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A 3d Model-Based Approach To Determine How Building Morphology And Surrounding Affect Solar Reception On External Surfaces: A Case Study Of Collective Housing In Skikda, Algeria

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Abstract

Economic and environmental concerns have raised ambitions for long-term progress at national and international levels. By conserving natural resources, reducing energy consumption and assessing the impact on ecosystems, the building industry can make a significant contribution to sustainable development. One of the ways to do this couldbe through the integration of thermal or photovoltaic panels in building energy systems in order to transition towards renewable clean energy. The aim of this research is to find out what factors influence the annual solar energy received by buildings and neighborhoods, and to select the best locations for the installation of solar energy systems in four different cases in the Algerian city of Skikda. This will be done by comparing them through a 3D model-based approach, using ARCGIS for modelling, before running simulations using INSIGHT 360 via REVIT Autodesk. The results show that vacant land far from urban and natural features is the most suitable location for installing solar panels. Next, the roofs of buildings are recommended, followed by their south-facing facades and then their east- and west-facing facades. They also show that the neighboring topography and the height of the building in relation to its urban surroundings, as well as the distance between it and other buildings, affect its reception of the cumulative annual insolation and, of course, the performance and productivity of the solar panels, which could also be affected by the shape of the building itself, especially if there are extensions in the roof or offsetsin the facades.

Keywords: *3D Model-based approach, Surroundings masks, Building morphology, Solar map, Urban collective housing, Solar system integration, Algerian city of Skikda.*

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1- Introduction

Economic and environmental concerns have led to increased national and global aspirations for long-term advancement. The building sector can play a crucial role in promoting sustainable development by using natural resources prudently, minimizing energy consumption, and evaluating impacts on ecosystems. Buildings account for over a third of worldwide energy consumption and the resulting greenhouse gas emissions in both developed and developing countries. The environmental impact of buildings is significant, where commercial and residential structures contribute to more than 60% of the planet's electricity usage (Ascione et al.,2016). However, it is also among those sectors where cost-effective mitigation measures can be taken.

Solar panels have considerable potential to provide sustainable electrical and thermal energy in urban settings for local renewable energy systems in urban contexts. Building-integrated photovoltaics, for instance, present a promising solution in supporting the transition towards sustainable energy for the building sector (Shukla et al., 2017), making it possible to take advantage of existing urban areas without the need for additional areas or infrastructure, and to produce energy where it is needed, especially given the growing demand for electricity from the building sector (Enerdata website, 2019), nevertheless, for many uses (e.g. production of electrical energy and thermal energy for cooling or heating, as well the other daily requirements as lighting, cooking, supply energy to appliances..) (Scognamiglio & Røstvik, 2013).

To tackle the requirement for energy conservation in buildings and electricity generation from local solar energy systems in urban regions, an attainable method to introduce in cities and urban neighborhoods is the combination of photovoltaic and thermal renovation of buildings' roofs and facades, as demonstrated by (Wu et al., 2017; Martinez & Choi, 2017), where the refurbishing of the facades is a practical approach to diminish the consumption of energy in buildings.

Various methods to renovate external surfaces can improve the energy performance of the envelope, the thermal comfort for building users, and the architectural quality of the building skin. These strategies depend on the original characteristics of the envelope prior to renovation, existing climatic conditions, and techno-economic constraints, in addition to regulatory requirements (Ma et al., 2012). One potential solution for renovating facades involves incorporating multifunctional photovoltaic or thermal elements into the building, which can achieve the aforementioned goals while also generating solar energy.

To ensure the successful installation of solar photovoltaic and thermal systems in urban areas, where a significant portion of energy demand is concentrated, it is crucial to assess local solar potential (Abu Qadourah et al., 2022).

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This potential is directly linked to local solar radiation, which varies considerably in urban environments. Indeed, the amount of irradiation that reaches a specific location over time changes according to global, local, geographical, temporal and climatic factors (Li, 2013).

Many approaches have been developed or adopted in a large number of studies to calculate the integrated photovoltaic and thermal potential of building facades. They can be classified into several main categories, and some of them are approaches based on 3D models with simulations of solar irradiation.

In these approaches, the archetype and its urban environment can be simulated in 3D and solar irradiance can be estimated taking into account building obstructions using accurate models or adjustment factors that reduce the total roof and facade area to the acceptable area for solar energy systems (Saretta et al., 2019).

(Amado & Poggi, 2014; Brito et al., 2019; Caamaño-Martin et al., 2012; Desthieux et al., 2018; Fath et al., 2015) are examples of studies that have used this method.

The aim of this study is to apply this type of approach, based on 3D models, to simulations of solar irradiation, on 4 case studies in the Algerian city of Skikda, as part of a scientific research project on the energetic and ecological renovation of collective housing buildings samples in thiscity, which suffers from a number of energy and environmental problems. This investigation takes into account the differences that exist between the morphologies of the 4 typologiesstudied, as well as the urban environment and the topographical context, in order to deduce their effects on the quantity of solar radiation received on the vertical and horizontal surfaces of the archetypes studied, extracting the factors and circumstances favorable to the integration of solar panels and their best locations, in the context of planning the energy renovation of these buildings, and changing their source of supply, towards the use of clean energy.

2- Methodology

2-1- Research workflow and materials

As shown in Figure 1, the process of this research was developed after a comprehensive review of previous research on the energy renovation of buildings, as well as on systems based on renewable energies, and especially that related to solar resource, in addition to the methods and approaches about their integration into the building sector, in a way that the user can optimally benefit from their production. A morpho-typological study of all existing and inhabited collective housing typologies in Skikda enabled the selection of four distinct research samples.

Subsequently, visits were made to the city's construction and urban planning services, as well as to the town hall, to gather further details on the geometry of the archetypes. Field trips were also conducted, capturing photographic images of the archetypes and the entire neighborhood. In order to collect more data, websites such as Google Maps and (topographic-map, n.d.) were utilized to extract the footprint of the buildings on the ground and the topography of the site, respectively. This allowed for the eventual modeling of the entire urban and topographical context.

