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The impact of urban compactness on the possibility of generating energy from sustainable urban form elements applied on Elsheikh Zayed city in Egypt

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Ahmed ABUNAZEL [1]
Yasmin HAMMAD[2]

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Renewable Energy;
Solar Energy; Urban form Elements;
Building Types;
Building Mass;
Compactness.

Abstract: It is well known that the seven sustainable urban form design concepts revolve around the following: compactness, mixed land uses, diversity, density, sustainable transportation, passive solar design, and greening [1], they are also fundamental pillars relied upon by urban designers in producing sustainable urban form. This research aims to introduce another important concept to the previous seven elements, which is energy production based on one of the urban form elements; that element is a building mass. Since building clusters with compacted form and mixed land use are the primary manifestations of compacted cities [2], such as in many locations in Egypt, it is important to study the extent of their ability to produce energy under the umbrella of compactness for adding more sustainable value to the compacted urban form layouts. Achieved by selecting a project distinguished by compact urban form, then calculating the amount of energy produced throughout the year by generating energy from building mass faced by using a vertical transparent solar cell. The research is important because it seeks to prove that the concept of energy production from the elements of urban form is not less important than the rest of the concepts of sustainable urban form design; therefore, it will be proven that renewable energy production based on one of the elements of sustainable urban form is an eighth element of the design concepts of sustainable urban form, which is one of the expected research results.

1. Introduction

The research presents a detailed study on the potential for increased reliance on renewable energy sources, such as solar photovoltaic energy, within the design framework of sustainable urban form. This presents a significant challenge to energy production processes, particularly due to the expected shadowing effects on building façades caused by the proximity of structures in compact urban forms. However, if the study succeeds in demonstrating the potential for generating electricity under these conditions, it may be

[1] Ph.D. in urban Planning, Department of Urban Planning, Faculty of Engineering, Al Azhar University, Cairo, Egypt. Sokrat19790@gmail.com
[2] Ph.D. in urban Planning, Department of Urban Design, Faculty of Urban and Regional Planning, Cairo University, Cairo, Egypt. hamad.y.e@furp.cu.edu.eg

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considered an extension of previous research that explored influential design strategies in sustainable urban planning such as the study on energy-efficient urban configurations for residential projects in Cairo [3] and another study that advocates a return to traditional urban forms characterized by mixed-use, high-density, fine-grained layouts that are outward-oriented, highly connected, and well-integrated into the surrounding city fabric [4].
The research results will also reflect the global trend toward achieving carbon neutrality and mitigating climate change, aligning with the outcomes of the COP 28 climate conference. A significant result of COP28 was the adoption of a fossil fuel phase-out agreement, which commits the parties to transition away from fossil fuels into energy systems in a just, orderly, and equitable manner to achieve net-zero emissions by 2050. This was the first time that the COP explicitly addressed the need to end the use of coal, oil, and gas, the main drivers of the climate crisis. The agreement also calls for tripling renewable energy capacity globally by 2030 and the acceleration of technologies such as carbon capture and storage [5]. Figure no.1 illustrates the roadmap reached by the climate conference in Dubai, which ultimately leads to a complete abandonment of fossil fuels. This goal is directly supported by the research, as mentioned earlier, by enhancing the capacity to produce energy from renewable sources.
The study referred to in this research, within the framework of urban integration, can be included in the nationally determined contributions as planned for 2025 as the first output of a global inventory. Accordingly, the techniques presented in the research can be applied to existing urban communities at this stage to transform these urban communities towards sustainability, then the idea of the research will be generalized to the design of future urban communities under the implementation of NDCs stage by the year 2028 to help reach a reduction in the carbon footprint with the 2nd global stock take output in the year 2030, after that the NDCs stage will be ready to transition to the target of COP 28 climate conference depends of expected development in transparent solar cells that the research will rely on to prove its hypothesis, this will contribute directly to reaching the goal of carbon neutrality & climate resilience in the year 2050. The research will compare the energy generated from compactness to assess the effectiveness of relying on compacted urban form as a source of renewable energy. The study will also examine the energy produced from non-compact urban forms. After comparing the results, the research can prove the importance of the main objective of the study.

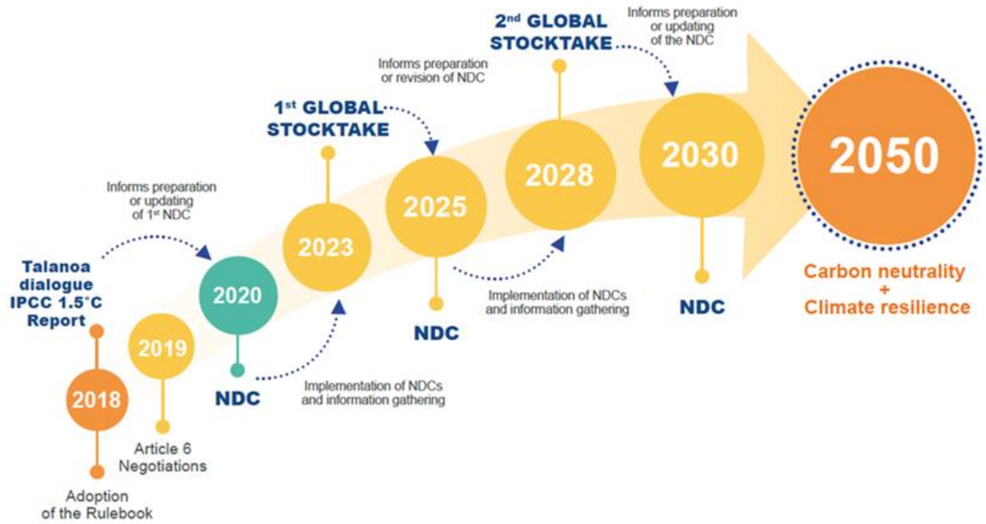


Fig. 1: COP 28: Charting the Roadmap for Climate Action [26].

2. Methods and tools

This study aims to highlight the importance of producing renewable energy from sustainable urban design elements and how this factor can impact urban design processes in general. The presence of an energy production factor within design concepts will be considered a scientific addition and a new starting point in urban design projects by dealing with building mass as a component of sustainable urban design as an integrated station that collaborates to produce renewable energy. This enhances the efficiency of sustainable urban form; this research's main point has not been prominently addressed in studies focusing on energy production based on building facades, and research will depend on compactness as a main foundation to study the process of generating the energy based on one of the design concepts of sustainable urban form, because it is an element that depends on the building's mass & the distance between the buildings.

Furthermore, this study aims to explore the potential of elements of urban design in generating renewable energy in general, with possibilities to enhance their efficiency through future research that will delve into the same research field. The research also aims to highlight the importance of integrating energy production into urban design elements, positioning it as an inspirational concept for achieving sustainable urban form. A review of the literature related to the research topic reveals a substantial body of work under the theme of Energy-Facade-Design-Related Buildings (EFDRB), which focuses on the role of building façades in reducing energy consumption and enhancing economic feasibility through strategies such as passive solar design. Also, several studies have explored the integration of transparent photovoltaic (PV) cells into building façades, reflecting a growing interest in merging renewable energy technologies with architectural and urban design [9].

Additionally, this research aims to conduct a case study of a project in the Greater Cairo area to offer practical insights on implementing this concept in one of the proposed projects in a Middle Eastern country, specifically Egypt, which is heavily involved in climate change mitigation. It will evaluate the success of this experiment in achieving the main goal of the research. The methodology will take the necessary steps to achieve the main goal of the research by relying on the dense urban configuration. This methodology will study using two from five elements of urban form [10], namely housing / building prototypes & layout as per shown in figure no. 4, where the building mass will be studied for its energy production capabilities. For the layout, it is the spatial context in which relationships between buildings are coordinated within that context.

The focus on the urban density element is crucial in producing photovoltaic solar energy due to the challenge of direct sunlight exposure to solar cells. The shade on these cells can partially or completely halt their operation, posing a challenge to energy production. Given the limited available land for residential and various service projects, the research will concentrate on one of these proposed projects that relieve urban density as a sustainability element for this configuration. The required simulation will be conducted on the buildings of this project to measure the energy quantities produced using an approved application to measure the possible areas of solar radiation falling on the facades of the built blocks of the project mentioned earlier.

Additionally, the energy quantities produced will be calculated based on equations measuring the electricity generated from solar radiation falling on energy generation panels mounted vertically on the facades of the building blocks. As illustrated in figures no. 2 and 3, the energy produced by the dense buildings will be measured over a year and compared to the expected consumption from these buildings during the same period to determine the efficiency of these buildings in energy production.
Subsequently, the research will dynamically adjust the buildings to prevent any of them from casting shadows on neighboring buildings. The shadows on the buildings will be limited to what each building casts on itself when not directly exposed to sunlight, altering the spatial relationships between the buildings depending on the AUTO DESK simulation tool using Revit application. After the previous step, it will need to test the urban form with less dense, and the energy produced by building masses in their new state will be studied. Subsequently, the results related to the quantities of energy produced will be compared with those produced based on the compacted urban form. This will enable the research to assess the effectiveness of the concept of energy production from sustainable urban design elements, serving as the fundamental idea of the research, which, as mentioned earlier, considers renewable energy production from urban design elements as one of the concepts of sustainable urban design.

