The using of generative algorithm aided design tool (Rhinoceros/Grasshopper/Ladybug) to control solar access in urban street of hot-arid climate (Ouargla)

Naidja Amina[1,*], Bourbia Fatiha[2]
(1), (2) University of Constantine 3, Department of Architecture, ABE Laboratory (Algeria)
E-mail : amna87_naid@yahoo.fr

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Summary:
Solar control is a major factor for thermal conditions in built forms. The intention of this study is to develop a parametric approach of generative algorithm aided design (Rhinoceros-Grasshopper-Ladybug) that examines and evaluates the effect of street geometry on solar radiation on ground surface of urban street. In order to achieve this aim a model of contemporary urban street will be analyzed. The investigation was conducted during summer period (21 Juin-21st September) in city of Ouargla (Algeria) characterized by hot dry climate. The results reveal that a number of useful relationships can be developed between the geometrical parameters of urban street dimensions, and solar radiation on ground surfaces of urban street.

Keywords: Generative Algorithm, Geometrical Parameters, Urban street, Solar Control, Solar Radiation

I- Introduction :

Outdoor thermal comfort in an urban environmental is a complex issue with multiple layers of concern. Outdoor thermal comfort is a composite function of atmospheric conditions, and physical, physiological, psychological, and behavioral factors [1]. Solar access is one of the most important elements affecting human thermal comfort. Geometrical parameters of the built environment, position and orientation of buildings influence solar access in urban spaces and have an effect on urban planning and design of urban areas. Requirements for solar access will vary according to climate. In hot climates in summer, thermal comfort in urban spaces is improved if solar access is avoided.

In order to control solar access in urban spaces, the urban street canyon has been adopted as the basic structural unit of analysis in much urban climate research, both measurement and modelling based [2,3,4,5,6,7].Some studies mainly focused on the using of generative algorithm aided design to control solar access in urban spaces such as [8,9,10].Design Algorithms gather various types of information and in order to fit the needs of designers, produce 'Geometry' as output. To be able to accomplish this task, the marriage between algorithms (Computation) and geometry was necessary. This marriage happened in 'Computational Geometry'. Computational Geometry is a branch of computer science, which uses algorithms to solve problems with geometrical aspects and outputs. For example, triangulation of a polygon needs an algorithm to process data and the product is geometry. 'Generative Algorithms' (basically design algorithms) utilize computational geometry to produce design products [11].The main aim of this study is to develop a parametric investigation, which is focused on the relationship between: Geometrical parameters of urban street (H/W ratio, length); orientation, and solar radiation. On this basis a workflow that combines generative algorithm aided design tool (Rhinoceros/ Grasshopper/ Ladybug) and a statistic tool SPSS.20 has been developed. (See figure 1)

II– Methods and Materials:

Digital tools have a wide influence on various aspects of urban design and planning. It has become noticeable that computer aided design and management software have allowed for a more profound, and multi criteria approach in this field [12].The solar radiation results presented in this paper have been obtained using generative aided design algorithm of three software applications: Rhinoceros, Grasshopper, and Ladybug. First step in the algorithm requires the provision of geometry in the Rhinoceros software package, consisting of closed polylines, representing blocks (See figure2). The geometry can either be generated in the actual program itself, or it can be imported from various other CAD supporting programs, such as AutoCAD, ArchiCAD, CityEngine, 3ds Max etc. After the modelling of built environment the geometry is referenced inside the Grasshopper plug-in, in order to be a valid parameter in the urban planning process (See Figure3). The grasshopper plug-in operates as a visual programming language, allowing a generative automated approach to architecture and urban planning. It utilizes visual nods instead of written computer language code, thus simplifying the code generation and connection of parameters.

Afterward the average values of solar radiation on ground surfaces have been assessed by using ladybug radiation analysis (component in ladybug software). Ladybug software enables the user to explore and examine direct relationship between elements of 3D model and environmental data through numerical and graphical data [10].