Geometric modelling was carried out using ArcGIS package via ArcMap, creating and modelling urban form models, with geographical data, which were then fed into REVIT AUTODESK, where they were edited to produce solar analyses as well as visualizations demonstrating the variability in the amount of incident solar energy accumulated, over the course of a year, based on hourly recording intervals, for each urban model via the AUTODESK INSIGHT plugin.

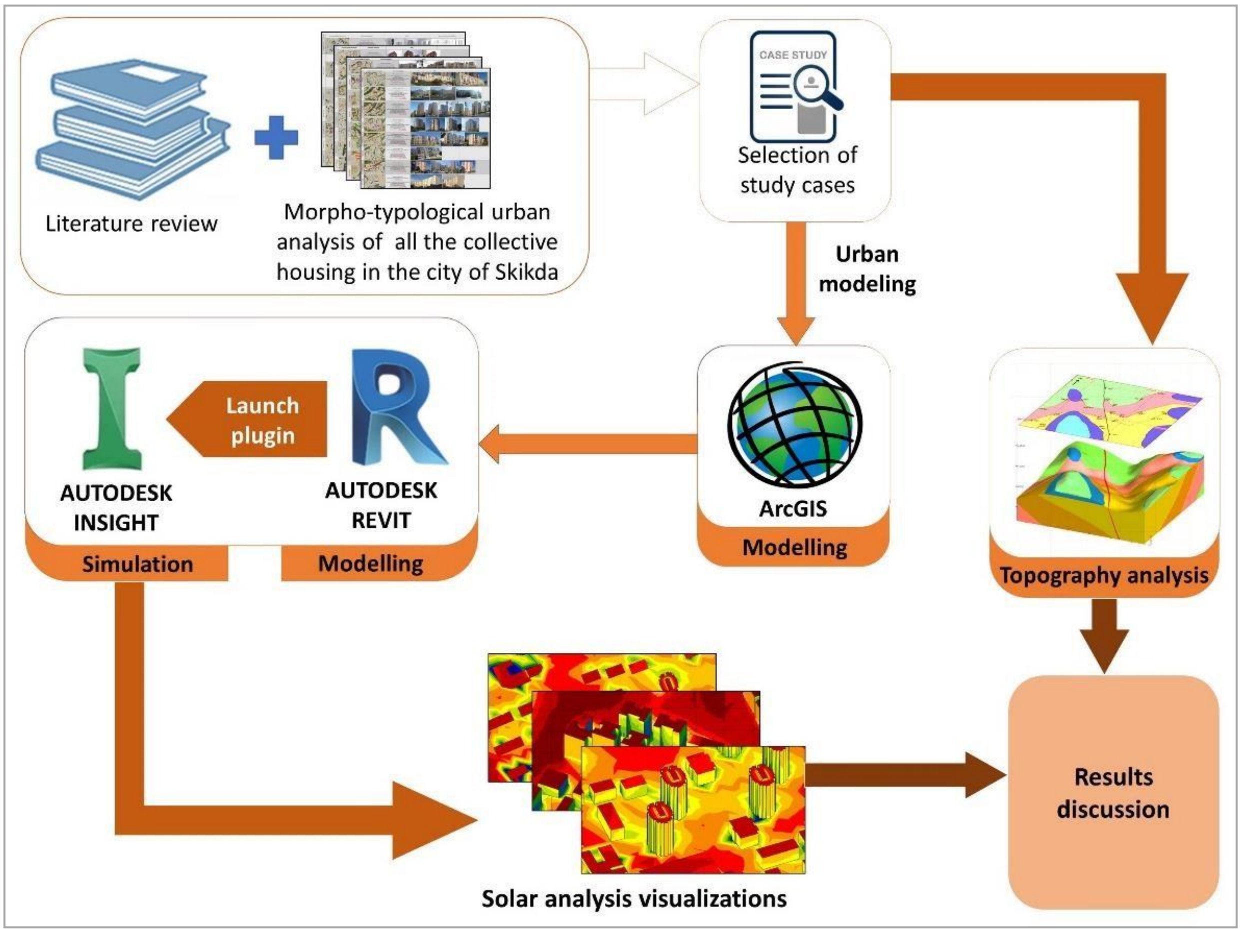

Figure N° 01: Research workflow.
Source: The author, 2023.

2-2- Presentation of the context of the city of Skikda

The city of Skikda varies in elevation from 0 to nearly 150 meters above sea level and is situated in a region with a moderate Mediterranean climate. This city which is the subject of this study, located in the northeastern of Algeria, and situated at 36° 86′ north and 6° 92′ east.

The region is characteristically humid and has hot summers, but relatively moderate winters, with February being the coldest month with an average monthly temperature of 12.9 °C, in

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accordance with data from 1991 to 2020 on daily temperatures and meteorological conditions, which also indicates that August experiences the highest temperatures, with a monthly average of 26.3 °C (Site Climats et voyages, 2020). So, due to the significant variation in annual temperatures, it is imperative to implement specific measures to ensure both energy efficiency and a comfortable indoor temperature.

Prior research suggests that these homes are in a vulnerable state, having become disconnected from their natural environment and climate due to their age and inability to withstand meteorological factors owing to an outdated design that lacks bioclimatic principles. This situation has been exacerbated by rapid urbanization (Brighet, 2018); buildings failed to meet current energy-saving standards and failed to provide adequate occupant comfort (Kassis, 2012). Moreover, these buildings were unable to respond to daily and yearly changes in the climate and demanded artificial industrial strategies, which resulted in pollution and high energy consumption (Boulkenafet, 2014).