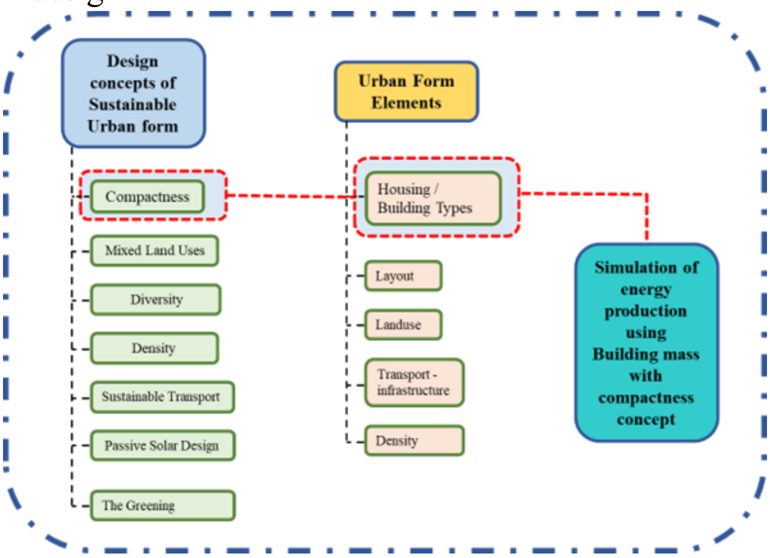


Fig. 2: Compactness that research will use to make a simulation of energy production (Authors).

2.1. literature review & definitions

This research focuses on one of the urban form elements (Housing/Building type) that shown in figure no. 4, which can be used as an objective to produce clear energy depending on solar energy, and research will use building masses of urban clusters to test this issue.

Sustainable Urban Form: The urban form, which is characterized by high density and sufficient diversity in activities and population groups, is considered an ideal and sustainable urban form, according to the design concepts of sustainable urban form, It uses public transportation, bicycles, and walking to move from one location to another, this form is characterized by the use of spaces and green spaces, and for the energy supply, it depends on solar energy.

Additionally, this form aims to reduce energy consumption, pollution and waste production & reducing dependence on the use of private cars on daily trips, as well as preserving sensitive and vulnerable ecosystems [1].

Design Concept of Sustainable Urban Form [1]: The thematic analysis identified seven concepts of repeated and significant themes of urban form:

1-Compactness.
2-Mixed Land Uses.
3-Diversity.
4-Density.
5-Sustainable Transport.
6-Passive Solar Design.
7-Greening.

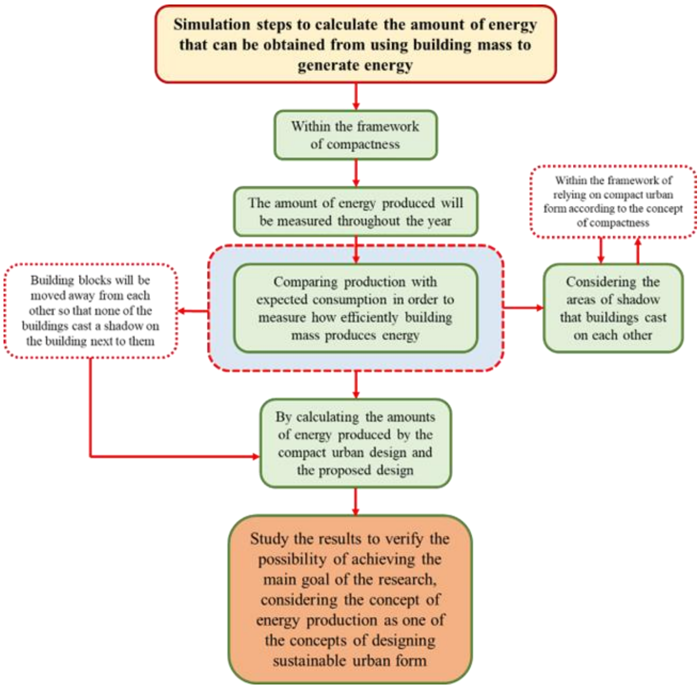


Fig. 3: Simulation steps to achieve the main topic of the research (Authors).

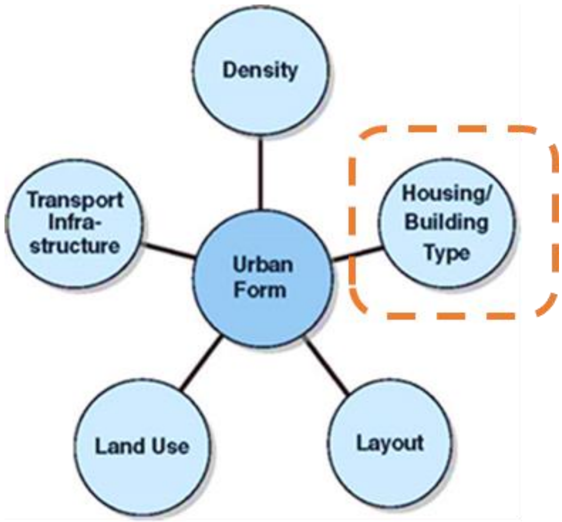


Fig. 4: Urban form elements [21].

For the needs of this research, it will be important to focus on the compactness as shown in the following.

The Compactness: Urban compactness is one of the most important urban features that characterize millions of cities around the world due to several factors, the most prominent of which is limited land ownership in general. Urban compactness is widespread in major cities, such as what is found in the city of Cairo in the Arab Republic of Egypt. where the concept of compacted cities refers to the creation of a friend of the environment in the city of high population, and the development of the old Amiri elements with the modernity and the struggle of the network of transportation.

Good communication, using public means of transportation, and giving the buildings an aesthetic and encouraging character. Walking on foot and reducing using vehicles to maintain a clean environment free of gaseous emissions and increasing pollution green spaces inside and outside the cities, and using the empty spaces inside the cities in a planned way that suits my neighborhood Residents' needs and use Renewable energy sources, to reduce environmental pollution [6]. Also, the compactness for an increased sustainable effectiveness through walkability, connectivity, increased density and compact building design is a main guideline for sustainable urban development [10], the urban form of the compact city, referred to as the compact urban form, is generally supposed to promote environmental, social and global sustainability by increasing the density of the built up area and residential population, intensifying urban economic, social and cultural activities and manipulating urban size, form, structure and settlement systems [11].

The numerous studies have examined urban compactness from various perspectives, and some countries have taken important steps that could prove successful and serve as a model for other cities. [12]. From the above, it will be important to increase the sustainability of the compact urban formation by adding an element of energy production from building blocks in the compact urban form.

2.2. The practical model for discussing and proving the research hypothesis

In this stage, the research will present the practical application of using one of the elements of urban form, which is building prototype blocks for generating energy, depending on one of the most important sources of renewable energy, that is, solar energy, which is based on the use of glass that generates electric energy from the rays of the sun falling on it, which is known as high-transparency PV window technologies.

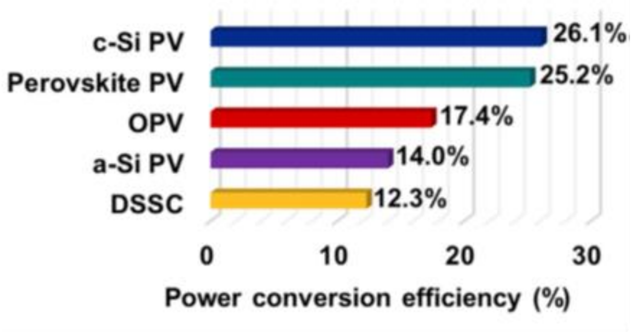


Fig. 5: Main key elements to consider when developing TVP [22].

In figure no. 5, crystalline silicon is shown (c-Si) and perovskite PVs exhibit a high PCE exceeding 25%, while organic photovoltaic (OPV)-based and dye-sensitized solar cell (DSSC)-based TPVs showed PCEs of approximately 5%–7% at a transmittance of 20%, and c-Si-based and perovskite-based TPVs exhibit PCEs of over 12% at a similar transmittance [13]. This research will depend on perovskite PVs, these cells were developed at an institute in Poland and tested at the Spark building in Warsaw, at Polish capital.
Perovskite PVs accepted only 15% conversion efficiency on average as the start to allow the use of perovskite PVs on all of the curtain walls and facades of the buildings in the practical building model of research. This selected efficiency is only 15% because 25% is still noncommercial at the present time, but with the revelation of PV industrial development, the industry leaders will achieve this percentage in the near future as shown in figure no. 8.
A team of researchers at Exciton Science institute that followed ARC Centre of Excellence and Monash University, succeeded in producing the next generation of perovskite solar cells that allow light to pass through them while generating electrical energy, with an efficiency of 17% and transmitting more than 10% of the incoming light [14].

Fig. 6: Perovskite solar cell degrees of transparency [14].

Fig. 7: Spark office building and the use of perovskite cells in its windows and glass walls [23].

