Impact of Urban Block Typology on Microclimate Performance in a Hot-Humid High-Density City

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Abstract. Because of their structure, urban areas induce very complex climate phenomena while notably impacting pedestrian safety and comfort in the urban microclimate. This paper presents the results of an investigation into the influence of urban block typology and building intensity on environmental performance in the context of the urban microclimate of a hot-humid high-density city. Qualitative and quantitative characterization of the building geometries used in this study was conducted to compare an existing block typology scenario with five new block typology scenarios in an area of 350 x 350 x 150 (L x W x H) meters. The scenarios investigated were composed of different settings for floor area ratio (FAR) and building coverage ratio (BCR) and different configurations of building elements (tower, podium, and courtyard). They were simulated and analyzed using the ENVI-met software. The simulation results indicate that the five new scenarios all improved the environmental thermal parameters and that the FAR has a greater influence than the BCR. FAR has the strongest correlation with air temperature, followed by solar radiation and relative humidity. The influence of BCR on humidity and wind speed is not as significant as that of FAR. A tower strongly influences wind speed in proportion to the height of the building. Open courtyards correlate with higher temperature and lower humidity than closed courtyards. The combination of a closed courtyard with a hybrid block consistently outperformed the other configurations in thermal performance. Within this framework, the proposed scenarios can provide recommendations for city design regulations and input for urban design methods to further improve microclimate performance.

Keywords: block typology, BCR, FAR, microclimate
1. Introduction

Urban microclimate modeling needs to include the performance of climate parameters. Variations in microclimate parameters are caused by the interaction between buildings and spaces between buildings, which significantly affect air temperature, solar radiation, wind speed, and relative humidity in outdoor spaces [1]. Not all urban block scenarios have a significant effect on microclimate performance. In previous researches, urban climate has often been investigated at the mesoscale and the local scale [2], [3]. However, the study of climate parameters at the microscale is much more important, because variations can occur within a distance of 1 to 100 meters and are felt directly by humans at an altitude of less than two meters above ground level [4], [1].

This study examined the impact of building intensity and urban block typology on the performance of a number of microclimate parameters, i.e. air temperature, wind speed, relative humidity, and solar radiation. Furthermore, this study compared the microclimate parameter performance of an existing block typology scenario to five proposed scenarios. Bandung was used as the location for the case study.

1.1. Microclimate Parameters

In general, the microclimate of an area can be defined as the interaction between several meteorological elements in an urban area, i.e. solar radiation, air temperature, relative humidity, wind speed, and rainfall. Solar radiation falling onto the earth’s surface is called insolation. Insolation is the reception of solar energy by the earth’s surface in the form of short wave rays that pass through the atmosphere. There are three types of radiation that can create an acceptable air temperature in urban areas, namely direct radiation, diffused radiation, and reflected solar radiation [5]. Air temperature is a measure of how hot or cold an area is and is often used as a reference parameter. Air temperature provides the largest contribution (> 40%) to human thermal sensation in outdoor areas [6], [7].

Relative humidity (Rh) is a term that measures the amount of water vapor in the atmosphere from evaporation from the surface. It varies depending on the fluctuation of temperature changes: the higher the temperature, the higher the ability of the air to absorb moisture [5]. Wind is the movement of air from a high-pressure location to a low-pressure location. The difference in air pressure in an area is caused by differences in air temperature. The main parameters for evaluating wind are its speed, direction and frequency. Wind is a very unstable parameter because its characteristics depend on weather conditions and the topography of the area [8].

1.2. Hot and Humid Climate Profile of Bandung

The hot humid tropical climate has as main characteristics a high humidity (up to 80%), relatively high air temperatures (up to 35 °C), relatively low wind speeds (between 0.5 and 1.5 m/s) with dominant east and west wind directions [9]. It has long been recognized that the sensation of feeling hot or cold does not only depend on air temperature but all climate parameters interact with each other in determining human thermal sensation. The climate comfort parameters of people living in tropical areas are above the average of those who live in cold regions. The air temperature that provides human comfort in the tropical climate of
Bandung is in the range of 23 °C to 30 °C. Wind speed that creates thermal comfort is 0.25 m/s to 2 m/s, while the humidity should be in the range of 45% to 65% [10], [11].

