Energy Planning and Urban Form: Solar Energy as a Design Parameter in Ouargla, a Southern City in Algeria.

[1*] PhD Student **BOULAHIA Meskiana** ,

[1] *Ecole Polytechnique d'Architecture et d'Urbanisme (EPAU), Laboratoire Ville, Urbanisme et Développement Durable (VUDD), Algiers, Algeria.*

***E-mail*[1]**: *m.boulahia@epau-alger.edu.dz*

[2] Associate Professor (MCA, HDR) **DJIAR Kahina Amal**

[2] *Ecole Polytechnique d'Architecture et d'Urbanisme (EPAU), Laboratoire Ville, Urbanisme et Développement Durable (VUDD), Algiers, Algeria.*

***E-mail*[2]**: *k.djiar@epau-alger.edu.dz*

Abstract

Energy planning plays a crucial role in the built environment, particularly when aiming at reaching sustainable cities. Today, most researchers are focusing on exploring the accurate potential of renewable energies. However, few studies have explored the correlation between urban forms and renewable energy inputs.

The objective of this paper is to examine the relationship between the incident solar irradiation, urban form and the potential of photovoltaic energy at a local level. The study focuses on the case of the city of Ouargla, which is located in southern Algeria. In terms of methodology, it adopts three main steps. Firstly, three different types of urban form have been identified according to three main criteria (morphology of streets and lot, buildings use and environment). Secondly, numerical simulations were performed based on 3D models of these urban forms, with the purpose of evaluating the distributions of solar irradiations on the different building roofs, which helps to determine the most appropriate urban form for solar energy use.

The study demonstrates that urban form has an impact on solar energy potential, which means that the latter provides a significant increase in the photovoltaic energy production. Thus, the findings of this research offer urban planners some crucial design parameters to optimize solar energy potential in new or existing urban areas.

Keywords: Urban form, Solar energy, Photovoltaic potential, Energy planning, Ouargla, Algeria.

1. Introduction

According to the latest analysis from the World Meteorological Organization (WMO), cities are responsible for 75 % of global energy consumption and 80 % of greenhouse gas emissions from electricity use, space heating and cooling [1]. Yet, few studies engaged in the exploration of the implications of urban form in energy consumption. The analysis of the overall urban energy performance requires the evaluation of both consumption and production [2] [3] [4]. In terms of urban environmental sustainability, the potential that spawns from the exploitation of renewable energy in the city, particularly solar energy, has to be fully explored.

In the literature, few authors tried to examine the potential of solar energy, which can be encompassed in the unused rooftop of multi-storey housing with the assumption that it might be usefully capitalized through photovoltaic (PV) energy technology deployment [2]. Such investigations require technical analysis through computer tools that can determine the incident solar radiations over various scales and regions, as it helps to predict the suitable locations of PV and their potential energy supply [5]. Indeed, it is largely agreed that the ideal PV potential does not depend only on the exposure of the sunlight, but it also takes into account both global and local temporal factors [4] [6]. At a larger scale, simulations of the solar irradiation appear as an essential and practicable strategy to foster the PV potential. The most used software tools are the ArcGIS Solar Analyst (ArcGIS, 2012), the GRASS GIS r.sun [7] [8]. Its simulation models work on a raster based geographic information layer, allowing consideration of spatially changing attributes in the radiation model, such as inclination, orientation and latitude over large regions [7]. They have been, reportedly, successfully used to determine the solar potential of an entire region based on a digital terrain model.