The new revolution in clean and renewable energy generation, as shown in Figure 6, was implemented at the Spark office building in Warsaw, Poland, which uses perovskite cells in its windows and glass walls of the building façade shown in Figure 7 [15]. Greater Cairo, which includes Cairo, Giza, and Qalyubia, is one of the cities where the compactness urban fabric and the prevailing pattern of urbanization are widespread in many developing cities due to unplanned growth and urban expansion at the expense of agricultural lands and state-owned lands, which began after World War II due to migration from the countryside to urban areas, which coincided with the economic development that occurred in the cities during the era of President Gamal Abdel Nasser. The most important of these areas are Kit Kat, Imbaba, and Mit Okba in Giza Governorate. the sixties are considered the first stage of the expansion of informal and unplanned settlements [16]. Within the framework of the compactness, the research will study one of the projects expected to be established in the service area of Sheikh Zayed City, located within the Giza Governorate. The research will assume the expected design of the project in terms of urban design. As for the use of buildings, which is administrative and commercial, it was planned by the state. The map shows the location of the practical experiment, located on the Central Axis of Sheikh Zayed City.

Fig. 8: The proposed site for the applied study Sheikh Zayed City [24].

The selected project is a proposed administrative project that consists of six retail & administrative buildings. This site was chosen due to its importance, and administrative buildings were also relied upon for ease of dealing with them in terms of convincing customers of the importance of relying on renewable energy, especially in the initial construction stages of renewable energy systems. Administrative buildings also provide a greater opportunity to finance renewable energy projects, as the financial return from commercial uses will be greater and more continuous. Research will use approved modelling applications by AUTODESK. The Revit application studies an area of building facades that are exposed to sunlight throughout the year to generate clean energy and to study the effect of shadows caused by the presence of buildings adjacent to each other. The following figure clarifies the general location of the buildings so that the intermediate distances separating them from each other are the distances specified according to the heights of the buildings, which are all 26 m in height, as shown in figures no. 8, 9, and 10.

Fig. 9: Project master plan, showing building allocations on the site (Authors).

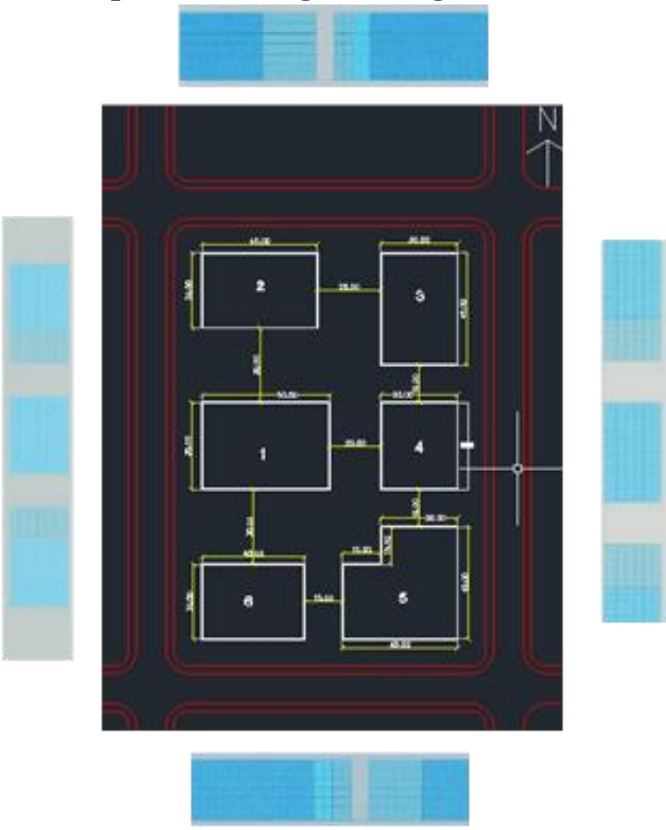


Fig10: Project master plan, showing distances between buildings on site (Authors).

Figures no. 8, 9, and 10 show the design of the buildings within the proposed site for the establishment of the project, as well as the distances between the buildings and the dimensions of the spaces. The previous data were entered in addition to the geographical location data for the project site and the engineering data for the buildings for the Revit application, and a three-dimensional model was created as shown in figure no.11. According to the Revit model, the areas of the glass facades of each building were calculated separately, and a code was made for each of these facades as per figure no. 12 and table no. 1.

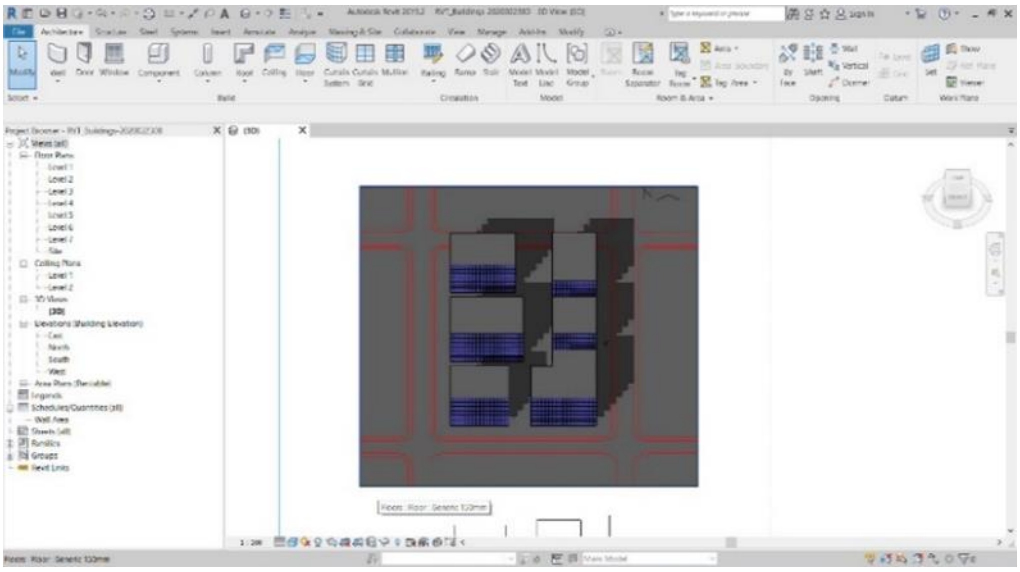


Fig11: Simulation for proposed buildings at Revit application (Authors).

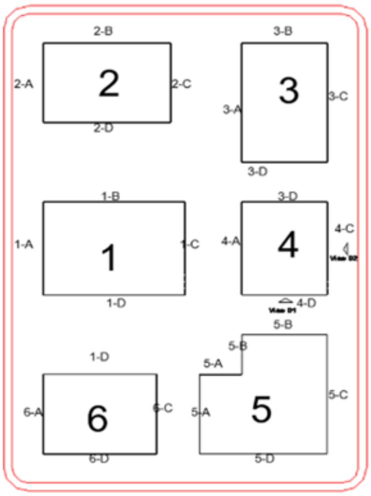


Fig12: Project master plan, showing building numbers and elevation codes on site (Authors).

Table 1: Building Façades calculations and ID information (Authors)

	Type	Elevation ID		Area
Building 01	Curtain Wall	1-A	Elev. 04	909.92
	Curtain Wall	1-B	Elev. 01	1300
	Curtain Wall	1-C	Elev. 02	909.92
	Curtain Wall	1-D	Elev. 03	1300
Building 02	Curtain Wall	2-A	Elev. 04	780
	Curtain Wall	2-B	Elev. 01	1170
	Curtain Wall	2-C	Elev. 02	772.2
	Curtain Wall	2-D	Elev. 03	1170
Building 03	Curtain Wall	3-A	Elev. 04	1170
	Curtain Wall	3-B	Elev. 01	780

	Type	Elevation ID		Area
	Curtain Wall	3-C	Elev. 02	1170
	Curtain Wall	3-D	Elev. 03	780
Building 04	Curtain Wall	4-A	Elev. 04	909.92
	Curtain Wall	4-B	Elev. 01	780.05
	Curtain Wall	4-C	Elev. 02	909.92
	Curtain Wall	4-D	Elev. 03	780.05
Building 05	Curtain Wall	5-A	Elev. 04	270
	Curtain Wall	5-A	Elev. 04	900
	Curtain Wall	5-B	Elev. 01	270.01
	Curtain Wall	5-B	Elev. 01	900.04
	Curtain Wall	5-C	Elev. 02	1170
	Curtain Wall	5-D	Elev. 03	1170.05
Building 06	Curtain Wall	6-A	Elev. 04	780
	Curtain Wall	6-B	Elev. 01	1040
	Curtain Wall	6-C	Elev. 02	780
	Curtain Wall	6-D	Elev. 03	1040

The following table no. 2 shows the total areas of the facades for each building. With reference to the main objective of the research, which is the production of renewable energy, depending on one of the elements of the urban form, namely, building mass, which consists of a number of facades, which are formed from glass panels that generate electric energy, using all of the buildings facades in all directions not only facades facing south, it was necessary to determine the maximum area that can be exploited to obtain clean energy from the group of buildings that can be used as a renewable energy production station, it is necessary to measure the areas illuminated by solar radiation throughout the year, and study the movement of shade on the facades of buildings adjacent to each other that are formed due the convergence of these buildings with each other as shown in figure no. 13, and to identify these measurements, a standard simulation was made during the days that represent the seasons (December 21, March 21, June 21, September 21) as shown from Figure no. 14,16,18 and f igure no. 20.

