The impact of building regional orientation and urban morphology on increasing solar energy absorption potentials in residential application.

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Abstract
Amongst academics and practitioners working in the fields of urban planning and design, there has been an on-going discussion regarding the relationships between urban morphology, regional orientation of buildings and environmental sustainability. A main focus of this study is to attempt to optimize the energy efficiency by good selection of form of cities and neighborhoods and buildings orientation, especially regarding the energy intensity of buildings and transportation. However, to analyze the overall energy performance of urban systems, both the consumption and the generation of resources by the side of regional orientation and morphology need to be assessed. Because of urban environmental sustainability and comfortability, the solar energy is a research topic of growing interest. This study evaluates some important parameter that are important to make a city with best condition for having most solar energy absorption. Different possible scenarios of urban morphology that have been done(Juan Jose Sarralde 2014) [1] ,(Zahra Barzegar 2013) [2] are analyzed and variables of urban form and building orientation are combined with the aim of increasing the solar energy potential of neighborhoods and buildings. Results show that by optimizing combinations of urban form and regional building orientation, the solar irradiation of roofs and façades could be increased .However,vertical walls and areas are so much important for attention and concentration.Finally, some recommendations for design strategies are offered with the aim of helping urban planners and designers improve the solar energy potential of new or existing urban areas and buildings.
Keywords: regional building orientation, urban morphology, solar potential

1. Introduction

Nowadays , improving life and comfort increase the need of energy .whereas, energy resources are limited. Also, the buildings consume 45% of total consumption of world energy. So, generating solar energy within the city boundaries can bring many advantages, a main one being the increase in efficiency due to the reduction of energy transmission losses. There are numerous reasons for increasing energy consumption of buildings like regional change, raising residential electricity needs, increasing buildings, changing in industrial, high consumption in existing buildings.Due to these explanations,research on this field is one of the Basic needs of society.The aim of this paper is adding up some results of a collaborative research effort aimed at developing a methodology of urban modeling for evaluating the solar renewable energy potential (REP) of cities, based on their urban morphology (Juan Jose Sarralde 2014) and regional orientation of building (Zahra Barzegar 2013) .

1.1. Urban morphology and renewable energy potential of cities

In the last decades there have been many examples of research looking at the solar potential of cities in order to reduce the electricity consumption in buildings. Back in 2014, Juan Jose Sarralde[1] , Zahra Barzegar 2013[2],1997,Project ZED[3] used the RADIANCE ray-tracing software to investigate the solar exposure of cities and the environmental contributions from solar penetration in an urban area. Some years later the PREC is project [4] built upon the experience of Project ZED to assess the potential for renewable energy generation in cities, by exploring the relationships between urban form and the energy and environmental performances of buildings. Furthermore, Yun and Steemers [5] analyzed the impact of urban settings on the potential for energy generation using façade-integrated photovoltaic (PV) panels. Further on the relationship between urban morphology and solar potential, the SOLURBAN project [6] used the extraction of urban form descriptors from 3D models and built upon the results of previous research [7,8] to evaluate the solar potential of three Swiss cities with different levels of building density. By comparing the results of the three cases, an inverse relationship was found between urban density (measured as plot ratio) and the potential for façade and roof mounted PV and solar thermal collectors. Other studies [9, 10] followed up on these results and looked into more detail at the efficacy of using aggregated measures of urban form such as the height-to-width ratio of street canyons, site coverage, plot ratio, horizontal distribution, and vertical uniformity of buildings, amongst others, for calculating irradiation availability at district level. Meanwhile, more recently, further tools to perform neighborhood-scale analysis of solar availability have been developed. SUNtool [11] and CitySIM [12] utilize complex computer modeling techniques to predict the performance of various energy generation technologies, including solar, within the city boundaries.

This paper builds upon the existing body of research to further expand the understanding of how this knowledge could influence urban planning and design to increase the solar potential of cities.

1.2. Aims of this study

The aim of this analysis is to test whether the combination of knowledge obtained on building regional orientation [2] and the relationships between urban morphology and solar potential [1] can help create cities that are more suited for harvesting solar energy. This is done by optimizing certain parameters of urban morphology in order to increase the solar potential of buildings' roofs and façades. It is acknowledged that the variables of urban form involved in this analysis are not easily modified in the case of existing neighborhoods. Hence, this parametrical exploration should be primarily considered as a theoretical exercise. However, it is expected that the insights gained through this research will be useful when briefing and designing new neighborhoods or towns and to help guide planning policy in order to increase the solar REP of cities.