On the other hand, many authors established advanced methods for the study of solar penetration into small-scale urban textures and neighbourhoods. To name but few of them, Wiginton L. K. adopted Feature Analyst (FA) extraction software extrapolation using roof area-population relationships. Reduction for shading, orientation and conversion to power and other energy outputs has been used in the quantification of roof area for PV deployment [7]. Erde´ly. R discussed the potential direct and diffuse solar radiation by using (SORAM) based on 3D urban solar radiation exposure at any time or over a selected time period [9]. For Miguel M., the connection between the cellular units and the city energy system can be observed using a theoretical model inspired by the structure of the atom [4]. Furthermore, Byrne J. presents a method by matching the computing study of a region to existing statistical data sets and the energy tool that allows to quantify the potential of facades and roofs for active and passive solar heating and photovoltaic electricity production [10]. In another approach, Redweik. P assessed this potential using a digital surface model (DSM) of the urban region with reference to LiDAR data and a solar radiation model based on climatic observations to calculate shadow maps and sky view factor both for roofs and facades [2]. These studies have focused on radiance lighting simulation software to calculate and visualize the solar potential in a similar manner, despite the difference in the approach and the ways of selection and the treatment of the urban areas that each one adopted. However, despite the importance of the approaches that have been adopted by these scholars, none on them has included the components of urban form as a parameter to determine solar potential in renewable energy production.

The aim of this paper is to present some early findings based on the exploration of the interactions between solar energy and urban form. The study focuses on analyzing different types of urban forms and their potential contribution to local produced energy in Ouargla, a southern city of Algeria. It shows the importance of considering solar energy by planners and urban designer when aiming at reaching sustainability.

2. Description of the urban site

Ouargla is located precisely in the south east of Algeria (Fig.1). The urban morphology of Ouargla is the result of a succession of historic, social and economic factors [11]. The city displays a superposition of three urban tissues. First, the Ksar, which is a compact circular urban area built during the 11th century. Then during the French colonial period, an extension of the Ksar was planned and constructed according to a modern approach with large streets and an orthogonal tissue. Finally, the post-colonial urban configuration is characterized by the construction of housing developments, infrastructure and industries dispersed with diverse urban typologies [11] [12] (Fig.2).

Today, as a result of industrial and economic development, the city of Ouargla houses an overall of 633.967 inhabitants, which is the biggest population density in the Algerian Sahara [12]. Accordingly, the energy consumption in the city is relatively high. Nevertheless, Ouargla enjoys a high solar potential, since the annual solar irradiation exceeds 6100Wh/m²[13] (Fig.1). Consequently, it has been selected by Algerian government to house one of the country's most important pilot project, as part of the National Program for the Promotion of Renewable Energy. The Ouargla project contains a photovoltaic station that is intended to produce 30 MW/h [13] for the reduction of energy consumption in the building sector [14].

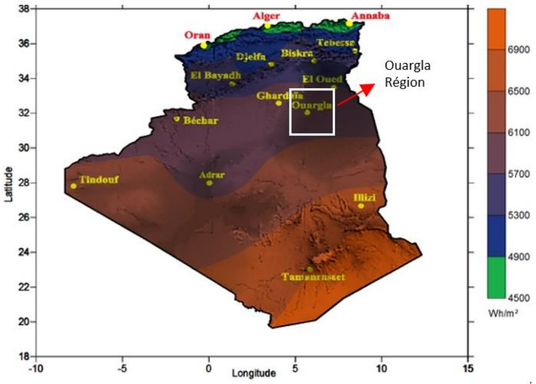


Fig. 1.Annual solar irradiation in Algeria [12]

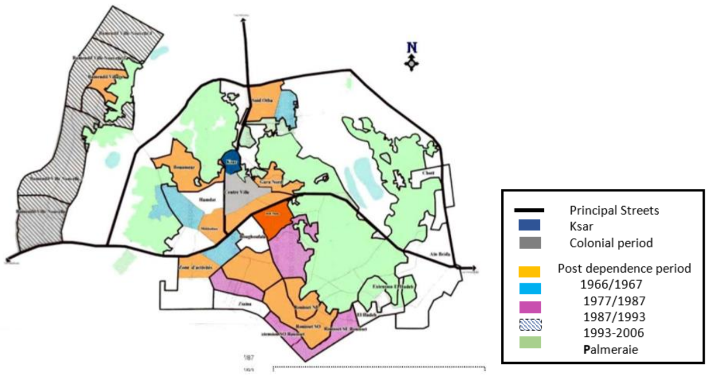


Fig. 2.The urban structure of the City of Ouargla [13];

3. Research method

Urban areas are characterized by the interconnection between several entities, which are interrelated to create a complex system [15] [16]. Therefore, in order to research this complex whole, it is fundamental to adopt a coherent method that can help to analyze the city and also map how and where energy is used and where can it be generated by photovoltaic panels when the latter are installed on buildings' roofs.