Table 2: Available areas that can use perovskite PVs (Authors)

Building No_	Solar panel Areas used as Curtain Walls (Glass)m²
Building 01	4419.84
Building 02	3892.2
Building 03	3900
Building 04	3379.96
Building 05	4680.12
Building 06	3640
Total	**23912.12**

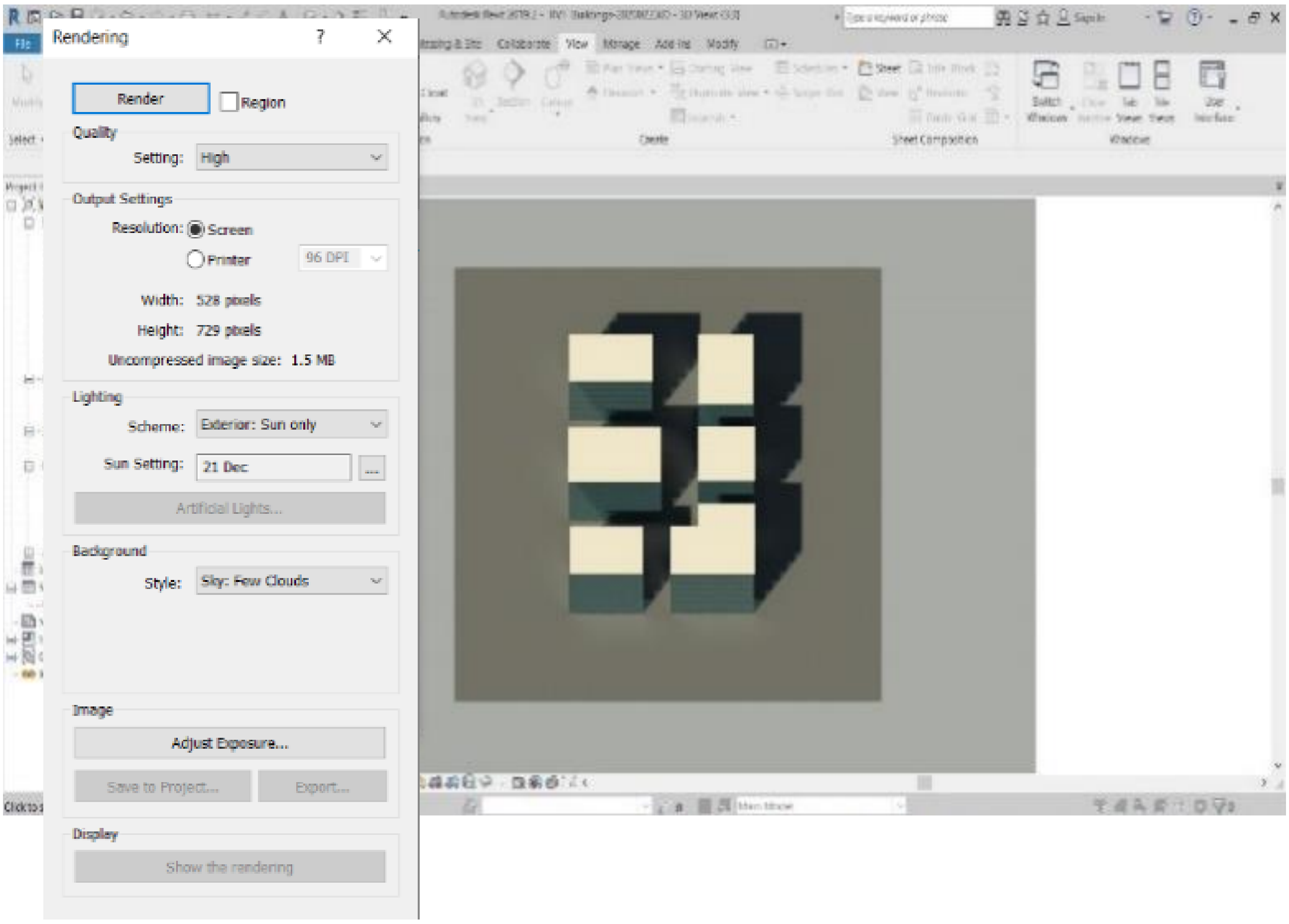


Fig13: Rendering with selected time in simulation application (Authors).

2.3. The areas that are illuminated by solar radiation during selected four days:

The following is a presentation of the models of this simulation, as well as the charts that show the areas illuminated by solar radiation during these days, and compare them with the total areas of facades, and show the length of the shade on the facades of adjacent buildings.

1. Date: 21 December Simulation layout:

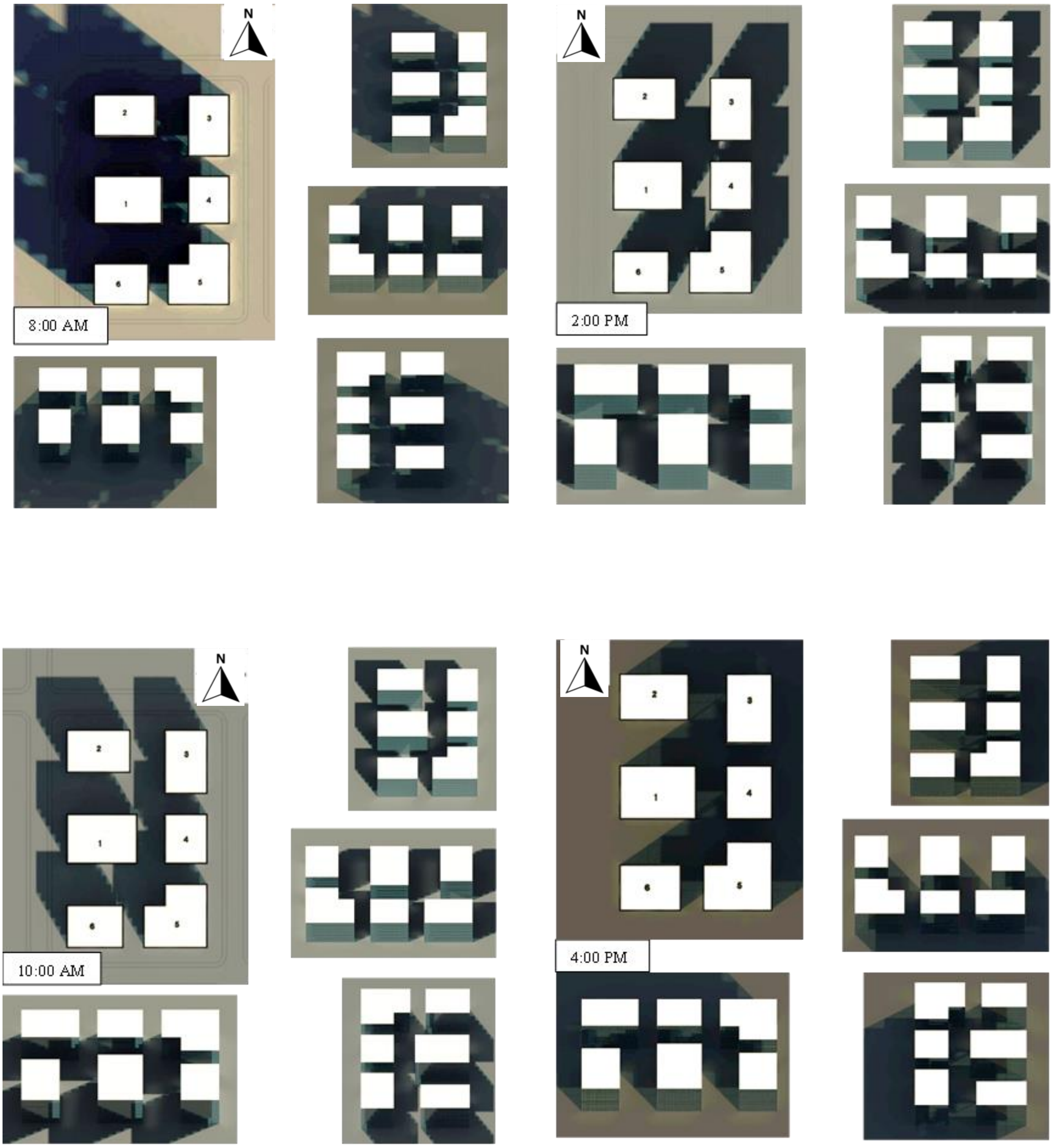


Fig14: 21 December - The length of the shade on the facades of adjacent buildings (Authors)

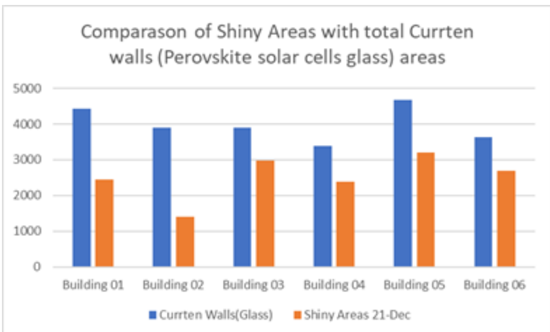


Fig15: irradiated areas from elevations for each building on 21 December (Authors).