Ladybug solar radiation analysis allows the user to select and input (North, Geometry, Context, Orientation study, Ladybug_selectSky9*-Mtx (selectSkyMtx) as shown in the figure (4). Also it allows the calculation of the radiation falling on input geometry using a sky matrix from the selectSkyMxt component .This type of radiation study is useful for building surfaces such as windows, where you might be interested in solar heat gain, or solar panels, where you might be interested in the energy that can be collected. This component is also good for surfaces representing outdoor spaces (such as parks or seating areas) where radiation could affect thermal comfort or vegetation growth. No reflection of sunlight is included in the radiation analysis with this component and it should therefore be used neither for interior daylight studies no for complex geometries nor for surfaces with high reflectivity. For these situations where the reflection of light is important, the Honeybee daylight components should be used instead of this one. Weather data were obtained from Meteonorm 7. In order to determine the correlation between the parameters, the treatment of the results has been done using SPSS.20.

III- Ouargla city and climate

The investigation was conducted during summer period (21stJuin-21stSeptember), in city of Ouargla (Algeria) located at (31°64′ N, 6° 14′ E). The climate of Ouargla is hot and dry, with an average temperature of 40 °C occurring in July. The air temperatures recorded reach a maximum of 40 °C and 43 °C, with occasional peaks of 52 ° C that occurs at about 14:00.The humidity is relatively low; it varies between 20% and 23% during some periods of drought and it can reach the minimum rates between 2 and 6%. The intensities of solar radiation on the region are very high; the horizontal solar radiation is important, it can reach 8039 W/m² between June and July. The wind is dry and hot steering north - east with an average speed between 2 and 3 m / s. All these elements contribute to the climate harshness of this city.

Three different architectural styles can be recognizing in Ouargla, vernacular architecture, colonial, and modern contemporary architecture. They are different in style, applied techniques and materials.

III-1- Site selection

In Algeria, unlike vernacular urban space heritage, which illustrates a real concern and consciousness in designing with climate, the contemporary urban space consists of recent urban rules application is not in accordance with the climatic context, and shading or sunlight needs for a given region. Under these circumstances, the shortcoming of the existing urban rules must be highlighted, also evaluated in comparison with solar rights. In order to achieve this aim, a contemporary urban space must be analysed. Compared to more inclusive descriptions of urban spaces, the urban street model makes it possible to simplify geometric relationships by reducing the description of the space to an essentially two-dimensional cross-section, defined as the ratio between the average height of adjacent vertical elements (such as building facades) and the average width of the space (The wall-to wall distance across the street) [13]. Therefore an urban street of (H/W=1, and length =70m) represents a model of recent urban rules application, will be investigated. The height, H, and the length L were varied relative to the fixed street width, W, to create building height/street width ratios (R=H/W) or urban canyon ratios of R=0.5; 1; 1.5; 2; 3; and 4. These ratios cover a wide range of traditional and contemporary building in North Africa [6]. For assessing the effect of the long axis of the urban street, the length (L) of street is taken as following

L/2; L; and 3L/2; 2. Correspondingly, for evaluating the precise urban street solar radiation values, street orientations are taken in steps of 450 from the north (S1) to the south (S4). (See figure 5).

IV- Results and discussion :

Under low latitude conditions, minimization of solar irradiance within the urban environment may often be an important criterion in urban design [14] .The height of buildings has a great impact on outdoor comfort condition because the buildings shade can mitigate temperatures of urban areas [15].This study aims to develop a parametric approach of generative algorithm aided design (Rhinoceros-Grasshopper-Ladybug) that examines and evaluates the effect of street geometry on solar radiation on ground surface of urban street. The algorithm is applicable to any geographical location and climate area, provided with the appropriate weather file. The results of this study for latitude 31^0 are presented in this paper as a test case.

IV-1- The effect of length on the average value of solar radiation on ground surface:

From the output (Table I), the correlation coefficient value was -0,032 between length parameter of street, and the Mean of the average values of solar radiation on ground surfaces variable, Recognizes that there is not a significant correlation between them. Because according to Deborah J. Rumsey when the correlation coefficient is around 0 means that there is none relationship [16].[1] Where this result is confirmed by the P-value which is considered as a tool of evaluation when is ranged under 0.05 (the significance level adopted in the study).i.e.; means that there is a significant correlation between the parameters. In this case the P- value (sig) is

0.882 which is more than 0.05; therefore the length parameter has not a significant effect on the mean of the average values of solar radiation on ground surface.

