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Research Article

The Impact of Neighborhood Urban Geometry on Direct Solar Radiation in a Hot Arid Climate: A Case Study of Biskra City, Algeria

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Abstract:

The human activities are strongly influenced by the level of exposure of outdoor spaces to direct solar radiation, which represents one of the main factors responsible for thermal energy accumulation in urban environments. In this context, the present study aims to develop a deeper understanding of the physical relationship between urban geometry and direct solar radiation in hot arid climates. The research focuses on the Sky View Factor (SVF) as a key indicator of urban density and examines its relationship with Direct Solar Radiation (DSR), considered one of the most influential climatic parameters affecting outdoor thermal conditions.The study was conducted through a three-stage methodology. First, three residential neighborhoods characterized by different urban geometry configurations were selected. Field measurements of environmental and thermal parameters were then carried out at multiple locations during the hottest period of the year. Second, numerical simulation and validation were performed using the software ENVI-met to analyze the DSR parameter. Finally, statistical modeling and regression analysis were applied to investigate the relationship between SVF and DSR.The findings obtained from field measurements, numerical simulations, and statistical analysis revealed a strong positive correlation between SVF and DSR. The variation in sunshine duration among the studied neighborhoods reached up to 10 daylight hours, while the difference in average accumulated direct solar radiation within outdoor spaces reached 531.26 W/m². In addition, the regression analysis demonstrated that an increase of 0.1 in SVF corresponds to an increase of approximately 956.63 W/m² in DSR.

1. Introduction.

Contemporary cities have undergone rapid urban transformations that have significantly altered local climatic conditions[1], particularly in relation to the distribution and absorption of solar radiation. Urban design is no longer confined to functional and aesthetic considerations[2]; it has become increasingly associated with climatic and environmental performanc[3]e. In this context, urban form represents a key factor influencing the amount of direct solar radiation reaching urban surfaces[4], thereby affecting the thermal balance of the urban environment[5]. Understanding how the built environment influences outdoor thermal conditions in hot arid climates[6], and developing strategies to mitigate the negative impacts of urban expansion on human thermal comfort, has become essential for creating thermally responsive urban spaces[7]. Urban areas generally experience higher temperatures than their surrounding rural environments due to the Urban Heat Island (UHI) phenomenon[8]. In this context, Biskra is considered one of the most densely populated cities within Algeria’s hot arid region[9], with a population exceeding 700,000 inhabitants. Owing to its desert climate[10], the city is exposed to extremely high levels of solar radiation, particularly during the summer season[11]. As a result, outdoor human activities during daytime hours become considerably limited[12]. Therefore, the role of urban designers and planners becomes crucial in creating urban environments that are better adapted to the constraints of hot arid climates[13]- [20]. Several previous studies have investigated the interaction between urban form and thermal conditions in Biskra. Boukhabla et al[21]. analyzed the influence of urban form on air temperature (AT) through field measurements conducted at five locations characterized by different urban morphologies.

Their findings confirmed that the Urban Heat Island phenomenon is widely present in the city[22]. Benamour et al[23]. investigated the relationship between urban form and heat storage in buildings using field measurements collected from canyon, dihedral, and open street configurations. Their results demonstrated that the Sky View Factor (SVF) is one of the most influential parameters affecting urban heat storage. In addition, Naidja et al. examined the impact of urban street geometry on shading requirements in contemporary streets of Biskra through numerical simulations of different urban canyon models. The study revealed that shading requirements can be significantly reduced through appropriate street orientation and optimized H/W ratios, while a negative correlation was identified between street length, H/W ratio, and shading requirements. Building upon these previous investigations, the present study aims to examine the relationship between the Sky View Factor (SVF), as a key indicator of urban geometry, and direct solar radiation within the outdoor thermal environment of Biskra[24]. The study seeks to provide a more comprehensive and quantitative understanding of the extent to which variations in SVF influence the amount of direct solar radiation reaching urban spaces. This objective arises from the limited number of studies that quantitatively assess the increase or decrease in direct solar radiation in relation to changes in the Sky View Factor, particularly in hot arid urban environments.