1.3. Building Intensity and Urban Block Typology
Urban structures are influenced by building intensity. Building intensity is used as a measure to control the density and shape of buildings. For horizontal size, the building coverage ratio (BCR) index is used. Regulation of the BCR aims to regulate the proportion between the building area that covers land surface and unbuilt space. Land surface that is not covered by buildings is able to receive direct sunlight to make the soil dry out so that the air around the building becomes less damp. For vertical size, the floor area ratio (FAR) index is used. Regulation of the FAR has the effect of controlling the altitude, shading and movement of wind entering an urban area.

With the same building floor area or intensity values, urban blocks with various configurations and different building mass values can be realized [12]. Based on city zoning regulations, the determination of land intensity is influenced by the hierarchy of roads that cross the land parcels. The maximum intensities in the study area were BCR 70% and FAR 5.6.

2. Methods
The focus of the analysis in this study was the ‘urban block’, which is defined as the smallest area in urban planning. The urban block typology modeling was based on the existing building intensity and urban block typology in the urban area of Bandung. We investigated the microclimate parameter performance of the existing city block typology in Bandung and five new scenarios. The proposed scenarios refer to those proposed by Zhang et al, 2019, [12] which were adjusted to the block configurations allowed in the local city regulation context. The study was limited to an area of 350 x 350 x 150 (L x W x H) meters. The building type used in the modeling was a simple building without roof shape or eaves, without arcades or cantilevers, and with a floor-to-floor height of 4 meters.

![Figure 1. Proposed Block Typology Model Tower (1), Podium (2), Courtyard (3), and Hybrid (4)](image_url)
The observation of the climate parameters was only carried out on the horizontal plane at the height of pedestrians (height $z = 1.5$ meters). Climate data observed only on vertical surfaces were ignored. ENVI-met was used as the simulation tool to obtain climatological data on the microclimate for 24 hours. In this study, the lite version of the ENVI-met software was used. This version only allows simulations on a $40 \times 40 \times 100$ pixel grid as the maximum model area.

The analysis investigated the effects of the BCR and FAR settings and several block configurations on four microclimate parameters, i.e. air temperature, relative humidity, wind speed, and solar radiation, by using the microclimate data profile of Bandung.

2.1. Urban Block Typology in Bandung

Table 1 summarizes the simulation settings for the existing urban block typology in Bandung and the five proposed scenarios.

| Scenario | Intensity | Configuration |
|----------|-----------|---------------|
|          | BCR      | FAR | Podium | Tower | Courtyard |
| Existing | 74.56%   | 2.2 | ●      | ●     |            |
| 1        | 70%      | 5.6 | ●      | •     |            |
| 2        | <40%     | 5.6 | ●      | ●     |            |
| 3        | 70%      | 5.6 | ●      | ●     |            |
| 4        | 70%      | 5.6 | ●      | ●     |            |
| 5        | 70%      | 5.6 | ●      | ●     |            |

Source: Author’s own work

3. Result and Discussion

The ENVI-met analysis was conducted to examine the correlation between the BCR and the FAR and the microclimates parameters. R squared linear ($R^2$) regression data validation was performed to prove the accuracy of the field data and proxy weather with the simulation results from ENVI-met. The validation was done using the original regression analysis of $R^2$, where the simulation model was assumed to represent the existing conditions and the regression or the value of $R^2$ was not less than 0.4 [13]. From the above regression results, the regression values were $R^2 = 0.5355$ for air temperature, $R^2 = 0.5729$ for air humidity, and $R^2 = 0.9283$ for wind speed.

3.1. Correlations of BCR and FAR with Microclimate Parameters

Table 2 shows that BCR only has a correlation with relative humidity (Rh), which has an $R^2$ value of more than 0.4. BCR has a negative correlation with RH at $R^2 = 0.4318$. FAR has a significant correlation with air temperature ($R^2 = 0.9186$) and a significant negative
correlation with direct solar radiation ($R^2 = 0.6711$). The correlation of relative humidity with FAR is more significant ($R^2 = 0.6034$) than with BCR.

**Table 2.** Correlation Matrix for $R^2$ BCR and FAR with Microclimate Parameters

|     | Ta   | RH   | V    | Rad. |
|-----|------|------|------|------|
| BCR | 0.3159 | 0.4318 | 0.3947 | 4E-06 |
| FAR | 0.9186 | 0.6034 | 0.2002 | 0.6711 |

The simulation and analysis results reveal that when the BCR value of the study area was increased, the relative humidity was reduced and the wind speed was only slightly affected. When the FAR value of the study area was increased, the relative humidity increased more significantly and the value of air temperature and solar radiation decreased. Thus, this study indicates that the effect of FAR on the microclimate characteristics is more dominant than that of BCR.

