Conference Paper

The Effect of Urban Geometry on Low-Carbon Development in Desa Sruni, Wonosobo

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Abstract

Urban geometry is one of the important issues in creating a low-carbon sustainable dwelling area. Open spaces located in the settlement area is one of many elements that help to balance the energy exchange process that occurs in the land surface. The balance between energy absorption and emittance can prevent the occurrence of Urban Heat Island (UHI) which increases air temperature. Desa Sruni is one of the high-density villages located in Wonosobo, Central Java. The village is dominated by settlements that almost reach 60% of the area while the rest is impervious surface used for circulation and vacant lands. This study aims to find the effect of urban geometry changes on urban climatic conditions in Desa Sruni. The research is carried out by using a quantitative method with the help of Envi-met to find the value of some variables such as Sky View Factor (SVF), Air Temperature (Ta), Mean Radiant Temperature (Tmrt) and Wind Speed (Ws). The outcome of this study can be used as a further reference to create a design recommendation on low-carbon development in Desa Sruni.

Keywords: envi-met, climate change, low-carbon development, urban geometry

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1. Introduction

Greenhouse gas (GHG) emissions resulting from population growth and economic activity have played a significant role in global climate change through the burning of fossil fuels. Without mitigation efforts to reduce GHG production, it is estimated that there will be a global mean surface temperature surge of 4.8°C in 2100 [1]. One of many ways to reduce GHG production related to the urban geometry is by efficient land use planning and compact building morphology that supports non-motorized movements, as well as the provision of green open spaces as a place of community activities [2].

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Indonesia is one of the archipelago countries located in tropical regions that have a hot-humid climate. The special characteristics of hot-humid climates are high average temperatures, slight variation between day-night and seasonal changes, high humidity, and heavy rain, as well as high and relatively diffuse solar radiation [3]. Desa Sruni is located on one of the highest density area in Wonosobo. According to the Decree of the Regent of Wonosobo [4], Desa Sruni is listed in the category of slum areas. Meanwhile, this village is also one of the tourism destinations in Wonosobo because of its cultural significance of Larung Sukerto held annually [5]. As an effort to eradicate slums, Ministry of Public Works and Public Housing started a strategic program called Kotaku (Kota Tanpa Kumuh). The general objective of this program is to increase access to basic infrastructure and services in urban slums to support the realization of livable, productive, and sustainable urban settlements. On this basis, the potential for developing and improving the quality of this area needs to be controlled so as not to reduce the climate conditions of Desa Sruni which can affect the quality of life of the inhabitants.

In creating a comfortable urban microclimate, a harmonious balance between the shape of the built environment and open space is necessary. Inadequate thermal conditions often disrupt the utilization of outdoor space for various activities. Rapid urban growth and lack of efforts to provide decent public spaces have harmed urban microclimate circumstances [6]. Open spaces must be considered in relation to the shape of the built environment as they complement each other [7]. The conditions of these spaces not only affect the social life but the climatological conditions will directly affect the energy use of nearby buildings. Encouraging ideas to design a building in relation to the outdoor space will encourage the development of building designs that simultaneously address the issue of declining urban space quality. Such spaces can foster vibrant urban social life, accommodating activities that lead to a more sustainable future of the city [8]. This paper seeks to investigate and evaluate urban geometric changes in climatic conditions in Desa Sruni. This research can be used as guidelines in further studies in implementing low-carbon development strategies in order to mitigate climate change.

2. Literature Review

2.1. Cities and climate change

From the fifth report of the Intergovernmental Panel on Climate Change (IPCC), it is clear that the mean surface temperature (MST) of the earth has increased by 0.85 degrees since 1880. Since the 20th century, the earth's temperature has risen by 0.89 degrees. Over the past century, sea level has increased by 19 cm, which is mainly due to the melting of ice and swollen seawater, while the leading cause of temperature rise was an increase in carbon emissions [1]. Cities are the leading cause of carbon emissions, from which solutions to greenhouse effects can be worked out. The massive emission of human-induced GHG since the beginning of the industrial era was found to be the dominant cause of current climate change. Therefore it is important for the international community to reduce GHG emissions, including CO2, CH4, and N2O. Rising GHG emissions have so far been linked to the development of modern industry and increasing living standards in most parts of the world [9].