2. Methodology

This section offers a brief summary of the data and methods used in study[1] and [2].

First [1], spatial data was used to characterize the urban morphology of neighborhoods by computing a variety of aggregated urban form descriptors. The same data was then used to model the solar irradiation of building envelopes by means of computer simulation. The next step was to perform a statistical analysis to explore the interrelations between the aggregated descriptors of urban morphology and the solar irradiation of building envelopes. The outcome of this analysis was the creation of two separate models capable of predicting (to different degrees) the solar irradiation of roofs and facades, based on the urban form of a neighborhood. These models are named Roof-SolREP and Façade-SolREP, respectively. Finally, the two models were used to test different scenarios of urban form. The aim of this was to explore whether the solar potential of building envelopes could be optimized by introducing changes to the urban morphology of neighborhoods. Lower Layer Super Output Area (LSOA) is the unit of analysis in this study and is assumed to represent a typical neighborhood as illustrated in Fig. 1. By definition, each LSOA contains a population of ca. 1500 inhabitants. Therefore, different LSOA can show great variations in terms of area, building typologies, building use, and urban morphology.

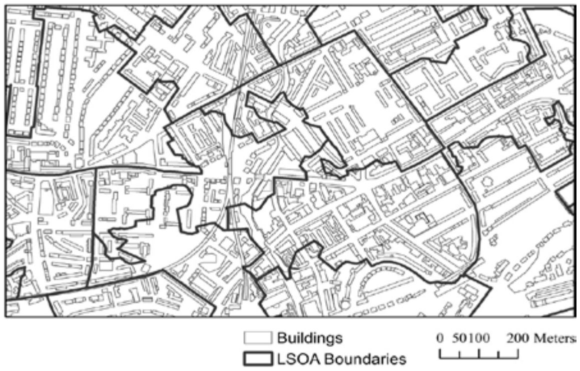

Fig. 1. Examples of LSOA divisions in a big city[1]

Table 1: Urban morphology descriptors to predict roof and façade solar irradiation [1]

Roof solar irradiation	Façade solar irradiation
1) Share of semi-detached houses	1) Average building heights
2) Share of area covered by private gardens	2) Site coverage
3) Average building perimeter	3) Average distance between buildings
4) Standard deviation of building heights	
5) Plot ratio	
6) Average distance between buildings	

Study[2] has been done by experimental and analytical methods including random sample , evaluation of random samples characters , calculation of total annually and monthly radiation on building walls and roofs(E_r) including solar radiation on horizontal areas (H_{hr}) and vertical areas (E_{vr}) , calculation of primary energy ($E_{primery}$) , calculation of heating and cooling energy consumption in building ($E_{cooling}$, $E_{heating}$) . analysis of E_r with $E_{primery}$ is to obtain effect of E_r on energy consumption in building.

3. Scenarios for optimizing the solar potential of neighborhoods[1]

The SolREP models were used to test different possible scenarios of urban morphology that could help increase the solar irradiation of building envelopes.

3.1. Comparing neighborhoods with similar predicted solar irradiation

First, an analysis was carried out to explore the scale of the influence that each urban form descriptor used in the SolREP models might have on the results of solar irradiation. For this, three samples of neighborhoods with similar predicted values of solar irradiation were compared, for roofs and façades respectively. The samples selected illustrate the high variability of urban form in neighborhoods with a similar solar REP, showing the complexity of combining different urban form variables to increase the potential for harvesting solar energy in neighborhoods. This exercise is illustrated with the results for roofs, which showed an overall higher variability than in the case of façades. Figs. 2-4 present three LSOA (samples A, B and C, respectively) that obtained very similar values for predicted solar irradiation of roofs (represented by variable Y, expressed in Wh/m2) using the Roof-SolREP model. Their Y values were the closest to 970,574 Wh/m2, which is the mean annual value of Y amongst all samples. With a simple visual check it can be observed that samples A, B and C display very different urban configurations. This is supported by the data presented in Table 2, which shows large variations between their respective urban form descriptors. Of all six variables examined, the share of area covered by private gardens shows the largest variation. Sample C has the largest share of garden area, which is 53% larger than sample A and 15.8% larger than sample B. This is followed by the share of semi-detached houses, where sample B presents the largest share with a difference of 43% over sample A and 34.1% over sample C. The average building perimeter also shows a relatively large variation of up to 31% between samples C and B (highest and lowest respectively), while the variable of plot ratio presents a maximum variation of 37.9% between the densest sample C and the least dense, sample A.

