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Back from parcel planning to future heritage of urban courtyard: The 5th generation of Egyptian cities as a sustainable design manifesto for neo-arid neighbourhoods

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A R T I C L E I N F O

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A B S T R A C T

As housing represents about 60% of cities land use and cities are responsible for 39% of global carbon emissions, this work investigates the emergence of a new generation of Egyptian cities having urban identity and architectural character revealed through climate responsive urban neighbourhood planning adjunct to its housing design in arid regions, while promoting heritage resembled qualities and eco materials. The methodology of planning and designing such cities' neighbourhoods, by connecting Urban-Building-Materials-Renewables (UBMR), has been manifested so that it can be disseminated for arid regions. A comparison between conventionally designed back to back parcel division planning that formulate dot patterns, with the courtyarded clustered free planning and energy plus designed neighborhood in Cairo, Egypt took place. A multi objective workflow assessment method was applied using ENVI-met V4.0 for urban microcimate simulations, Radiance for annual cumulative radiation and Energy-plus for urban energy use intensity to quantify different environmental sustainability measures and persuade decision-makers of the suggested design paradigm shift. Further, life cycle cost (LCC) analysis took place to correlate and quantify assessment measures of applied environmental and socio-economic sustainability systems, such as the Building Integrated Photovoltaic (BIPV), low-cost Stabilized Compressed Earth Blocks (SCEB) construction that support envelope passive design, affordability, and housing diversity. Combined UBMR solutions showed improved comfortable outdoor areas by 47.8% during extreme summer afternoon, increased annual solar energy generation potential by 13.87% and the energy-efficient envelope reduced cooling energy consumption by 28.9% while reducing cost of construction by 95.5%. As of socio-economic sustainability, all measures showed an evidence of preferability for the court-yarded clustered urban form attributed to the low-cost construction that offered more affordability over 50 and 100 years with green industrial and construction mechanism that empowered job opportunities, more housing designs' diversity that can be generated per each cluster, and more walkable streets according to pedestrian comfort maps.

Modeling the 3D recipe of environment consciousness while retrieving the socio-economic flavor values of ancestors' free planning renewed the architectural character and urban identity picture, as if getting back to heritage free planning that generates courtyarded urban clusters could evolve a future class climate responsive Neo-Arid city.

Abbreviations

LCC	life cycle cost
SCB	solid cement brick
CEB	compressed earth brick
SCEB	stabilized compressed earth brick
UBMR	urban, building, meterials, renewables
PET	physiological equivalent temperature
TSV	thermal sensation vote
BIPV	building integrated photovoltaic
WWR	window to wall ratio
Duplex	2 levels flat

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Triplex	3 levels flat
BC	existing base case
DS1	Neo-Arid urban form design suggestion no. 1
DS2	Neo-Arid urban form design suggestion no. 2
MWh	mega watt hour
GWh	gega watt hour
W/m. K	watt per meter kelvin
°C	degree celisius
kWh/m^2.year	kilo watt hour per square meter in a year
kWh/m^2	kilo watt hour per square meter
RC	reinforced concrete
EGP	Egyptian pound
m	meter
m^2	square meter
r	the inflation rate
i	the interest rate
e	the effective interest rate
A	the equal annual installments
P	the present value (investment)

1. Introduction

To assure the sustainable development of cities in arid regions, practitioners proposed reling on the generation of renewable energy using incident radiation. However, whereas sustainable cities have been regarded as complex urban science systems (Lobo, et al., 2020), it was crucial to be passively designed and constructed, in the first place, to reduce the potential heat gains and the resulted mechanical cooling emissions. Despite the fact that passive urban forms (Fahmy & Sharples, 2009a) can promote favorable climatic conditions within its outdoor spaces, the weakness of environmental vision in urban design strategies often leads to Urban Heat Island (UHI) in most cases (Krüger et al., 2011) if compactness is only applied strategy. Johansson and Emmanuel (2006) reported that giving the thermal performance of outdoor spaces a minor role in the urban design process is one of the most important causes of urban design deterioration and, in turn, discomfort. Subsequently, evaluating outdoor thermal comfort in public areas can enhance a city's livability. Ensuring that outdoor spaces will adequately serve the residents is essential to high-quality urban living (Johansson & Emmanuel, 2006).

Moreover, there is a significant correlation between urban form or urban configuration, i.e., ways of placing buildings on the land, and the potential increase of required energy for cooling in buildings located in hot-arid regions, like Egypt. Likewise, the geometrical composition of neighborhood-built environment elements: fabric, network, and vegetation have a significant role in modifying arid local climates and microclimates (Fahmy & Sharples, 2009a; Mirzaei & Haghighat, 2010; Galal et al., 2020; Mahmoud et al., 2021). Therefore, different urban pattern types have different microclimates (Oke, 1987). In arid climates where solar radiation has excessive rates along with low percentages of relative humidity, urban spaces passive cooling is a crucial demand for pedestrian thermal comfort enhancement as part of urban quality of life (Devi, 2013; Mirzaei & Haghighat, 2010). Further, urban environments are motors for energy efficiency improvements (Fahmy et al., 2017; Moonen et al., 2012; Pan et al., 2018), climate change adaptation (Fahmy et al., 2017; Fahmy et al., 2017) and urban heat island mitigation (Fahmy et al., 2018; O'Malley et al., 2015).

Nevertheless, in a country like Egypt, where most of its map is arid and contrary, the crucial issue is that most of the new urban development patterns continue to apply the back to back parcel division planning discipline that generates a dot ir-responsive climate patterns. In hot arid city like Cairo where urban patterns that receive a maximum average monthly global radiation levels are 7316 and 6893 Wh/m^2 for June and July respectively, the dominance and stucking to continued construction of back to back parcel division planning cities accombanied with high thermal conductance envelope materials is a mess. The gap between climate responsive arid heritage forms and present urban design practice (Fahmy & Sharples, 2009a, 2011a) is increasing as more public and governmental stakeholders continue to construct against microcliamte whereas both evironmnetal and urban dimensions have to be integrated. Cairo witnessed continuous historical developments since 641 AD until its existing populated master-plan and a fast development process since the late 20th century when the Egyptian government started constructing generations of new cities at the rural reserve areas of the main and mega ones (Hegazy & Moustafa, 2013). The recent 4th generation, which includes the new Capital, New Mansoura, Alamain and other cities, has many sustainable and smart design applications and is a real move towards quality of life and social equity but still apart from a sustainably and passively designed housing neighbourhoods in terms of urban patterns, housing design, construction system and materials.

As housing contributes to 50-70% of cities' land use budgets, it is crucial on a national level and even on regional and international levels to investigate how housing design can be generated and designed to cope with the 21st century changing climate and the geo-political-economic-food-energy crises whereas cities is responsible for 39% of global carbon emissions and buildings are responsible for more than 40% of any country's energy consumption. Therefore, neighborhood master-plan ing as an urban planning unit has to respond to arid climate where built environment Surface Temperature for example can easily reaches above 50°C in un-shaded areas owed to the harsh microclimate conditions even in a coutry city surrounded closely with agriculture like Aga city, Egypt. Fig.1 is a drone assisted thermal imaging by authors indicating Aga city apartment housing, constructed typically as concrete multi-story dot pattern, on the 25th of June whithin its hot summer week. Despite the aforementioned arid microclimate conditions, the extreme dominant housing construction system and materials are the reinforced concrete structures with cement bricks and cement plaster for building envelopes. Knowing that thermal conductivity (W/m. K°) of solid cement bricks (SCB) and contrary the stabilized compressed earth bricks (SCEB) are 1.60 and 0.548 respictevely with about 20% less cost per square meter for SCEB constructions against SCB (Fahmy et al., 2022), a big exclamation mark has to appear in fornt of such un-explained paradigm!

From this standing point, after studying courtyards in clustered urban form as a fabric passive cooling application that sums the control of aspect ratio (H/W), sky view factor (SVF), orientation, and compactness degree by (Fahmy & Sharples, 2009a), their extended research included improving the courtyarded clusters outdoor effects on indoors with the utilization of SCEB building envelopes in comparison to SCB and found remarkable thermal performance and nenergy efficiency differences (Fahmy et al., 2022). The clustered urban pattern as a linear fabric stands at a middle distance between the compact fabric that reduces daytime heat gain but traps heat in the early evening and the dot fabric that gains heat but releases it quickly (Fahmy & Sharples, 2008c). Furthermore, the existence of the courtyard as an innovative heritage concept for housing is well established in the metropolitan zone of old Fatimid Cairo and proved its role in modifying indoor climates. Although the courtyard design element is a responsive and intelligent fabric form in arid regions (Muhaisen, 2006; Swaid, 1992), it might not solely create desirable conditions (Al-Hafith et al., 2017; Forouzandeh, 2018; Nasrollahi et al., 2017). Therefore, the courtyard has to be gathered with other passive cooling applications that stimulate shading, ventilation, and evaporation, especially in hot arid climates (Bourbia & Boucheriba, 2010; Chow et al., 2011). Therefore, adjusting compactness and microclimate regulatory design elements, like the courtyard supported with ec-friendly construction material like SCEB, could have had an increasing role if such combined co-benefit mitigation effects have been critically elaborated.

On the other hand, cooling benefits of urban green coverage either in the form of trees (Morakinyo and Lau, 2018; Santos Nouri et al., 2018), ground coverage and green roofs (Dvorak, 2009; Razzaghmanesh et al., 2014), and walls (Alexandri & Jones, 2008; Jänicke et al., 2015) or all of

Fig. 1. A drone assisted capture about 90.5m above ground level indicating Aga city (30.944°N, 31.286°E) typical concrete multi-story apartment dot pattern housing, on the 25th of June 2022. Surface temperature scale (left) ranged from 19-89°C taken by authors using Zenmuse H20T infrared thermal imager mounted over DJI Matrice 300RTK quadcopter plan.

them distributed on the neighborhood TranSect (Fahmy et al., 2019) is having more listeners in the interdisciplinary field of urban climatology because of its innovative role in modifying microclimates conditions (Mullaney et al., 2015; Shashua-Bar & Hoffman, 2000), and hence improving the energy efficiency (Akbari et al., 2016; Fahmy et al., 2017). The GreenSect combined cooling effects are owed to shading and evapotranspiration of its elements such as trees (Oke et al., 1989; Taha, 1997). Urban trees shading is generated because of intercepted direct short wave radiation through the different canopies of trees (Morakinyo et al., 2017). In contrast, evapotranspiration is generated from the roots-leaves-air mechanism. In this process, moisture transpires from roots to leaves, and evaporation occurs from leaves to air depending on the stomata of each foliage leaf specie (Fahmy et al., 2010; Kong et al., 2017), foliage and roots density, tree geometry, soil moisture content and on the near microclimate of the tree leading to cooler surroundings of the tree. Extended microclimatic effects of trees can also be introduced when canopies ground projection or plantation area percentage and plantation patterns are considered (Tolba, 2017).

1.1. Problem definition

Where development heritage of urban communities in arid country like Egypt is well known by the character and identity of compact and courtyarded forms that proven better microclimates while present practice ir-responsive housing paradigm failed environmental connections with both scales of urban pattern and building, there has to be a way out. There is a need to connect and direct the formulation of housing neighbourhoods' patterns towards generating courtyarded clusters of housing by free urban planning discipline rather than generating and only stucking to the back to land parcels division urban planning discipline that generates only dot pattern apartment buidings. Therefore, the complexity of connecting specific urban microclimate conditions (as an environmental derivative) to urban, and socio-economic sustainable design real practice is the reason of why this study took place.

On the other hand, it is not a place to say that it is complex connecting environment, urban and socio-economic aspects because it is! In the 21st century where climate change and the witnessed global geo-political-economic energy conflict exist, there should be out of the box solutions for the most energy consuming part of the world; i.e. cities.

It is the place and the time to mention that such continueing spatio-temporal dilemma necessitates a comprehensive approach where only focusing on; either the environmental or socio-economic indicators, either urban or building, either design or construction, either with or without renewables is no longer an achievement. This is simply becuase the practiced paradigm concluded heavy carbon emitters and incomfortable concrete monster communities as shown in Fig. 1.

A sustainable neighbourhood have to consider at the same time how patterns, envelopes, construction systems and materials, renewables can be facilitated especially as the design complexity is maximized when talking about how to assess all of this using, statistical, CFD or parametric methods for example. However, the complex assessment of such complexity shouldn't sink researchers in an endless loop of uncertainty while the public and governments are continuing environment inconscious construction and their argument is because life is short and the needs are many!

From these standing points and derivatives, it can be figured that a 21st century urban design paradigm that has the recipe of friendship with environment while keeping the social flavor values of our ancestors can be manifested for arid regions to rise a Neo built environment heritage.

1.2. Aim and scope

According to Robbert Dijkgraaf who commented on Abraham Flexner classic essay (1939) of "The Usefulness of Useless Knowledge" (Flexner, 2017); "*A forty-year tightening of funding for scientific research has meant that resources are increasingly directed toward applied or practical outcomes, with the intent of creating products of immediate value. In such a scenario, it makes sense to focus on the most identifiable and urgent problems, right? Actually, it doesn't ….. The search for answers to deep questions, motivated solely by curiosity and without concern for applications, often leads not only to the greatest scientific discoveries but also to the most revolutionary technological breakthrough …. Flexner's defense of the value of "the unobstructed pursuit of useless knowledge" may be even more relevant today than it was in the early twentieth century …. basic research has led to* *major transformations in the past century and explains why it is an essential precondition of innovation and the first step in social and cultural change.*"

In this concern, the philosophy of aim and scope itself here means that answering the research complexity is not necessirely direct or quantifieable, it has to be mixed with passion and unquantifiable measures, it might be seen and felt but is it difficult? Again, yes. Thus, to provide evidence-based design suggestions for sustainable housing development is crucial as a direct aim, but preserving the urban identity and the architectural character inherited traditions is the missing urban realm and a Neo-Arid city is un-foreseen aim.

This work is a further design step on the continuum of the research line of scrutinizing and developing urban and architectural design and construction systems for a sustainable housing in Egypt, which was adopted by the corresponding author since 2008 until the review of urban microclimate research in Egypt (Fahmy et al., 2020) that summarizes milestones of the above mentioned research line, (Fahmy and Sharples 2008c; Fahmy and Sharples, 2009a; Fahmy et al., 2017; Fahmy et al., 2019; Fahmy et al., 2022). This study investigates reforming the heritage of the responsive free planning court-yarded housing typology, SCEB construction and renewables into the scale of neighborhood instead of single parcel division urban planning.

Therefore, selected performance indicators that reflect the environmental and socio-economic sustainability measures, were compared among different cases to demonstrate the favorability of the suggested design, and the possibility of developing the concluded urban identity and architectural character for neighbourhoods, in future work, into a consistent theory of sustainable city planning.