2- Materials and methods

2.1. Study area.

Biskra is located in southeastern Algeria, approximately 430 km from the national capital, Algiers. The city represents an important strategic connection between northern and southern Algeria and has historically been known as the “Gateway to the Desert.” Geographically, Biskra is situated in the northern part of Biskra Province at approximately 5°43′ east longitude and 34°51′ north latitude. The study sample consisted of three residential neighborhoods located within the city center area, selected to represent different urban density and morphology patterns. The investigated neighborhoods were: Al-Istiqlal (N1), Al-Nasr (N2), and Al-Zamala (N3). These neighborhoods were characterized by distinct urban configurations and varying height-to-width (H/W) ratios, resulting in different levels of urban compactness and solar exposure. The selected samples were classified in descending order according to urban density, ranging from the lowest-density urban fabric to highest-density . and different sky view factor (SVF) value .

2.2.The measuring stations.

A total of 30 measurement stations were selected, as shown in the following figure, with 10 stations distributed within each neighborhood to measure the climatic factors. The measurement stations were arranged sequentially along the central area of each neighborhood and in different orientations to ensure accurate and representative average values of the climatic parameters for each urban fabric. Measurements were recorded every two consecutive hours over a 24-hour period. Data collection was conducted during 25–26 July 2021 for the summer season, . Table 1 presents the average technical parameters of each neighborhood[25].

Figure 1. *The measuring stations within urban fabric.*

Table 1.*The Technical Card of Neighbourhood*

average	Al-istquala Neighbourhood N1	Al-Nasr - Neighbourhood N2	Al-Zamala Neighbourhood N3
BD	12/ha	35.51/ha	59.52/ha
floor	1	2	*2+TR*
H	3,6	8.33	*8.33*
W	9	8.16	*3,8*
H/W	0,40	1,02	*2,1*
Dir-tion	Nw/Se	Nw/Se	*N/S*
S,V,F	0,77	0,42	*0,22*
FICHE EYE			

3. Methods.

To investigate the relationship between the urban form SVF variable and the outdoor thermal environment variable, this study adopted a four-step research methodology.First, three neighborhoods with varying urban form characteristics were selected. Second, field thermal measurements were conducted at multiple locations within these neighborhoods during the hottest period of the year, on July 25 and 26, 2021. Air temperature data were collected using a Testo 480 device . In the third step, numerical modeling and simulation were carried out for the three neighborhoods using the ENVI-met software to analyze the remaining outdoor thermal environment parameters. Finally, statistical modeling and regression analysis were performed to determine the interaction between urban density SVF and DSR indicator.

3.2. Simulation settings and validation.

Envi-met was used to conduct numerical modeling and simulations on three neighborhoods in order to investigate the outdoor thermal environment Parameter that had not been previously measured, that is determining the (DSR) in each neighborhood. Envi-met is a software tool that allows users to simulate and analyze the microclimate within an urban environment. It can be used to create virtual models of an urban fabric, including buildings, streets, and other urban features, and to predict outdoor environmental thermal parameters. One of the key advantages of Envi-met is its ability to produce detailed and accurate simulations of the microclimate efficiently [26]. In contrast, traditional measurement tools such as sensors and weather stations can be time-consuming to set up and maintain, and may not provide a comprehensive understanding of the microclimate in a given area. Table 2 shows the simulation settings and parameters inputs in the ENVI-met model.

3.3. The Correlation and Regression Analysis.

Correlation analysis is a statistical method used to analyze the relationship between two continuous variables. It determines if there is a relationship between the variables and measures the strength and direction of that relationship [27]. In this research, correlation analysis was used to examine the impact of neighborhood building density on outdoor thermal environmental parameters. The analysis was applied to the variables of (SVF) and the Direct solar radiation variable (DSR) using the following equation:

$$r = \sum(x-\bar{x})(y-\bar{y}) \Big/ \sqrt{\sum(x-\bar{x})^2}\sqrt{\sum(y-\bar{y})^2}$$