2. Date: 21 March Simulation layout:

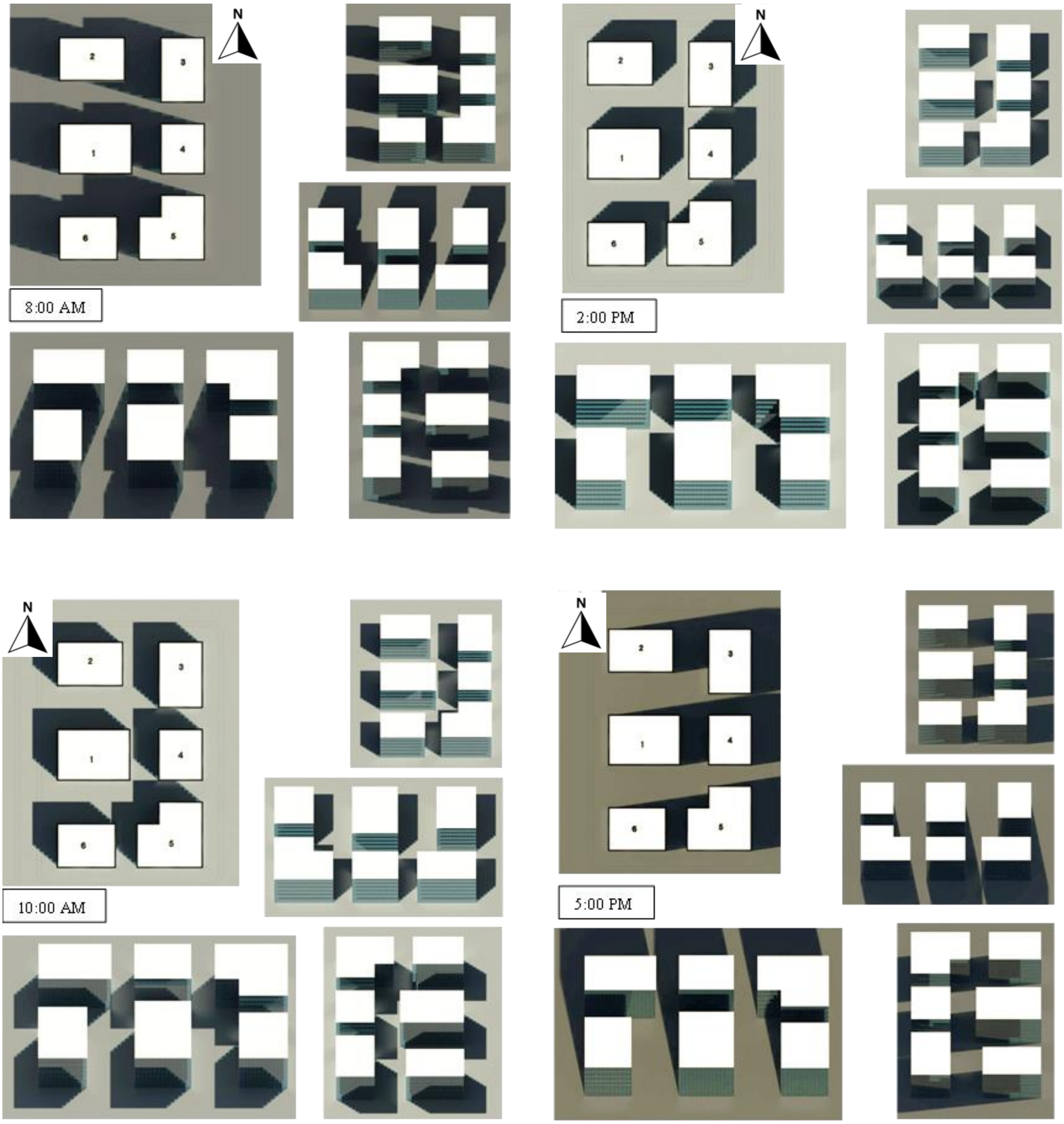


Fig16: 21 March - The length of the shade on the facades of adjacent buildings (Authors).

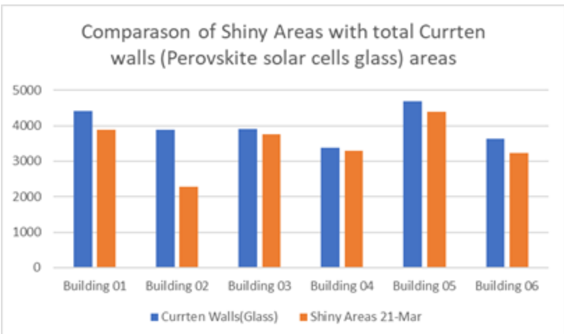


Fig17: irradiated areas from elevations for each building on 21 March (Authors).

3. Date: 21 June Simulation layout:

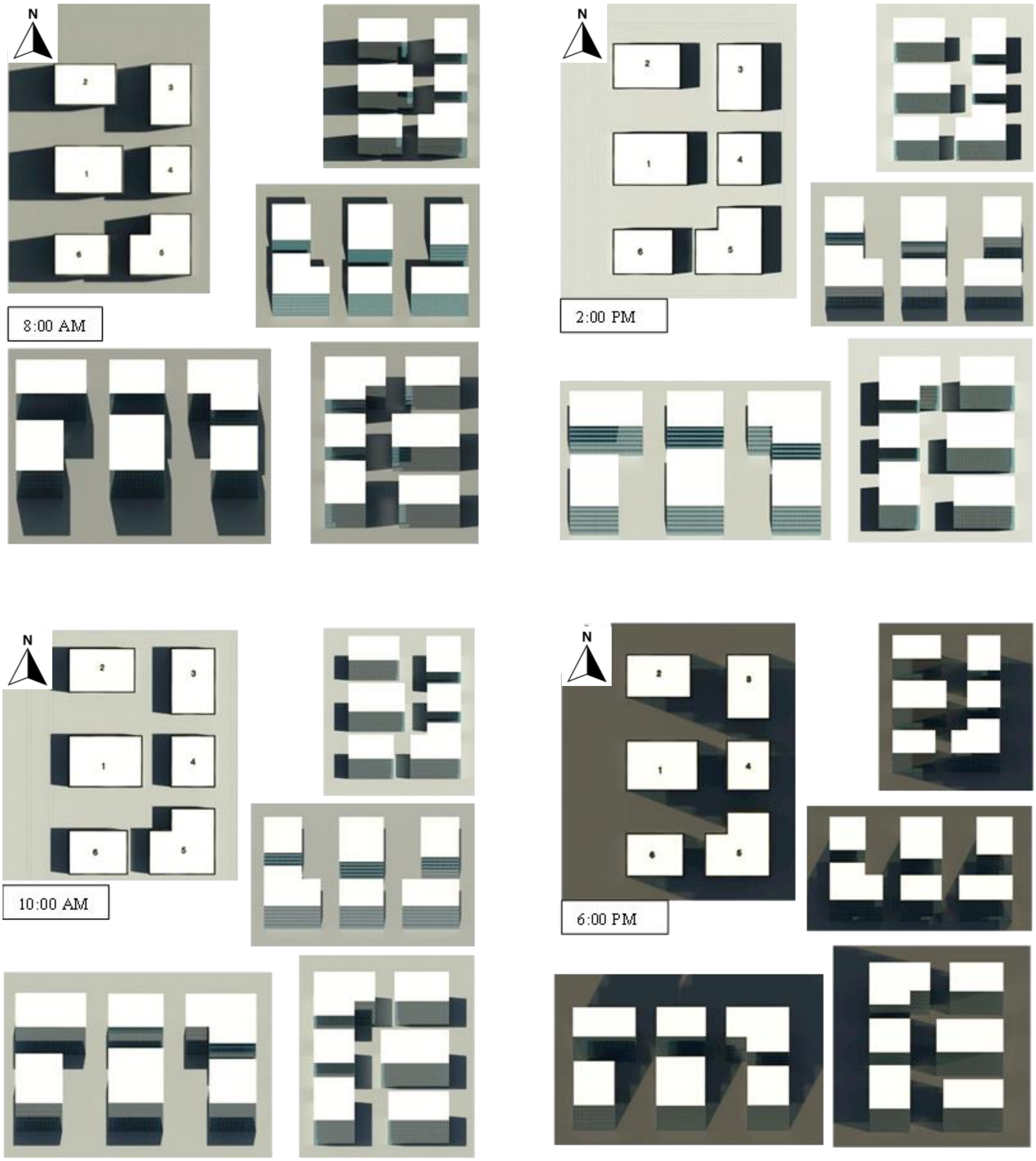


Fig18: 21 June - The length of the shade on the facades of adjacent buildings (Authors).

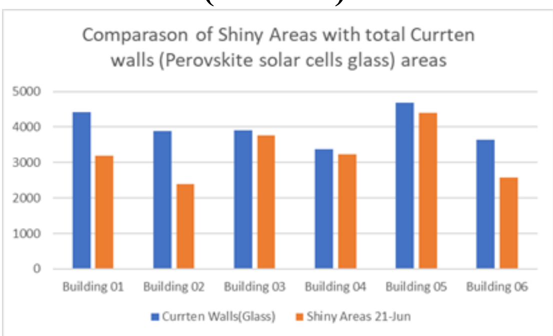


Fig19: irradiated areas from elevations for each building on 21 June (Authors).

