE calculation. For early carbon optimization, it amends a large generic and environmental product declarations (EPD) database for global manufacturers which is considered among the largest of its kind, and it is also designed to find easily the information for material EPDs; it also complies with EN/ISO standards and 40+ certifications [26, 27]. The software provides also the embodied

Table 3 Conventional construction material specifications to be implemented in DesignBuilder [1, 12, 19, 23].

Item	Unit	Thermal Properties				Embodied Carbon CO2kg/kg
		Denisty kg/m³	Conductivity W/m-K	Specific Heat J/kg-J	Resistivity m² K/W	
Base Model						
BM-Reinforced Concrete	m³	2400	1.65	1050		0.2
BM-Plain Concrete	m³	2200	1.4	1000		0.15
BM-Fired bricks 120 mm thickness	m²	2400	0.54	850	0.15	1.145
BM-Cement Blocks	m²	1800	1.4	880	0.09	0.208
BM-Outer Cement Mortar for plastering	m²	1650	0.74	870		0.17

Table 4 Alternative model construction material specifications to be implemented in DesignBuilder [1, 12, 24]

		Thermal Properties				
Item	**Unit**	**Denisty kg/m³**	**Conductivity W/m-K**	**Specific Heat J/kg-J**	**Resistivity**	**Embodied Carbon CO2kg/kg**
Alternative Model						
AM-Low E Concrete	m³	2406	1.1			0.059
AM-Compacted Earth Blocks (CEB)	m³	2200	1.13	2000	0.354	0.082
AM-Cement Mortar for plastering	m²	1650	0.74	870		0.17
AM-Mortar for wall plastering	m²	1900				0.208

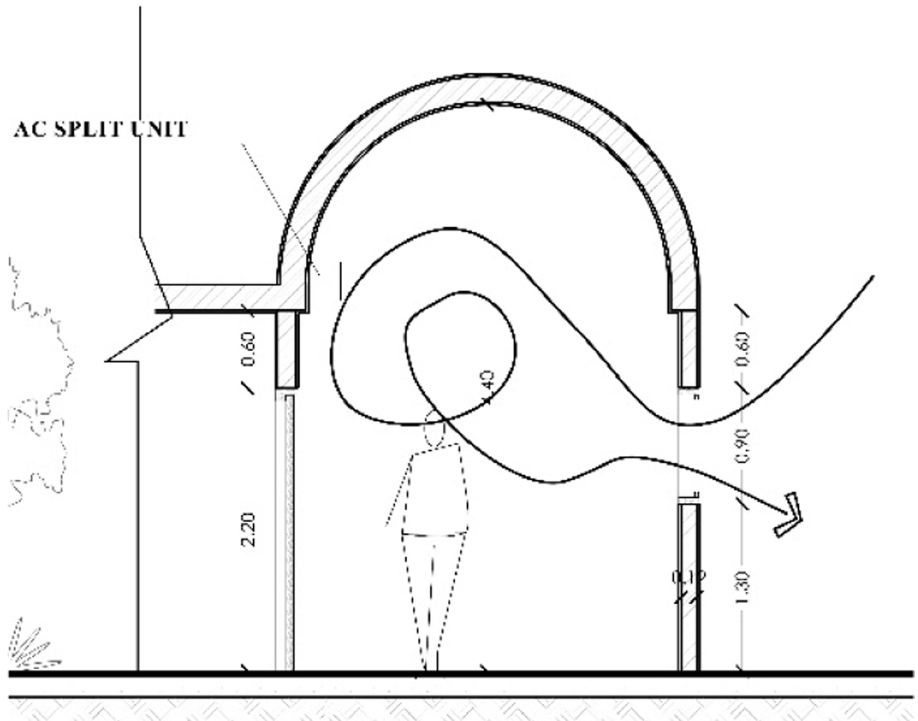

Fig. 8 Illustration for base model ventilation

carbon benchmark for construction materials, which gives information for the LCA first stage for any construction project, that can be useful for building industry professionals in analysis for whole LCA [28].

Importing gbXML models and simulated annual data from DesignBuilder to One-click LCA platform of the three models for LCA simulation with reference to LCA tool EN-15978. Importing data includes the scope of construction process, project's type, and structure type. Mapping construction materials for each model took place by linking each construction material (conventional and alternative) with local suppliers' database on One-click LCA platform; this process is important for calculating embodied, LCA, CE, and energy consumption.

Implementing building floor(s) area and annual energy consumption (Table 5) for each model as concluded from DesignBuilder simulation output. Afterwards, importing constant data for the three models of construction site operations phase with reference to construction methods followed in Egypt, like transportation distances, was estimated with 60 km per truck. Finally, importing LCA calculation period with 50 years.