2.2. Low-carbon development and urban geometry

Since the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992, the world has collaborated on the global response to climate change. The Paris climate conference in December 2015 succeeded in reaching an agreement, setting long-term goals and a new mechanism for the post-2020 global response to climate change, which drives the process of global cooperation. The Paris Agreement sets a long-term goal for the global response to climate change, namely, to hold global average temperature increases below 2o C above pre-industrial levels and to pursue efforts to limit temperature increases to 1.5o C above pre-industrial levels [10]. It urges all countries, especially developing countries, to combine responding to climate change, eliminate poverty and their sustainable development, take a climate-friendly low-carbon development path, and achieve carbon reduction.

The link between urban geometry and low-carbon development is close. Urban geometry is the one that gives shape to a city, and urban shape is one of the many considerations of low-carbon development strategies [2]. Urbanization tends to direct urban development in the use of private transportation and excessive air conditioning equipment [11]. The city must understand the local climate situation if a city does not want to be oriented towards private transportation that can affect many things starting from urban sprawl, traffic, and ultimately global warming. Outdoor activities undertaken by the community, such as walking, sports, and using public transportation, should be comfortable and maybe widely interacted with the surrounding environment comfortably. The thermal comfort of outdoor space for tropical climates can be obtained through shading. In the context of tropical climates, a significant challenge in designing thermal responsive paths is to achieve a shade from excessive solar radiation gain, due to the higher sun angle. The proposed design should be able to facilitate and provide shading that is capable of creating passive cooling [12]. The design of the city has an important role in creating thermal comfort, some things to note in the design are as follows [13]:

1. Road layout and road network system. Road orientation is recommended to optimize the movement of the incoming wind in the region. On the pedestrian pathways it is advisable to use wide-canopied vegetation and able to be a shelter for road users.
2. The density of the built area should consider the distance between buildings.
3. The height of the building is recommended to have variations.
4. Building typology is recommended to have openings or compact shapes.
5. The green open space or green space plan in the design requires careful planning to create thermal comfort especially at the pedestrian level.

In tropical countries, wind movement and urban ventilation become an important factor in decreasing the temperature in the environment. On the urban scale, urban geometry is critical for urban design strategies that can be used to improve the thermal performance conditions in cities. Tropical locations need to get wind that moves inside the area [14].

3. Study Area

Desa Sruni is one of the villages in Wonosobo district located at 7.36° S 109.9° E with a height of 794 m above sea level and has a tropical-rain climatic condition with average rainfall in July of 101-150 mm [15]. Desa Sruni is a densely populated settlement dominated by one-story buildings with an irregular road pattern. This village has a relatively steep slope with a circular network built from asphalt and concrete. The building coverage ratio (BCR) of this village is quite high with only a few vacant land remaining and doesn't serve as open space accessible to the general public.

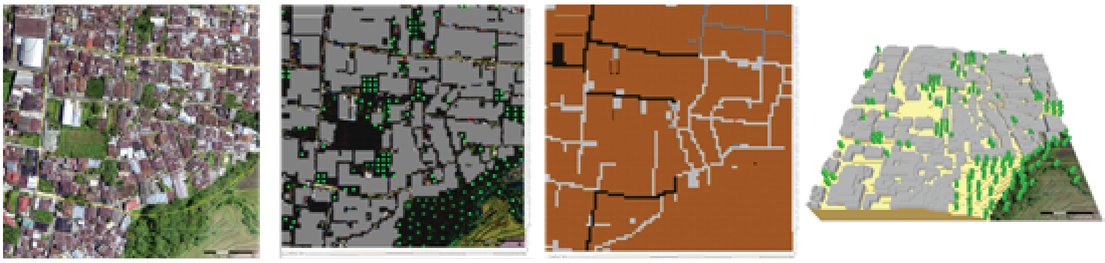


Figure 1: Results of buildings, vegetation, soil layers, and contours interpretation using ENVI-met software.

4. Methodology

This research is carried out by using a quantitative method. This method emphasizes collection and analysis of information in the form of numbers, collecting the values of measuring instruments both individually and in groups, and comparing between groups or linking individual factors in experiments, correlation studies, and surveys [16]. This method is used by analyzing the simulation result using ENVI-Met program to find the value of some variables such as air temperature (Ta), wind speed, and Sky View Factor (SVF) in some interventions on urban geometry in Desa Sruni. ENVI-met is a three-dimensional non-hydrostatic microclimate model including a simple one-dimensional soil model, a radiative transfer model and a vegetation model [17]. ENVI-met microclimate simulation can be used to estimate the influence of building time, open space, and vegetation on changes in climatic conditions and human thermal comfort in an area. Regression analysis was then conducted to find the relation between the urban geometric interventions and climatic conditions in Desa Sruni.