VI-2- The effect of the H/W ratio parameter on the average value of solar radiation on ground surfaces:

Another importunity of this study was to examine the correlation between H/W ratio parameter, and the mean of the average values of solar radiation on ground surfaces. According, to Bourbia, and Awbi (2003), solar access to streets can always be decreased by increasing H/W ratio parameter to larger values [6]. Bakarman A. M., and Chang J.D (2015) reported that the Ta inside a deep canyon (H/W= 2.2) is lower than in a shallow canyon (H/W=0.42) by an average variation in the maximum temperature of 4.3°C [7]. Naidja and al (2017) confirmed that increasing H/W ratio leads to decrease shading requirement on ground surface, and over building facades in hot arid climate [17].

The results obtained by SPSS.20, show the correlations coefficients between H/W ratio parameter of urban street, and the mean of the average values of solar radiation on ground surface was -0,980** as represented in table I. Hence, there was a strong negative correlation between them. This means that increasing H/W ratio leads to decrease solar radiation on ground surface, where the urban street model of recent urban rules of length (L), height to width ratio (H/W=1), and NS direction, receives higher solar radiation of 281.95 KWh/m2 in comparison with urban street of length (L), height to width (H/W=4) which receives 95.84 KWh/m2 (See figure6-7). Therefore recent urban rules are not adapted to hot arid climate. However the previous table (I) shows that the significance level P-value (sig) was 0.000

[1] The Pearson Correlation degrees as following:
Exactly –1. A perfect downhill (negative) linear relationship
–0.70. A strong negative linear relationship
–0.50. A moderate negative relationship
–0.30. A weak negative linear relationship
0. No linear relationship
+0.30. A weak positive linear relationship
+ 0.50. A moderate positive relationship
+ 0.70. A strong positive linear relationship
Exactly +1. A perfect uphill positive linear relationship

indicating that there was a significant correlation between the above mentioned variables (H/W ratio of urban street, and the average value of solar radiation on ground surface).

VI-3- The coefficient of determination between H/W ratio and the mean of the average values of solar radiation on ground surface:

In order to determine accurately the effect of H/W ratio parameter of urban street on the mean of the average values of solar radiation on ground surfaces, the coefficient of determination between them R(Chi- Square) must be calculated. . Tables (II; III; IV) obtained after analysis of the results by SPSS.20, show that R (Chi-square) is 0.961. This value designates that 96.1% of the change in the mean of the average value of solar radiation on ground surface is due to the H/W ratio parameter. While the 03.9% (100% -96.1%) remains as an unexplained change, which may be attributed to the presence of other variables that we will examine in other studies. Since the P-value (sig) is equal to 0.000, which is less than 0.05(the level of significance adopted in our study), consequently, the Null Hypothesis (H0) is refuted and the Alternative Hypothesis (HA) is confirmed. This result is based on a relationship between H/W ratio parameter of urban street, and the mean of the average values of solar radiation on ground surface.

The last tables (II; III; IV) also show the linear regression between H/W ratio parameter of urban street, and the mean of the average values of solar radiation on ground surface. The latter is represented by the following equation (1):

$$Y = -55.730\ X + 414.744 \quad (1)$$

Knowing that:

-Y: Represents the dependent variable for the mean of the average values of solar radiation on ground surface.

- X: represents the H/W ratio parameter of urban street.

VI-4- The effect of orientation on the average values of solar radiation on ground surfaces

Street canyon geometry’s parameters (height-to-width ratio (H/W)) and the street orientation are the most relevant urban parameters responsible for the microclimatic changes in a street canyon [18]-[19]. Street orientation hardly influences the amount of solar radiation of the canyon; it causes differences in the distribution of the total radiation over the different street surfaces. Street orientation significantly influences the diurnal and seasonal pattern of irradiation of the street surfaces and it is more affective on the vertical surfaces of the street [20]-[21]. In order to discover the effect of H/W ratio on the average values of solar radiation for each orientation, the coefficient of determination between them, must be calculated for each orientation (in this study θ=450 clock wise from the north).(See table V)

As displayed in table (V), the coefficient of determination (Chi-square) of the (NS;NE-SW,EW,SE-NW) directions were respectively as following: 0,939; 0.957; 0.987; 0.939 .These values designate that 93,9% ; 95.7%; 98,7%; 93,9% Represent the effect of H/W ratio on the change of the average values of solar radiation on ground surfaces correspondingly to their orientations (NS;NE-SW,EW,SE-NW). Since the level of significance P-value (sig) of H/W ratio for all urban street configurations is equal to (, 000) which is less than 0.05 (the level of significance adopted in our study), consequently, the Null Hypothesis (H0) is refuted and the Alternative Hypothesis (HA) is confirmed.