Estimation of site PV needed to achieve net zero target and its LCA CE

RETScreen Expert PV simulation software is a reliable tool for estimation of PV capacity, cost, and CE [14, 29]. Using it as a tool for estimation, the solar power needed to reach net zero carbon target with reference to geo-location for Al-Wadi Al-Jadid governorate that was implemented into the software to calculate the exact power needed. In order to reach zero carbon target in the NZCB model, selection and implementation

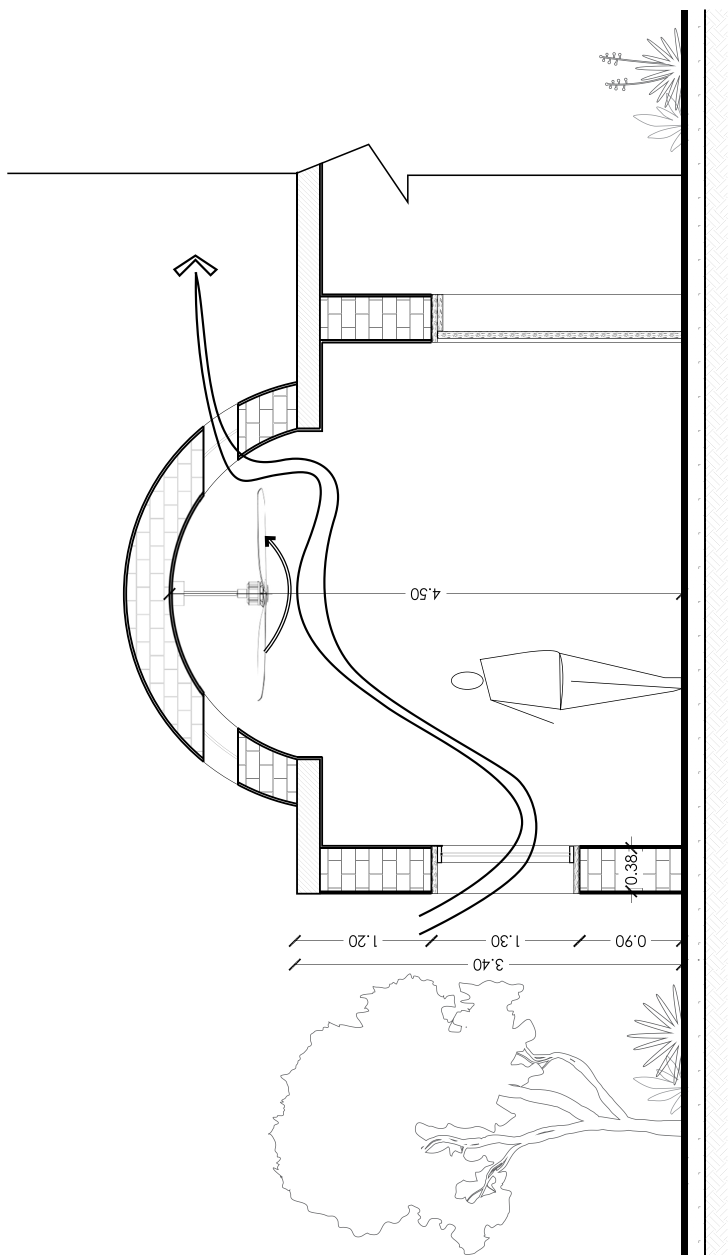

Fig. 9 Vernacular architecture style in the western desert showing the local clay used in building construction and other passive solutions like wind catcher for natural ventilation enhancement [19]