4. Date: 21 September Simulation layout:

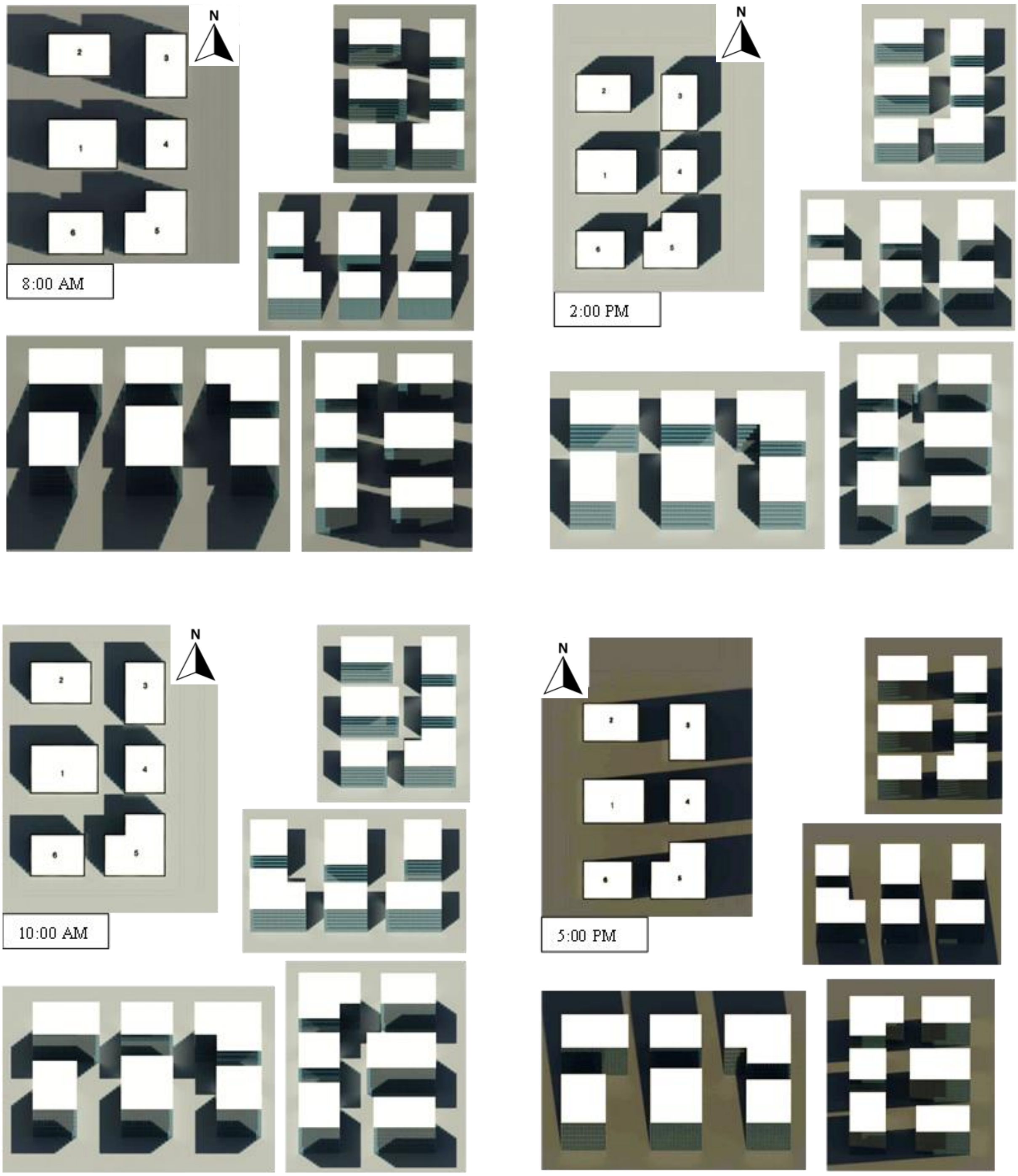


Fig20: 21 September - The length of the shade on the facades of adjacent buildings (Authors).

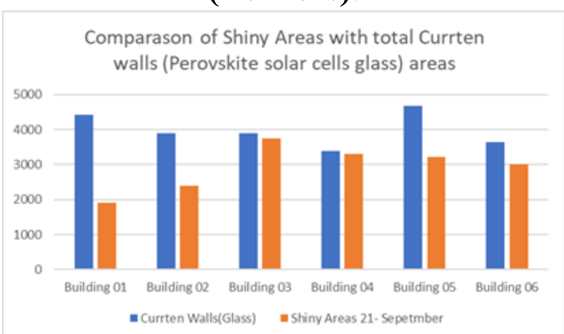


Fig 21: irradiated areas from elevations for each building on 21 September (Authors).

As shown in figures no.15, 17, 19, and 21, the research provides the average irradiated area for each building on the aforementioned four days. The research presents the estimation of solar radiation energy received per m² per day on a tilted surface facing the equator, where solar radiation is always measured on a horizontal surface and is denoted by HB, measured as global radiation on a horizontal surface in kWh/m²/day [17]. Before conducting energy estimation, the following figure no. 22 shows the solar angles on which the energy estimation equations depend.

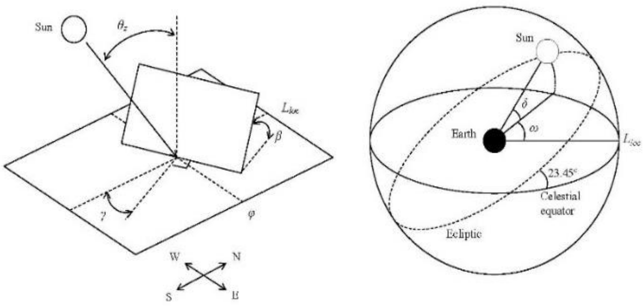


Fig22: Solar angles used in the calculations [18].

-**β**, tilt of the plane with respect to the horizontal, 0°≤ β ≤ 180°.
-**γ**, azimuth angle of the tilted plane, zero due south, west positive, −180 °≤ γ ≤ 180 °. [18]
-**φ**, latitude of the location, north positive, −90◦ ≤ φ ≤ 90◦.
-**δ**, declination of the sun, the "vertical" position of the sun on the celestial sphere, measured in degrees above or below the celestial equator, north positive −23.45°≤ δ ≤ 23.45°.
-**ω**, hour angle, angular displacement of the sun relative to the local meridian, zero at noon, afternoon positive, −90 °≤ ω ≤ 90°.
-θ is the angle of incidence, the angle between the normal to the tilted plane and the beam radiation on that surface, −180°≤ θ ≤ 180°.

2.4. The electricity output calculations:

As per figure 22 Solar angles used in the calculations define the location and orientation of the tilted plane, these are the plane tilt β, azimuth angle γ and latitude φ. Additionally, the longitude Lloc and the zenith angle θz the angles defining the sun's position relative to the Earth and the celestial sphere are shown, as well as the declination δ and the hour angle ω. [18]. In this step, the research can estimate monthly average daily radiation on a tilted surface called H_T (Kwh/m²/day) using the following equation: [17] [19]

$$HT = HB\,[1.13\,KT\ Rb + 0.5\,(1 + Cos\,\beta)(1 - 1.13\,KT) + 0.5\,f\,(1 - Cos\,\beta)]$$ So that:

(K_T) *is a Clearness index*, and its calculation equation is: $KT = \frac{HB}{Hext}$

So that:
H_{ext} is a monthly average daily extraterrestrial solar insolation (kW/m²/day) on a horizontal surface at the same latitude (φ) of the site consideration, and its calculation equation is:

$$Hext = \frac{24}{\pi}\,Gsc\,[Cos\,\delta\,Cos\,\varphi\,Sin\,\omega_s + \omega_s\,Sin\,\delta\,Sin\,\varphi]$$

So that: G_{sc} is a constant value, for extraterrestrial solar irradiance (kW/m²) on a surface normal to solar beams is constant and equal to the solar constant (1.35 kW/m²).

$$Rb = \frac{Cos\,\delta\,Cos\,(\varphi-\beta) Sin\,\omega_s' + \omega_s' Sin\,(\varphi-\beta)\delta}{Cos\,\delta\,Cos\,\varphi\,Sin\,\omega_s + \omega_s\,Sin\,\varphi\,Sin\,\delta}$$

So that: $f = 0.2$ is constant value, $\omega_s = Cos^{-1}(-\tan\delta\tan\varphi)$, $\omega_s' = Cos^{-1}(-\tan\delta\tan(\varphi-\beta))$
Based on the previous equations, the H_T values for angle **β** (30°) for the roof solar cells and angle **β** (90°) for building facades using high-transparency PV window technologies (photonic glass.

The available solar cell areas angled at 30° should be calculated according to the number of solar cells that are allocated on the rooftop of the building, which can be calculated according to the following equations: As per the following figure no. 23, 24 (X) refers to the height of the solar cell board. In the case study, it will be 2 m, (W) the angle between the solar cell board and horizontal axis for Egypt at the best angle of 30°; (H) is the difference in height of the row of solar cells is between the highest and lowest point, (L1) Horizontal projection of the row of solar cells and its symbol, (a) angle refers to average sunshine angle value approximately 30° on average, with multiplication by a factor of 0.5, which prevents the cells from being exposed to shade for approximately 6 h a day, giving them approximately 85% of their production capacity, and (L2) is the distance between solar cell boards. [20]

$$L1 = \cos(W) * X \quad , \quad L1 = 0.866 * 2 = 1.7321 \quad , \quad L2 = \frac{H}{\tan(a)} \quad , \quad L2 = \frac{\sin(W)*2}{\tan(a)} = \frac{\sin(30)*2}{\tan(15)}$$

$$L2 = \frac{1}{0.267949} = 3.73$$

Figure no. 23 shows the maximum area that can be utilized by solar panels that can be placed on the roofs of those buildings.