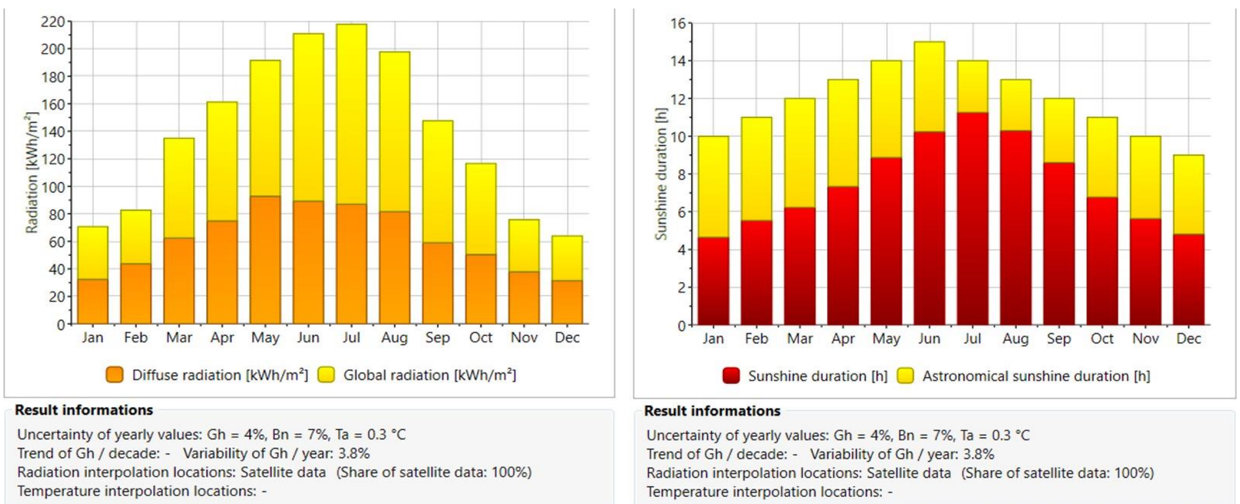

Figure N° 02: Simulation of monthly amount of radiation, monthly sunshine duration, in the zone of Skikda, during 2021, through METEONORM.
Source: The author, 2023, on the basis of METEONOTM tool.

According to the source of (Site Climats et voyages, 2020) also, Skikda receives an average of 2675 hours of sunshine per year. In relation to Figure 2, which displays a graphic presentation of the solar radiation simulation and its duration for the year 2021 via the METEONORM climate simulation tool, diffuse and global radiation levels are highest in the summer, with a maximum monthly value of 220 kwh/m² and with 70 kwh/m² in its lowest monthly value in the winter. Additionally, sunshine duration is greater in the summer, reaching its peak in July with more than 11 hours of daylight.

This signifies that Skikda has immense potential in terms of solar energy, which can be harnessed in the transition towards a clean, renewable energy system. Currently, the urban parkof Skikda relies entirely on polluting fossil fuels to meet its daily energy needs.

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2-3- Presentation of study cases

Four case studies were chosen, and they were: Khaldi Brothers neighborhood (Case A), Messiouene neighborhood (Case B), Merdj eddib neighborhood (Case C), in addition to Saadi Brothers neighborhood (Case D); their locations are depicted in (figure 3).

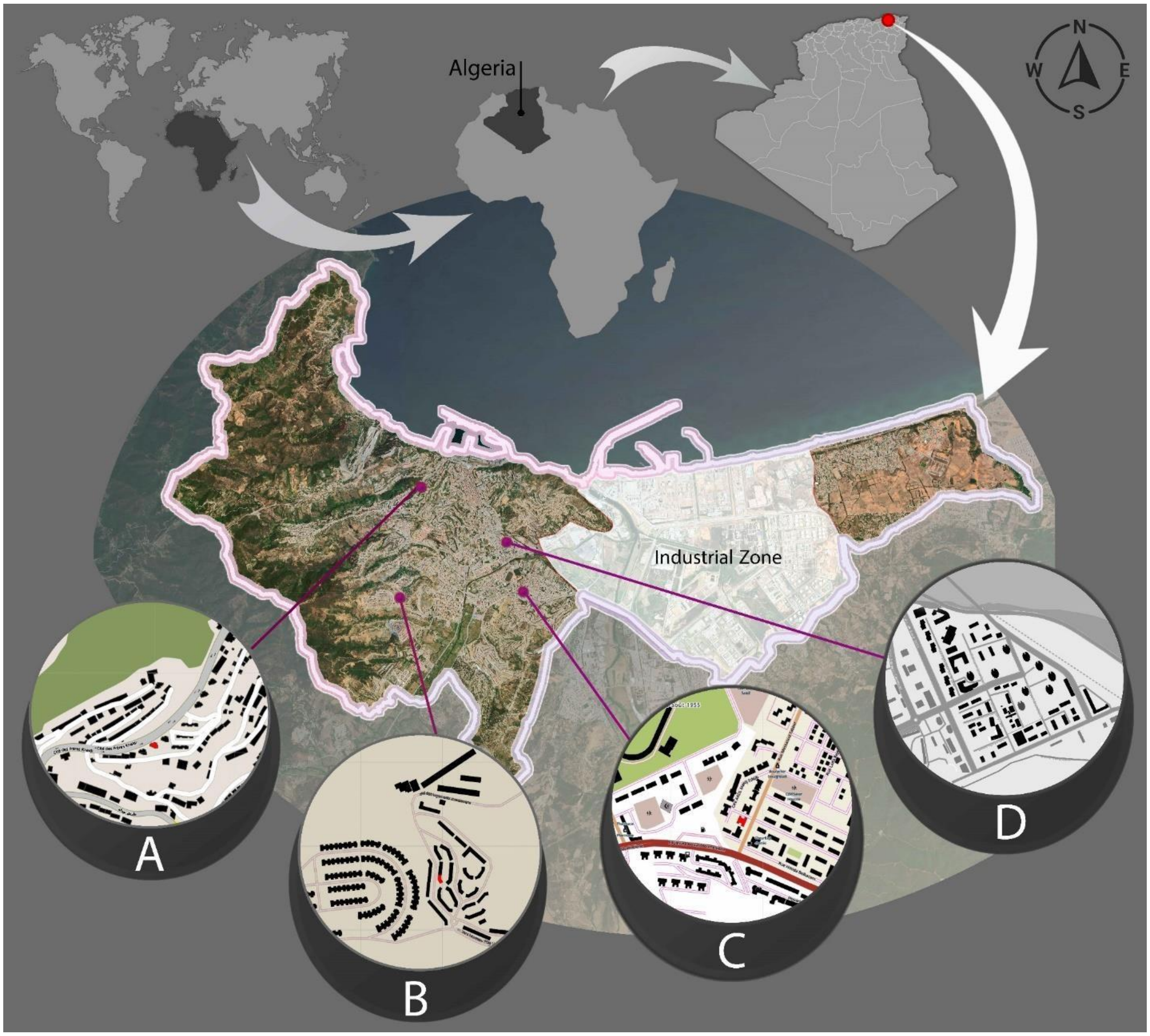


Figure N° 03: Identification of the location of the case studies.
Source: The author, 2023.