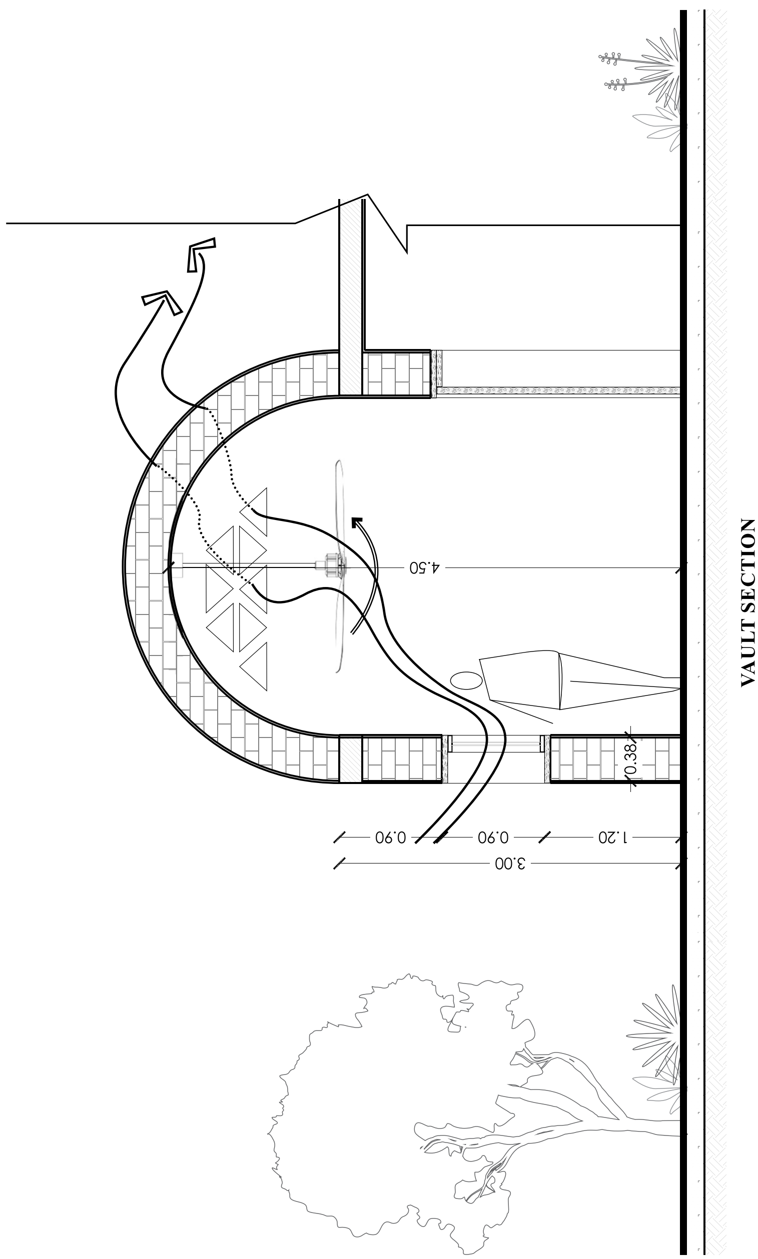

Fig. 10 Illustration for passive techniques was used to overcome mechanical HVAC

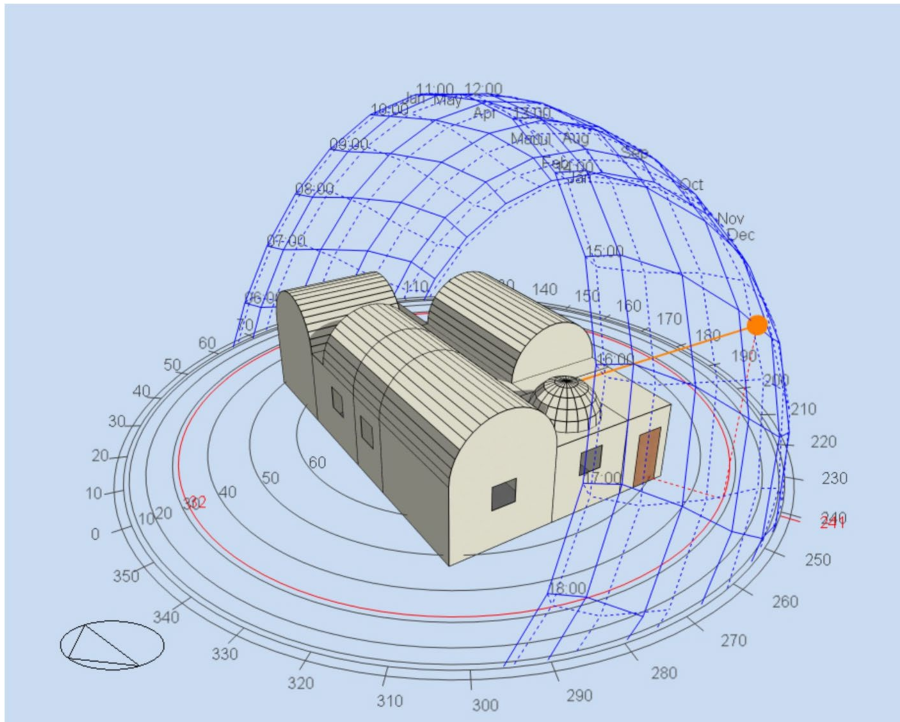

Fig. 11 Base model (BM) modelling on DesignBuilder interface with its orientation

of 10.175 KW PV system of 55 units array of model CSUN185-48M China Sunergy product, which produce 18,337 kWh annually with reference to RETScreen simulation. The PV system also emits 0.83 tons CO_2e per year with reference to emission factor 45 gCO_2-e/kWh [30]. This data was imported again to One-click LCA software to offset CE and achieve zero CE target.