The previous table (V) also shows the linear regressions between H/W ratio, and the average values of solar radiation on ground surface of each direction.

The aforementioned linear regressions are represented by the following equations (2, 3, 4, and 5) respectively to their orientations:

$$Y1\ (\text{Solar radiation NS}) = -52{,}097x1+387{,}367 \quad (2)$$

$$Y2\ (\text{Solar radiation NE-SW}) = -57{,}668x2 +419{,}515 \quad (3)$$

$$Y3\ (\text{Solar radiation EW}) = -58{,}625x3+448{,}607 \quad (4)$$

$$Y4\ (\text{Solar radiation SE-NW}) = -54{,}530\ x4+ 403{,}487 \quad (5)$$

Knowing that:

-Y: Represents the dependent variable for the mean of the average values of solar radiation on ground surface.

- X: represents the H/W ratio parameter of urban street.

- (52,097; 57,668; 58,625; 54,530) represent rectal coefficient

- (387,367; 419,515; 448,607; 403,487) the constants; they indicate the effect of the other parameters

These equations (2, 3, 4, 5), proof that all urban street configurations which are mainly oriented on the EW direction, receive more solar radiation than the other orientations. Therefore, the EW direction must be avoided in this kind of climate. Though, the NS direction receives less solar radiation in comparison with all other orientation. Also, the above equations show that the deviation of the street from NS orientation to east orientation leads to increase the received average value of solar radiation, whilst the deviation of the street from EW orientation to north orientation leads to decrease the received average value of solar radiation. This means that for ground surfaces NS direction is the best orientation, diagonal street direction (NE-SW/SE-NW) may often be a second best orientation. Figures (8, 9, 10,11) show that there is a strong negative correlation between H/W ratio and the average values of solar radiation on ground surface of urban street for each orientation (NS; NE-SW; EW; SE-NW).

IV- Conclusion:

In this study a workflow that combines generative algorithm aided design tool (Rhinoceros/ Grasshopper/ Ladybug) and a statistic tool SPSS.20 has been developed to assess the average values of solar radiation within the urban street, also to determine the correlations between the geometrical parameters of urban street, orientation, and solar radiation. The results of this study indicate that the effect of length on the average values of solar radiation on ground surface is trivial because the correlation coefficient is around zero; also the P-value is more than 0, 05. However, we note that there is a strong negative correlation between H/W ratio and the average value of solar radiation on ground surface of urban street. The findings of this study have also shown that all urban street configurations which are mainly oriented on the EW direction receive more solar radiation than the other orientations. Though, the NS direction receives less solar radiation in comparison with all other orientations.

The developed workflow can be used for any urban environment. User has to have appropriate weather data with appropriate location information. The results demonstrate how digital technologies can be efficiently used for heat mitigation in any urban fabric.

Haut du formulaireBas du formulaire

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- Appendices:

Figure1.-Workflow schema showing work process

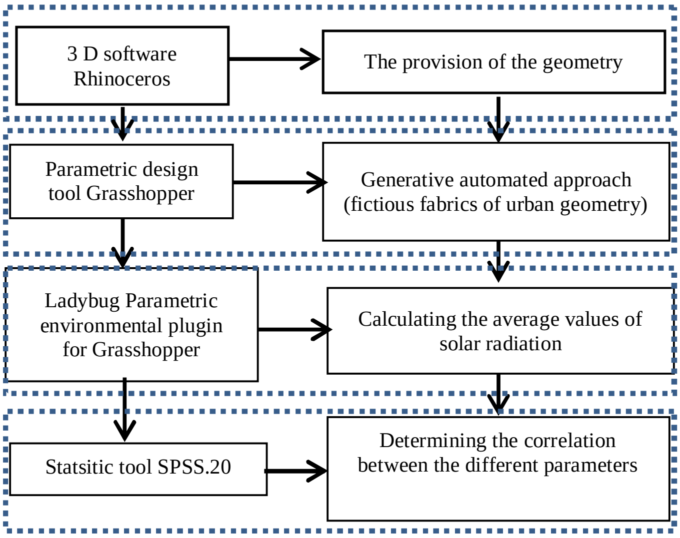


Figure 2. The provision of geometry in the Rhinoceros software.