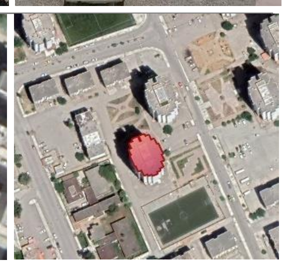
The choice of the study cases was after a typo-morphological investigation of Skikda's collective dwellings based on the following factors:

- The height of the building.
- The degree of complexity of the building's envelope.
- The height of surrounding buildings.
- The spacing between buildings.
- The topography of the site and its surroundings.

The factors were selected based on their relation to the morphology of the building, in order to investigate the influence of its shape on the reception of solar radiation. Additionally, the criteria were chosen also to consider the impact of the surrounding urban morphology on the solar radiations received by the archetype studied and the effect of the site's topography on the solar energy it receives. These factors were chosen for their relevance to the study's objectives.

Table 1 below gives more details about the study cases, it shows the actual photographic shots, the footprints of the cases studied, as well as their heights, surfaces and altitudes.

Table N° 01: More details about the studied cases.
Source: The author, 2023.

Study Cases	Case A	Case B	Case C	Case D
Real photographic shots of the typologies				
Typologies footprint				
Altitude	83 m	84 m	8 m	11 m
Number of floors	10	6	16	15
Surface area	323.7 m²	208.1 m²	573.8 m²	519.4 m²

2-4- Topography overview

Topography is the study and understanding of the natural features of the earth that are used to shape land forms, terrain, as well as architectural structures; the latter may have an effect on the structure and how much energy it uses.

Therefore, before planning to start the building of a new structure or even just doing renovations, it is crucial to examine the topography of the site (Spatialpost website, 2021). This analysis was done utilizing (topographic-map, n.d.) website.

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The topographic map (Figure 4) displays the visualizations created using the websitetopographic-map, s. d., which show the variation in altitudes as well as reliefs throughout the entire town of Skikda, including the locations of the four study samples.

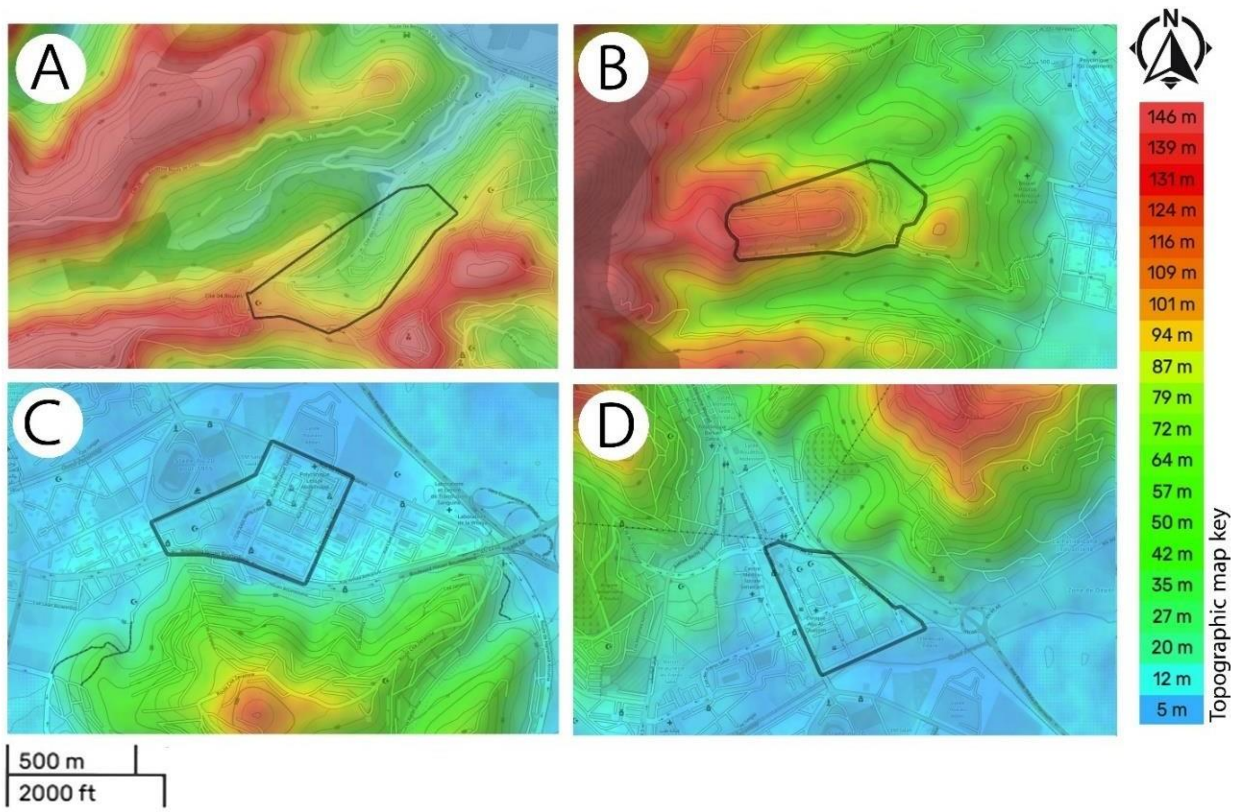

Figure N° 04: Topographical map of the city of Skikda, including locations of study samples.
Source: The author, 2023.