Results and discussion

Three models were simulated on DesignBuilder and One-click LCA software. The base model (BM) was following the governmental prototype in Al-Kharj Oasis — the western desert with conventional construction materials as discussed in literature review; the alternative model (AM) was a transitional model between BM and the NZCB model, with the application of low CE alternative construction materials as one of many passive techniques can be applied; and the last model is the NZCB model which followed the alternative model with implementation of 10 KW solar panels array as an active technique to offset CE; results for simulation on both software were presented in Table 6 as follows:

Construction materials embodied CE and their benchmark

Based on carbon emissions simulation data on DesignBuilder for BM, AM, and NZCB construction materials, a drop in embodied carbon emissions is in favor of alternative construction materials with 56% than conventional materials; this emphasizes the

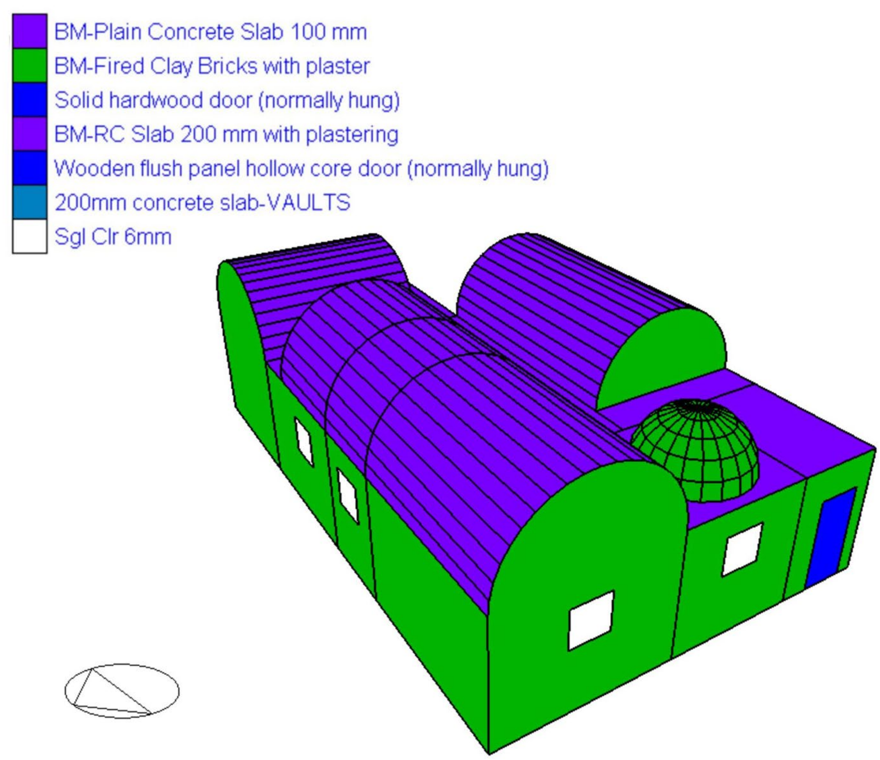

Fig. 12 Base model (BM) architectural style 3D from DesignBuilder interface

importance and priority of alternative materials implementation and replacement in construction industry. Figure 14 shows the reduction in embodied carbon emissions. Figure 15 shows One-click LCA results for carbon benchmarking between BM and AM.

Annual energy consumption

Based on the input data for the three models to DesignBuilder, BM was partially air-conditioned with un-insulated construction materials consumed amount of 32,285 kWh/yr., both AM and NZCB models are naturally ventilated with better construction materials insulation consumed 14,941 kWh/yr., and there is a massive drop with the amount of 53% in annual energy consumption between the first model and both second and third models, taking into consideration users environmental control culture, their behavior for natural ventilation, and application of high mass construction materials with proper insulation. Figure 16 illustrates the simulation results with application of solar panels as an active technique for NZCB which offsets the energy consumption and exports 3396 kWh/year to the official grid to overcome the embodied CE and PV system CE to reach zero CE target.