On a more operative scale, accurate results can be obtained when collecting data through several vectors and layers through satellite imagery, which all help to define the urban system in the ArcGIS® platform [8] [10]. In the present study, automated rooftop estimation was not possible as there were no existing building footprint files available. Due to time constraints, it was not feasible to analyze every rooftop in the study area, so the decision was made to draw from the analytical methods that have been used by Wiginton et al. [7], focusing on a sample set of urban area to characterize the region. This was accomplished in the steps that are described below (fig.3) :

Fig 3. Research method

3.1 The Morphologic Delimitation Analysis

The urban form analysis has always been a fundamental step to identify the spatial and functional factors of the built environments, which are related to solar potential and energy consumption issues

[16] [17] [18]. In order to grasp the complexity of urban forms, Albert Levy defined it as a composition of elements, which are interrelated together in a set of five inter-related folders: urban tissues, urban design, urban landscape, social form, bioclimatic form [19]. These five folders allow to synthetize the different dimensions of the urban form, since they constitute a basis for the identification of specific criteria. Each criterion is composed of a set of variables that meet a range of requirements that directly affect energy efficiency of the built environnement (fig.4) (fig.5)

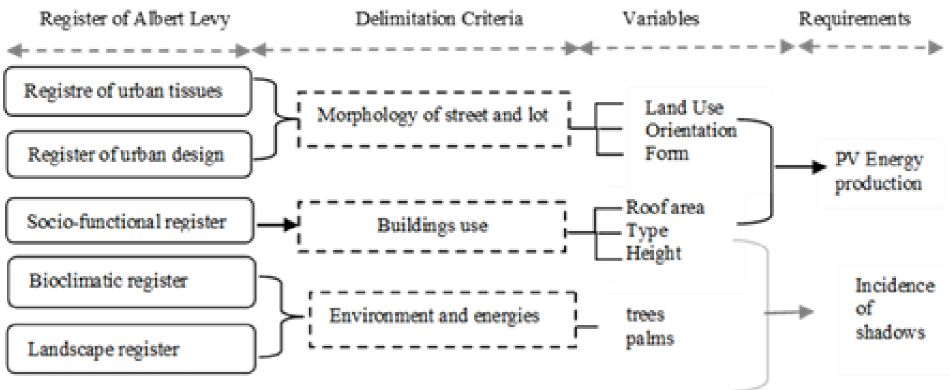


Fig 4. Morphologic delimitation criteria

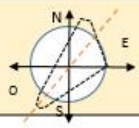
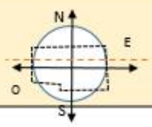
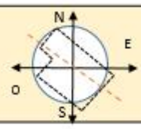
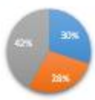
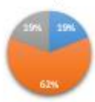
		UF.3 	UF.2 	UF.1 
Morphologic Level	Form	Linear and loops	Orthogonal	Parallel
	Orientation			
	Land Use Coverage: Street, Buildings, Open Areas			
Socio-functional level	Roof Area	7600 m²	12400 m²	3600 m²
	Height	Mid rise R+3	Mid/Low Rise	Mid rise R+3
	Type	Habitations	Habitations	Habitations
Environmental Level	Trees and palm Number /Height	19	55	18

Fig. 5. Morphologic delimitation Analysis

3.2 Solar Access Analysis

Solar access refers to the availability of incident solar irradiation on surfaces. In order to fulfil the computer solar analysis in the urban context, it is important to define a set of input data, which helps to calculate the annual radiance [16] [17]. The workflow has been developed according to several steps (Fig. 6):