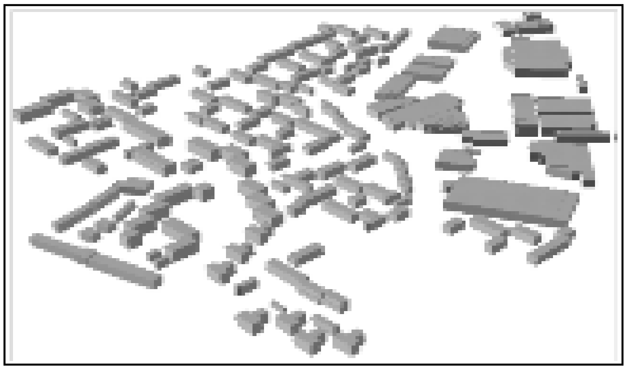

Fig. 2. Sample A: LSOA representing the mean value for predicted solar irradiation of roofs.[1]

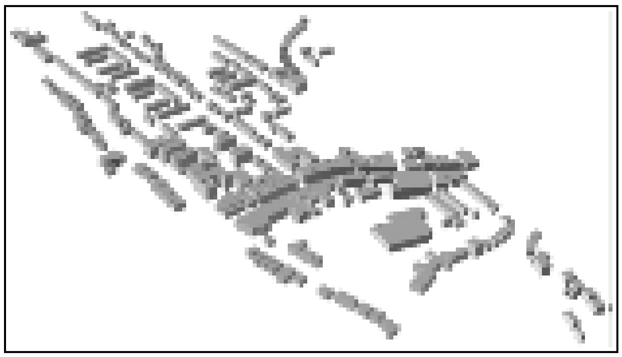

Fig. 3. Sample B: LSOA representing the mean value for [1]
solar irradiation of roofs

On the other hand, two other descriptors of urban morphology show relatively small percentages of variation between samples. The maximum variation in the average distance between buildings is 11.1%. Finally, in the standard deviation of building heights, the highest-ranking sample B and the lowest-ranking sample A show a variation of just 10.1%. This means that all three samples show a relatively uniform skyline, with standard deviation values of just over 2 m in building height. This analysis shows that, while it might be sometimes difficult to strike a balance between the different variables of urban form to maximize solar REP, it is still possible to have a very diverse range of neighborhood patterns that yield similarly high results in terms of solar potential.

Table 2: Comparison of values for the descriptors of urban form used in the Roof-SolREP model; based on three samples with similar predicted solar irradiation[1]

Urban form variable	Unit	A	B	C	Max. Variation
1) Share of semi-detached houses	Fraction	0.07	0.12	0.08	43.1%
2) Share of area covered by private gardens	Fraction	0.17	0.31	0.37	53.0%
3) Average building perimeter	m	86.36	74.68	108.30	31.1%
4) Standard deviation of building	m	2.13	2.37	2.19	10.1%

heights					
5) Plot ratio	-	0.92	0.93	1.28	27.9%
6) Average distance between buildings	m	21.86	19.68	22.09	11.1%
Predicted irradiation of roofs (Y)	**Wh/m^2**	**970,580**	**970,564**	**970,587**	**0.002%**

3.3. Scenarios for the optimization of solar irradiation of roofs

Different scenarios of urban morphology are tested in order to optimize the amount of solar radiation that can be harvested on building roofs. The optimization is carried out by increasing those variables that are in a direct relationship to solar REP, while at the same time decreasing the variables that are detrimental to it. The results of these scenarios are then compared by quantifying the increase in the solar irradiation of typical neighborhoods as a result of varying the urban form parameters of the different variables involved.

The first step for testing different scenarios was to define a base-case scenario against which the improvements could be compared.

The chosen sample was the LSOA previously presented in Fig. 2 (sample A), as it has the predicted solar irradiation value that is closest to the mean. As presented in Table 3, a total of eight scenarios for increasing solar REP on roofs are analyzed. Of these, scenarios 1, 2 and 3 are aimed at simultaneously modifying the values of all six independent variables. The optimization is performed to different degrees, introducing variations to the values of the urban from descriptors that reflect an increase or decrease of 10%, 20% or 50% of their value, as well as the maximum variation. It is important to note that for the maximum variation, the values used are the minimum or maximum values of each descriptor as found within the whole sample of LSOA, rather than the theoretical extreme values for each variable.