In performing simulation of each scenario, a clear sky condition is assumed for all model situations. Climatic conditions used in ENVI-Met simulation was formulated through several climate websites accessed at the time of the simulation. Data configuration used for model parameters and climatic condition in all scenarios can be seen in **Table 1**.

The limited grid size allowed by the basic version of the ENVI-met program causes the elevation of the region to be represented as close as possible with a maximum height of 30 Meters. In conducting the simulation process, the constituent building elements are simplified so that the wall and roof material are assumed to be the same across the whole region to understand the relative impact of urban geometry to the climate conditions rather than the impact of building materials. Several different scenarios have been developed to determine the correlation between urban geometry to changes occurring in regional climatic conditions in Desa Sruni. The intervention of urban geometry is considering the condition of existing buildings and road networks in the region. The

TABLE 1: Data configuration of ENVI-met.

Grid size	90x90x20
Model height + DEM (m)	38
Date of start of simulation	10 July 2018
Time of start of simulation	7:00 am
Simulation period	24 hours
Wind speed at 10 m height (m/s)	1.67
Wind direction	180°
Roughness length	0.01
Initial air temperature	25°C
Specific humidity at 2500 m (g/kg)	14
Relative humidity at 2 m height (%)	70

values of each variable obtained from several climate variables such as air temperature (Ta), wind speed, sky view factor (SVF), mean radiant temperature (Tmrt), and relative humidity (RH) were then compared with the results of the simulation of the existing conditions to determine the impact of these interventions on changing regional climate conditions. Some of these scenarios are listed as follows:

1. Scenario 1 (**Figure 2a**) is an intervention of compact building blocks and the addition of streets adapted to the existing road network.
2. Scenario 2 (**Figure 2b**) is an intervention of the amount of open space with some additions at some points which is a continuation of scenario 1.
3. Scenario 3 (**Figure 2c**) is an intervention of increasing the width of the main/major roads and still a continuation of scenario 2.

Figure 2: Three different scenarios used to determine the impact of urban geometric changes on climatic conditions in Desa Sruni.

5. Results and Discussion

Simulation of the existing condition of Desa Sruni is done to get the value of variables that will be used as the basis in comparing the result of the intervention which has been determined in 3 different scenarios. Three receptor points, as seen in **Figure 3**, with different spatial characteristics are used to compare the simulation results for climatic conditions at specific locations, then to compare them on a regional scale. The simulated results of the existing conditions indicate significant differences between receptor 1 lying parallel to the direction of the wind compared to the other two receptors blocked by the building. There were no significant differences in temperature variables (Ta), receptor 3 located at the lowest elevation had the lowest average temperature when compared with other receptors.

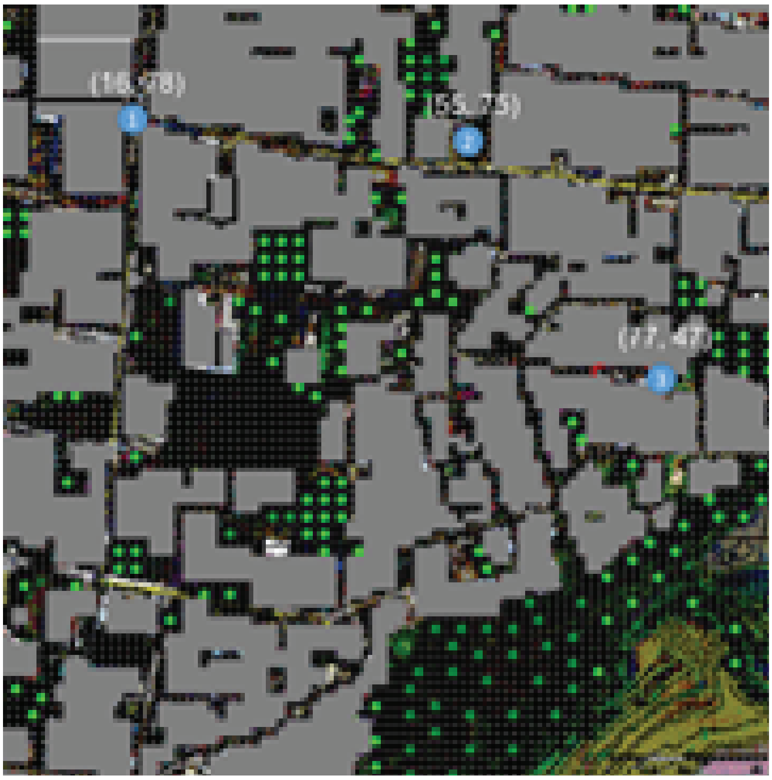


Figure 3: The location of three pre-determined receptors.