- Firstly, the working process started with the gathering of statistical climate data of the site using *Metronom software*;
- Secondly, the 3D digital model of the urban site was created through *Autocad and Sketch Up softwares*;
- Thirdly, both data sets were processed by computer simulation "*City Sim pro*" to determine the solar radiance on the building roofs over a year by specifying an analysis grid of 0.5 x 0.5 m, in the period of 1 Jan- 31 Dec from 7:00 h to 19:00. [19]
- Finally, all generated results have been exported to excel providing numerical irradiations values, which are necessary for the photovoltaic solar electricity potential as showed in the next step.

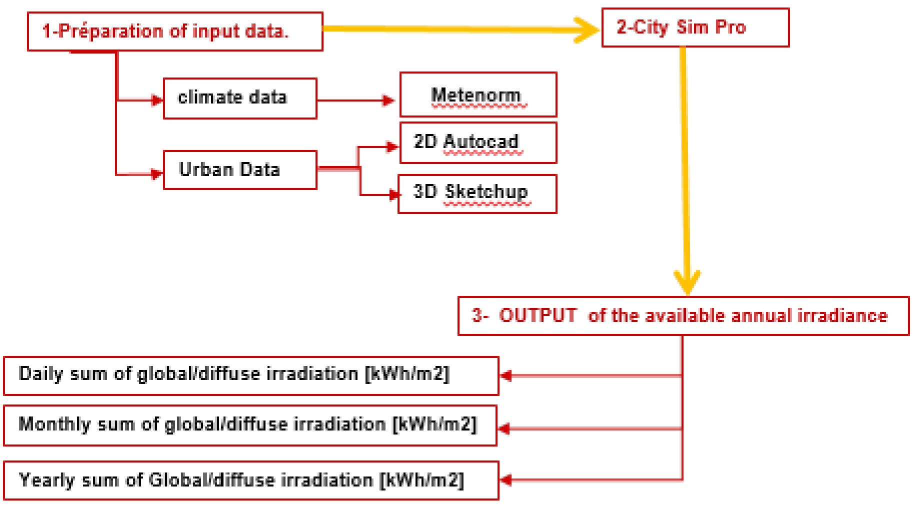


Fig 6. solar radiation assessment workflow

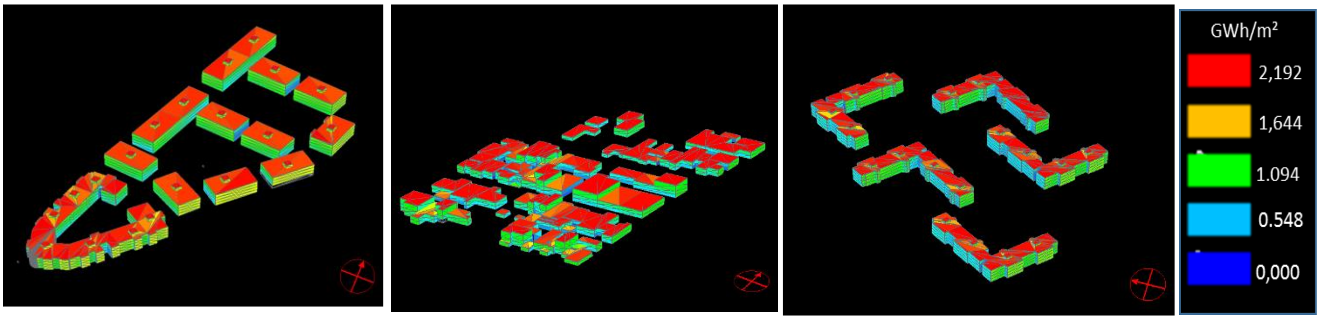


Fig. 7. Simulations by City Sim Pro

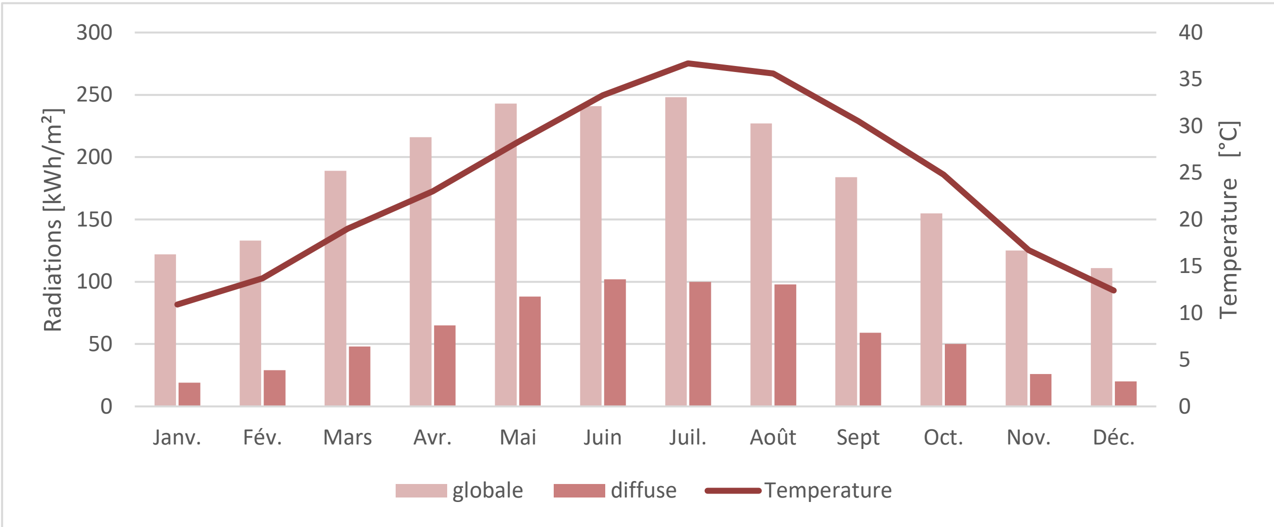


Fig.8. Global horizontal irradiation and air temperature - climate reference.

3.3 Photovoltaic Solar Electricity Potential

In order to quantify the solar potential of a buildings' surface, some economy and technology factors that help in defining the suitable and unsuitable areas for the installation of a PV system have been identified by Compagnon (2004) [4] [16] [21].

In this study, another set of factors have been taking into account – these being minimal irradiance, shading effects, areas and orientation.

Table. 1. Exclusion Factors

Exclusion factors	
Annual Minimal Irradiance	Inferior than 800KWh
Roofs areas	Inferior than 42m²
Incidence of shadows	superior than 30%

Accordingly, in order to estimate the annual energy production by PV systems, the equation that has been used for the calculation is the one that was elaborated by Amado and Poggy [4]:

$$\mathbf{Y = PR \times Me \times (Gr \times A)} \qquad (2)$$

PR: Ratio that considers the energy losses in the balance of system

Me: Module efficiency rating at Standard Test Conditions

Me = 13 %

Gr: Annual global solar radiation (value obtained from CitySim Pro simulation)

A: Suitable roof area for PV installation.

4. Results and discussions

The Solar performances of the three urban forms are discussed in two ways.

1- The percentage of urban form total roofs, which receives an appropriate solar irradiation for PV.
2- The annual electricity that can be produced locally.

Table 2 shows the PV and the energy production potential of the three different urban forms that have been studied.