3.4. Scenarios for the optimization of solar irradiation of façades

After analyzing scenarios for optimizing the solar potential of roofs, the same was done for façades based on the three independent variables included in the Façade-SolREP model. The base-case scenario selected was the LSOA illustrated in Fig. 1, which presented the Y value closest to the mean solar irradiation of façades of the neighborhood sample.

Table 3: Comparison of the results of eight scenarios for optimizing solar REP of roofs (where: Y ¼ predicted solar irradiation; DY ¼ percentage increase in Y over base-case)[1].

Scenario	**Description**	**Y (Wh/m^2)**	**DY (%)**
Base-case scenario Sample A, Fig. 3		970,580.18	
1) Variation 20%	All modified by 20%	981,501.47	1.12%
2) Variation 50%	All modified by 50%	997,883.40	2.81%
3) Max. variation	All modified to max. value	1,055,870.18	8.78%
4) Low density	Plot ratio at min. value	980,245.41	0.99%
5) Dispersed neighbors	Avg. distance between buildings at max. value	1,018,167.97	4.90%
6) Even skyline	Std. dev. of building heights at min. value	974,901.60	0.44%
7) Uniform development	Share of semi-detached houses at max. value	984,923.48	1.47%
8) Green suburbia	Share of area covered by gardens, plot ratio and avg. distance between buildings at max. values	1,039,866.60	7.13%

Table 4: Comparison of the results of five scenarios for optimizing solar REP of façades (where: Y ¼ predicted solar irradiation; DY ¼ percentage increase in Y over basecase; values used are based on the Camden borough sample)[1].

Scenario	**Description**	**Y (Wh/m^2)**	**DY (%)**
Base-case scenario	LSOA in Fig. 6	163,840.32	163,840.32
1) Variation 20%	All modified by 20%	186,586.48	13.88%
2) Variation 50%	All modified by 50%	220,705.72	34.7%
3) Max. variation	All modified to max. value	238,413.56	45.51%
4) Low rise	Avg. building height at min. value	172,402.44	5.22%
5) Dispersed low density	Site coverage at min. value; avg. distance between buildings at max. value	229,851.44	40.28%

The results of five scenarios for optimizing solar irradiation of façades are presented in Table 4. Scenarios 1, 2 and 3 are aimed at modifying all three urban form descriptors used in the statistical model. The fourth scenario is based on the maximum value of just one variable: the average building height. Meanwhile, scenario 5 is based on the combination of the two variables with largest influence on the prediction of Y, which were the site coverage and average distance between buildings. The discussion of the results of all scenarios, for both roofs and façades, is presented in the next section.

4. Discussion of results

After comparing the results of the various scenarios presented earlier[1], possible conflicts or trade-offs between the variables involved in each statistical model are analyzed. This is followed by a discussion on the variables that should be prioritized when trying to optimize the solar irradiation of roofs and façades. Finally, a brief analysis of possible design strategies for the applicability of the models is presented.

4.1. Comparison of scenarios for roofs

For the analysis of solar radiation falling on roofs, a total of eight optimization scenarios were tested against a base-case scenario. Fig. 5 shows a graph with the comparison of results. First, it can be observed that the variation between different scenarios is relatively small. As could be expected, the scenario that performs best is number 3: 'Maximum Variation'. However, its DY value (the difference between this scenario and the base-case) is just 8.78%. Moreover, the second best-performing scenario is number 8: 'Green Suburbia', with a DY of 7.13%. This confirms the relatively much larger impact of the three variables optimized in scenario 8, as seen in Table 5. Even though this scenario is based on the maximum variation of just three out of the six variables involved in the statistical model, there is a small difference of just over 1.75% between the DY of scenarios 3 and 8. With this, scenario 8 is probably the most efficient way of optimizing the solar irradiation of roofs without having to modify all six variables involved.

Furthermore, in third place is scenario 5: 'Dispersed Neighbors', which achieves a DY of 4.9% by only modifying the descriptor of the mean distance between neighboring buildings. Finally, on the other end of the spectrum, scenarios 4: 'Low Density' and 6: 'Even Skyline' only help increase Y by less than 1%, with DY of 0.99% and 0.44% respectively.

The overall outcome of this analysis shows that the potential for increasing the solar irradiation of roofs by modifying the urban morphology of neighborhoods is relatively small, ranging from 0.44% to 8.78% of increase in Y over the base-case scenario. However, considering that the difference between the mean and maximum values of Y in the whole sample is just 4.32%, all three best-performing scenarios (3, 8 and 5) are producing better results than the maximum observed in the sample.