2. Interrlations between environmental and socio-economic indicators

As a development strategy followed by the Egyptian government to drive out population into new satellite urban settlements around mega cities (Fahmy et al., 2018), in-adequate studies on the interrelation between environmental and social dimensions were considered leading to intensifing the adverse consequences on the natural and built environment and, in turn, on the residents' quality of life by continuous development using dominant dot pattern apartment reinforced skeleton housing communities.

For example, walkability plays an essential role in diverse fields, such as planning, health, transportation, and the environment. The term walkability has many definitions in the literature according to different points of view. Some scholars linked it with the walkable neighborhood (Talen & Koschinsky, 2013); others attributed walkability to population density, land use, and connectivity which encourage residents to walk (Dill, 2004; Leslie et al., 2007; Newman & Kenworthy, 2006; Southworth, 2005). Further, Kamel (2013) defined walkability as the extent of a walking-friendly built environment. Alawadi et al. (2021) generalize the definition of walkability as the factors and objectives that motivate residents of a community to walk. Various approaches had been used previously to assess walkability that can be summarized in three approaches: 1) GIS-based approaches (Hajna et al., 2013), 2) fieldwork (Schlossberg, 2006), and 3) a mix of computerized methods and fieldwork (Aultman-Hall et al., 1997; Lee & Talen, 2014; Mavoa et al., 2012). Moreover, fieldwork represents the primary method for assessing walkability that can be divided into two approaches: 1) quantitative approach that rely on land use, transportation efficiency, and travel choice in which this approach aims to predict the walking behavior of communities to support the present and the future decisions of these communities (Lo, 2009; Saelens et al., 2003; Yu & Song, 2007); and 2) qualitative approach that studies the user satisfaction, and walking pattern and behaviors of individuals (Ewing et al., 2006; Millonig and Gartner, 2007). In addition, walking activities can be divided into two categories which are utilitarian purposes and non-utilitarian purposes. The utilitarian purposes such as walk to work, transit or school, whereas non utilitarian purposes are recreational or leisure trips to parks, shopping and restaurants.

According to previous studies, there are many factors affecting walkability. Southworth (2005) proposed connectivity, linkage with other modes, fine-grained land use, safety, quality of the path, and path context as primary factors that affect walkability. In contrast, feasibility, accessibility, safety, thermal comfort, and pleasurability were the factors concluded by Alfonzo (2005). Further, Mehta (2008) added two more factors: usefulness and some belongings. In addition, Lo (2009) suggested new factors such as the presence of continuous and well-maintained sidewalks, universal access, path directness and connectivity, safety at grade crossings, absence of heavy, high-speed traffic, pedestrian separation from traffic, land use density, building and land-use diversity, street trees and landscaping, visual interest and sense of place, and perceived or actual safety. Moreover, Ewing and Handy (2009) suggested image-ability, enclosure, human scale, transparency, complexity, legibility, coherence, and tidiness. Additionally, Talen and Koschinsky (2013) proposed factors such as urban form, social, economic and land use diversity, equitable accessibility, and protection of environment and human health.

Furthermore, previous studies concluded that there is a direct correlation between climatic factors and walkability; among these climatic factors are heat, humidity, intense sunshine, and rain storms, in which the increased temperature and humidity reduce the activity of people and discourage them to walk because of discomfort (Kamel, 2013; Lin, 2009; O'Hare, 2006; Zahran et al., 2008; Zeng & Dong, 2015). However, various mitigation strategies can be applied to improve the outdoor thermal comfort and conditions for walking, such as shading features, trees, grass, and other landscape elements (Maghelal et al., 2011; Mahmoud, 2011; Shashua-Bar et al., 2011; Zeng & Dong, 2015). Alawadi et al. (2021) used two approaches to investigate the reason for walking, the impact of the built environment and climate on walking activity, walking pattern, and rhythm; these approaches are; 1) counting of pedestrian movements through the use of the free multi-counter application, and 2) questionnaires. The study revealed that the sites with parks, pleasant microclimatic conditions of temperature, sunlight, shade, and wind encourage people to walk, either for utilitarian or non-utilitarian purposes. Also, converting existing surface parking to green areas within building blocks and shading structures and natural shading can promote walking in addition to social habbits. Moreover, Yang et al. (2016) concluded that integrating electrical fans, air ducts, and water misting devices in the shaded walkways can increase wind velocity, reduce sensible heat, and enhance the walking experience. More studies spotlight the importance of natural shading, as trees, in improving the urban microclimate (Aboelata & Sodoudi, 2020; Ali-Toudert, 2005; Fahmy et al., 2016). However, a precise selection of tree type is crucial for the efficient improvement of urban microclimate which is attributed to the increased maintenance cost, water consumption, growth period to obtain proper canopy size (Dimoudi & Nikolopoulou, 2003; Fahmy et al., 2014). Accordingly, practicing urban design for outdoor thermal comfort in cities have to be given more attention (Johansson, 2006b) because of the complexities and dynamic nature of the urban environment that impede an accurate prediction of the meteorological parameters and signify the pedestrian thermal sensation and comfort (Naboni et al., 2017). In the last decade, outdoor microclimate and pedestrian thermal comfort gained their importance in the urban design research field due to its significant impact on pedestrian and its connection with the occupants indoor conditions and buildings energy consumption (Fahmy et al., 2017; Moonen et al., 2012). To account for outdoor thermal comfort as an assessment strategy for the built environment's urban spaces in Egypt, some thermal comfort indices rely on models considering heat wave fluxes within the fabric, humans, vegetation, and anthropogenic heat gains (Ramadan, 2010). As an example, physiological Equivalent Temperature (PET) is one of the most commonly used indices that constitutes all environmental variables influencing the heat balance of the human body (Ali-Toudert, 2005). Although PET has not been calibrated in Cairo, it was the base for

Thermal Sensation Votes' (TSV) assessments in an open urban park and an urban street in Cairo (Elnabawi et al., 2016; Mahmoud, 2011). The studies concluded a comfort range between PET 23°C to PET 32°C with a preferred temperature of PET 29°C (Elnabawi et al., 2016). This was 2°C higher than the open urban green park and around 7°C higher than the PET comfort range according to the climatic circumstances in Europe.

Moreover, the construction of nearly zero-energy urban settlements urges the promotion of a renewable energy production system that could compensate a huge percentage of the total electricity demand. Concerning their environmental and economic benefits, renewable energy systems are nowadays the optimum electricity supply alternative, especially in the developing regions (Foster et al., 2009). While the installation of Building Integrated Photovoltaics (BIPVs) may require higher initial costs (Dabaieh et al., 2016), technological advancements nowadays yield lower priced and highly efficient systems (Zhang et al., 2014). In addition, conducting a shaded microclimate to reduce thermal discomfort may undesirably dominate solar access (Compagnon, 2004; Compagnon & Raydan, 2000; Montavon et al., 2004), reducing daylight availability solar energy potential. However, exploiting solar power generation in Hot-Arid regions might become congruent with urban compactness that employs the quality of shading passive cooling strategy if adjusted orientation of urban patterns and buildings are compatible with solar panels' orientation. Therefore, a compromise between passive design, energy consumption and renewable energy production, based on its compensated percentage of energy demand and the payback on investment is another example for the interralational effects between environmental and socio-economic sustainability measures that should be considered during the urban planning and design process (Naboni et al., 2019).

3. Methodology

3.1. Introduction

As shown in previous sections of this study, Egypt map shows hot and arid climatic conditions. In the past where compact city heritage having courtyard and many other passive design elements have been applied, it was easy for a visitor to Cairo mideaval and metropolitan areas to recognize a making in urban places (because of architecture character and urban identity) while feeling environmentally comfortable in buildings (because of eco-friendly design and materials). Nowadays, despite the continuing mega development projects especially in housing, construction sector in Egypt do not rely but on concrete structures of parcel devision planning revealing climate irresponsive urban forms on dot patterns that consume more energy, repel more carbon and couldn't show an out of the box solution to correlate environmental with socio-economic / quantifiable and non quantifiable sustainability measures.

From these standing points, a combined design methodology with a multi-objective assessment workflow method for different sustainability measures took place and explained in the following sections.

3.2. Neo-Arid urban form design manifesto

Following an international design procedure, this research is presenting a design manifesto based on the heritage court-yarded clustered housing free planning combined with microclimate conscious urban design, with an overlay of climate change mitigation and adaptation strategies using Stabilized Compressed Earth Bricks (SCEB) and BIPV as a renewal (Neo) and regeneration of the Arabic arid city heritage which is so called the Neo-Arid city.

Neo-Arid neighborhood free planning with sketching and land use budget calculations was implemented to manifest the considerable knowledge of the four dimensions of Urban, Building, eco-Materials, and Renewables (UBMR). At the same time that these four dimensions of UBMR can be considered a forward move towards a 5th generation of Egyptian cities which have been applied for this article's case study, it establishes an expository model of practicing urban housing design and introduce a new urban identity and architectural character for housing projects in similar climatic regions, (Fig. 2).

Neo-Arid neighborhood design paradigm is composed of UBMR steps urban design steps as following:

1- Land use budget calculations to account for lot area coverage needed according to Law no.3 (1982) and its amendments for; fabric (housing and services), network (vehicular and pedestrian roads) and open areas (recreational and vegetation).
2- Site meteorology and microclimatic analysis.
3- Zoning and 2D sketching of the required functions mentioned mentioned in step no.1.
4- Zoning and 2D sketching of the required housing typology units (social economic class 96m^2 flats and/or medium class 150m^2) replicated around a courtyard to formulate a basic cluster with the required orientation and geomtrical adjustment.
5- Sketching and drawing road netwroks to formulate lot areas needed to replicate the basic court-yarded cluster with resilience; i.e. modifications might take place by the application of the iterative architecture and urban design principles using free compact and/or linear pattern planning on a passive cooling microclimatic responsive basis.
6- Application of SCEB and BIPV overlays, (knowing that other types of sustainability applications might take place in different cases; such as waste to energy and e-mobility).
7- Defining measures and indicators for environmental, and socio-economic sustainability assessment of suggested urban form, building, materials and renewables according to UBMR dimentions.
8- Modeling and evaluating the Base Case (BC) and Design Suggestions (DS) using simulations and simple calculations.
9- Analyitical comparisons for different alternatives according to the extracted simulations and calculations outputs that reflect environmental and socio-economic sustainability outcomes.
10- Generting 3D model models for presentations.

3.3. Methods and sustainability measures

The assessment of the suggested reformed model of Neo-Arid city is based on selected environmental socio-economic interrlational quantitative measures, and design practices to compare a back to back parcel division dot pattern neighbourhood, with the courtyarded clustered free planning and energy plus neighborhood in Cairo, Egypt.

As shown in Fig. 5, the workflow diagram for the methodology of this research study, is a multi objective quantitative environmental and socio-economic sustainability assessment workflow that was derived according to UBMR dimensions and the presented literature of section 1 and section 2 of this research, (Figs. 3 and 4).

The environmental sustainability measures were extracted among the governing urban and building design credit points of the Leadership in Energy and Environmental Design's rating systems for Building Design and Construction (LEED-BD+C) (Rivera, 2009) and Neighborhood Development (LEED-ND) (Garde, 2009; Niswonger, 2013; Talen et al., 2013), as well as the Green Pyramid Rating System for New Construction (GPRS-NC) (Shamseldin, 2016) and the Egyptian energy efficiency code for residential buildings (HBRC, 2008).

The environmental sustainability measures include:

1- The annual cumulative direct solar radiation as an indication for interception by designed geometry.
2- PET as the pedestrian thermal comfort indicator in an outdoor environment, which is crucially influenced in hot-arid regions by the mean radiant temperature that represents all short-wave and long-wave radiations' incident at a specific urban space point.

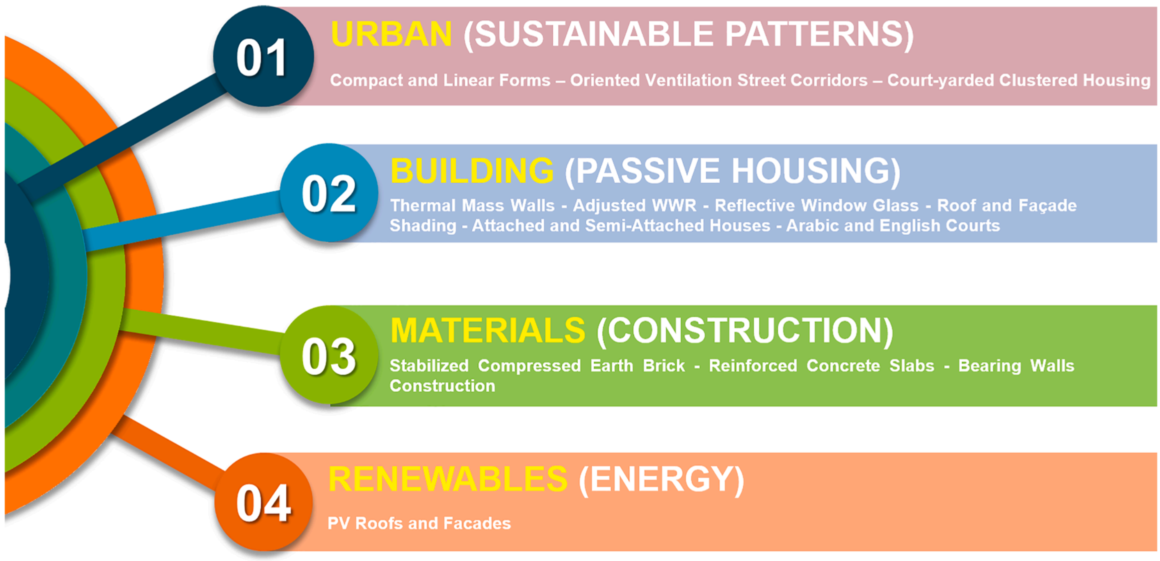

Fig. 2. A summary for the physical design criteria offered to fulfill the environmental sustainability indicators of UBMR dimensions for sustainable housing of the 5th generation of Egyptian new cities modified after Fahmy et al. (2020) and Fahmy et al. (2022).