Table. 2. PV *and Energy Production Potential*

	UF.3	**UF.2**	**UF.1**
Annual Solar Irradiation Kwh/m²	2192	2192	2192
Roof area m²	4327	9952	3600
Suitable roof area for PV (m²)	4276	4223	3454
the annual solar energy output of PV system (Kwh/m²/y)	850516	966068	768925

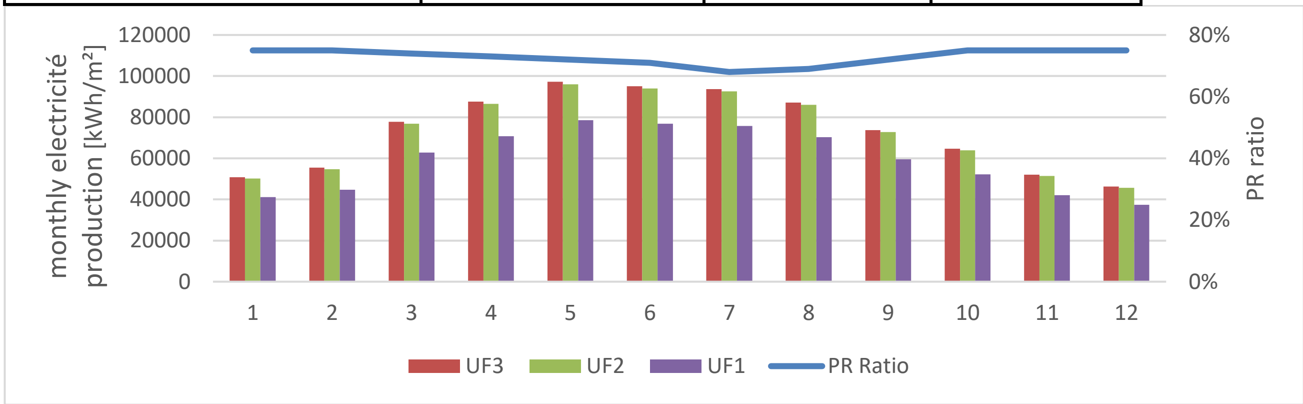


Fig.9. PV electricity production from the three urban forms

Although the solar irradiation values are the same, Uf.2 suitable roofs area have mostly decreased with about 45% of the total roof area, due to exclusion factors as shown in table 1. Yet, UF.3 and UF 1 was less sensitive to exclusion factors except the orientation reduction. Indeed, the incident shadow of palms in UF2 have reduced the roof area to gain a greater amount of solar radiation, and the compact tissue with small roof areas have also reduced its ability to receive PV panels. Furthermore, even that UF.2 roof's area is twice of UF.3 UF.1 roof's area, the suitable area for PV in Uf.3 and UF.1 are higher. This implies that a relative big part of the PV potential is linked to the high vertical density and the low horizontal density. Moreover, the table 2 demonstrates also that the three urban forms have a very impressive sum of annual energy can be produced on a local scale through solar photovoltaic energy, which could contribute to their needs in cooling and heating.

As could be expected, results revealed that the impact of the urban form on the solar potential is significant. In most cases, UF.3 gave the best PV potential and energy production, while UF.2 gave the worst potential which is due to morphologic, land use and environmental parameters. It can also be observed that the variation between UF.3 and UF.1 is relatively small because of the same morphologic parameters, which means that only the orientation makes the difference.

However, Ouargla is an arid zone and the compact morphologies as in UF .2 offers more human comfort than the low densities (UF1 and UF 2). As a result, the electricity consumption is lower in UF2 . than UF.1 and UF .3 .

In conclusion, the urban form that performs the best is UF.2. Even that its potential is lower than UF1 and UF 2, it still remains a relatively high production, that can cover the energy needs while favouring a human comfort ensuring the reduction of electricity consumption.

5. Conclusion

Urban planning constitutes an operative key to increase sustainability and achieve energy efficiency in city developement. The present results highlight the impact of some urban form parameters on PV potential and renewable energy production, which can help to improve urban policy and practice.

The study has examined three main aspects:

- the minimization of energy consumption;
- the maximization of solar energy production;
- the optimisation of energy performance.

The results show that, on the one hand, minimizing energy consumption in the existing urban area could be achieved through the implementation of local production of energy when buildings are provided with PV systems.