With the exception of the northeastern side, which is lower, the archetypal in case study (A) is situated on a sloping site and is at a lower level compared to the nearby sites.

In contrast, the archetype in case study (B) is situated on a sloping site and is higher than the neighboring sites—that is, except for the western portion, which extends continuously towards the peak of Messiouene mountain.

Within a neighborhood scale, and especially in the case (C), the model appears in a low-altitude area with relief that vary between flat to slightly sloped, surrounded by urban areas with altitudes identical to the archetype investigated, beyond the southern limit, during which the plateaus climb to almost 137 meters.

In case (D), the archetype is additionally located in an area in which the relief fluctuates between flat to slightly sloped, at a low elevation, bounded to the south through urban areas at identical altitudes, but limited by terrain at greater heights ranging from almost forty meters to a height of 150 meters to the east as well as the west.

The Cases (D) along with (C) are placed on a city scale in contiguous locations that are surrounded by greater elevation terrain in every direction with the exception of the east.

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2-5- Solar analysis

The annual solar map's three-dimensional visualizations, created with the help of the Insight Autodesk plugin for the Revit Autodesk tool, yielded several observations, utilizing the three-dimensional model-based approach via solar irradiance computational methods. The generated visuals made clear the several factors that impact incident solar energy collection and solar accessibility to building outsides, allowing solar systems to be installed in the most advantageous locations.

3- Results And Discussion

The solar maps at the neighborhood scale, as shown in (Figure 5) as well as (Figure 6), reveal that the maximal quantity of radiation from the sun fluctuates and varies between one location to the next, considering the fact that the research instances correspond to the same town. The study case (D) had the highest cumulative yearly solar radiation, followed by study case (B), with values of 1753 to 1731 KWh/m2 per year, respectively, whereas study cases (A) in addition to (C) had amounts of 1708 as well as 1567 KWh/m2 per year, respectively.

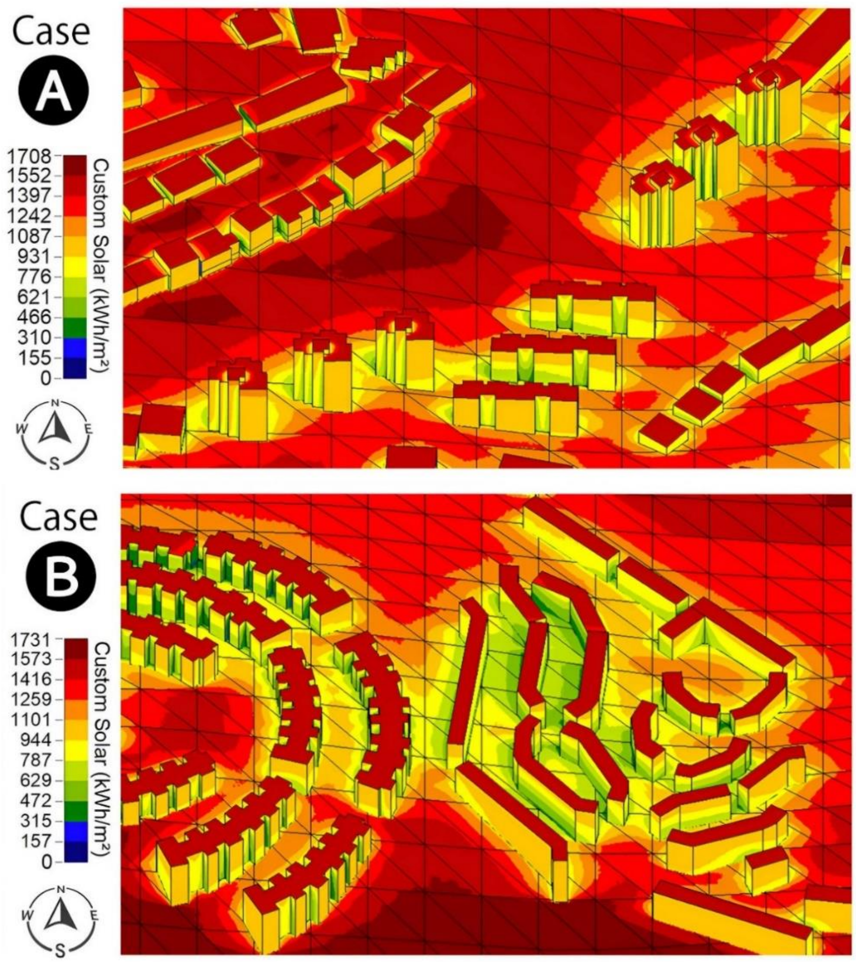

Figure N° 05: 3D annual solar map for the existing situation of the study cases (A and B), at neighborhood scale (south view).
Source: The author, 2023.