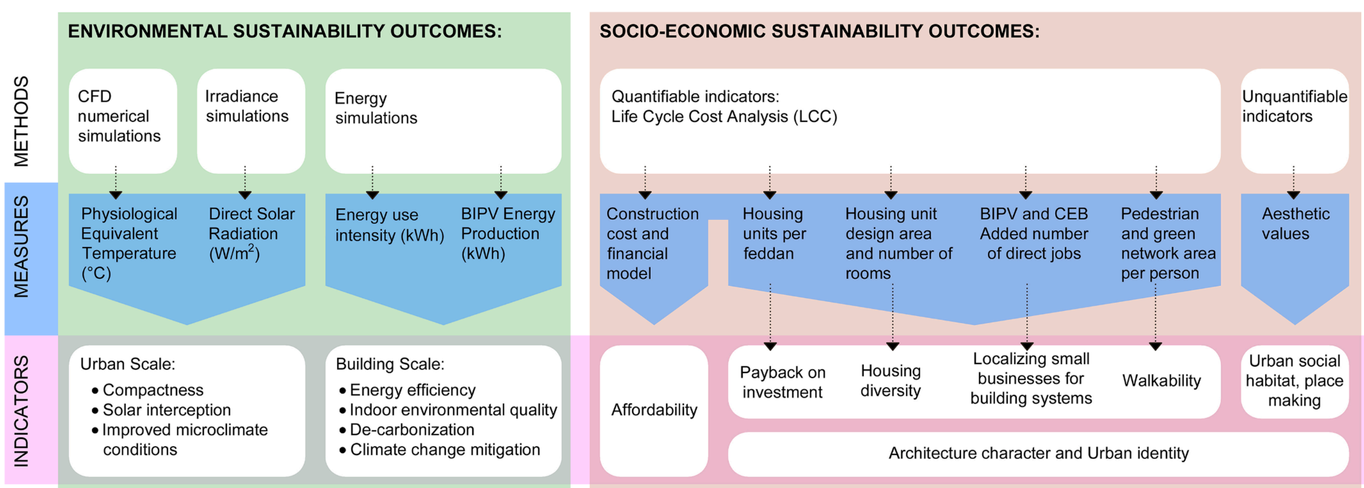

Fig. 3. Investigated sustainability measures and indicators of the research Urban-Building design manifesto.

3- Energy use intensity for heating and cooling indicating the thermal performance of urban and housing design and envelope construction materials,
4- Energy produced from BIPV system which indicates the amount of de-carbonization from the atmosphere and climate change mitigation in turn.

Such measures will be presented as an extracted outputs after ENVI-met numerical simulations of the base case and suggested cases' to assess gathering both passive urban and architectural details from being just knowledge to design action.

Utilizing ENVI-met V4.0 numerical CFD simulations for urban microcimate simulations, Radiance for annual cumulative radiation and Energy-plus for urban energy use intensity, BIPV energy generation potential calculations, quantifiable sustainability measures of improved urban microclimate and indoor environment in addition to selected socio-economic measures are extracted to persuade decision-makers of the suggested design paradigm shift.

ENVI-met was used in a holistic three-dimensional simulation of surface-plant-air interactions embodying the proposed scenarios. It is used to simulate urban built environments (Bruse, 2019) and has been validated and calibrated in many studies for its ability to simulate thermal environmental conditions on the microclimate scale (Crank et al., 2018; Elwy et al., 2018; Forouzandeh, 2018). ENVI-met simulation course includes, (Ali-Toudert et al., 2005; Elnabawi et al., 2016): 1) modeling the master planning scenarios, 2) data entry for site microclimate conditions, building physics such as the albedo and thermal conductance of walls and roofs and human bioclimatology, 3) running ENVI-met simulation core, and 4) output data extraction either in thermal maps or numerically. Outputs can be represented by hourly values for various meteorological parameters converted into outdoor thermal comfort in terms of PET. As shown in Table 1, ENV-met data entry is calibrated through meteorological data collected from WMO weather station no. 623660 (EnergyPlus, 2009) for the selected simulation day. Since the current study was directed to compare three different design cases, the choice of the simulation day was to represent the summer season, which is highly affected by harsh heat stresses in Egypt and in similar regions, (Ali-Toudert et al., 2005; Elnabawi et al., 2016; Galal et al., 2020; Mahmoud et al., 2021). Thus, ENVI-met simulations were held for 12 hours from 06:00 to 18:00 of local solar time on the extreme summer day of July the 1st.

Furthermore, a radiation analysis, using Radiance (Ward, 1994)

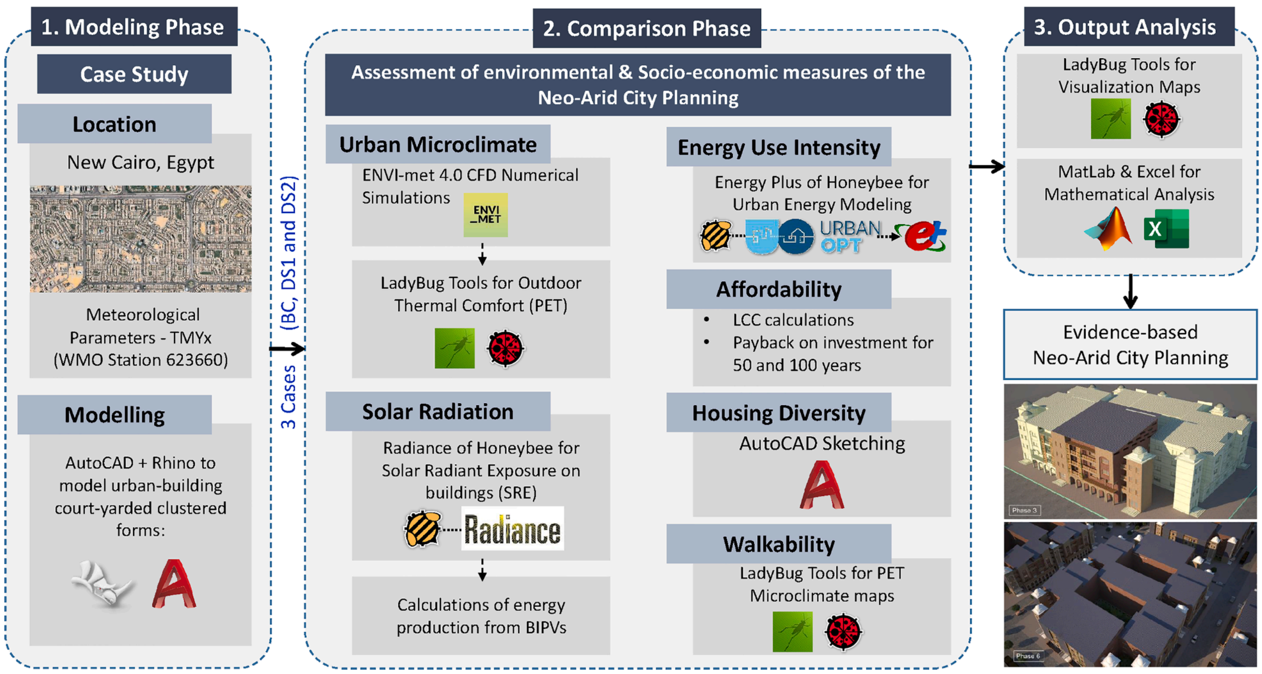

Fig. 4. A workflow s howing for procedure of assessing the environmental and socio-economic measure of Neo-Arid city on based on UBMR design dimensions illustrated in Fig.1.

Table 1
Data entry for simulations on the 1st of July.

Parameter	Value
Ta	301.95 K
RH	59%
V	3.5 m/s at 10m height
U value Walls	1.7 W/m^2.K
U value Roofs	2.2 W/m^2.K
Albedo Walls	0.25
Albedo Roofs	0.15
Albedo Pavement	0.40

interfaced by Ladybug Tools plugin for a Grasshopper (Roudsari, 2017), took place to determine the annual cumulative radiation (kWh/m^2-year) falling on the façades and the roofs of all buildings. The analysis results were divided according to the directions of the exterior building surfaces; i.e., into walls oriented towards North, East, South, and West as well as roofs in all cases, to categorize solar energy generation potential per orientation according to Eq. (1) that roughly estimates annual energy production of BIPVs from the yearly average solar radiation.

$$E_p = a \times Y \times R_{av} \times \eta \tag{1}$$

In which, E_p is the annual average produced energy (kWh), a is the total area of the PV panels (m^2), Y is the PV panel yield (%), R_{av} is the annual average solar radiation incident on the PV panels (kWh/m^2), and η is the performance ratio regarding various energy losses. The solar panel yield (Y) is estimated from the maximum power (kW_p) that a PV cell can generate at specified Standard Test Conditions (STC), usually at 1 kW/m^2, 25°C, and 1.5 air mass, divided by the surface area of this cell. Thus, the solar energy yield for commonly used PV cells of 250 W_p and an area of 1.67 m^2 is 14.97%. Additionally, the performance ratio (η) of the installed PV system, which comprises potential losses due to temperature, dust, reflections, inverter, or cables, is estimated to be 0.75.

Moreover, utilizing the cutting edge tools of Energy Plus modeling and simulation for a whole neighborhood, monthly and annual energy use intensity were simulated for the entire urban area of each case using the connection between UrbanOpt software tool and Dragonfly plugin for a grasshopper (Charan et al., 2021). Using the provided default settings for ideal cooling and heating loads and generic mass materials, the simulation setup varied only by the selection of the sual weather file of Cairo and the envelope wall materials with thermal characteristics shown in Table 2. Since the building envelope material is an underlying factor for UBMR design dimensions, the commonly used Solid Cement Bricks (SCB) and SCEB exterior wall materials were interchangeably applied to the design cases of DS1 and DS2.

Concerning the fragmented conceptualization and lack in defining socio-economic factors of sustainability, as described by Larimian and Sadeghi (2021), the design practices can affect the socio-economic sustainability indicators. Apart from unquantified aesthetic values, the nature of some of those socio-economic indicators can be quantified while others are qualitative. The low cost construction implication on affordability and the offered industry and economy derived by SCEB construction systems as socio-economic factors had the focus of this research to evidence that Neo-Arid urban forms utilizing SCEB court-yarded clustered housing is not only beneficial from an environmental point of view but also from socio-economic one. That is why life cycle cost (LCC) method was sufficient as a simple methd to persuade decision makers of the feasibility of the suggested paradigm; its design and construction economics.

In this study, socio-economic sustainability measures comprise five aspects;

1- Affordability of Neo-Arid housing units.
2- Housing design diversity offered to the public.
3- Walkability within suggested urban form.
4- Green job opportunities offered by the SCEB construction economy.
5- Payback period that affect the initial investment value.

Table 2
Thermal characteristics of different external walls materials.

Thermal Data	SCB	CEB
Thermal conductivity (W/m. K°)	1.60	0.548
Density (Kg /m^3)	1800	1629
Specific heat (J/Kg. K°)	880	826

Some of these aspects were analyzed considering the time value of money translated into life cycle cost analysis (LCC) based on the interest rate, inflation rate through 50 years, and 100 years life cycle horizon using the sustainability assessment index developed by Mahmoud et al. (2019). Moeover, the comparison of the affordability aspect was conducted between the conventional method of construction (skeleton construction) and the proposed one using SCEB construction. The traditional construction method used reinforced concrete skeleton, represented in slabs, beams, and columns on every floor. The floor area of a single slab is 150 m^2, the area of RC in conventional construction is 60 m^3. As stated previously, in the case of SCEB construction, only the slabs of building utilities such as kitchens and bathrooms are RC. A single flat's kitchen and bathroom areas are 12 m^2 and 6 $m^{2,}$ respectively. The RC slab thickness is 15 cm. Therefore, the RC consumed in a single apartment in the case of SCEB construction is 2.7 m^3.

The price of one cubic meter of RC work in Egypt is 3200 LE (2022). Hence, the cost of RC work in the case of skeleton construction and SCEB construction for a single flat is 192000 LE and 8640 LE, respectively. Knowing that the inflation rate and the interest rate in Egypt are 7.67% and 8.25%, respectively. Based on Eq. (2) and appendix A, the effective interest rate is 0.00539 or 0.539%, in which this value was used in the LCC analysis. The LCC analysis was utilized to show that using the SCEB construction method will save the amount of investment needed for the RC work through paying installments over 50 years and 100 years life cycle planning horizon, knowing that the analysis was performed for one unit (one apartment). In this analysis, a capital recovery method was utilized that depends on distributing the total investment that is needed to be paid in the present over equal annual installments, taking into account the effective interest rate using equations (2 and 3), (Newnan et al., 2004; Riggs et al., 1997; White et al., 2012).

$$e = \left(\frac{1+r}{1+i}\right) - 1 \tag{2}$$

$$A = P\left(\frac{e\ (1+e)^n}{((1+e)^n - 1)}\right) \tag{3}$$

Where: r is the inflation rate. i is the interest rate. e is the effective interest rate.

A is the equal annual installments.

P is the present value (investment). n is the number of years.

In addition, some of the socio-economic indicators have a mutual effect on each other; for example, introducing BIPV and SCEB systems to the housing industry does not only offer an added number of direct jobs opportunities through small and medium-class businesses to install and operate those systems but also increases the payback on investment in such newly sustainably designed houses. Affordability can also be maximized by the payback on investment in BIPVs constructed over a double ceiling of the building roof. Further, the affordability implication of SCEB low-cost construction has another cross-cutting measure for socio-economics; it can be maximized through a well-prepared financial model of housing such as long-term co-operative installments rather than cash and carry or short term installments' finance.

Moreover, the effects of clustered urban geometry on walkability, which has been designed on a microclimate basis and simple urban design principles such as order, symmetry, and proportions, will be assessed by calculating the percentage of cool spots for pedestrian among the walkable network. On the other hand, from an urban and architectural design discipline point of views; it can be argued that the suggested housing unit attachment in relation to other units, its area and building systems form the cluster at its architecture character scale, whereas the arrangement order of those clusters forms the neighborhood at its urban identity scale (Moughtin, 1992; Moughtin et al., 2000). Hence, the hypothesis of improved interralational quantifiable measures attributed to connecting courtyarded housing and neighborhood clusters' UBMR design manifesto that could lead to important but unquantifiable socio-economic indicator such as the architectural character and urban identity, could be argued as a repitative order, symmetry and unity can be seen, (Moughtin, 1992; Moughtin et al., 2000). From this standing point, it can be laso argued that the renewed arid heritage UBMR courtyarded clustered neighbourhood overlayed with BIPV and SCEB is a considerable approach to shift the practiced housing paradigm for a 5th generation of Egyptian cities.

3.4. Modeling Neo-Arid neighbourhood case study

New Cairo is one of the famous suburban developments of Egypt in the last 50 years. However, it followed the traditional western neighborhood development master planning. New Cairo doesn't represent an arid city at all. Contrary, this research is pointing that such paradigm of back to back parcel division planning is not adequate in a hot arid region and that is why a manifesto based on the heritage court-yarded clustered housing free planning combined with SCEB and BIPV is suggested as a renewal and regeneration of heritage with an overlay of climate change mitigation and adaptation strategies and so called the Neo-Arid city. The case study is located in the fifth community of New Cairo (30°00′41"N, 31°26′14"E), a hot semi-arid neighborhood area. It was built in the late 20th century and is located east of the 1st Greater Cairo's ring road. Fig. 5-a indicates the case study's situation plan in relation to New Cairo, Metropolitan Cairo, and the nearest weather station of Cairo International Airport. The current urban form of Fig. 5-b, which is referred to as the base case (BC) in this study, was initially designed as a dot pattern single-family housing adapted later to accommodate 2 apartments per floor. Thereby, per building heights regulation of ground and two typical floors, one parcel can comprise up to 6 housing units as long as it follows the Egyptian urban planning laws (Law3, 1982; Law106, 1999).