5.1. Air temperature

The intervention of the three scenarios that have been done in this study raised the air temperature in the region. Increasing air temperature affects the thermal comfort felt by local residents and potentially increasing energy use. In **Figure 4**, it is known that the addition of open spaces done in scenario 2 can lower the air temperature caused by previous interventions. Scenario 3 interventions further increase the air temperature at each receptor.

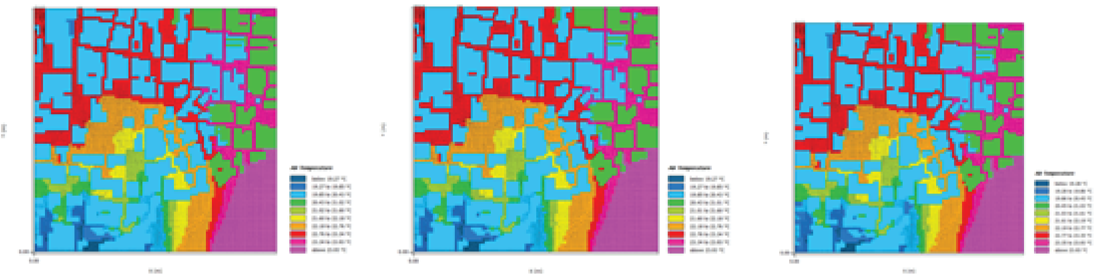


Figure 4: Comparison of simulation results from 3 different scenarios against air temperature.

Figure 5 shows that each simulation results from several different scenarios on a regional scale increase the air temperature, especially the 23.0-23.5°C intervals**. Figure 5** also shows the highest increase in scenario 3 which may be caused by the aspect ratios of buildings along the increasingly higher main roads causing a decrease in passive shading against solar radiation during the day.

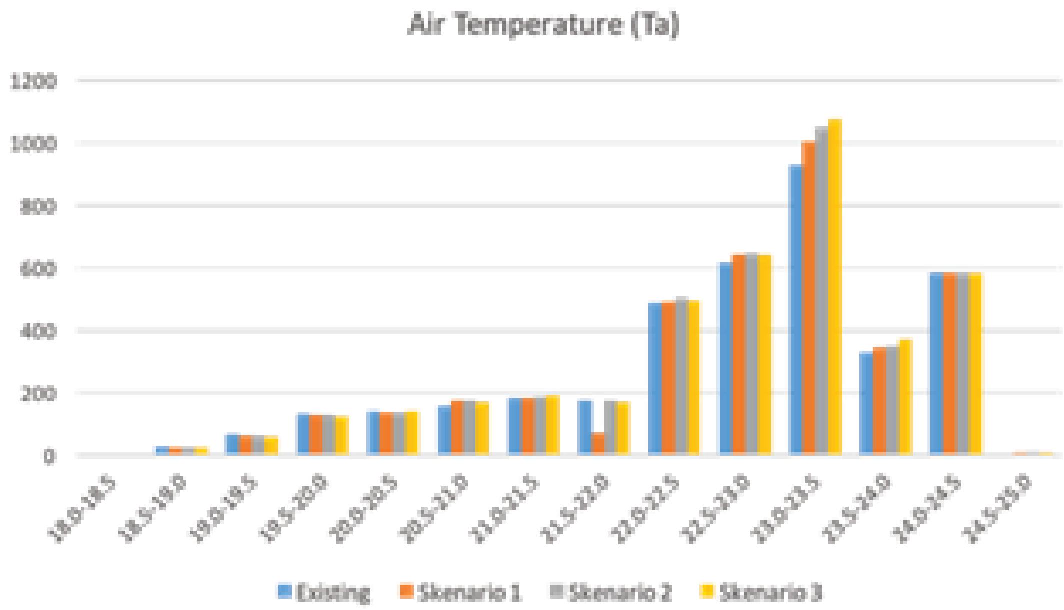


Figure 5: Comparison of simulation result of existing condition and 3 scenario of intervention to air temperature.