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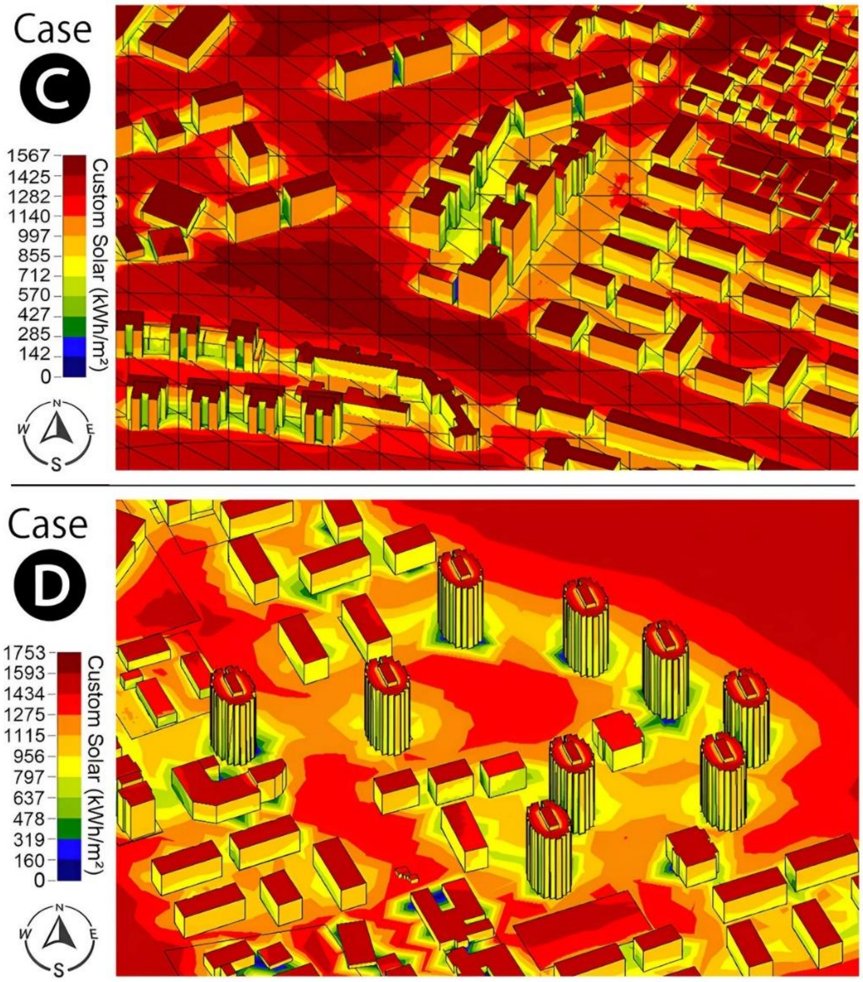

Figure N° 06: 3D annual solar map for the existing situation of the study cases (C and D), at neighborhood scale (south view).
Source: The author, 2023.

As in case (D), in which the greatest accumulative yearly solar radiation was determined, the location is well exposed to solar rays because of its altitude, that roughly corresponds to that of nearby sites, with the sole exception of the northern limitations, which have a negligible impact on the direct reception of sunlight irradiation, knowing that, in the northern hemisphere, where Skikda is located, the sun is in the southern sky all day during autumn and winter; whereas, during the summer and spring months, the sun sets and rises are in a wider angle, reaching some northern angles, but the sun is in the southern sky for most of the day, according to (Sullivan & Meyer, 2014), as shown (Figure 7).

Case study (C), on the other hand, despite having nearly flat relief and an altitude similar to most of the other surrounding sites, its high-altitude southern limits had an effect on the reduction of cumulative solar radiation quantities.

Cases (A) and (B) were located at very high altitudes compared to the study case (C), but received less than the latter due to their rugged terrain, which prevents the site from being easily accessible to solar radiation, which means that the regularity of the relief is more favorable and more influential than altitude, especially in the absence of any significant near natural or urban obstacle in the direction of the sun's path.

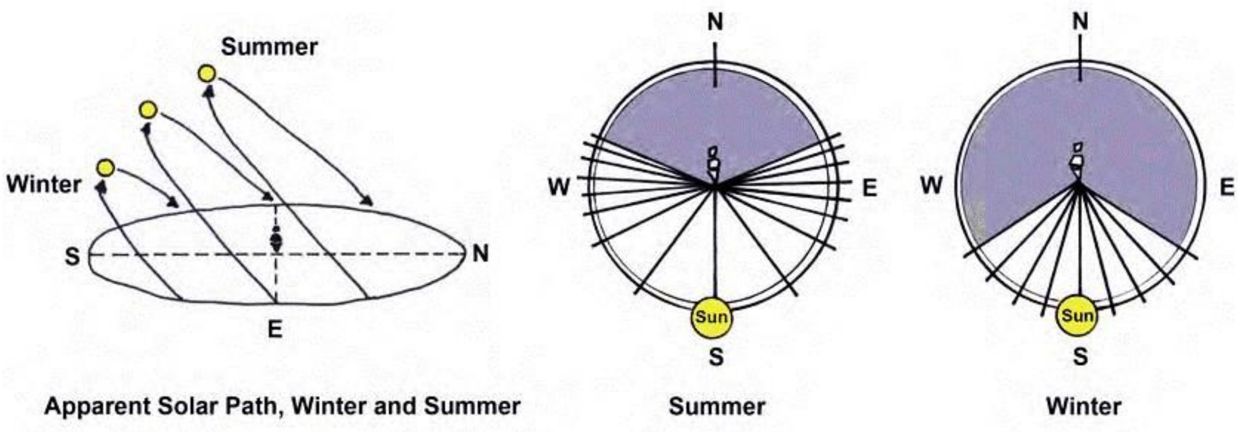

Figure N° 07: Winter and summertime apparent solar paths and rising and setting locations in the hemisphere's northern part.
Source: (Sullivan & Meyer, 2014).

The greatest quantities of solar energy accumulated in the four study cases were on roofs and undeveloped land, far from natural or man-made shading sources, and were estimated at between 1397 and 1753 KWh/m² per year.

It has been also noted that even roofs that are far from being influenced by urban or natural masks almost always receive a lower amount of annual accumulated solar energy than those on empty land and away from obstacles that block the sun's rays. This may be due to the height of the sun, which is reduced during sunrise and sunset, so that its rays can reach lower spaces such as blank terrain, but cannot reach the roofs of buildings, particularly those of great height.

South-facing facades received a maximum amount of energy, estimated at between 931 and 1140 KWh/m² per year for the 4 case studies, and they are consequently the most receiver solar irradiance places after roofs and empty lands.

To get more idea on the effect of the site topography on the cumulative insolation of the building surfaces, a scenario was simulated for Case Study B, changing its mountainous topography, as mentioned earlier, to a flat topography (B2), and the results of the solar simulation are shown in (Figure 8).

The comparison between the real (B) and simulated (B2) scenarios showed that in the case of flat terrain, roofs and vertical surfaces receive more annual accumulated solar energy, with more homogeneity and bigger surfaces, compared with sites with difficult topography, slopes or mountains.