Cairo's climate is classified according to the climate classification of Köppen-Geiger (Kottek et al., 2006) as a hot semi-arid region. According to the WMO Station no. 623660 at Cairo International Airport, which is the nearest weather station to the neighborhood case study, the extreme

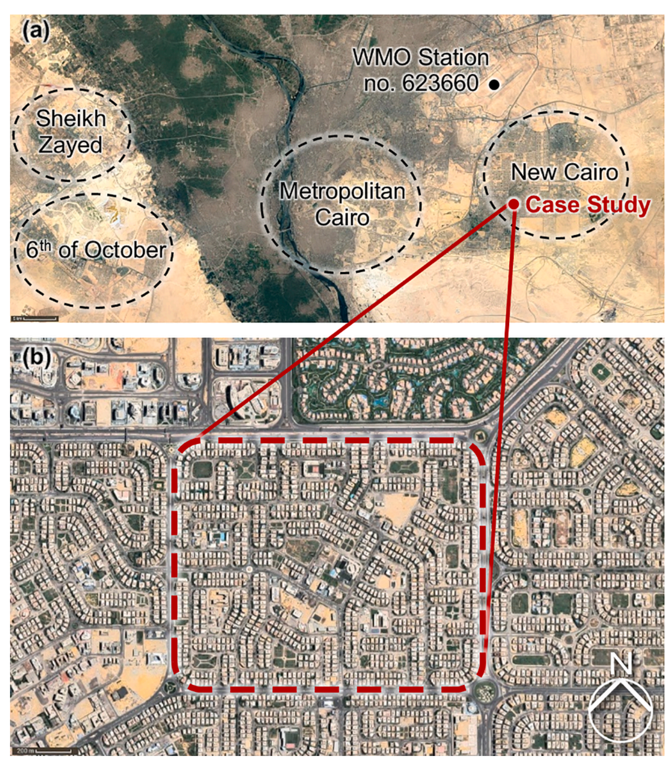

Fig. 5. Satellite images derived from Google maps showing (a) the case study location in relation to New Cairo and the nearest weather station and (b) the urban form and scale of the selected neighborhood.

hot week starts from June 26th till July 2nd. The maximum air temperature is maximum 44°C. Moreover, during the summer months, the maximum daily-averaged relative humidity is 60% in August, while the maximum wind speed is 3.5 m/s in June and July. The maximum cumulative direct average radiation was 6285 Wh/m^2 in June.

Nevertheless, two design alternatives were suggested in the same neighborhood area to offer different housing types of clustered urban forms. The design suggestions provide relatively higher vegetation coverage, building floors, compactness degree, and population density (Table 3). The first design suggestion (DS1), shown in Fig. 6-a, is a clustered urban form designed over the same zoning and land use percentages as that of BC (Fig. 6-b). The main reason for DS1 is to study the effect of only clustering the existing dotted pattern into court-yarded buildings regardless of their orientation or their courtyards' closure ratio. The second design suggestion (DS2), on the other hand, has completely different zoning using the same land use percentage of services, in which the courtyards heritage of medieval Arabic housing were reformed into urban clusters following the UBMR dimensions, including the courtyards' closure geometry ratio and primary axis orientation. Besides, both clustered suggestions had tree species of Cassia Leptophylla and Cassia Nodosa numerically modeled after Fahmy et al. (2017). Fig. 7, on the other hand, indicates the 3D numerical model for the clustered urban form of DS2.

This research is arguing that the paradigm of back to back parcel division planning which is acombnied with reinforced concrete and SCB construction is not adequate in a hot arid region. That is why a design manifesto based on the heritage court-yarded clustered housing free planning combined with CEB and BIPV is suggested as a renewal and regeneration of heritage with an overlay of climate change mitigation and adaptation strategies which is so called the Neo-Arid city and having the UBMR dimensions.

The suggested urban form design followed the work of Fahmy and Sharples (2009a), where the clustered court-yarded housing took place instead of the commonly adopted dot or linear patterns. The compact urban form includes adjustments of urban street canyon's aspect ratio of width to height of 1:1.5 and orientation towards the prevailing wind from North. As a housing climate regulatory system, the courtyard itself has a closure geometry ratio of width to length to the height of 1-1.5 : 2-3 : 1.3-1.5, includes a garden at its core, and its main axis is oriented 15 degrees with the East-West axis. This orientation enables maximum cooling in summer and heating in winter for the courtyard walls, (Waziry, 2002; Fahmy and Sharples, 2009a). From a housing design point of view, connecting and directing the formulation of housing neighbourhoods' patterns by free planning discipline can be done by replicating the required housing unit (flat) around the geometry of courtyard as shown in Figs. 1 and 2. The easy way is stucking to the back to back land parcel division planning discipline that generates only apartment buidings dot patterns. However, in order to optimize the clustered form for microclimate conditions, ENVI-met microclimate simulations kept the 15° orientation of the cluster main axis after which a parametric optimization using Ladybug Tools plugin for Grasshopper was held to study wheather the southern orientation required for BIPV could be applied for DS2 clusters' courtyards or not.

As demonstrated from the 3D models in Fig. 8 and the typical floor plan in Fig. 9, the housing cluster comprises a ground and three typical floors; each floor includes ten attached housing units, whereas this number increases when attaching two or more basic housing clusters. The gross area of each dwelling unit is 150 m^2 for medium-class housing of 96m^2 for social housing, while two or three stacked dwelling units can be connected to the form of a duplex or a triplex. The modeling of the clustered urban form passed through 6 steps as shown in the figure below, in which façade and roof design enhancements took place in an urban and architectural iterative design discipline following the least design basics: order, unity, and proportions, and the land use budget calculations of the neighborhood case study planning. Fig. 8 shows the development phases of the 3D modeling for the preliminary housing typology applying UBMR dimensions. It can be noticed that UBMR design paradigm cannot be separated from the featured low-cost material and construction system that supports passive building envelope while maintaining a specific texture, color and, in turn, architectural character. The UBMR clustered urban form features a load-bearing walls construction system using Stabilized Compressed Earth Block (SCEB), (HBRC, 2019), where only the ceiling of housing utilities can be fromed of reinforced concrete, and the rest is nearly flat brick vaults. Also, the SCEB walls of the ground and the 1st floors have a thickness of 38 cm and decrease to be 25cm on the 2nd and 3rd floors. CEB is characterized by natural color and texture without other manufactured finishing materials. In addition, SCEB has been examined in a pilot ground floor housing unit which was the core of the Egyptian code for SCEB, (HBRC, 2019) Fig. 10. SCEB construction system is found to be energy efficient in comparison to traditional brick types (Masoud et al., 2019), compliant with the Egyptian residential energy efficiency code (HBRC, 2008) and is acceptable in many regions for its mechanical properties (Muntohar, 2011), as a low-cost construction (Waziri et al., 2013) and a low carbon footprint material (Asman et al., 2020). SCEB construction provides a lower cost per square meter than the traditional RC skeleton construction attributed to the lower cementious content, minimum façade finishing and less embodied energy, minimum reinforced concrete slabs and columns, and minimum transportation cost. It is a place to mention that the Egyptian code for SCEB describes the manufacturing process and application using different soil mixtures with minimum cement and steel content (HBRC, 2019).

Other outcomes of UBMR typologies include but are not limited to generating urban identity through the arrangement order of clusters and their courtyards and green cooling spots, architectural character through the design unity of facades openings, BIPV and SCEB application. It is a place to mention that the green infra area that forms the cooling spots of clusters has been saved from the commonly adopted urban patterns by clustering the housing units themselves. Outcomes also extend to walkability, urban social habitat attributed to the place making generated by saving the housing parking area if the clusters are 1.5m above ground to construct underground parking. In comparison to the common dot housing, the high ground floors offer more pedestrian area added to that saved by clustering without exceeding the five floors high limit argued by Jabareen for sustainable cities (Jabareen, 2006, Jabareen, 2014). It is a place to mention that the clustered urban form contains a ground and three typical floors, offering almost doubled population density and housing units, compared to the current and commonly used urban forms, which increase the investment benefit in sustainable urban housing from policy, decision-makers and investors points of view.

3.5. *Limitations of the study*

The complexity of this research study limited some essential data entry parameters required for a comprehensive sustainable urban form

Table 3
Urban planning statistics for different cases of the examined neighborhood site.

	Urban site area	Green coverage (%)	Construction (%)	Number of floors	Population (persons)	Population density
BC	380.15 Feddans	0.368	0.252	Ground + 2	14950	39.7 p/f
DS1		0.291	0.299	Ground + 4	46662	123 p/f
DS2		0.476	0.310	Ground + 4	50448	133 p/f

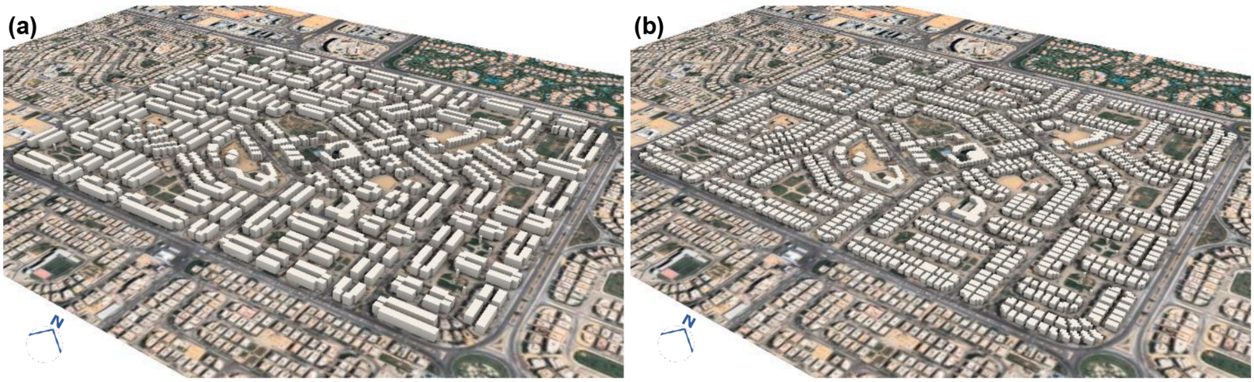

Fig. 6. 3D models for the urban fabric over the same land use and network -without trees- of (a) DS1 and (b) BC, which were modeled using the Spaces tool of ENVI-met V4.0, (Bruse, 2019).

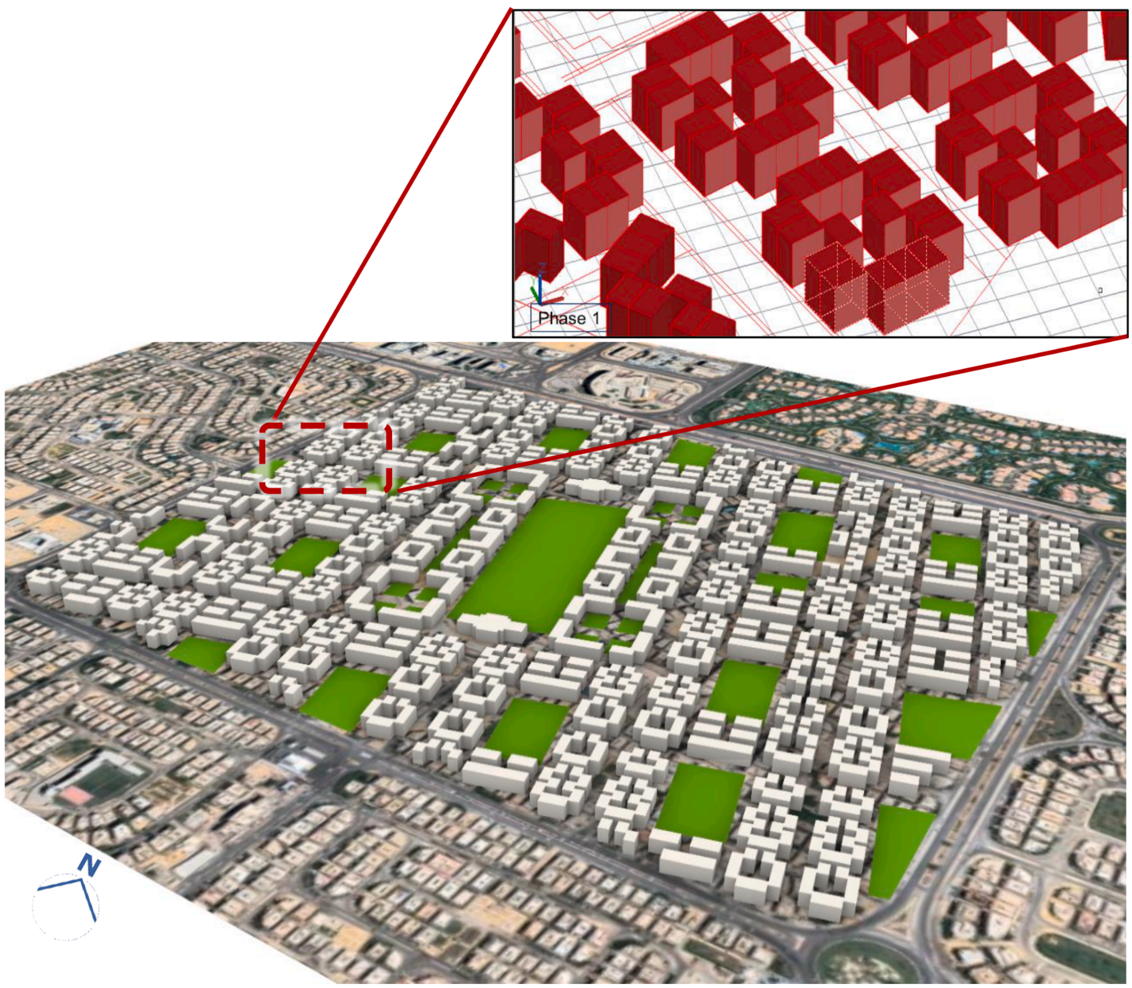

Fig. 7. 3D model for the clustered urban form of DS2 extracted from the Spaces tool of ENVI-met V4.0 without trees to indicate urban geometry, order, symmetry, unity and proportions. The enlarged capture is the primary modeling phase (1) of presenting the 5th generation (UBMR) criteria as a design manifesto for Neo-Arid city planning, correlate with Fig. 8.

design such as the orientation of the main axis of clusters courtyard was kept 15° from the E-W direction in the main ENVI-met simulations which is not compliant with the southern orientation needed for the PV cells when mounted over roof top as double ceiling for shading and as a BIPV applicaion as shown in Fig. 8.