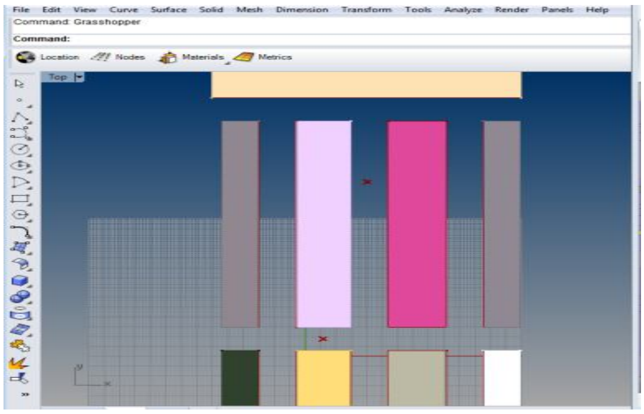


Figure 3.The algorithm of urban street design in grasshopper

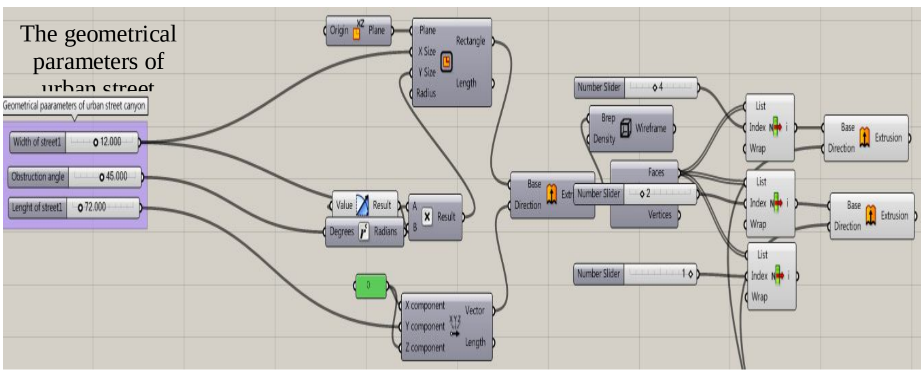


Figure 4. Ladybug solar radiation analysis

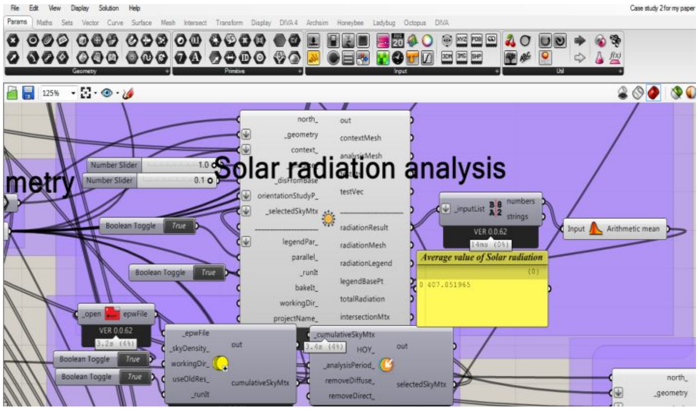


Figure 5. Geometrical profil of the study canyon

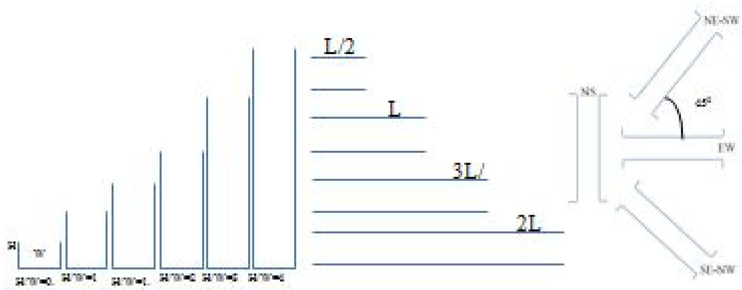


Table I. - The binary correlation coefficient of lenght, H/W ratio, and solar radiation on ground surface

Correlations

		Mean of the average values of solar radiation on ground surfaces
Length of street	Pearson Correlation	-.032
	Sig. (2-tailed)	.882
	N	24
W/H Ratio of street	Pearson Correlation	-,980**
	Sig. (2-tailed)	.000
	N	24

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 6. Solar radiation within urban street of H/W=1