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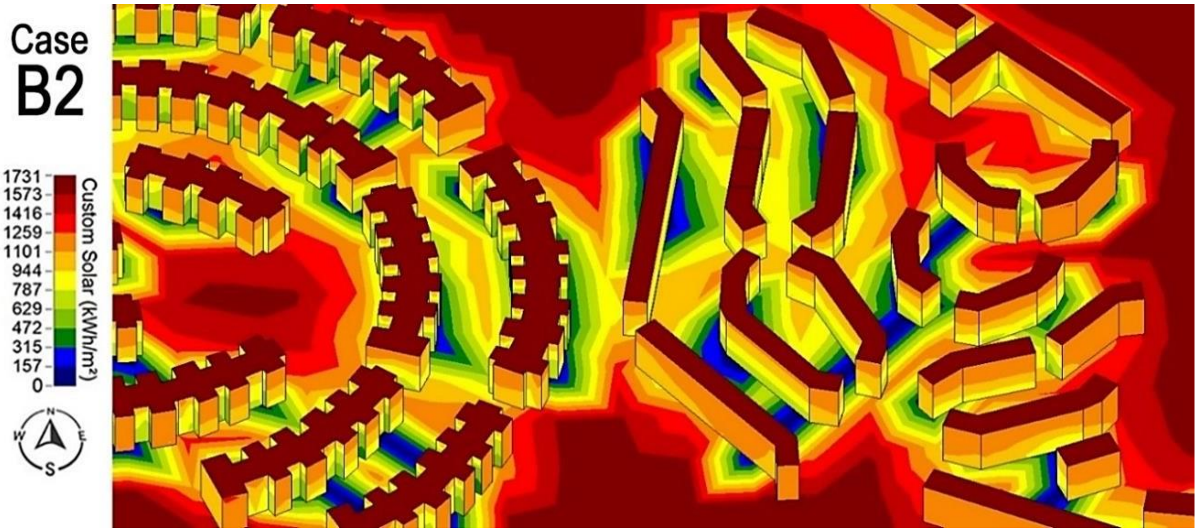

Figure N° 08: 3D annual solar map for a simulated scenario (B2) of the study cases (B), at neighborhood scale (south view).
Source: The author, 2023.

The annual solar visualization of the various orientations for each case study's current situation at local shading scale is visualized in three dimensions in (Figure 9), it provided additional information about the envelope, shape, orientation, degree of complexity, and nearby environment of each archetype at this scale.

The simulations showed that buildings influenced by urban masks are divided horizontally into two parts: the upper part, which is independent of urban mask effects, and the lower part, which is influenced by surrounding factors, where it appears that the taller the building, the more surface area it offers for a significant amount of accumulated incident energy, when a comparison was made, as example, between the case studies (B and C) (the shortest and longest archetypes, successively). Conversely, the amount of accumulated incident energy received may be more homogenous across all building heights in cases where spacing between buildings increases and the height of adjacent buildings is reduced, as observed in the southern view of study case (A) for example.

Both of neighborhood and local shading scales show that in the case of certain lower parts of the south-facing facades, in the existence of urban mask, the reception of solar energy is reduced significantly compared with the upper parts, seeing that the annual accumulations in the lower part of southern façade in the archetype (B), for instance, was less than 315 KWh/m² per year, while the maximal cumulative insolation was between 944 and 1101 KWh/m² per year. And also,it was between 997 and 1140 KWh/m² per year, in the upper south-faced external surface of archetype (C), while the lower part received only about 427 KWh/m² per year.

Likewise, where there are no buildings or where the buildings are far apart, the amount of incident energy accumulated may be more uniform over all the surfaces of the building, as shown in the 3D solar maps, across the 4 case studies.

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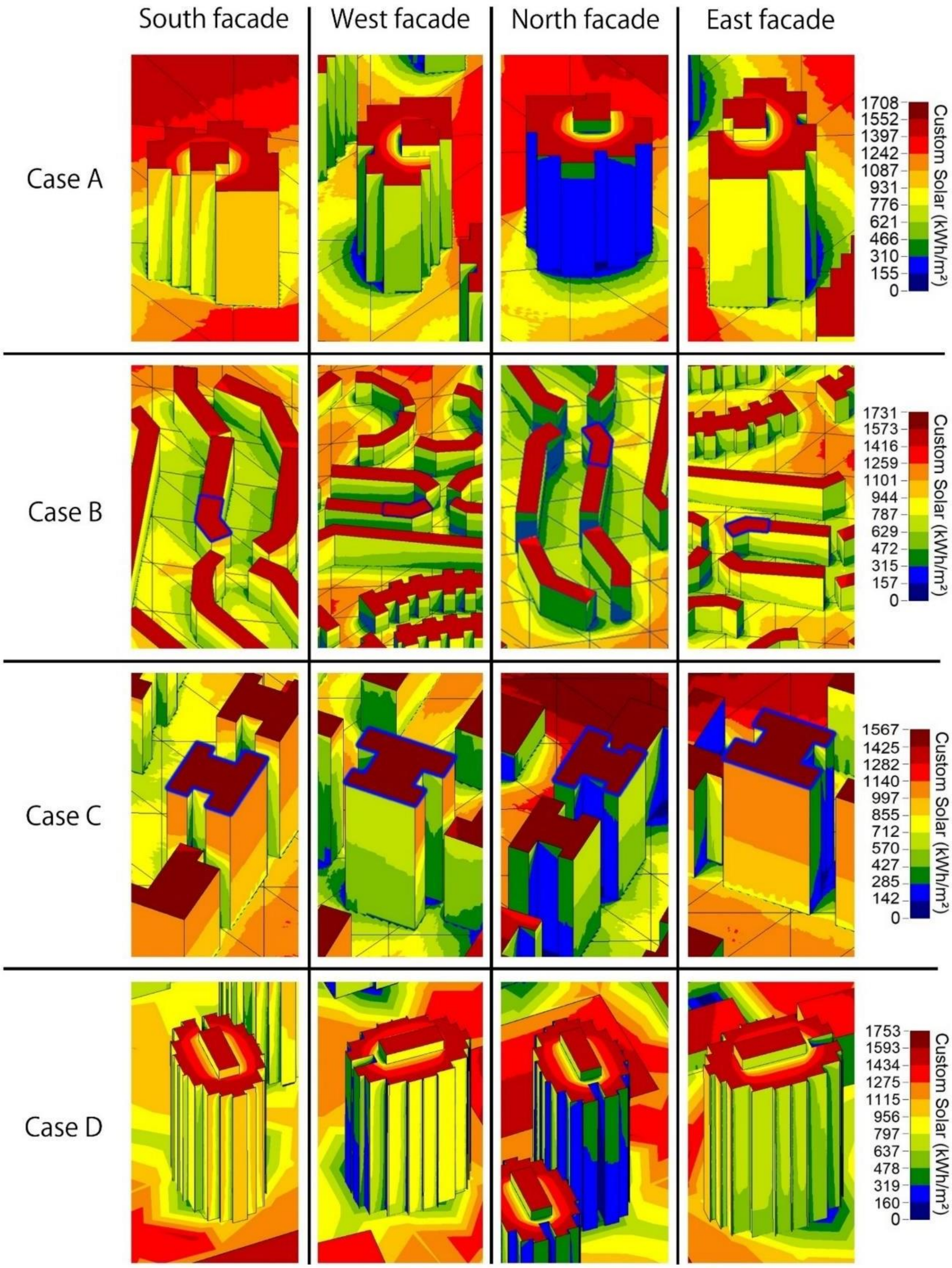