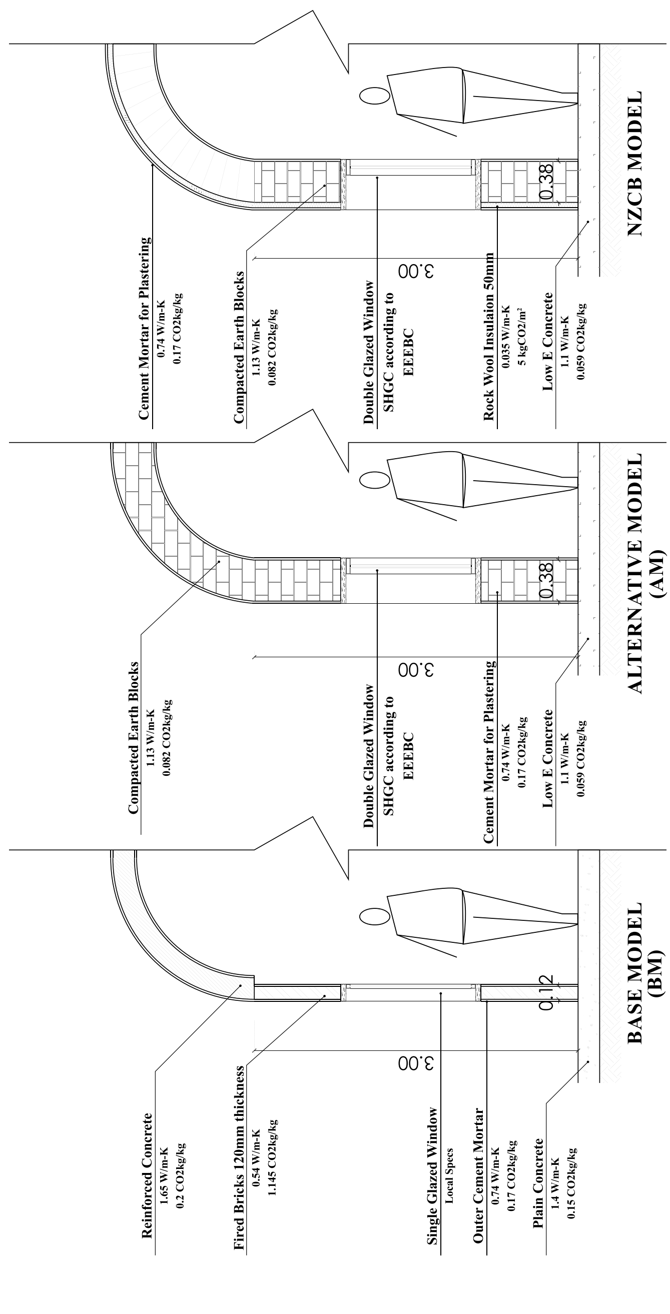

Fig. 13 Wall sections for three experimental models with construction material specifications

Table 5 Annual electricity subdivisions consumption for BM and AM as simulated by DesignBuilder in kWh

Electricity Item	BM	AM
Cooling	16,945	0
Interior Lighting	10,105	8232
Interior Equipment	5232	4836
Fans	0	1873
Total electricity consumption	32,282	14,941

Total LCA carbon emissions

BM CE was simulated with the amount of 1282 tons CO_2e on its overall LCA, while AM scored 604 tons CO_2e (reduction of 47% than BM CE using only some passive techniques). NZCB model CE were almost zero amount (−9.8 tons CO_2e) for adding 10 KW solar panels as active technique. The reduction was around 101% of total LCA BM CE as presented in Figs. 17 and 18. The emission factor which was used to estimate operating CE from operational energy consumption, specifically for Egypt, was 0.71 kg CO_2e/kWh based on International Energy Agency IEA (2016) and simulation program database.

Passive and active techniques applied

Using passive techniques, that were popular in the western desert vernacular architecture, to be the experimental methods applied to differentiate between BM, AM, and NZCB simulations. These passive techniques were changing the conventional construction materials to low-carbon alternative materials in addition to the natural ventilation enhancement, which dropped annual energy consumption as stated in previous point. Regarding the active technique applied for NZCB model only, implementation of PV with 10.175 KW power which generates 18,337 kWh/year, and produces extra 41 Ton CO_2e over its life cycle. The selection and calculation of PV sizing and its CE took into consideration offsetting the overall LCA CE and energy consumption for NZCB model.

LCA CE for the models' elements and life cycle stages

Figure 19 and Table 7 illustrated the three models of LCA as per elements; operational phase electricity use has the highest contribution in carbon emission elements with the amount of 1282 ton CO_2e for (BM) LCA simulation, (AM) optimization reduced to amount 604 ton CO_2e with passive techniques implementation, while (NZCB) scored −9.8 ton CO_2e with almost 103% reduction lower than BM.

Discussion

Despite the lack in $LCCO_2$ studies on NZCB having similar climatic conditions, Dabaieh and Johansson (2018) evaluated only the operational performance of an existing low carbon building in Bahariya Oasis in the western desert. The building's area is 300 m^2 with relevant criteria of similar conditions but without consideration of embodied energy for building's materials. The reduction in calculated operational CE for such building was approximately 8 ton CO_2e per year (26.66 kg CO_2e/m^2/year) using 400 m^2 PV farm for energy supply and CE offset. The PV farm generated 14,800 kWh/year, while the measured consumed electricity in 2015 was approx. 13,900 kWh (46.33 kWh/m^2).