From an urban marketing point of view, it can be simply said that some neighbourhoods' housing prototypes would be with BIPV rooftop while others won't, however in the case of having BIPV, the rectangular shape of a cluster won't be compliant if it kept the main axis of clusters courtyard 15° from the E-W direction.

In this regard, Ladybug Tools plugin for Grasshopper has been applied to check whether the absolute shouthern orientation would be suitable for the long side (main axis) of the cluster. This auxiliary simulation considered calculating the Solar Radiation Exposure (SRE) incident over the walls of cluster courtyards in different orientations while calculating thermal comfort (PET) within the courtyard itself to

Fig. 8. 3D imaginary modeling for the preliminary medium-class clustered housing applying UBMR dimensions.

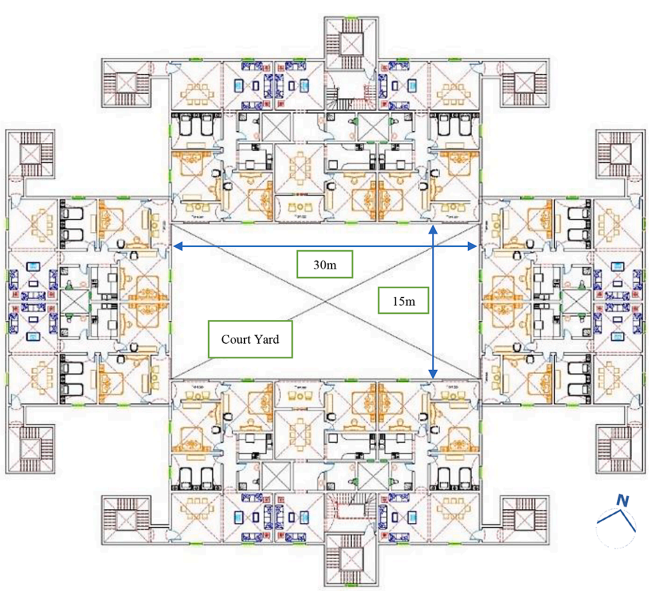

Fig. 9. Typical floor plan for the UBMR basic clusters having 40 housing units.

Fig. 10. The pilot ground floor housing unit constructed as shown in the SCEB Egyptian code, (HBRC, 2019).

assure microclimate performance. The results of this auxiliary simulations shown in Fig. 11 indicate that in terms of SRE, the option of orienting the main axis of courtyard E-W, i.e. the long side facing south, is the most suitable as it has the least heat gain from walls (SRE) with a value of 58.7 kWh/m^2, while PET of all orientations are almost the same ranging from 36.8-37°C. The higher SRE values on ground of the E-W orientation only concluded 0.2°C increase in PET values which would be treated with ground vegetation or with a fountain. To summarize, if BIPV is required to complete the sustainability picture of a

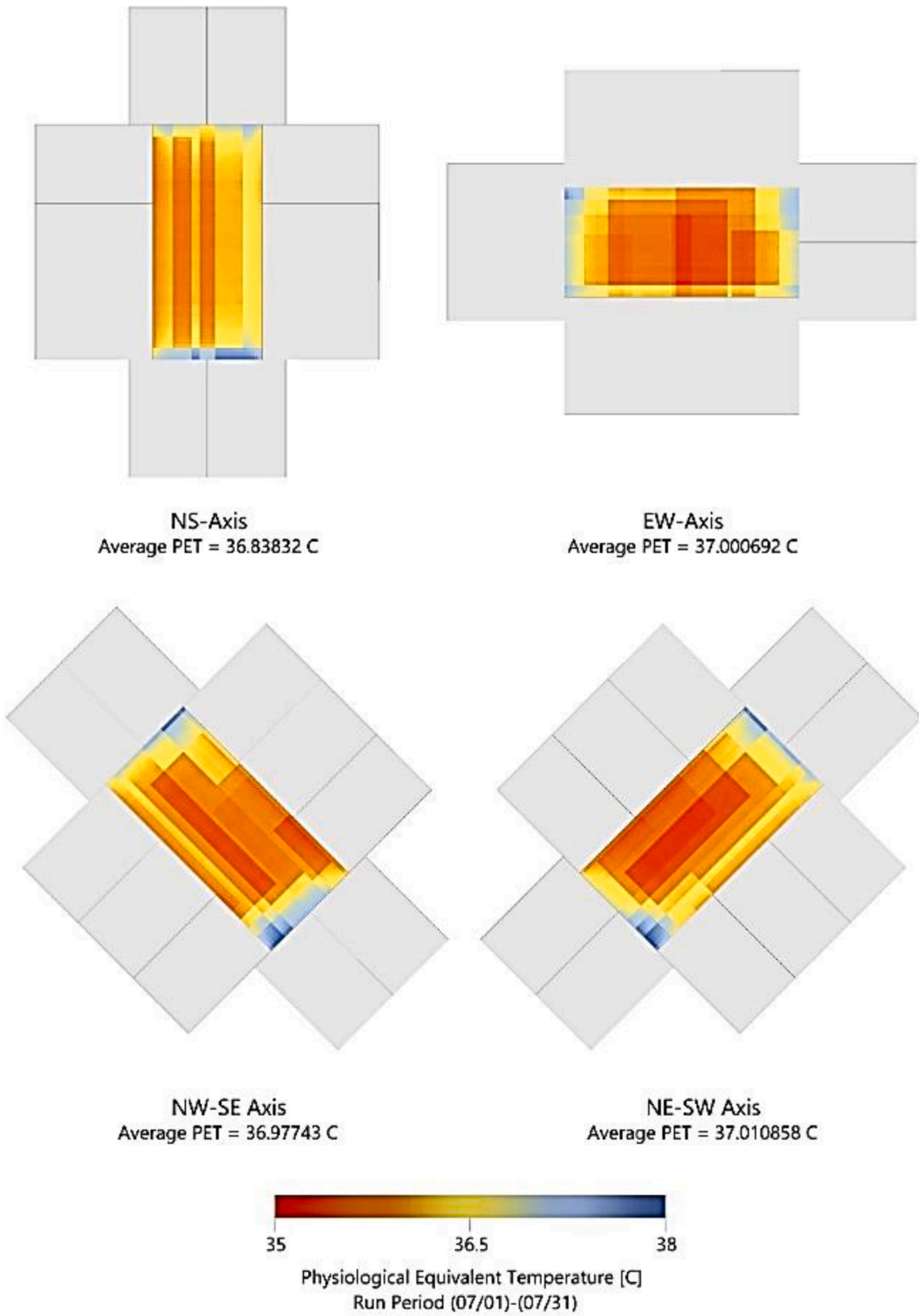

Fig. 11. Up) at all orientations PET values were 36.8-37°C. Bottom) average monthly SRE of July at the walls of E-W main axis orientation is the least value with 58.7 kWh/m^2 despite the higher SRE values on ground of the same orientation because it can be treated with ground vegetation or with a fountain to reduce its PET.

neighborhood on an UBMR and microclimate design manifesto basis at the same time (which sustainability measures assessment will be shown in section 4), it would be acceptable to orient the whole courtyarded cluster main axis towards the E-W direction not only with a 15° from the E-W direction as the basic target of orientation is to reduce heat gain from courtyard walls of the reformed urban cluster.

4. Results and analysis

For a reasonable comparison between the base case and the design suggestions, all data outputs, according to the corresponding sustainability measuers, were extracted and visualized in terms of thermal maps of the neighborhood or plots of numerical figures. However, a correlation between Figs. 12-16 and Table 4 can be noticed as the outdoor thermal comfort improved in terms of PET with the clustered urban form, annual cumulative solar radiation incident on roofs and walls has been reduced as an indication for the indoor environmental conditions in addition to higher BIPV energy production as shown in Fig. 15, and a reduced housing energy consumption intensity normalized by floor area as shown in Fig. 16 because of the stabilized SCEB envelope that has higher thermal mass and resistivity compaered with SCB walls.

4.1. Neighbourhood microclimate and outdoor thermal comfort

Fig. 12 shows thermal mapping examples of daily-averaged PET as proof for the microclimatic conditions' improvements of the clustered

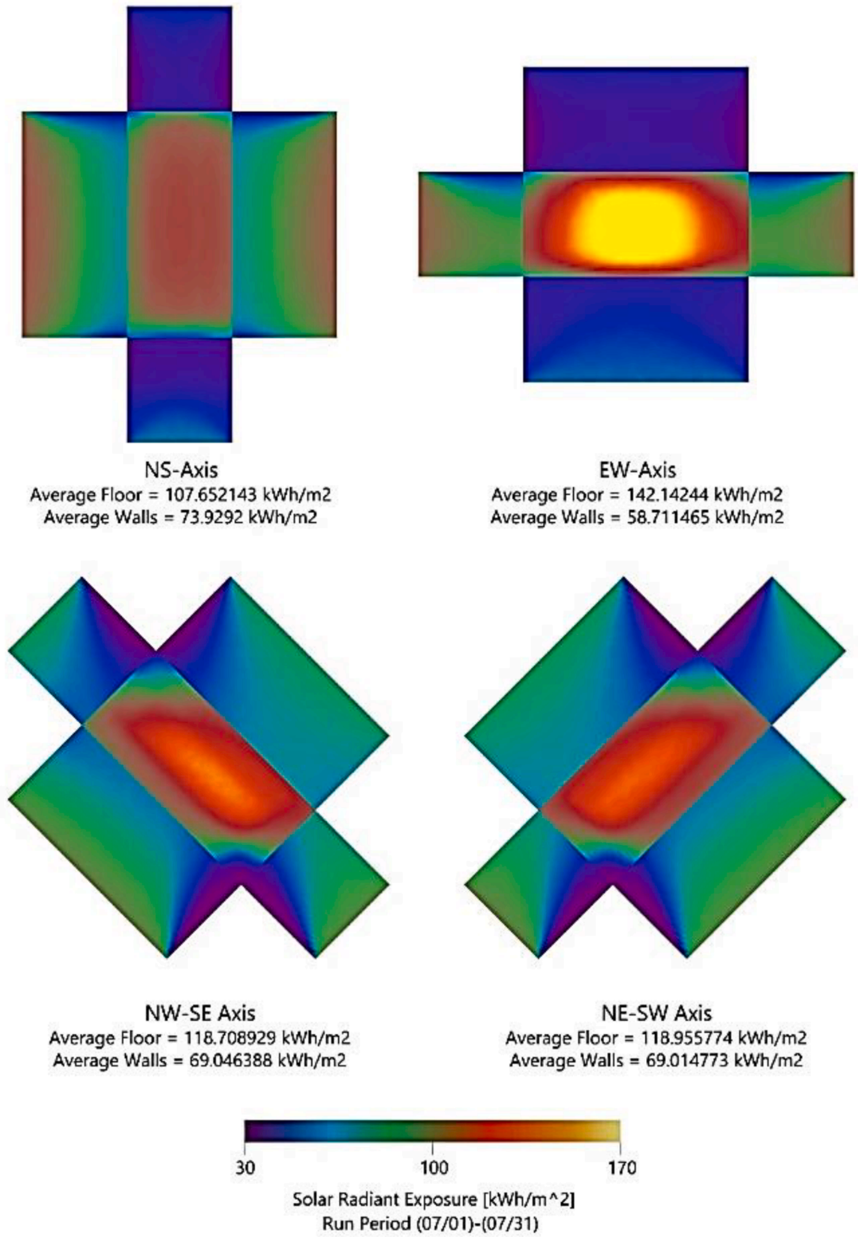

Fig. 11. (*continued*).

urban housing compared to the dot pattern existing case. The comparison between the urban microclimate maps for all cases indicates that the adopted measures of courtyard clustering, increasing urban compactness, and the choice of urban vegetation can significantly reduce the PET. While none of the cases achieved the aforementioned thermal comfort range during the extreme summer day simulations, i.e., only 1.23% of the outdoor area in DS1 reached PET less than 32°C, an adaptive outdoor thermal comfort scale that comprises the mid-range of the slightly warm category, i.e., PET less than 36.5°C, was realized in nearly 20.9% of the outdoor area of DS1, followed by 10.3% in DS2 and 8.7% in BC. This enhanced outdoor thermal comfort resulting from the urban form design of UBMR could passively and indirectly promote pedestrian activities like walking or cycling.

To statistically compare the PET distribution from the sensor points on a predefined grid for open spaces at 1.5 m above the ground, Fig. 13 illustrates the same microclimatic parameter between DS1 and DS2 but in violin plot distribution on the whole neighborhood area. The shaded area of BC results represents the range between the 1st and the 99th percentile of the hourly PET readings from all sensor points. Correspondingly, the same inter-percentile range, i.e., from 1% to 99%, was applied for the kernel distribution of the violin plots of DS1 and DS2. The shaded areas elucidate most sensor points that read a specific range of PET levels. In contrast, the box plots represent the PET interquartile range, i.e., from q1=25% to q3=75%, for both cases.