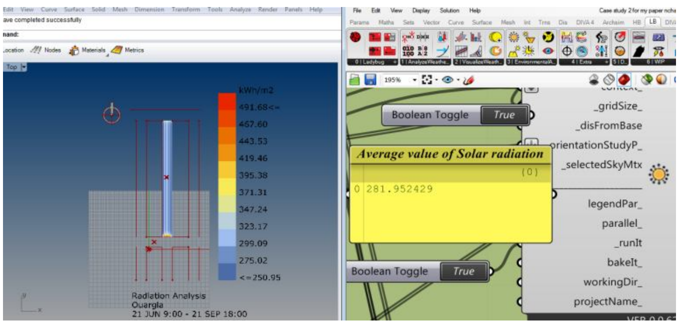


Figure 7. Solar radiation within urban street of H/W=4

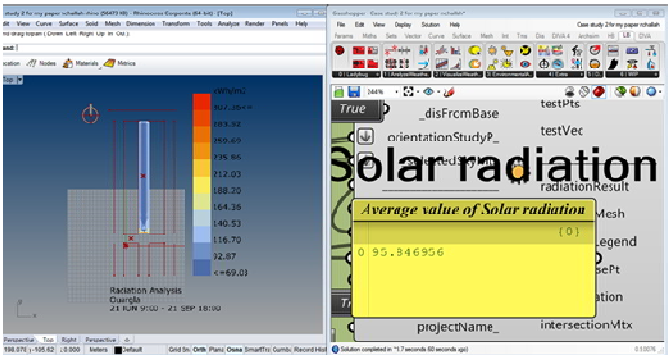


Table II, III, IV. Linear regression test between the H/W ratio of street and the mean of the average values of solar radiation on ground Surface

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.980	.961	.959	20.081

The independent variable is W/H Ratio of street.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	217406.352	1	217406.352	539.122	.000
Residual	8871.718	22	403.260		
Total	226278.070	23			

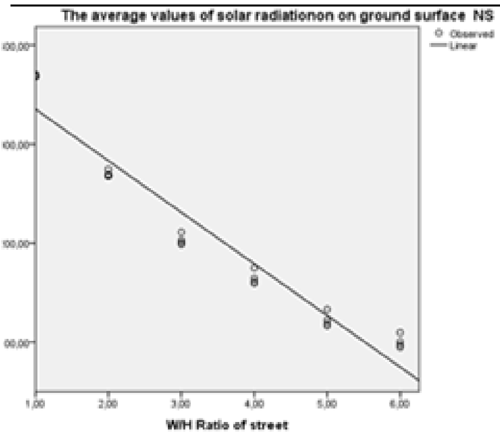
The independent variable is W/H Ratio of street.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
W/H Ratio of street	-55.730	2.400	-.980	-23.219	**.000**
(Constant)	414.744	9.347		44.370	.000

Table V.-: The coefficient of determination between H/W ratio, and the average values of solar radiation of each orientation

	The average values of solar radiation on ground surfaces			
	Solar radiation NS	Solar radiation NE-SW	Solar radiation EW	Solar radiation SE-NW
R (Correlation) (H/W Ratio)	*0,939*	0,959	0,987	0,939
R(Chi-square) (H/W Ratio)	387,367	419,515	448,607	403,487
Constant (H/W Ratio)	867	2,979	3,353	3,013
H/W Ratio	-52,097	-57,668	-58,625	-54,530
Sig. (H/W)	000	000	000	000



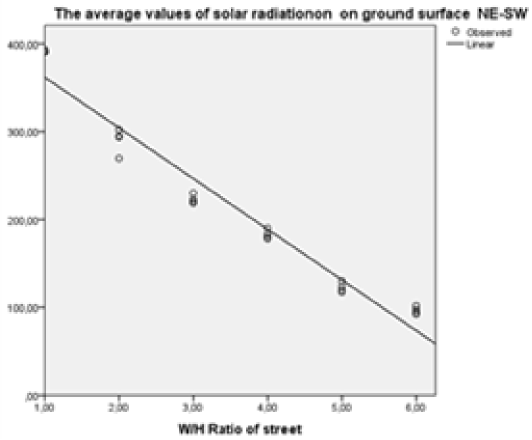


Figure 8, 9. The linear of diffusion between H/W ratio and solar radiation at the (NS; NE-SW) orientations

Figure 10, 11. The linear of diffusion between H/W ratio and solar radiation at the (EW; SE-NW) orientations