Moreover, considering that this analysis uses the mean value of the whole sample as a base-case scenario, a much greater increase could be expected when trying to optimize the performance of other samples that are under the mean. With this, it can be said that there is an overall good scope for improving the solar REP of roofs by introducing modifications in the built form of neighborhoods.

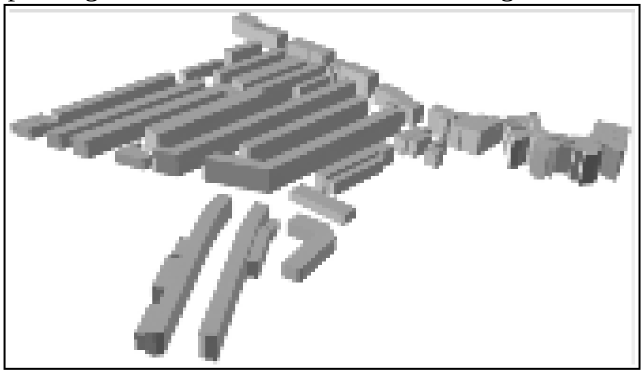

Fig. 5. LSOA representing the mean value for predicted for predicted solar irradiation of façades[1].

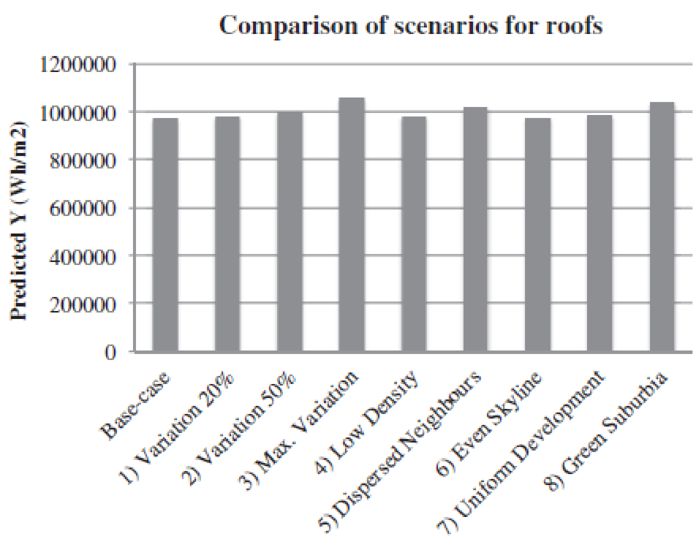

Fig. 6. Comparison of the results of scenarios for optimising solar irradiation of roofs (where: Y ¼ predicted solar irradiation in Wh/m2)[1].

4.2. Comparison of scenarios for façades

Fig. 7 presents a comparison of the results obtained for the five scenarios analyzed for the optimization of the solar irradiation of façades. A much larger variation can be observed here than in the case of roofs, with the best-performing scenario 3: 'Maximum Variation' showing a DY of 45.51% over the base-case. Furthermore, scenario 5: 'Dispersed Low Density' presents an important DY of 40.28% over the base-case scenario, achieved by modifying two of the three variables involved in the statistical model, as seen in Table 4. In third place is scenario 2: 'Variation 50%', with a Y 34.7% larger than the base-case scenario, while the scenario with the lowest DY is number 4: 'Low Rise', with a result for Y just 5.22% larger than the base-case scenario.

The large DY values observed in the case of façades show the relatively high impact of the different independent variables on the prediction of Y. Considering that the difference between the mean and maximum values of Y within the Camden sample is 14.74%, four out of the five scenarios tested here can significantly outperform the best sample analyzed. Thus, the results exposed here show that there is a great scope for improving the solar irradiation of façades by modifying the urban form of neighborhoods. However, it is worth noting that, while the results for façades seem much more auspicious than the results of the scenarios for roofs, the absolute solar REP of roofs is much larger than that of façades. Hence, while there is more room for improvement in increasing the amount of solar radiation received on façades, this is still a small portion of what can be achieved on roofs. In fact, the best-performing scenario for façades receives just under a quarter of the amount of solar radiation per squared meter received in the base-case scenario for roofs.