Table 6 Simulation results comparison

	Simulation Output		BM			AM			NZCB		
	Item	Sub-Items	Amount	Unit	Notes	Amount	Unit	Notes	Amount	Unit	Notes
EXPERIMENTAL RESULTS	Building Materials Embodied Carbon	Vertical Structures	**50**	Tons CO2e	4%	**24**	Tons CO2e	4%	**24**	Tons CO2e	-244%
		Horizontal Structures	**5**	Tons CO2e	0.4%	**9**	Tons CO2e	1.5%	**9**	Tons CO2e	-91.4%
		Other Structures	**4**	Tons CO2e	0.3%	**9**	Tons CO2e	1.5%	**9**	Tons CO2e	-91.4%
	Plausibility checker	Lack in Online Database	Grade **A**		OneClick LCA	Grade **B**		OneClick LCA	Grade **B**		OneClick LCA
	Embodied Carbon Emissions for construction materials	Materials specs as in Literature Review	**116**	Tons CO2e	DesignBuilder	**66**	Tons CO2e	DesignBuilder	**66**	Tons CO2e	DesignBuilder
	Annual Energy Consumption	Electricity	**#REF!**	kWh/yr	DesignBuilder	**#REF!**	kWh/yr	DesignBuilder	**#REF!**	kWh/yr	DesignBuilder
	District Cooling	HVAC Split units system	**32**	Tons CO2e	Semi Air Conditioned	**0**	Tons CO2e	Naturally Ventilated	**0**	Tons CO2e	Naturally Ventilated
			#REF!	kWh		**0**	kWh		**0**	kWh	
	Annual Water Consumption	Constants on Three models	**176**	m3	Constant	**176**	m3	Constant	**176**	m3	Constant
	Construction Site Operations		**86**	Tons CO2e		**86**	Tons CO2e		**86**	Tons CO2e	
	BuildingArea		**110**	sqm	Literature	**110**	sqm	Literature	**110**	sqm	Literature
	Calculation Period		**50**	years		**50**	years		**50**	years	
	Passive Techniques Applied	Literature Review Data	**NA**			**Low-E Construction Materials**			**Low-E Construction Materials EEEBC Based**		
	Active Techniques Applied	Technique Discription	**NA**			**NA**			**10.175 KW PV system**		$27,000
		Annual Gen. Power							**18,337**	kWh/yr	RETscreen Expert
		CE production							**41.26**	Tons CO2e/50 yrs	Literature+RETscreen
		Carbon Offset							**-655**	Tons CO2e offset	OneClick LCA
	Total Carbon Emissions	Overall LCA - with PV Panels	**1,282**	Tons CO2e	One click LCA	**604**	Tons CO2e	One click LCA	**645**	Tons CO2e	One click LCA
		Overall LCA - After PV Offset	**1,282**	Tons CO2e		**604**	Tons CO2e		**-9.8**	Tons CO2e	
		Research unit	**233**	KG CO2e/sqm/yr		**110**	KG CO2e/sqm/yr		**-1.8**	KG CO2e/sqm/yr	
	Embodied Carbon Benchmark		**539**	KG CO2e/sqm		**377**	KG CO2e/sqm		**617**	KG CO2e/sqm	
		Carbon Label	Grade **E**			Grade **C**			Grade **E**		

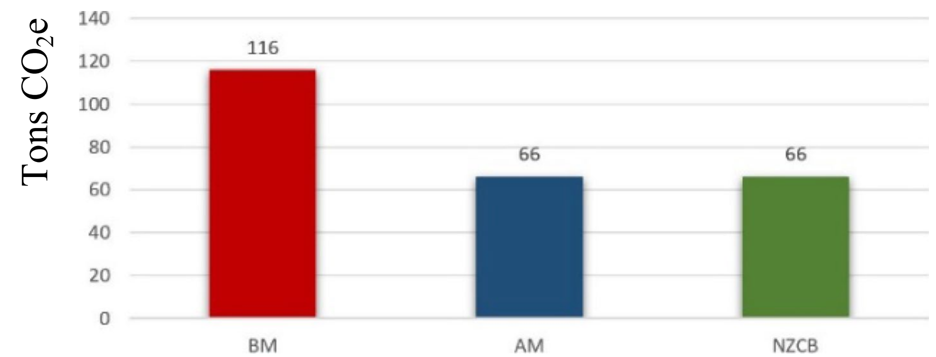

Fig. 14 Construction materials embodied CE for the three models

The consumed electricity was relatively low due to the application of climatic responsive design, which integrated various passive techniques such as high thermal mass envelope and wind catchers, in addition to the user's awareness with power consumption optimization.

In comparison with NZCB model simulation results, the present study concluded that overall $LCCO_2$ reduction was 614 ton CO_2e in 50 years (12.28 ton CO_2e/year and 111 kg CO_2e/m^2/year) with the implementation of PV farm that produces 18,337 kWh. Contradictorily, the building may consume 14,941 kWh (135 kWh/m^2). Integration of various passive and active techniques has a great potential for a massive reduction in operational energy consumption, which can reduce the PV farm size and cost accordingly, in order to achieve overall LC net zero CE.

Conclusions

The research shows the possibility of achieving building with net zero carbon emissions on overall life cycle stages (from cradle to grave) with reference to time (e.g., 50 years) taking into consideration NZCB strategies, outlines, and its challenges" and its unit of measurement for carbon emissions performance that can be simulated/measured with reference to over life cycle (kg CO_2e/m^2/50 years = zero.)