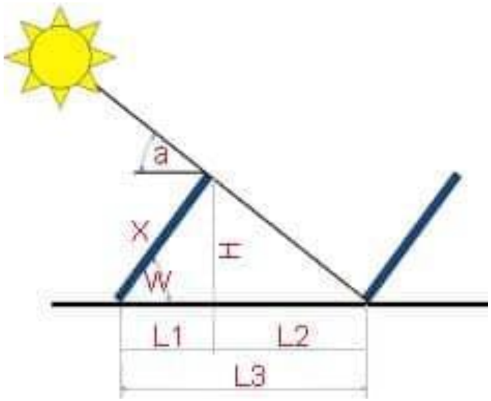


Fig23: Distance between solar cell board calculation factors [20].

By calculating the average values of HT electrical energy resulting from calculating the average of the lighted areas during the four days referred to as December 21, March 21, June 21, and September 21, as well as for the solar cells installed on the roofs of buildings shown in figure no. 24, and the conclusion of the total electrical energy determined during the year (365 days), considering the following points when calculating the values of HT, whether for cells placed at an angle of 30° with the horizontal axis or for perovskite solar cells on the building façades.

1- For all building façades that do not face directly south, the saturation values were calculated by half-value calculations.

2- The efficiency of all solar cell types was 15%.

Therefore, the estimated values of the electric energy, kWh/year, are presented in table no. 3

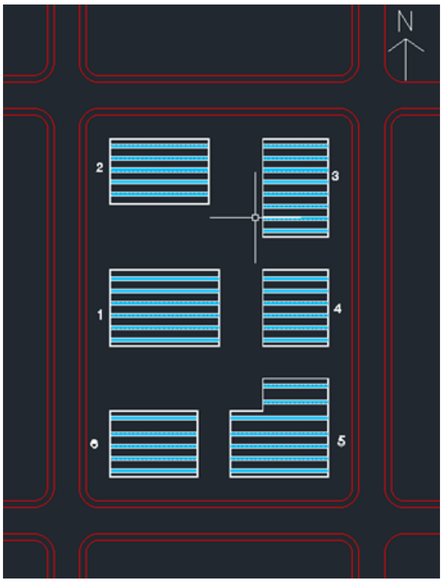


Fig 24: Distance between solar cells boards allocated on building roof (Authors).

Table 3. Using the average of shiny areas of buildings facades and solar cells at building roof (Electric Energy calculations per year) (Authors).

Building No_	Energy kWh/m²/day				Available areas to use as solar cells	
	21-Dec	21-Mar	21-Jun	21-September	Curtain Walls(Glass)	Roof
Building 01	959	1904	2347.50	1547.73	4419.84	540.00
Building 02	754	754	1923.25	1505.08	3892.2	405.00
Building 03	1200	1200	2776.36	2486.92	3900	432.00
Building 04	1090	1090	1923.85	1955.70	3379.96	324.00
Building 05	1301	1301	2959.13	2152.02	4680.12	513.00
Building 06	869	869	1717.84	1504.75	3640	360.00
	6173.53	7118.16	13647.92	11152.20	23912.12	2574.00
(Kwh/Year)	3,475,877				26486.12	

The total kWh/Year calculated in the upper table is the result of the following equation:

Total (Kwh/Year)= Σ ((Kwh/m^2)/day)/4*365

The results of the research to be evaluated from the values of electrical energy production must be compared with the expected needs of these buildings according to the area of each building, as shown in table 4.

Table 4. Building electric energy consumption per year, no._ of solar cells needed and the assumption of solar panel areas (Authors).

Building No_	Buildings BUA	Current energy consumption (occupancy patterns, HVAC & lighting loads) (kW/H/Year)	No_ of Solar Panels	Solar panel Areas m²
1	10500	376411	240	1441
2	8100	290374	185	1111
3	8100	290374	185	1111
4	6300	225847	144	864
5	10800	387166	247	1482
6	7200	258111	165	988
Total	51000	1,828,284	1166	6998

The previous table no. 4 shows the total construction areas of the buildings, as each building consists of six floors, as well as the total electrical loads expected for each building separately. The table also shows the number of solar panels required to be provided to cover the electric energy needs of these buildings. Finally, the table displays the area required to be provided for the installation and operation of the solar energy system with the same efficient production of solar cells 15%, only solar panel areas without panel construction stand for the required areas. By studying the results contained in the two previous tables, we find that the electrical energy produced using the power generator using one of the elements of urban form, which is the mass of buildings, is approximately 1.9 times higher than that obtained using traditional solar cell stations for energy production, as shown in figure no. 25.

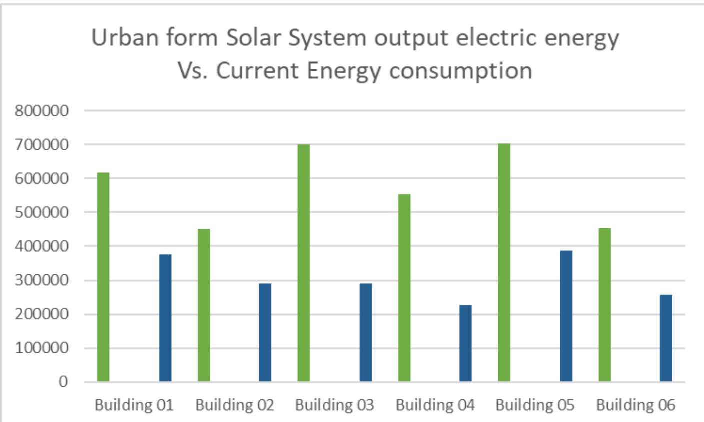


Fig25: Urban form solar system output electric energy at green bars vs. current energy consumption at blue bars (Authors).

As shown in the previous figure, no. 25, the difference between the energy required to supply buildings and the energy that can be produced using the masses of these buildings themselves is almost double, which confirms the importance of using building blocks or masses through facades and roofs to generate electrical energy by relying on sunlight. According to the practical study that was conducted in the same geographical area that was chosen for the research, about 42% of the total area of the building masses will be relied upon to generate energy to meet the expected consumption needs [8]. Building blocks were considered the energy production stations, depending on solar energy.

To obtain the largest possible amount of energy generated by reducing the areas of shadow that buildings cast on each other, which are within the urban form that was studied previously, it is expected that the volume of energy produced will increase due to the reduction of the areas of shadow on building blocks and thus the areas exposed to radiation. So, research will study the possibility of increasing the energy produced based on the practical approach presented in the research and using the equation in figure no. 23. The building masses will be moved away from each other so that none of the buildings cast a shadow on the building next to them, as shown in figure no. 26. However, the research assumes that urban form will generate a different energy with a high percentage rather than the income from the current design of the urban form.

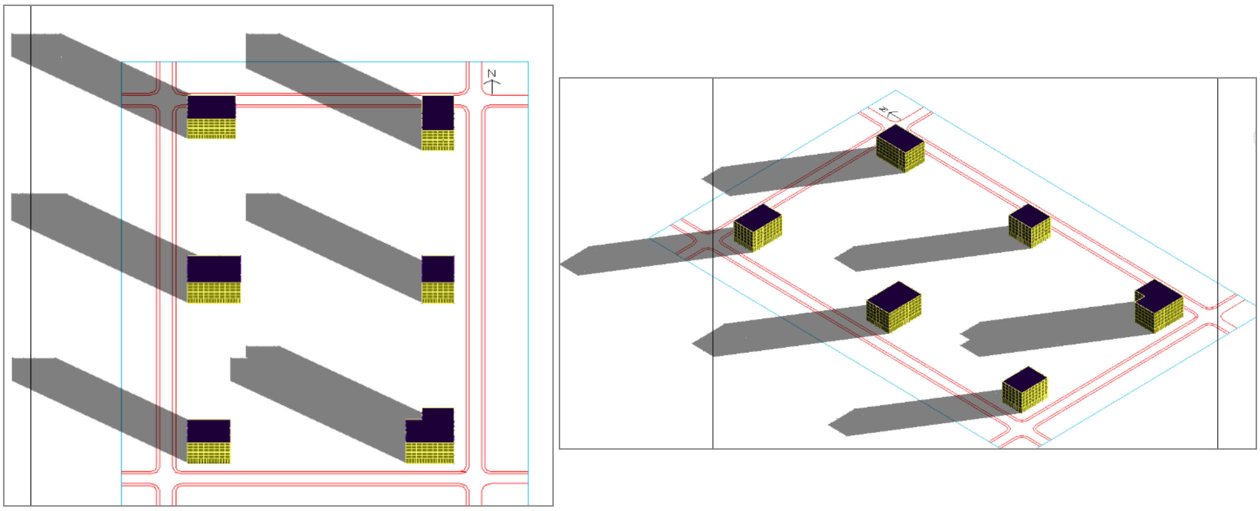


Fig26: New building distribution layout after building masses were moved away from each other so that none of the buildings cast a shadow on the building next to them (Authors).