5.2. Wind speed

Intervention conducted on the existing condition of Desa Sruni as seen in scenario 1 and 2 turned out to have a negative impact on wind speed on each receptor. In scenario 1, the intervention to add streets between buildings lowers the wind speed when compared with the existing condition with the difference of 0.188 at receptor 1 recorded at 08.00. However, this decrease in speed can also mean that wind flow is fragmented and penetrates better through new streets with one of its aims is to increase the permeability of the area. **Figure 6** shows the simulation results from three scenarios for wind speed condition.

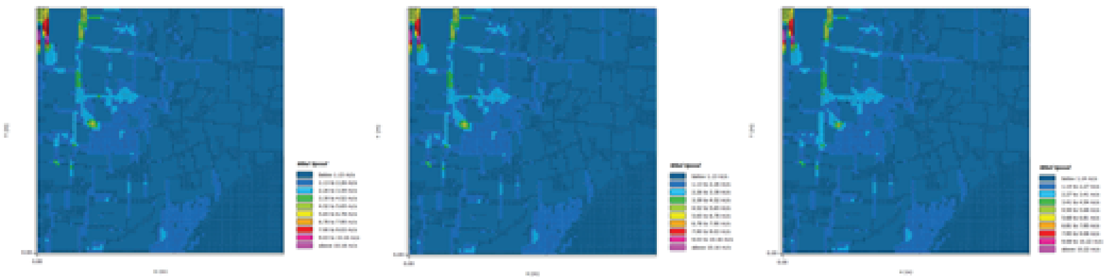
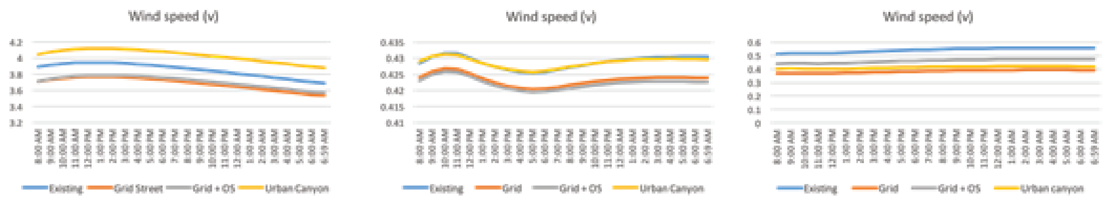


Figure 6: Simulation results from 3 scenarios to wind speed in Desa Sruni.

In contrast to the previous two scenarios, the intervention performed in scenario 3 shows the positive impacts as seen in receptor 1. The simulation result conducted at 08.00 shows a difference of 0.15 m/s when compared to the existing climatic conditions. This condition illustrated in the **Figure 7**. This is due to the receptor point located on the main road network according to the direction of the annual average wind blow coming from the South [18, 19]. The previous result was quite different from receptor 2 which located on the open space adjacent to the main road that shows an average value that is almost the same as the existing condition.



(a) (b) (c)

Figure 7: The graph of the simulation results of 3 scenarios against the wind speed from each receptor points.

The comparison of each receptor point to the existing climatic conditions shows that only scenario 3 has a positive impact on the increase in wind speed. When viewed on a regional scale, wind speed has increased in the interventions of scenarios 1 and 3. In **Figure 8** there is a decrease in the 0.0-0.5 m/s interval and an increase in the interval 0.5-1.0 to 1.5-2.0 m/s. In scenario 2, the addition of some open space and vegetation can cause the wind to get stuck in these spaces and lose its speed.