After examining NZCB outlines, we can add eight outline which is early design phase optimization regarding passive and active techniques implementation and integration. Putting scenarios for design stages with proper criteria will reduce dramatically the gap between early design CE and actual operational CE, which will ease the process for decision-makers regarding achieving net zero carbon target.

For reaching the best practice for NZCB in the western desert, integration of passive and active techniques is considered a viable solution for mitigation of carbon emissions and reaching net zero carbon buildings target over buildings life cycle. PV as an active technique used in this research can be increased in power for reaching net zero target to 10.175 KW system.

Limitations

In order to reach more detailed LCA CE simulation, software used in this research like DesignBuilder, One-click LCA, and RETScreen needs to accommodate more inventory data for suppliers and embodied CE data for various sustainable materials. Moreover,

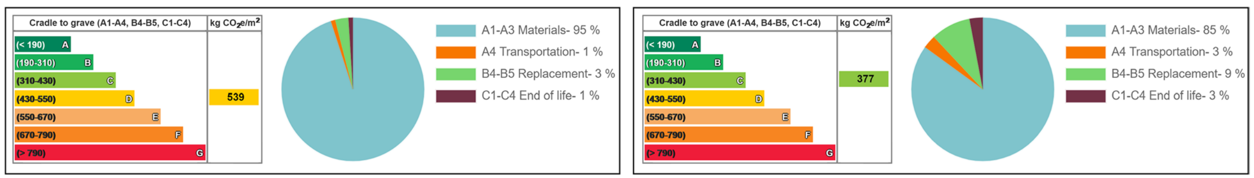

Fig. 15 Carbon benchmarks for BM and AM, One-click LCA results interface

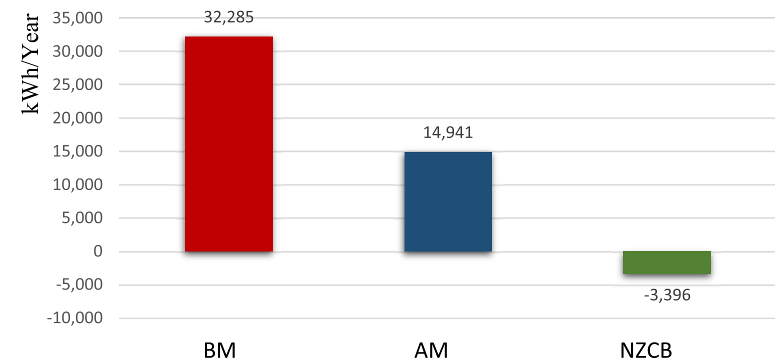

Fig. 16 Annual energy consumption for the three models

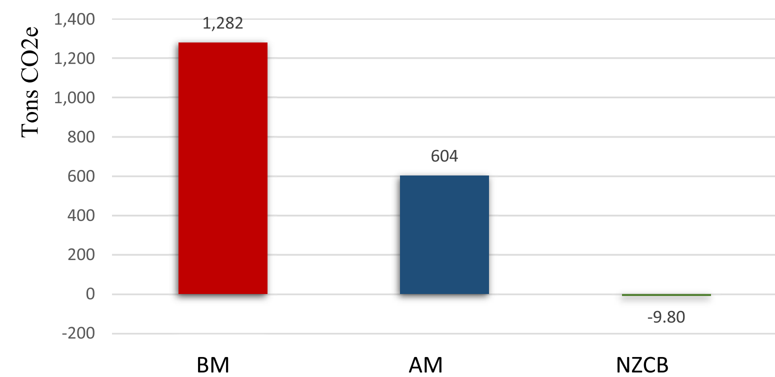

Fig. 17 Total carbon emissions over LCA for 3 models

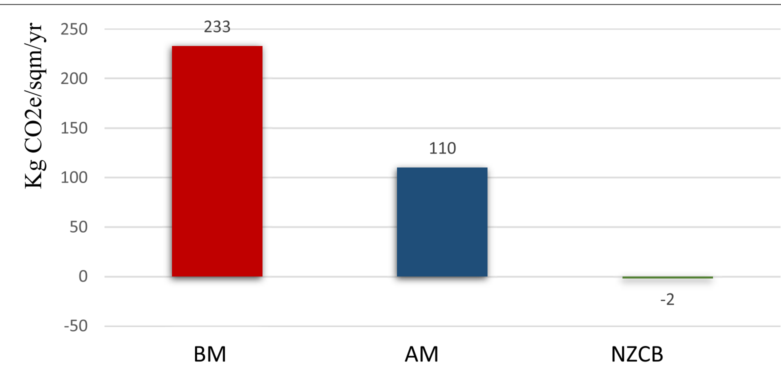

Fig. 18 Total carbon emissions for 3 models in kg CO_2e/sqm/yr

there is a considerable lack in CE studies in hot arid regions like Egypt, which makes comparison with previous researches with the same climatic settings difficult.