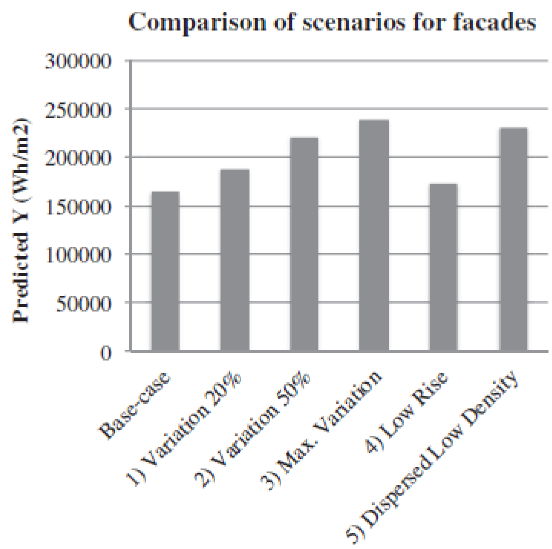

Fig. 7. Comparison of the results of scenarios for optimizing solar irradiation of façades

5. Applicability of the models

The analysis of optimization strategies for solar REP has been performed separately for roofs and façades. This section offers a discussion on the possible conflicts and trade-offs involved in the model applicability, in terms of developing design strategies to optimize the solar REP on whole building envelopes. This order is given according to the individual or combined impact of descriptors of urban form on the overall result, as explained below:

a) The first priority should be given to modifying the variables included in the model of roofs, since the amount of solar radiation that can be harvested on roofs is usually much larger than that on façades. Also, by prioritizing the variables of one model over the other, possible conflicts between variables of different models are avoided. An example of this would be the case of trying to modify both, the average building height (which needs to be reduced to optimize irradiation of façades) and the average building perimeter (which needs to be reduced to optimize the solar irradiation of roofs). When constricted by boundary conditions such as a set target of floor area and a limited plot size, a conflict between these two variables can arise. This is because reducing building height can lead to an increase in average building perimeter and vice-versa.
b) The next priority would be to modify combinations of variables that are very effective together, such as scenario 8 for roofs: ‘Green Suburbia’.
c) The variable of average distance between buildings has the largest impact on Y and is included in both models. Hence it should be the most important single variable to maximize.

d) When trying to modify the rest of the variables in the Façade-SolREP model, combinations of variables such as scenario 5: 'Dispersed Low Density' should be prioritized over the modification of single variables.

e) Finally, there might be a conflict between the average building height and site coverage. The aim in the model for façades would be to reduce both variables. However, this is not possible with the boundary conditions mentioned earlier, since decreasing one will inevitably lead to increasing the other. In this case a trade-off has to be considered. Even though the average building height has a larger impact than site coverage on the results of the Façade-SolREP model, the priority should be given to reducing the site coverage because it is complementary to increasing the average distance between buildings.

Table 5: Order of priority for the modification of variables to optimize the overall solar REP of neighborhoods

Variables in order of priority	
1	All variables in the *Roof-SolREP* model
2	Variables in 'Green Suburbia' scenario
3	Average distance between buildings
4	Plot ratio
5	Standard deviation of building heights
6	Average building perimeter
7	Share of area covered by private gardens
8	Share of semi-detached houses
9	All variables in the *Façade-SolREP* model
10	Variables in 'Dispersed Low Density' scenario
11	Site coverage
12	Average building height

5.2. Limitations and further research[1]

Although the primary objectives of this study are theoretical and experimental separately ,it would be recommended to use of combination of all parameters like morphology , angle of roofs and regional orientation for building. Then ,with optimizing all results ,we will achieve to more applied strategies. So, this is one of the immediate next steps that should be taken in future research in order to further test the usefulness of these findings.

6. Conclusions

According to study [2] , it is calculated that regional building orientation is so important. For a city like Shiraz the optimized orientation for building is north-West , East-South . Also, the best building walls to absorb the oriented solar Energy are vertical walls, if orientation of building would be suitable. The study [1] presented here demonstrated the applicability of research carried out to investigate the relationships between urban morphology and the solar renewable energy potential (REP) of neighborhoods. Using statistical models developed to predict the solar irradiation of roofs and façades, a total of 13 scenarios for the optimization of solar REP were tested. Results show that by introducing changes in aggregated descriptors of urban form, the solar irradiation of roofs could be increased by around 9%, while that of façades could grow by up to 45%. Furthermore, possible strategies for the applicability of the findings were presented, where some variable combinations are prioritized over others in order to increase the overall solar REP performance of neighborhoods. In conclusion ,according to above results, it is concluded that for having maximum solar energy gain and efficient condition for cooling and heating energy consumption in buildings we should be considered regional orientation , urban morphology and angle of roof together and optimize the best condition.

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