The hourly violin plots of both design cases concerning BC, including the median, the mean, the quartiles, and the distribution of the simulation readings, demonstrate the favorability of the court-yarded urban patterns, as the adopted urban design basis for the 5th generation of Egyptian cities, in terms of outdoor thermal comfort. The violin plot distribution shows that most PET values per hour for both design cases are lower than BC for most of the simulation day or even within the adaptive outdoor comfort range mentioned above. Besides, with an exception for 12:00 pm in DS1 and from 3:00 to 6:00 pm in DS2, the hourly median values of PET are much lower than those of BC, in which the maximum reduction in DS1 reached 17.6% at 3:00 pm and nearly 9.4% at 9:00 am and 2:00 pm, while in DS2 it reached 33.7%, 16.9% and

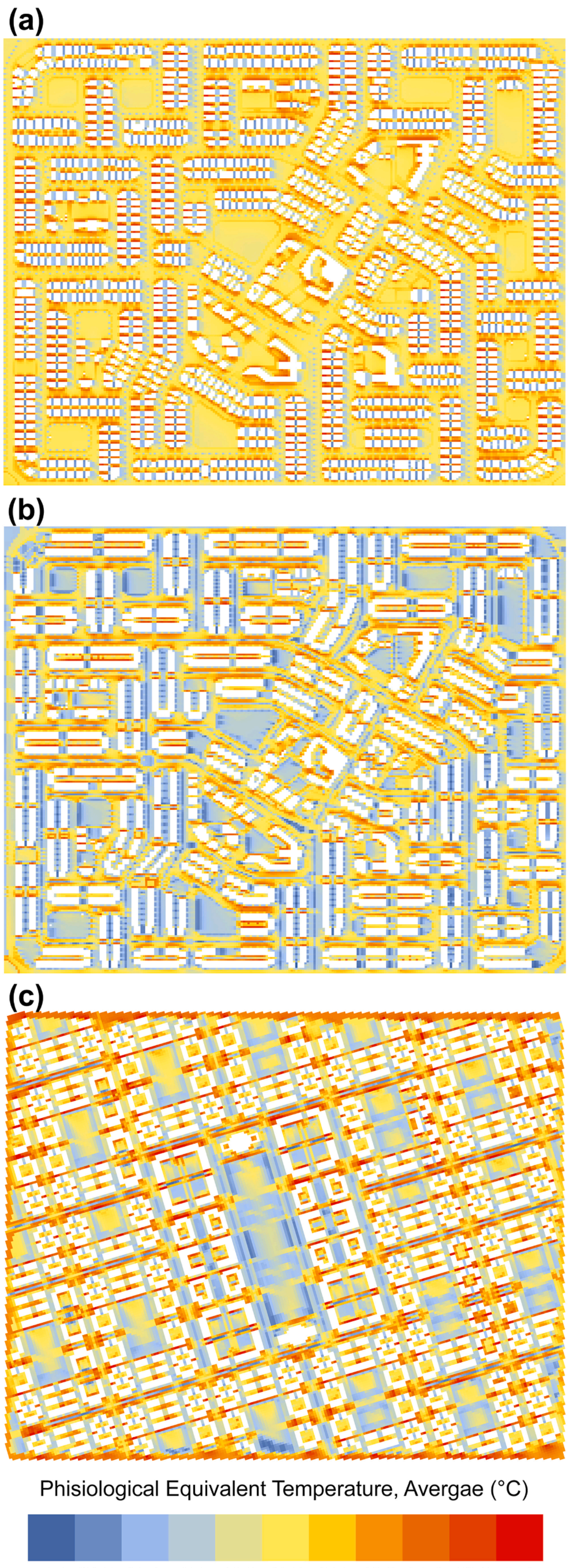

Fig. 12. Daily averaged PET microclimate maps for (a) BC, (b) DS1, and (c) DS2.

Table 4
Annual cumulative radiation per wall orientation.

Case	Cumulative radiation (kWh/m^2-year)			
	North	East	South	West
BC	353.56	703.49	989.46	806.13
DS1	351.07	769.59	1068.2	900.47
DS2	350.76	613.02	918.72	906.95

11% at 7:00, 8:00 and 9:00 am, respectively.

Moreover, the comparison between the interquartile range of BC, i.e., the range between the dotted lines, and the box plots of both design suggestions show that the minimum and the maximum values of DS1 are lower than those of BC, with an exception for the maximum values at 12:00 and 1:00 pm. In addition, it illustrates the consistency of the PET daily patterns of those cases. On the other hand, in DS2, the peak hour was shifted two hours later due to changes in the urban form design and the degree of compactness which is attributted to what can be called urban thermal mass. This phenomenon of Peak Time Displacement, described by Fahmy et al. (2020), and the denser vegetation are the potential reasons behind the major differences in the daily PET readings of DS2, especially during the first and the last three hours of the daytime. In addition, while the daily average PET in DS1, which was 40.33°C for the whole site, was 4.43% lower than that of DS2 of 42.2°C, the peak hours' site average and medians were nearly the same for both cases as the PET differences did not exceed 0.3°C. It is worth noting that the site average peaked at 13:00 in DS1 with PET of 48.05°C and at 15:00 in DS2 with PET of 48.35°C while the median PET values were 49.03°C for DS1 and 48.78°C for DS2 during the same hours.

4.1.1. Solar radiant exposure and BIPV de-carbonization

The next phase of the environmental sustainability assessment was to compare the incident solar radiation on the facades and roofs of all case studies' buildings. Fig. 14 illustrates the annual cumulative radiation differences according to surface orientations, in which the ceilings capture the most annual radiation that reaches an average value of 2145 kWh/m^2, while the average yearly radiation on all walls was 770.26 kWh/m^2 in DS1 by, followed by 711.76 kWh/m^2, and 694.99 kWh/m^2 for BC and DS2, respectively. Furthermore, Table 4 shows the average cumulative radiation on walls according to each orientation for each case study, which demonstrates a higher value in South-oriented walls of DS1 by nearly 16.27% than that of DS2 and 7.96% than that of BC and for the East-oriented walls for the same case of almost 25.54% than DS2 and 9.4% than BC. While the lower incident cumulative radiation on walls in DS2 might affect the energy generation potential, it advances the implications of diminishing envelope heat gains and, correspondingly, reducing cooling energy loads.

From the same perspective of annual cumulative radiation, the annual energy production potential for each case study in GWh, were estimated by considering the whole solid parts of the building envelopes for BIPV installations. Nonetheless, the area of walls was calculated by subtracting a Window to Wall Ratio (WWR) of 10%.

Fig. 15 and Table 4 show the annual solar energy production breakdown according to each orientation for all cases. It is evident that, due to the relatively larger façade and roofs areas, DS2 possesses the maximum solar energy generation potential of 205.37 GWh, which is generally more significant than that of BC by 13.87% and DS1 by 5.38%. Although the total area of south-oriented walls in DS2, for instance, is greater than that of DS1 by 21.03%, the solar energy production of the same walls exceeded DS1 by only 4.09% due to the lower incident cumulative radiation on DS2 walls.

4.1.2. Energy use intensity

Although the energy demand for both design suggestions is much higher than that of BC due to the increased number of residential units, the breakdown of annual and monthly energy loads, plotted in Fig. 16,

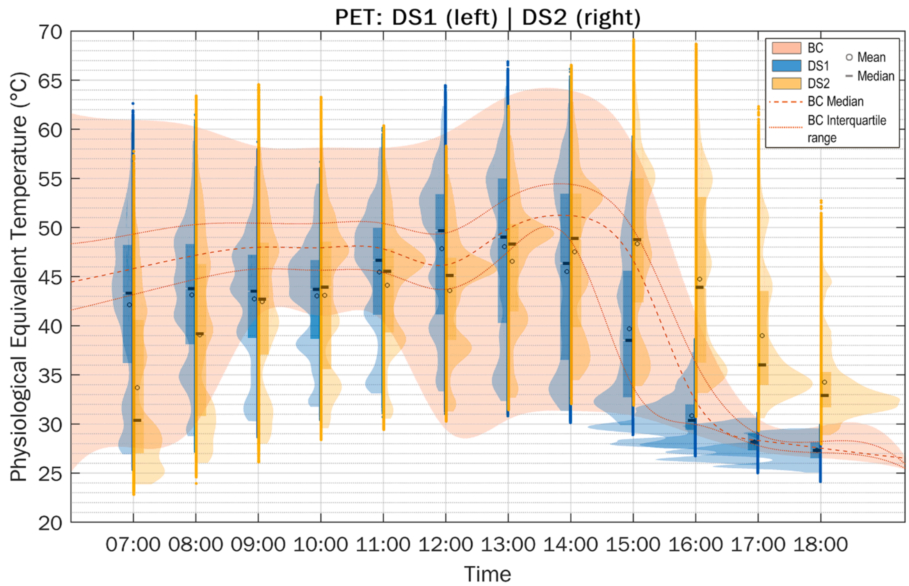

Fig. 13. Violin plot comparisons between DS1 (left) and DS2 (right) per each simulation hour. For both design suggestions, the box plots represent the interquartile range (q1 to q3), while the dots represent the raw data of hourly PET. The shaded area of PET inter-percentile range for BC as well as their hourly median and interquartile range are illustrated to compare the PET potential reduction of both design suggestions.

were normalized per floor area, i.e., in kWh/m^2, to conduct a fair comparison between all cases. The energy use intensity of BC was shown to be the maximum among all cases. The urban typology of court-yarded microclimate reduced the overall energy loads, in relation to BC, by nearly 10.66% in DS1 and 14.17% in DS2 without changing the wall material. Furthermore, applying the energy-efficient material of SCEB for the building envelope in the design cases resulted in a further reduction of cooling loads by 15.6% and overall loads by 12.06% compared to the correspondent cases with SCB material. DS2 with SCEB material recorded the minimum energy use intensity of 139.63 kWh/m^2, which is less than that of BC of 182.43 kWh/m^2 by 24%, while the cooling load of the same case is less than that of BC by nearly 28.9%.

4.1.3. Socio-economic sustainability outcomes

Generally, all of the socio-economic measures showed an evidence of preferability for the court-yarded clustered urban form overlayed with both BIPV and the SCEB. The reason is attributed to the low-cost construction that offered more affordability over 50 and 100 years, more housing designs' diversity that can be generated per each cluster, more walkable streets according to PET comfort maps. Additionally, the manufacture of SCEB, for instance, exploits the benefits of the existing earth materials without burning fuel, promotes the green circular economy that tends to reduce wasted energy and materials by recycling, and provides green socio-economic urban industry mechanism for local residents which is an added value to the 5-6 years payback period on the investment of BIPV for a single apartment.

4.1.4. Life Cycle Cost for 50 years

4.1.4.1. Affordability. In the case of the skeleton construction, the amount of installments that are needed to be paid in equal payments over 50 years to recover the money paid for the RC work in a single flat is 4390.89 EGP Contrarily, the equivalent annual payments that are needed to recover the RC work for the kitchen and bathroom slabs in SCEB construction is 197.59 EGP, which is 22 times less than that incurred in the skeleton construction based on appendix B.

4.1.4.2. Housing diversity. The typical apartment multi-story houing typology in Egypt comprises 3 floors with two apartments on each floor with six units. That can accommodate two duplex units, two single units, two triplex units, or six single units. Contrarily and refering to the floor plan of the basic court-yarded cluster in section 3.2., the proposed Neo-Arid housing typology comprises four floors with ten apartments on each floor with 40 single units. The land area needed to construct the cluster form building is 50 m in width and 60 m with an area of 3000 m^2.

The proposed building can achieve various housing diversity that can provide the residential market with various alternatives as this building can accommodate one of the following alternatives as shown in Fig. 17: 1) 40 single units of 150 m^2 each; 2) 20 duplex units with an area of 300 m^2 each; 3)10 triplex units and ten single units; 4) 5 triplex, ten duplex, and five single units; 5) 10 duplex and 20 single units; or 6) 5 triplex, five duplex, and 15 single units. The 3000 m^2 can accommodate six land areas used to construct a single residential building, of a conventional building typology, on each land. Moreover, based on the previous information, these six buildings of the traditional building typology can achieve one of the following housing diversities: 1) 12 triplex units, 2) 12 duplex units and 12 single units, or 3) 30 single units. Therefore, the proposed clustered building typology can achieve more housing diversity alternatives and accommodate more families, which is considered a profit for the investors as indicated in Fig. 17.

4.1.4.3. Walkability. As presented in section 2 (interraltions between environmental and socio-economic indicators), the walkability is not only an international measure to indicate imropving a social sustainability urban habit following the improved thermal comfort measure as an environmental sustainability indicator, but also is a measure for urban health as a whole urban heat stress has been alleviated in terms of better PET levels. From the Violin figure no. 13, the walkability assessment period was the peak hours, consisting of the three consecutive hours when the site-averaged PET reached its maximum, was determined to be from 12:00 to 2:00 pm in both BC and DS1 from 2:00 to 4:00 pm in DS2. To adequately assess the walkability for each case that would be affected by the outdoor thermal conditions, thermal comfort maps of PET during the period of peak hours, as shown in Table 5, were analyzed for each case to determine the percentage of cool spots in relation to the total area of outdoor spaces.

It is evident from the outdoor thermal comfort readings, especially for the extremely hot day simulations, that a negligible area, of less than 1%, of outdoor spaces reached PET levels within the thermal comfort range, i.e., less than 32°C, at all the peak hours in both design

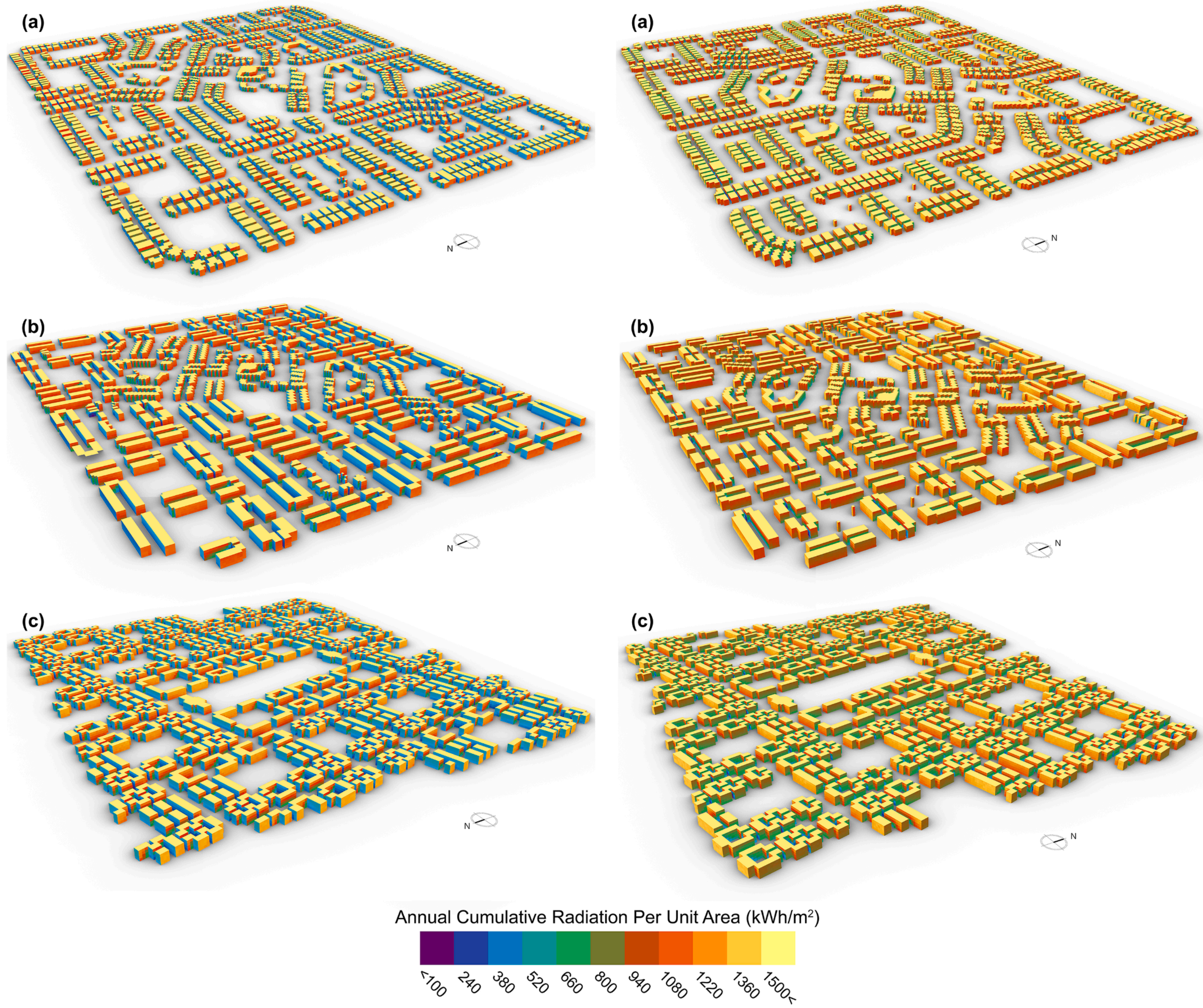

Fig. 14. Annual cumulative radiation maps on roofs and walls of this research case study oriented towards North and West (left) and towards South and East (right) for the cases (a) BC, (b) DS1, and (c) DS2.

suggestions. However, cool spots, regarding the adaptive comfort range of PET less than 36.5°C, emerged at the three consecutive peak hours in nearly 9%, 16.3%, and 25% of outdoor spaces, respectively, in DS1, and almost 9.4%, 12.8% and 26.6% of outdoor spaces, respectively, in DS2. The outdoor thermal comfort improvements due to the design suggestions expanded the outdoor cool spots at the middle peak hour, compared to BC of 11.3% of outdoor spaces, by 44.25% in DS1 and 13.27% in DS2. While at the last peak hour, this area exceeded that of BC, of nearly 18%, by 38.9% in DS1 and 47.8% in DS2. Furthermore, as illustrated in the PET maps of each hour, while the cool spots were dispersed all over the site in BC, they were gathered along paths and avenues in both design suggestions due to the denser urban fabric and the clustered building typology.