This research was conducted to test the methodology for achieving NZCB in hot arid climate with reference to literature data and the case study, which can be taken as a guideline in design phase decision-making process. It did not address uncertainty analysis as some of the concluded or estimated key variables are subjected to change

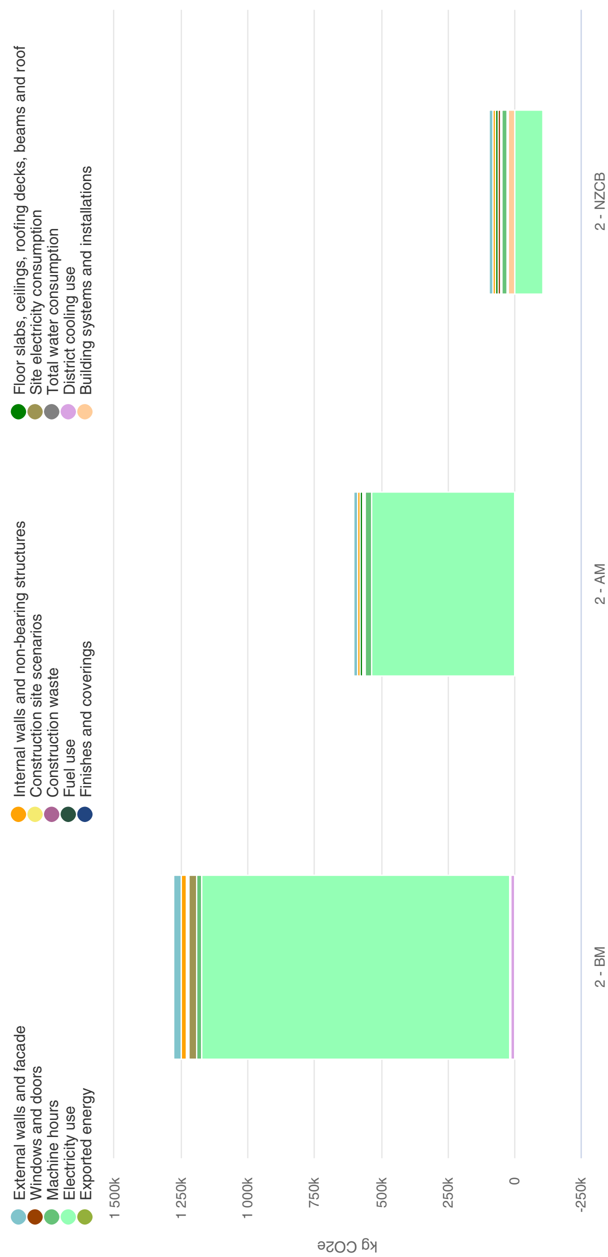

Fig. 19 Life cycle assessment — global warming, kg CO_2e — model elements comparison

Table 7 LCA for the three models' element as concluded from One-click LCA in kg CO_2e

ELEMENT	BM	AM	NZCB
External walls and façade	32666	15038	15038
Internal walls and non-bearing structures	17446	8519	8519
Floor slabs, ceilings, roofing decks, beams and roof	5460	8780	8780
Windows and doors	3769	7492	7492
Construction site scenarios	805	805	805
Site electricity consumption	26313	5000	5000
Electricity use	1153011	533560	
District cooling use	13684	0	0
Exported energy	0	0	594202

according to specific project's conditions. Some of these variables are (1) construction site operations scenario, (2) operational energy consumption estimation that can be dramatically reduced due users' performance and awareness, (3) plausibility checking for database of simulation programs, (4) embodied CE for construction materials database in Egypt and hot arid regions, (5) including the loss factor in the PV LCA performance simulation, and (6) demolition scenario.

Abbreviations
NZCB: Net zero carbon building; CE: Carbon emissions; LCA: Life cycle assessment; GHG: Greenhouse gases; $LCCO_2$: Life cycle assessment based on carbon emissions; GWP: Global warming potential; CEB: Compacted earth blocks; SCMs: Supplementary cementitious materials; RE: Renewable energy; PV: Photovoltaics; EPD: Environmental product declarations; BM: Base model; AM: Alternative model.

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Authors' contributions
Prof. ARA suggested the problem of the present study, supervised the technical procedure and solved its obstacles, and finally reviewed the manuscript. SEAF shared the problem suggestions, collected the literature needed for the present study, carried out the methodology formulation, performed the simulations and analyzed the data, and prepared the manuscript in its final form. The author(s) read and approved the final manuscript.

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Availability of data and materials
The data and materials of the present study are available under request to Architecture Department, Faculty of Engineering, Cairo University, Egypt.

Declarations

Competing interests
The authors declare that they have no competing interests.

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