On the other hand, designing new urban areas through the visualisation and quantification of solar energy potential in relation to urban form could become an effective way in terms of energy security and urban sustainability provided that some specific parameters such as temperature and the specifications of the site are taking into account.

Overall, this paper confirms that energy consumption at the city scale could be compensated by quantifying the solar energy potential of city blocks. The aim is to improve global energy performance of cities for both the reduction of energy consumption and the integration of solar energy systems through smart grid technologies in urban context.

References

[1] WMO, "The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2010," Geneva, 2011.

[2] Redweik, P., et al. (2013). "Solar energy potential on roofs and facades in an urban landscape." Solar Energy 97: 332-341.

[3] Hofierka, J. and J. Kaňuk (2009). "Assessment of photovoltaic potential in urban areas using open-source solar radiation tools." Renewable Energy 34(10): 2206-2214.

[4] Amado, M. and F. Poggi (2014). "Solar Urban Planning: A Parametric Approach." Energy Procedia 48: 1539-1548.

[5] Eicker, U., et al. (2018). "New 3D model based urban energy simulation for climate protection concepts." Energy and Buildings.

[6] Sarralde, J, D. Quinn and D. Wies, "Urban modelling for resource performance analysis: estimating cities' renewable energy potential," in Proceedings of Building Simulation 2011, Sydney, 2011.

[7] Wiginton, L. K., et al. (2010). "Quantifying rooftop solar photovoltaic potential for regional renewable energy policy." Computers, Environment and Urban Systems 34(4): 345-357.

[8] Theodoridou ,I and et al, "Assessment of retrofitting measures and solar systems' potential in urban areas using Geographical Information Systems: Application to a Mediterranean city.," Renewable ans sustainable energy reviews, vol. 16, pp. 6239-6261, 2012.

[9] Erdélyi, R., et al. (2014). "Three-dimensional SOlar RAdiation Model (SORAM) and its application to 3-D urban planning." Solar Energy 101: 63-73.

[10] Byrne, J., et al. (2015). "A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul." Renewable and Sustainable Energy Reviews 41: 830-844.

[11] Kadi.S.R, (2006). Les Ksour face à la dynamique urbaine : cas du ksar d'Ouargla,mémoire de magistère, université de Biskra

[12] MAZIANI.H, (2001). Espaces publics à Ouargla, essai sur les espaces publics dans une ville saharienne, mémoire de magistère, Ecole Polytechnique d'Architecture et d'Urbanisme « EPAU », Alger

[13] https://www.cder.dz/spip.php?article1441

[14] Himri, Y., et al. (2009). "Review and use of the Algerian renewable energy for sustainable development." Renewable and Sustainable Energy Reviews 13(6): 1584-1591

[15] Amado, M.and F. Poggi, "Towards Solar Urban Planning: A New Step for Better Energy Performance," Energy Procedia, vol. 30, p. 1261–1273, 2012.

[16] Compagnon, R. (2004). "Solar and daylight availability in the urban fabric." Energy and Buildings 36(4): 321-328

[17] Cheng ,V, K. Steemers, M. Montavon and R. Compagnon, "Urban form, density and solar potential," in PLEA2006-Conference on passive
and low energy architecture, Geneva, 2006

[18] Yang, P. P.-J. (2015). "Energy Resilient Urban Form: A Design Perspective." Energy Procedia 75: 2922-2927

[19] Chatzipoulka, C., Compagnon, R., & Nikolopoulou, M. (2016). Urban geometry and solar availability on façades and ground of real urban forms: using London as a case study. Solar Energy. https://doi.org/10.1016/j.solener.2016.09.005

[20] Albert.L «Formes urbaines et significations : revisiter la morphologie urbaine.» Espaces et Societes, 2005:25-48

[21] Zhang, X., et al. (2015). "An Integrative Approach for Solar Energy Potential Estimation Through 3D Modeling of Buildings and Trees." Canadian Journal of Remote Sensing 41(2): 126-134.