Linear regression is a statistical technique that is used to analyze the relationship between a variable that is being attempted to be predicted or explained (the dependent variable) and one or more variables that are believed to have an effect on it (the independent variables)). This allows us to make predictions about the dependent variable based on the values of the independent variables and to understand the strength and direction of the relationships between the variables. [26] In this study a linear regression analysis was performed on the average values of the independent variable' SVF in each spot in the three neighborhoods, as well as the average daily values of dependent variable DSR, during the daytime period from 6 a.m. to 8 p.m. in all neighborhoods. The regression coefficient (B1) represents the change in the dependent variables (DSR) resulting from a change in the independent variables (SVF).

$$y = \beta_0 + \beta_1 X + e$$

Table 2 : *The simulation settings and parameters inputs in the envi-met model*

Parameters	Al-Istqulal neighborhood (N1)	Al-Nassr neighborhood(N2)	Al-Zamala neighborhood (N3)
3D model			
Date of Simulation	25/07/2021	25/07/2021	26/07/2021
Start time	05:00 AM	05:00 AM	05:00 AM
Total simulation time (hour)	24	24	24

To validate the output of the ENVI-met urban model, a comparison was conducted using field measurements collected on 25–26 July 2021. According to ASHRAE Guideline 14, a simulation model is considered valid when the hourly Mean Bias Error (MBE) values remain within ±10% and the hourly Root Mean Square Error (RMSE) values are below ±30% [27].

4. Results

4.1. Day Length and Solar Exposure.

The simulation results of the Direct Solar Radiation (DSR) parameter revealed significant differences in sunlit duration among the investigated neighborhoods. Al-Istiqlal Neighborhood (N1) recorded the highest exposure to direct sunlight, with approximately 12 hours of sunlit time per day. In contrast, Al-Nasr Neighborhood (N2) experienced nearly 8 hours of solar exposure, while Al-Zamala Neighborhood (N3) showed the lowest exposure, with only about 2 hours of direct sunlight. These variations can be attributed to differences in urban geometry and urban density among the studied neighborhoods, particularly the Sky View Factor (SVF) and the H/W ratio, which strongly influence the penetration and duration of solar radiation within urban open spaces. figure 2 presente the average DSR values for each neighborhood in addition to the corresponding duration of sunlit exposure.

4.2. The Relationship Between SVF and DSR Variables.

The results revealed a strong relationship between the Sky View Factor (SVF) and Direct Solar Radiation (DSR). The findings indicate that reducing the SVF value by approximately 0.56 can decrease the average daily DSR by more than 530 W/m². Table 3 and figure 2 present the average daily DSR values measured at different locations within the three studied neighborhoods, together with their corresponding SVF values. The results demonstrate that Al-Zamala Neighborhood (N3), which recorded the lowest SVF values (0.21–0.23), also exhibited the lowest average DSR levels. In contrast, Al-Istiqlal Neighborhood (N1), characterized by the highest SVF values (0.71–0.81), showed the highest average DSR values, exceeding 725 W/m².These findings confirm that urban spaces with higher sky exposure receive greater amounts of direct solar radiation, whereas compact urban configurations with lower SVF values contribute to reducing solar exposure and improving shading conditions within outdoor spaces.

Table 3: *average SVF , DSR , each neighborhood*

The Variables	*N1*	*N2*	*N3*
Average SVF	*0.78*	*0.43*	*0.22*
Average DSR W/m²	*726.56*	*537*	*195.3*

Table 4 : *The regression results*

Dependant Variables (Y)		DSR
Independantes Variables (X)	SVF	Y = 24.78 + 959.63 ??

4.3. Results of Correlation and Regression Analyses.

Tables 4and 5 present the results of the correlation and regression analyses conducted to examine the relationship between the urban form variable, Sky View Factor (SVF), and the average daily Direct Solar Radiation (DSR). The statistical analysis revealed a strong and statistically significant positive relationship between SVF and DSR, with correlation values of R=0.941R = 0.941R=0.941, R2=0.881R^2 = 0.881R2=0.881, and p<0.05p < 0.05p<0.05. These results indicate that variations in urban geometry strongly influence the amount of direct solar radiation received within urban spaces. The relationship between SVF and accumulated DSR can therefore be considered a very strong positive linear relationship within urban climate studies, demonstrating that urban form directly controls the quantity of solar energy available for surface heating and thermal accumulation. The regression analysis further confirmed this positive association between SVF and DSR. The regression model obtained for the relationship between the two variables:

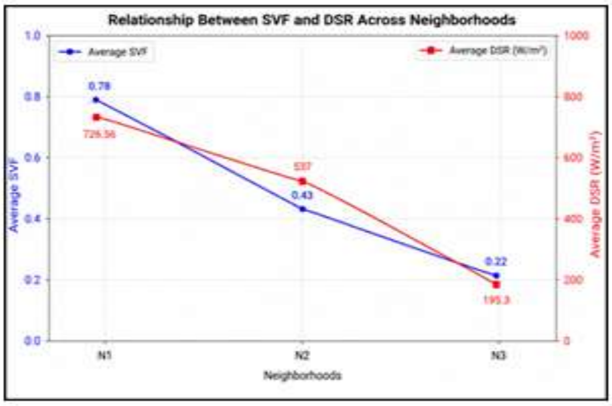

Figure 2. *The Relationship Between SVF and DSR Variables.*

Table 5 : *The correlation results*

Independent Variables	Dependent Variables	R	R2	Constant	B	SIG
SVF	DSR	0,941	0,886	24,78	959,63	0,00

5. Discussion

5.1. Relative Relationship Between SVF and DSR Variables.

The results obtained from Tables 3 and figure 2 demonstrate that the relationship between the Sky View Factor (SVF) and Direct Solar Radiation (DSR) is characterized by a stable positive proportional relationship. The average SVF ratio between Al-Istiqlal Neighborhood (N1) and Al-

Zamala Neighborhood (N3) was estimated at approximately 28%, while the corresponding ratio of average DSR values between the same neighborhoods reached approximately 27%. These findings indicate that the physical relationship between SVF and DSR remains relatively constant across the studied urban configurations, suggesting that urban geometry is the principal controlling factor governing solar radiation exposure within the urban environment. The results confirm the existence of a stable and systematic physical coupling between urban form and direct solar radiation.

5.2. Statistical Relationships and Design Implications.

The simulation and statistical analyses demonstrated that lower SVF values are associated with lower exposure to direct solar radiation. According to the regression analysis, a decrease of 0.01 in SVF can reduce DSR by approximately 95.96 W/m². The Sky View Factor (SVF) can therefore be considered one of the most important urban form indicators for controlling the amount of direct solar radiation reaching building surfaces, streets, and open urban spaces. In this context, SVF may be interpreted as a "window to the sky": the larger the sky exposure, the greater the amount of incoming solar radiation. The results further indicate that SVF has a substantial influence on the outdoor thermal environment in hot arid climates. Consequently, urban design strategies for streets and neighborhoods in such climates should prioritize reducing SVF values in order to improve shading conditions and enhance outdoor thermal comfort. The findings of this study provide practical implications for urban designers and planners by quantitatively demonstrating the relationship between urban geometry and outdoor thermal environmental parameters, thereby offering valuable guidance for the development of thermally responsive urban environments in hot arid regions.

6. Conclusions.

The accumulated energy from solar radiation is the primary determinant of the daily heat load in the urban environment.determines the heating level of surfaces, influences thermal comfort, and contributes to the Urban Heat Island effect. The research was conducted using field measurements with Testo 480 tools, modeling and simulation with ENVI-met software, and statistical analysis including correlation and regression. This study aims to achieve a more precise and in-depth understanding. the relationship between one urban form variable, sky view factor SFV, and one of the most important o outdoor thermal environmental parameters, direct solar radiation DSR, , in three neighborhoods in Biskra., Algeria, a hot and dry region. The results demonstrated that a dense urban environment is important for a comfortable built environment in hot and dry cities. Additionally, the data showed that while a decrease in the SVF by 0.1 reduces DSR 959.63 W/M2, and the number of hours that open urban spaces are exposed to direct solar radiation. These findings contribute to the literature and can serve as a guide for urban planners designing comfortable cities in hot and dry climate. Controlling urban form represents an effective strategy for reducing thermal stress and improving the environmental performance of cities, particularly in hot and arid climates.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:**The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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