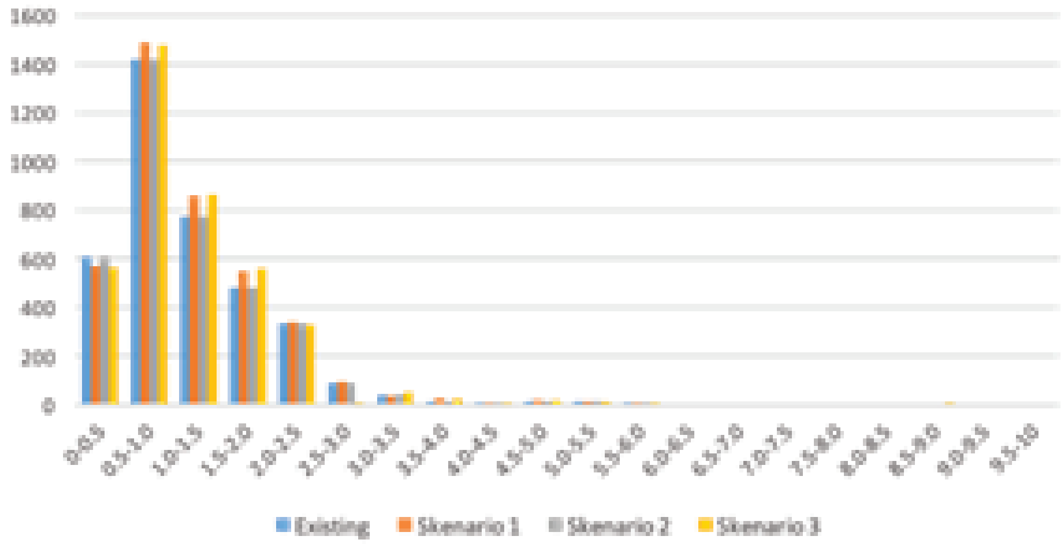


Figure 8: Comparison graph of 3 scenario in entire study area.

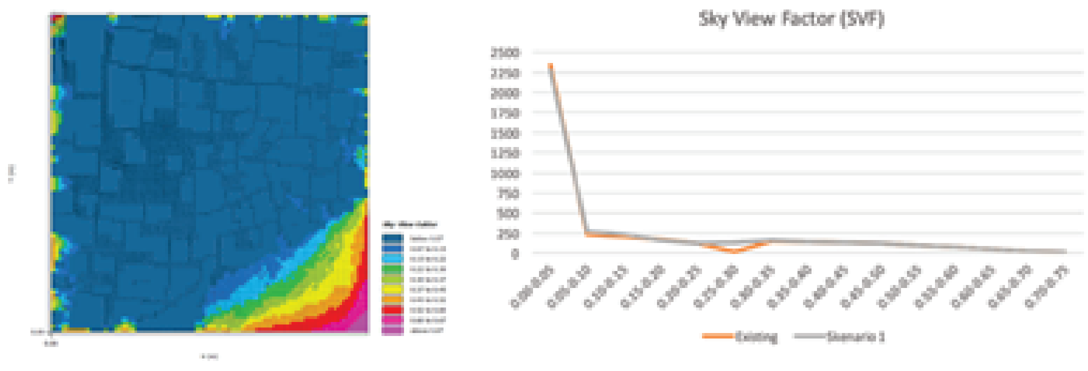
5.3. Sky view factor

Sky view factor (SVF) is the ratio between the radiation received by the planar surface from the entire hemispheric transmitter environment [20]. SVF, in this sense, is a measure of the exposure of the sky to radiation emissions in relation to a particular location, where a value of 0 means that all radiant outflows are inhibited and a value of 1 means that all radiation will radiate freely back to the sky [21]. SVF measures the amount of daylight that can be received from the ground that would affect thermal comfort and solar availability in the buildings.

The data used to assess the impact of the intervention is the simulation result using ENVI-met at 08.00 am. By comparison with the SVF values before and after the intervention, an increase in SVF values at the regional scale is found. In **Figure 9b** there is a decrease in the interval of 0.00-0.05 which means the decrease of nodes that have obstacles to the sky and a significant increase at the interval of 0.25-0.30.

6. Analysis

Comparison results from ENVI-met simulation show how far urban geometry characteristics affect the climatic conditions. The aspect of the urban form of Desa Sruni described in Building Coverage Ratio (BCR), Floor Area Ratio (FAR) and aspect ratio (H/W). The variables used for the climatic condition are Ta, Ws, RH, Tmrt, and SVF. For the correlation analysis, regression analysis was done using the help of a scatter graph to show the trendline. The value of each climatic condition variables in this analysis are



(a) (b)

Figure 9: (a) Simulation result of the intervention; (b) Comparison between existing and intervention graph of SVF.

obtained through calculating the average of the 12-hour simulation results based on each different scenarios.

TABLE 2: Analysis of urban geometry and climatic conditions of each scenario.