Figure N° 9: 3D annual solar map for the existing situation of each of the study cases, at the local shading scale.
Source: The author, 2023.

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Though with smaller receiving surfaces or little accumulated energy than south-faced ones, both east alongside west facades also received substantial amounts of energy every year.

The least quantity of received solar energy, which ranged from between zero and 319 KWh/m2, was received by the north building exterior facades.

The maximum cumulative insolation on the southern facade is limited to values lower than those on the roofs and vacant areas, and at the same time they were higher than those on the eastern and western facades, which were higher than the cumulative insolation values on the northern facade, This could be interpreted in terms of the exposure time of this facade to the sun, knowing that during the daily solar cycle it rises from the east with a low height, then passes through the south, where it spends a large part of the day at angles close to this direction, and finally its height decreases until it sets in the west. During all this time, it does not pass over the north, which receives only diffuse rays (Sullivan & Meyer, 2014).

According to the archetypes studied, with regard to their orientations, and its influence by its surroundings, the southern facades contain more surfaces that receive the greatest quantities of accumulated energy after the roofs, with the exception of study case (C) which contains fewer surfaces that contain a large quantity of energy, reaching between 997 and 1140 KWh/m2/year, compared with the eastern facade, this is due to the existence of a very close adjacent building, 30 m high.

Based on the analysis of archetypes studied concerning both of their orientations and surrounding environments, the southern facades have more surfaces that accumulate largeramounts of energy, except for the case of study (C), which has fewer surfaces with a high energyaccumulation ranging between 997 to 1140 KWh/m2/year than the eastern facade. This deviationis attributed to the presence of a nearby 30-meter-tall building in the southern side.

In cases (A, B and C), the archetypes receive a large amount of energy from their east facades, more than from their west facades, unlike case study (D) where the west facade receives more annual energy than the east facade, noting that the east facades of the archetypes (A, B and C) are less influenced by the various obstacles that prevent the reception of solar rays, compared with the west facades; conversely, in case (D) where the facade faces an adjacent building of the same height.

The 3D visualizations also show that the complexity of the building envelope has a significant impact on solar energy capture. For example, the archetypal cases (A) and (D) have vertical roof extensions that reduce the amount of solar energy accumulated on neighboring surfaces, whereas examples (B) and (C) have maximum and homogeneous solar energy accumulation over the entire roof surface. The same principle applies to facades: the more complex a facade is, the less annual energy it accumulates and the less evenly it distributes this energy over all the receiving surfaces of the facade.

4- Conclusion

This study is an application of the 3D model-based approach, using ArcMap, Revit and the Insight 360 plugin, to simulate annual cumulative insulation, of 4 case studies in the Algerian city of Skikda, as part of a scientific research project on the energetic and ecological renovation of samples of collective housing buildings in this city.

This investigation took into account the differences between the morphologies of the 4 typologies studied, as well as the urban environment and the topographical context, in order to extract the favorable location of solar systems, in the context of planning the energy renovation of these buildings, and changing their source of supply, towards the use of clean and renewable energy.

The analysis of the 3D solar maps shows that the quantity of solar rays received by each area differs despite the fact that all the areas studied belong to the same city. The highest cumulative amount of insolation was observed in vacant areas that are distant from urban zones and natural obstructions, followed by rooftops, and thirdly, the upper parts of southern-facing facades. This implies that the optimal sites for solar panels can be vacant land at elevated heights compared to the surroundings far from urban zones, through structures like solar energy plants that supply power to buildings undergoing renovation or even the public grid, depending on the scale of the energy transition scheme.

Then, the roof is a suitable location to integrate solar systems, provided there are no vertical extensions obstructing access to solar rays or surrounding buildings of greater heights creating urban or natural masks. Afterwards, the upper parts of the south-facing facades provide vast surfaces for the integration of solar panels, given that they receive significant amounts of annual cumulative solar energy with immense spaces that automatically increase with the height of the building.

The east and west-facing facades, particularly their upper parts, also receive important amounts of cumulative annual solar energy. These last ones can prove useful, particularly when technical difficulties arise during the placement of solar panels on the roof or south-facing facade. However, integrating solar systems on the north-facing facade is entirely unsuitable.
The optimal advantage of energy potential through the integration of this kind of panels is always in favor of simple architectural forms, without numerous extensions or offsets.

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