4.1.4.4. SCEB and Green Socio-Economic mechanism. While UBMR design manifesto provides a potential for lowering energy consumption, carbon emissions, and maintenance and construction costs as a climate change mitigation strategies, it offers a wide range of economic empowerment by offering direct jobs opportunities in a green economy that can be generated by small enterprises to establish climate change adaptation strategies by the industrialization of eco-Materials. The term green economy, which promotes environmental preservation or restoration, refers to the production process or the final output. Thus, shifting towards de-carbonization and net-zero energy communities is the driving factor of increasing the number of these job opportunities, especially in the manufacturing and construction sectors. The manufacture of SCEB, for instance, exploits the benefits of the existing earth materials without burning fuel, promotes the green circular economy that tends to reduce wasted energy and materials by recycling, and provides direct job opportunities for local residents. By reviewing the recently available SCEB manufacturing machines in the global market, it was found that their production rate ranges, according to the model and the manufacturer of each machine, from 100 to 180 blocks/hour for single block manually operated machines and from 240 to 480 blocks/hour for double block manually operated machines and, from 1920 to 3840 blocks per 8-hour shift, for automatic and half-automatic ones. However, the manpower needed to operate these machines is usually five to seven workers which increases the societal working man power, roots a green local economy in the city and improves the construction sector dependency on a green material industry such as SCEB manufacturing rather than regular SCB. Knowing that each low-cost social housing unit requires about 70 thousands of SCEB, it can be realized that how for example a new city of 20 thousands housing units can motorise the economy of an entire region amonge the 7 regions of

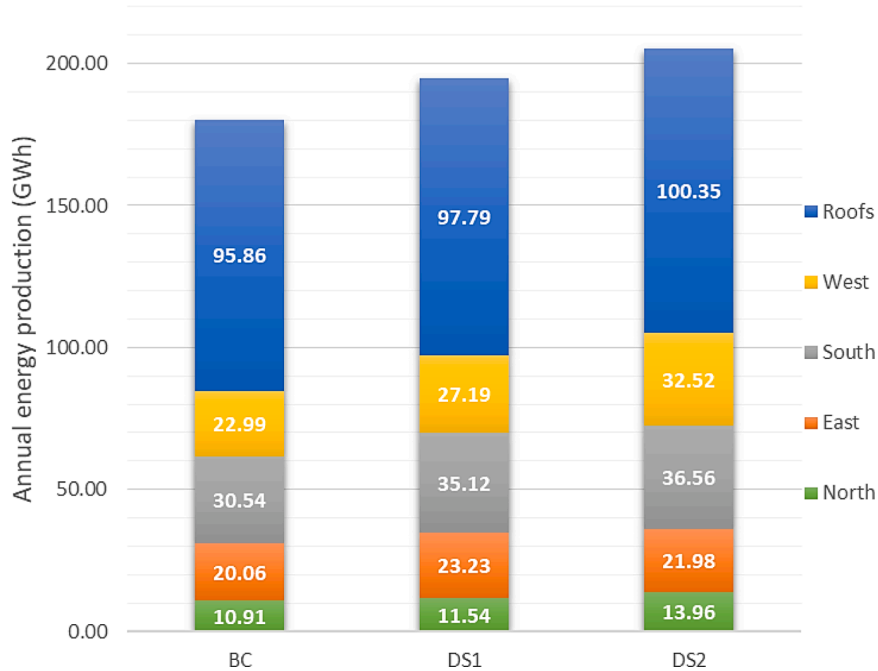

Fig. 15. Annual BIPV energy production for each case, in GWh, divided according to the faces' orientation.

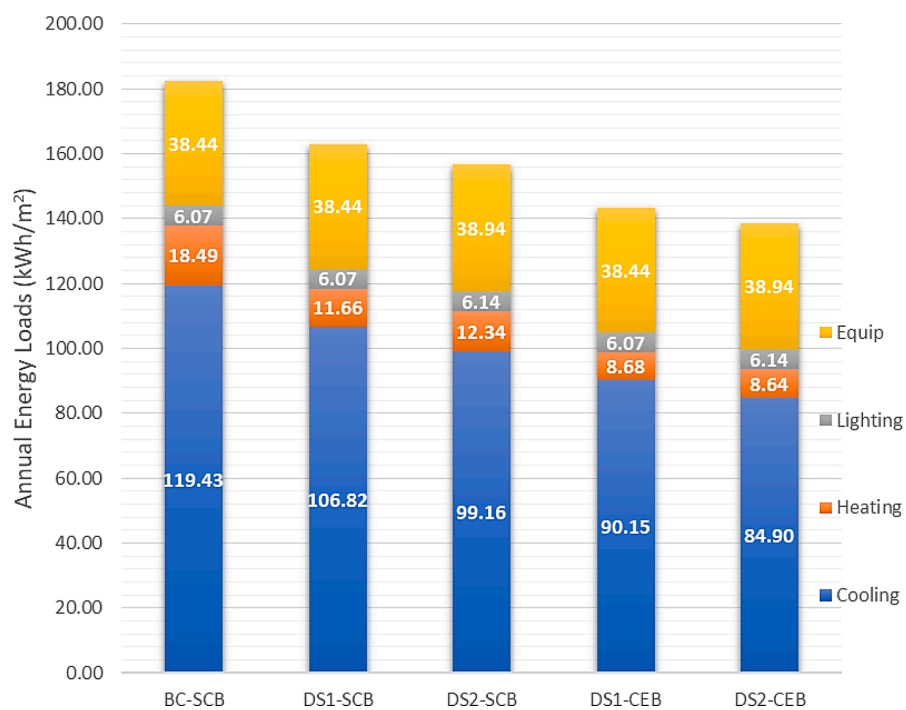

Fig. 16. The annual breakdown of energy use intensity for each case was normalized by floor area. The design suggestions were simulated twice using the two predefined building envelope materials of SCB and CEB.

Egypt while contributing to environment.

4.1.4.5. Payback on BIPV investment. The average electricity consumption for a residential apartment containing two split air conditioning units is 1500 kW per month, which will cost the resident around 2000 EGP. The BIPV power plant of 10 kW\h produces around 1600 kW per month and costs 140000 EGP as a direct cost and 1800 EGP every eight years, a recurring cost for operation and maintenance. The payback period on the investment in BIPV for a single apartment is from 5-6 years. However, when it is required to compare two alternatives on a financial basis, cash flows and time value of money principles should occur. These comparisons can be based on determining the present worth values and the capital recovery (annual payments) for both alternatives, which are using BIPV or on-grid municipal electricity. In the following analysis, a 50-year planning horizon will be utilized. To determine the present worth value for the BIPV, based on the aforementioned data, Eq. (4) and appendix C were used, and the result was 149316.1 EGP. Furthermore, Eq. (5) was used to determine the present worth value for 50 years payment of on-grid municipal electricity

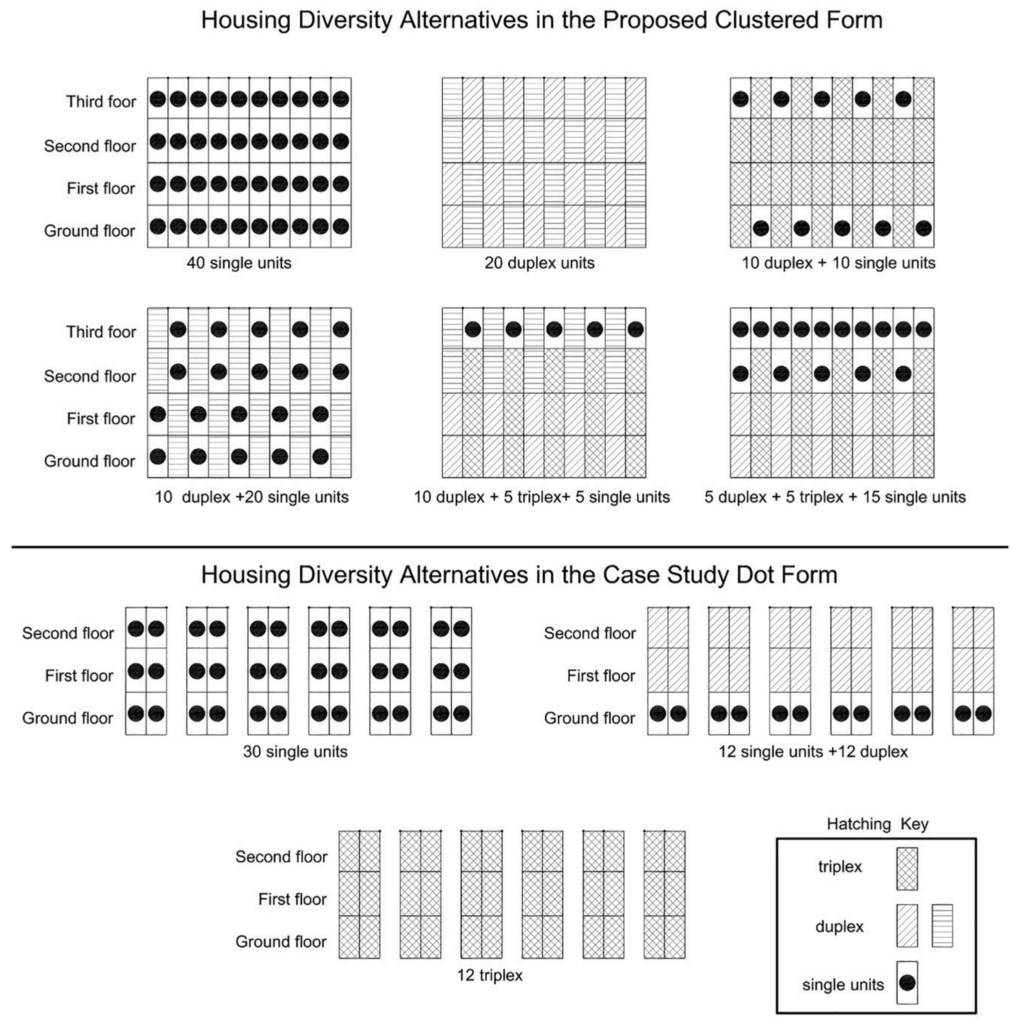

Fig. 17. Housing diversity alternatives in the clustered and dot urban form.

consumption was 1049280 EGP.

On the other hand, the equal annual payment of BIPV over 50 years based on the effective interest rate utilizing Eq. (2) was 3415.28 EGP equal annual payments. Therefore, when comparing the present wort value for BIPV and the on-grid electricity payment, it can be recognized that the BIPV saves seven times the amount of money needed to be paid for on-grid electricity. Additionally, by comparing both alternatives based on equal annual payments, it can be found that the resident will pay for on-grid electricity seven times more money annually than using the BIPV alternative.

$$P = F\left(\frac{1}{(1+e)^n}\right) \tag{4}$$

$$P = A\left(\frac{(1+e)^n - 1}{e\ (1+e)^n}\right) \tag{5}$$

4.1.5. Life Cycle Cost for 100 years

As, the methodlogy of analyzing LCC for 100 years is similar to LCC for 50 years, only affordability as a direct housing result and payback of BIPV investment as a direct climate change mitigation economic result were only extracted in this section.

4.1.5.6. Affordability. In the case of the skeleton construction, the amount of installments that are needed to be paid in equal payments over 100 years to recover the money paid for the RC work in a single flat is 2488.75 EGP. On the other side, the equal annual payments that are needed to recover the RC work for the kitchen and bathroom slabs in SCEB construction is 111.99 EGP, which is 22 times less than that incurred in the skeleton construction based on appendix C, which is similarly the same ratio between the two types of buildings for 50 years planning horizon analysis.

4.1.6. Payback on BIPV investment

Similarly, as illustrated in 50 years planning horizon analysis, 100 years planning horizon will be utilized instead. To determine the present worth value for the BIPV, based on the aforementioned data, Eq. (3) and appendix E were used, and the result was 156464 EGP. Furthermore, Eq. (4) was used to determine the present worth value for 100 years' payment of on-grid municipal electricity consumption was 1851534 EGP. On the other hand, the equal annual payment of BIPV over 100 years based on the effective interest rate utilizing Eq. (2) was 2020.05 EGP equal annual payments. Therefore, when comparing the present wort value for BIPV and the on-grid electricity payment, it can be recognized that the BIPV saves 11 times the amount of money needed to be paid for on-grid electricity. Additionally, by comparing both alternatives based on equal annual payments, it can be found that the resident will pay for on-grid electricity 11 times more money annually than using the BIPV alternative.

On the other hand, UBMR also offered energy plus opportunity through the BIPV system after the energy-efficient urban-building passive design. Table 6 indicates the de-carbonization and energy statistics

Table 5
PET microclimate maps for the three case studies during the corresponding peak hours.