	Urban Geometry			Climatic Condition				
	BCR	FAR	H/W	Ta	Ws	RH	Tmrt	SVF
Existing	52.86%	1.029	1.675	22.444	2.000	80.547	18.617	0.0651
Scenario 1	51.34%	1.030	1.675	22.497	1.968	80.325	18.766	0.0650
Scenario 2	50.34%	1.030	1.137	22.495	1.980	80.376	18.799	0.0655
Scenario 3	49.33%	1.031	1.132	22.534	1.977	80.237	18.918	0.0657

A significant correlation value should be more than 0.25 [22]. In **Figure 10** we can see examples of the use of scatter graphs in assessing BCR to climatic condition. BCR has a significant correlation to all climatic variables, but is only positive on Ws and RH. Increasing BCR will further increase the Ws because the road network is responsive to the direction of wind and the building can direct the flow of wind. Negative correlation values indicate an inverse comparison of two variables, for example the value of T_a decreases as value of BCR increases. This is due to the impact of building shade on average T_a when measured as high as 1.8 meters from the ground.

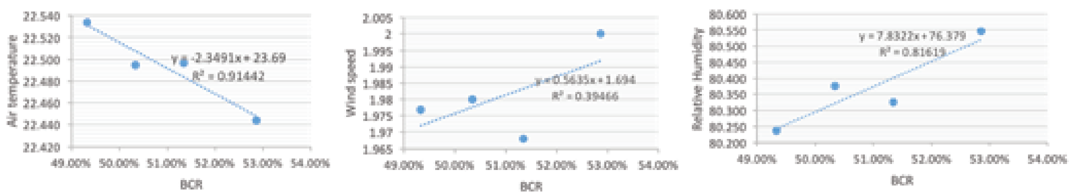


Figure 10: Scatter chart used for regression analysis between urban geometry and climatic conditions.

The high FAR value will increase T_a, T_{mrt}, SVF and reduce Ws and RH significantly. This significant relationship is because all the regression values of each climatic condition are more than 0.25. Increased H/W can reduce T_a, T_{mrt}, SVF, but increase Ws and RH. The relationship of H/W with Ws is not too significant because the value is less than 0.25 (**Table 3**). After regression analysis of all variables are done, the highest regression value found was the relation between FAR and T_{mrt} (R^2: 0.975). It means, the increase of FAR increases T_{mrt} in Desa Sruni. High FAR provides many building surfaces that store and emits heat. Since the increase of FAR also increases the SVF, the sky becomes less obstructed and the stored heat will be radiated to the surroundings. As seen in the **Table 3**, the relationship between T_a and T_{mrt} is very close. The changes that occur are always directly proportional (R^2: 0.98142), where rising air temperature is always accompanied by an increase in T_{mrt} and vice versa. Regression analysis' results can be used as consideration for preparing the design responses to the existing condition of Desa Sruni in order minimize the negative impact to the climatic condition.

Table 3: Regression analysis result between urban geometry and climatic condition.

	T_a	Ws	RH	T_{mrt}	SVF
BCR	-0.91442	0.39466	0.81619	-0.97184	-0.72559
FAR	0.91704	-0.37925	-0.81628	0.97501	0.73694
H/W	-0.47594	0.0556	0.33162	-0.60934	-0.92674

7. Conclusion and Recommendation

Urban geometry intervention conducted through the three scenarios above is not an appropriate solution in realising a low-carbon development in Desa Sruni. On the three scenarios, an increase in T_a, Ws, and SVF were found. Intervention value of urban geometry such as BCR, FAR and H/W, and climatic condition such as T_a, Ws, RH, T_{mrt} and SVF, from ENVI-met simulation was then analyzed using scatter graph to see the relationship between each variables. Based on the results of regression analysis, a strong relationship between urban geometry and climatic condition was found. As seen in Table 3, all variables have close relationship with the exception of H/W with Ws. The results of each correlation analysis can be used as a basis for considering regional development strategies, such as:

- Higher BCR increases Ws and RH, while decreases T_a, T_{mrt}, and SVF;
- Higher FAR decreases Ws and RH, while increases T_a, T_{mrt}, and SVF;
- Higher H/W increases Ws and RH while decreases T_a, RH, T_{mrt}, and SVF.

This research is only a preliminary step in realizing low-carbon development in Desa Sruni. Urban geometry is only one of many aspects that low-carbon development has and need to be considered. The result of this research can be used as study material for further research in formulating strategy of developing a low-carbon region suitable with local geographical and climatic condition in Desa Sruni, Wonosobo.

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