3. Results

As shown in the previous figure, no. 26, the difference between the energy required to supply buildings and the energy that can be produced using the masses of these buildings themselves is almost double, which confirms the importance of using building blocks or masses through facades and roofs to generate electrical energy by relying on sunlight. Building blocks were considered the energy production stations, depending on solar energy.

In addition, as per the study model, the required solar panel areas only the solar cell area without holding frames or construction stands required allocation spaces of approximately 7000 m² to install solar stations to serve these six buildings alone for one year. If the buildings use the top roof to install the solar cell panels, then the required solar cell areas will be approximately 4400 m², which is needed to install outside the buildings without any extra increase in energy production, but the method provided in this research can generate approximately double the amount of energy produced by traditional solar power stations.

It is clear from the practical study that compact urban form can be effective in producing clean energy based on one of the renewable sources, which is solar radiation, and this is done by comparing the quantities of energy produced according to the practical study with the expected consumption, which increases the sustainability of the urban form. When modifying the urban design by moving the buildings as shown in figure no. 26 so that no single building casts a shadow on the building next to it and using the same mathematical steps previously used to calculate the energy produced by the proposed urban design, the increase in energy produced was about 20% more than the amount of energy generated by the current urban design for the practical case, which indicates that the original design has good efficiency in energy production with a compact urban layout as shown in figure no. 27. Also, one of the most important features of the aforementioned modification is that it increased the distances between buildings by about seven times the original distance between the building blocks, which, from a design perspective, does not serve the standard proportions of both mass and space that contributed to the success of the urban design. So, the buildings in the original compact design layout could generate a sufficient amount of energy compared with the buildings' energy consumption. Also, the energy produced can be controlled by changing the distances between the buildings, which indicates a new result that had never been provided in other studies before.

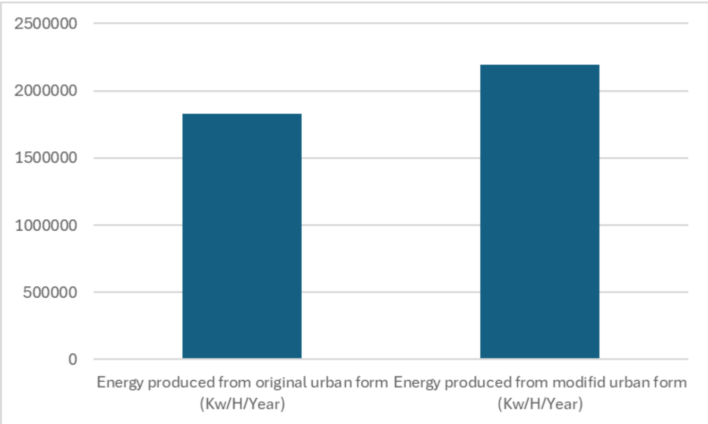


Fig27: Comparison between the values of energy production from two different urban form layouts (Authors).

4. Discussion

This research shed light on a different research point that previous research did not directly address, which is maximizing the benefit from urban compactness and employing it in the production of renewable energy under the umbrella of considering that urban compactness is one of the concepts of sustainable urban formation based on studying one of the urban designs that can be implemented in Sheikh Zayed city within the scope of Greater Cairo, which serves the local community directly with these results. Then, the results of this research can be used to apply them within the scope of Middle Eastern cities that enjoy the same climatic features as Cairo or are close to it. Also, research that approached the research topic, such as on the development and optimization of an urban Design Comfort Model (UDCM) on a Passive Solar Basis at Mid-Latitude Sites [7]. It was also proceeding in the field of research to reduce energy consumption based on urban formation. Therefore, through what was mentioned above, it can be said that the research proved that urban compactness is considered the most important design element from the point of view of energy production from sustainable urban formation. Accordingly, the research proposes dividing the seven elements mentioned by Jabareen according to their capabilities in the field of renewable energy production and reducing energy consumption.

Also, the research approach is aligned with Egypt's Nationally Determined Contributions (NDCs) and development and climate change policies, including the Sustainable Development Strategy: Egypt Vision 2030, the Long-Term Low-Emission Development Strategy 2050 (LT-LEDS), and the National Climate Change Strategy 2050 (NCCS), in addition to sectoral strategies, such as the Integrated Sustainable Energy Strategy 2035 and the National Energy Efficiency Action Plan.[27]. The research depends on perovskite solar cells (PSCs), which have rapidly advanced as a promising alternative. Despite their relatively short history, PSCs are progressing at an unprecedented rate, driven by global research efforts that capitalize on their unique advantages. These innovative cells offer lower manufacturing costs; simpler fabrication processes and greater mechanical flexibility compared with traditional silicon cells. Remarkably, their power conversion efficiency has recently surpassed 26%, approaching that of silicon cells.[28]

5. Conclusions

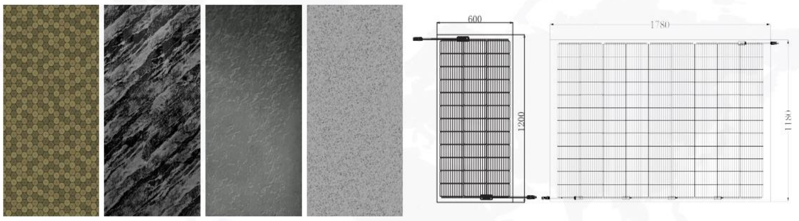
1-The importance of the concept of urban compactness in relation to other design concepts: The research provides practical evidence that renewable energy production based on urban form elements within the concept of urban compactness as one of the concepts of sustainable urban form design increases the chances of achieving sustainability for the urban form. Therefore, the concept of urban compactness can be considered the most important concept of sustainable urban form design, and it also qualifies the process of energy production based on urban form elements to be one of the concepts of sustainable urban form design.

2-The required area of the building mass to generate energy equivalent to the expected consumption needs: The research provides, through the previous calculations, the possibility of not using all the building masses at once to produce energy equivalent to the buildings' electrical energy needs. This means that by knowing the expected consumption of the building, the required areas will be exploited to generate energy equivalent to consumption only, without the need to cover the entire building mass with solar cells, whether transparent or opaque.

3-Urban form renewable energy stations: The research provides a new definition of renewable energy stations, which are sustainable urban form stations that produce clean energy by using one of the urban form elements, which is building mass in the fram work of the urban compactness.

4-Achieving the goals of the COP 28 climate conference: The research contributes to increasing the ability of urban communities to achieve sustainability by increasing reliance on clean energy, which increases the chances of achieving the goals of the COP 28 climate conference.

5-The new generation of the building façade cladding materials: It is possible to rely on modern, opaque cells that do not take the form of traditional cells and can be used in facade cladding, as shown in figure no. 28, which shows one of the samples of this type of façade cladding sheets, which can be integrated with the design of the building's facades and the to be a main parts of building façade design.



ELECTRICAL PARAMETERS(STC)				
Module type	JS115DG-13.5e 1/2	JS75DG-13.5e 1/2	JS60DG-13.5e 1/2	JS105DG-13.5e 1/2
Color (customizable)	JSA01105-LG	JSC1101-WFX	JSC0801-SSD	JSA10-110-XS-S
Power output (P_{max})	115W	75W	60W	105W
Power output tolerances (ΔP_{max})	0-5W	0-5W	0-5W	0-5W
Module efficiency (η_m)	15.97 %	10.42%	8.3%	14.58%
Voltage at Pmax (V_{mpp})	20.86V	26.17V	24.29V	20.84V
Current at Pmax (I_{mpp})	5.47A	2.80A	2.40A	4.85A
Open-circuit current (V_{oc})	24.90V	29.95V	27.92V	24.75V
Short-circuit current (I_{sc})	5.67A	2.97A	2.59A	5.01A

Fig28: The opaque cells products that can be cover the building mass with perovskite solar cells [25].

6. Recommendations

The research is recommended the following:

1-Providing eighth element of design concept for sustainable urban form: Considering that generating of clean energy based on one of design concepts of sustainable urban form & buildings mass as an eighth element of design concept for sustainable urban form that will be added to the previous seven sustainable urban form design concepts.

2-The future researched in the same field: The research is preferring to keep going depending on more elements of design concepts of sustainable urban form for example, the diversity and what is impact of decrease the diversity on the renewable energy production.

7. List of abbreviations

Abbreviations	Definitions
SDIs	Sustainable development indicators
OPV	Organic photovoltaic
HB	is a monthly average daily value of solar radiation on horizontal surface (kwh/m²/day).
HT	is a monthly average daily radiation on a tilted surface a monthly average daily extraterrestrial solar insolation , (kW/m²/day) on a horizontal surface at the same latitude (φ) of the site consideration
Hext	
Gsc	is a constant value, for extraterrestrial solar irradiance (kW/m²) on a surface normal to solar beams is constant and equal to the solar constant (1.35 kW/m²).
Kwh	Kilowatt per hour
TPVs	Transparent photovoltaics
PVs	Solar photovoltaic
PCE	power conversion efficiency
NDCs	Nationally Determined Contributions
c-Si	Crystalline silicon
DSSC	dye-sensitized solar cell
BUA	Buildings (Built Up Area)

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