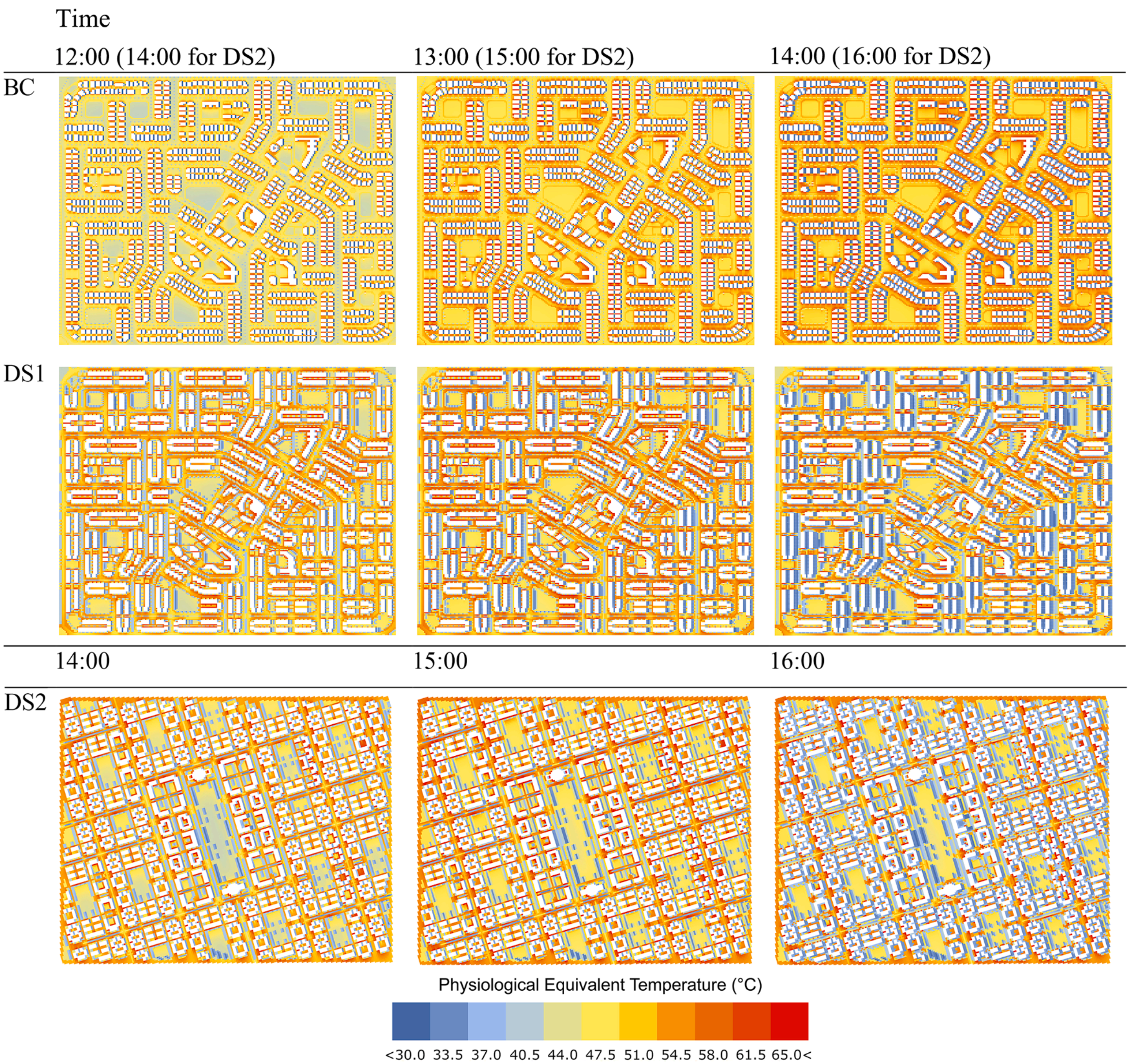

Table 6
BIPV statistics for the 64 units double housing cluster shown in Fig. 8.

Criteria	Value / Annum	Unit
Housing Demand	192	MWh
BIPV Roof Area	2200	m^2
BIPV Supply	370	MWh
De-Carbonization	148	Tone
Payback Period	16	Years

of the 64 double cluster housing shown in Fig. 8.

5. Discussion and Conclusion

This research presented a reformation of the Arabic courtyard into neighbourhood urban form design considering a combined sustainable urban, building, materials and renewables (UBMR) design manifesto. In a country like Egypt, where most of its map is arid and contrary, the crucial issue is that most of the new urban development patterns continue to apply the back to back parcel division planning discipline that generates a dot ir-responsive climate patterns. In a hot arid city like Cairo where urban patterns that receive a maximum average monthly global radiation levels are 7316 and 6893 Wh/m^2 for June and July respectively, the dominance and stucking to continued construction of back to back parcel division planning cities accombanied with high thermal conductance envelope materials is a mess. Therefore, this research presented a preliminary housing typology design, modeling and calculating interrelational sustainability measures obtained through the four UBMR dimensions as a comprehensive renewal design model based on the climate-responsive court-yarded urban clusters in hot arid regions. Multi objective workflow manifesto is executed to compare a conventionally designed back to back parcel division planning that formulate dot pattern, with the courtyarded clustered free planning and energy plus designed neighborhood in Cairo, Egypt. The complexity of the study is raised through the muti-disciplinary design derivatives, assessment of a combined environmental and socio-economic complex indicators and measures, and it is maximized when having the different assessment tools and methods in the count. Nevertheless, practitioners and researchers shouldn't fall in an endless loop of uncertainty while the public and governments are continuing environment in-conscious construction. Assessment of environmental sustainability measures included; outdoor comfort (PET), 2) annual cumulative solar radiation, 3) Energy intensity and 4) Energy production from BIPV and the corresponding decarbonization. The socio-economic sustainability measures included; 1) Affordability of Neo-Arid housing units, 2) Housing design diversity offered to the public, 3) Walkability within suggested urban form, 4) Green job opportunities offered by the SCEB construction economy, and 5) Payback period effect on initial investment value. ENVI-met CFD numerical simulations for the microclimate main assessment course of the study were held whereas Ladybug Tools plugin for Grasshopper, LCC along with simple calculations took place for assessing the rest of design manifesto measures workflow.

An auxiliary simulation step was held to check whether the absolute southern orientation needed for mounting BIPV would be compliant for the cluster courtyard walls. The governance issue in this concern is the heat gain through walls caused by the incident solar radiation exposure (SRE) while having optimum PET at courtyard ground. The results of this auxiliary step indicate that if BIPV is required to complete the sustainability picture of a neighborhood on an UBMR and microclimate design manifesto basis at the same time it would be prefereable to orient the whole courtyarded cluster main axis towards the E-W direction in order to comply with BIPV orientation.

The comparison between the urban microclimate maps for base case (BC), design suggestion no. 1 (DS1) and design suggestion no. 2 (DS2) indicates that the adopted measures of courtyard clustering, increasing urban compactness, and the choice of courtyard as a cooling spot can significantly reduce the PET. While none of the cases achieved the aforementioned thermal comfort range during the extreme summer day simulations, i.e., only 1.23% of the outdoor area in DS1 reached PET less than 32°C, an adaptive outdoor thermal comfort scale that comprises the mid-range of the slightly warm category, i.e., PET less than 36.5°C, was realized in nearly 20.9% of the outdoor area of DS1, followed by 10.3% in DS2 and 8.7% in BC. This enhanced outdoor thermal comfort resulting from the urban form design of UBMR could passively and indirectly promote pedestrian activities like walking or cycling.

Correlating the outputs of all environmental sustainability measures, it can be noticed that as outdoor thermal comfort has been improved using the clustered urban form, other measures were improved. The annual cumulative solar radiation incident on roofs and walls has been reduced as an indication for the indoor environmental conditions, higher BIPV energy production, along with reduced housing energy consumption intensity normalized by floor area because of the stabilized SCEB envelope that has higher thermal mass and resistivity compaered with SCB walls. Further calculations, the above mentioned four dimensions of urban, building, material, and renewables comprehensive design model (UBMR) decarbonize the environment and mitigate climate change with more than 148 tons annual reductions considering the average energy consumption rate per family per annum. Combining UBMR solutions showed improved comfortable outdoor areas by 47.8% during extreme summer afternoon, increased annual solar energy generation potential by 13.87% and the energy-efficient envelope reduced cooling energy consumption by 28.9% while reducing cost of concrete work by 95.5%.

As of socio-economic sustainability, all measures showed an evidence of preferability for the court-yarded clustered urban form overlayed with both BIPV and the SCEB. The reason is attributed to the low-cost construction that offered more affordability over 50 and 100 years, more housing designs' diversity that can be generated per each cluster, more walkable streets according to PET comfort maps. Additionally, the manufacture of SCEB, for instance, exploits the benefits of the existing earth eco-friendly construction materials without burning fuel, promotes the green circular economy that tends to reduce wasted energy and materials by recycling, and provides green socio-economic urban industry mechanism for local residents which is an added value to the 5-6 years payback period on the investment of BIPV for a single apartment. Furthermore, the de-carbonization and energy statistics of the 64 double cluster housing shown in Fig. 8 argues that such free planning reformation with overlayed with both BIPV and the SCEB can stand for an international COP27 sustainable cities initiative, (Fahmy, 2022) where cities are responsible of 39% of global carbon emissions and buildings are responsible for more than 40% of any country's energy consumption.

On the other hand, from an urban and architectural design discipline point of views; it can be argued that the suggested housing unit attachment in relation to other units, form the cluster at its architecture character scale, whereas the arrangement order of those clusters forms the neighborhood at its urban identity scale. Hence, the hypothesis of improved interralational quantifiable measures attributed to connecting courtyarded housing and neighborhood clusters' UBMR design manifesto that could lead to important but unquantifiable socio-economic indicator such as the architectural character and urban identity, could be argued as a repitative order, symmetry and unity can be seen. From this standing point, it can be laso argued that the renewed arid heritage UBMR courtyarded clustered neighbourhood overlayed with BIPV and SCEB is a considerable approach to shift the practiced housing paradigm for a 5th generation of Egyptian cities.

Modeling the 3D recipe of environment consciousness while retrieving the socio-economic flavor values of anccestors free planning renewed the architectural character and urban identity picture, as if getting back to heritage free planning that generates courtyarded urban clusters could evolve a future class climate responsive Neo-Arid city.

Declaration of Competing Interest

None.

Aknowledgment

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It is a place to mention that professor Mohammad Fahmy, founder and head of the Research Excellence Center for Urban Environment and Sustainability Governance (which has been funded by STDF project ID45851), is the basic and principal contributor to the concepts, ideas and expressions of the 5th Generation of Egyptian Cities and the Neo-Arid city mentioned in this article.

Appendix A

Calculating actual interest rate

$$e = \left(\frac{1 + 0.0825}{1 + 0.0767}\right) - 1$$

$$\boldsymbol{e} = 0.00539$$

Appendix B

Calculating capital recovery (equal annual payments) for RC for skeleton construction

$$\boldsymbol{A} = 192000\left(\frac{0.00539\ (1+0.00539)^{50}}{\left((1+0.00539)^{50}-1\right)}\right)$$

$\boldsymbol{A} = 4390.89$ ***EGP***

Calculating capital recovery (equal annual payments) for RC for CEB building utility slabs given present initial payment

$$\boldsymbol{A} = 8640\left(\frac{0.00539\ (1+0.00539)^{50}}{\left((1+0.00539)^{50}-1\right)}\right)$$

$\boldsymbol{A} = 197.59$ ***EGP***

Appendix C

Calculating capital recovery (equal annual payments) for RC for skeleton construction

$$\boldsymbol{A} = 192000\left(\frac{0.00539\ (1+0.00539)^{100}}{((1+0.00539)^{100}-1)}\right)$$

$\boldsymbol{A} = 2488.75$ ***EGP***

Calculating capital recovery (equal annual payments) for RC for CEB building utility slabs given present initial payment

$$\boldsymbol{A} = 8640\left(\frac{0.00539\ (1+0.00539)^{100}}{((1+0.00539)^{100}-1)}\right)$$

$\boldsymbol{A} = 111.99$ ***L.E***

Appendix D

Calculating Present worth value of BIPV given future payments

$$P = 140000 + 1800\left(\left(\frac{1}{(1+0.00539)^{8}}\right)+\left(\frac{1}{(1+0.00539)^{16}}\right)+\left(\frac{1}{(1+0.00539)^{24}}\right)+\left(\frac{1}{(1+0.00539)^{32}}\right)+\left(\frac{1}{(1+0.00539)^{40}}\right)+\left(\frac{1}{(1+0.00539)^{48}}\right)\right)$$

$P = 143916.08$ *EGP*

Calculating capital recovery of BIPV given present worth value

$$\boldsymbol{A} = 149316.1\left(\frac{0.00539\ (1+0.00539)^{50}}{\left((1+0.00539)^{50}-1\right)}\right)$$

$A = 3415.28$ *EGP*

Calculating Present worth value of the on- given annual payments

$$\boldsymbol{P} = 24000\left(\frac{\left((1+0.00539)^{50}-1\right)}{\left(0.00539\ (1+0.00539)^{50}\right)}\right)$$

$P = 1049280$ *EGP*

Appendix E

Calculating Present worth value of BIPV given future payments

$$P = 14000 + 1800\left(\left(\frac{1}{(1+0.00539)^{8}}\right) + \left(\frac{1}{(1+0.00539)^{16}}\right) + \left(\frac{1}{(1+0.00539)^{24}}\right) + \left(\frac{1}{(1+0.00539)^{32}}\right) + \left(\frac{1}{(1+0.00539)^{40}}\right) + \left(\frac{1}{(1+0.00539)^{48}}\right) + \left(\frac{1}{(1+0.00539)^{56}}\right) + \left(\frac{1}{(1+0.00539)^{64}}\right) + \left(\frac{1}{(1+0.00539)^{72}}\right) + \left(\frac{1}{(1+0.00539)^{80}}\right) + \left(\frac{1}{(1+0.00539)^{88}}\right) + \left(\frac{1}{(1+0.00539)^{96}}\right)\right)$$

$$P = 156464.42\ EGP$$

Calculating capital recovery of BIPV given present worth value

$$\boldsymbol{A} = 156464.42\left(\frac{0.00539\ (1+0.00539)^{100}}{((1+0.00539)^{100}-1)}\right)$$

$$A = 2020.05\ EGP$$

Calculating Present worth value of the on- given annual payments

$$\boldsymbol{P} = 24000\left(\frac{((1+0.00539)^{100}-1)}{(0.00539\ (1+0.00539)^{100})}\right)$$

$$P = 1851534.45\ EGP$$

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