In addition, an analysis of the climate parameters was also carried out. The simulation results show a positive correlation between air temperature and relative humidity ($R^2 = 0.753$). The increase in air humidity was inversely proportional to the fluctuation of temperature change. When the air temperature increases, the relative humidity decreases, and conversely, when the relative humidity increases, the air temperature decreases [5].

### 3.2. Effect of Urban Block Typology on Air Temperature

All scenarios had an average air temperature of 30.13 °C in 24 hours. The data in Figure 3 show a lower temperature difference between the existing scenario and the proposed scenarios. The difference in maximum temperature decay was 0.44 °C, which shows that the proposed scenarios all performed better than the existing scenario. This is consistent with the results of the previous analysis (see Figure 2). When the value of area outbreak was increased, the air temperature decreased. All the proposed scenarios had a higher FAR (5.6) than the existing scenario, which had an FAR of 2.2. Scenario 2 had an average temperature
as low as 29.98 °C due to the different intensity values, where the FAR was 5.6 and the BCR was lower than 40%. These settings create a configuration with a tower building. Leonardo’s analysis map shows that the BCR does not directly affect air temperature. Meanwhile, the FAR reflects building height. Tall buildings create more shade and thus lower the value of the daily average air temperature [14].

![Figure 3. Effect of urban block typology on air temperature in Bandung.](image)

The ENVI-met analysis showed that open courtyards correlate with a higher air temperature than closed courtyards. This result is different from the findings from other studies, according to which courtyard buildings and perimeter blocks store hot air [15]. This study revealed that when a courtyard has ventilation or openings, hot air and radiation from the surrounding area can enter and potentially increase the air temperature inside the courtyard. The orientation and height of the courtyard perimeter can also affect the air temperature. A courtyard orientation towards the north or south provides more shading.

### 3.3. Effect of Urban Block Typology on Relative Humidity

All scenarios had an average relative humidity of 54.07% in 24 hours. Based on the above analysis (see Figure 4), the correlation of R2 relative humidity with the FAR ($R^2 = 0.6034$) was greater than the correlation value with the BCR ($R^2 = 0.4318$). This means that increasing the FAR has a more significant effect on the relative humidity than increasing the BCR. Relative humidity also has a negative, or inverse, correlation with air temperature ($R^2 = 0.753$). When the air temperature increases, the relative humidity value decreases and vice versa [14].

In this study, the air humidity in the existing scenario was lower and considered better than the condition in the proposed scenarios. This is because the FAR in the existing scenario is lower (2.2) than in the proposed scenarios (5.6). A lower FAR value means more sunlight entering the area because less shadow is formed, which can reduce the relative humidity. Meanwhile, a higher FAR value has the potential to provide more shade from the building.
Figure 4. Effect of urban block typology on relative humidity in Bandung.

Scenario 2 (tower) shows that an increase of the BCR reduced the relative air humidity, where the FAR value remained 5.6. When the BCR value dropped to 40%, the humidity remained the highest compared to the other scenarios. The reason is that if the BCR value is lower, the amount of open land will be larger. Open land may be covered by materials such as soil, grass or pavement, which can increase evaporation and thus contribute to an increase in relative humidity. Having a courtyard is inversely proportional to air temperature. The relative humidity in an open courtyard is lower than in a closed courtyard. The relative humidity decreases due to reduced shading and the entry of wind into the courtyard. Conversely, in a closed courtyard there will be more shadow, which increases the humidity. Radiation from sunlight and wind movement can reduce the water vapor concentration in the atmosphere.

3.4. Effect of Urban Block Typology on Wind Speed

All of the scenarios had an average wind speed of 0.56 m/s. Referring to the results of the previous analysis (Figure 2), the BCR and FAR did not significantly affect the wind speed in the study area. Based on the graph below it can be seen that Scenario 2, which has a tower configuration and a low building density, had the highest average wind speed ($v = 0.67$ m/s) and the lowest BCR (40%). The wind is a very unstable climate parameter because its characteristics depend on the topographic conditions of the area, the height of the building, and the configuration of the building. On the other hand, the wind speed can be increased through the effect of channeling or blocking by the building composition to create high turbulence around the building [16].
Based on Leonardo’s map, it can be seen that there is stronger wind movement around tall buildings than around podium buildings or lower buildings. The simulation shows that the length and height of a building with a tower configuration greatly affect wind speed. This is in line with Beranek’s statement in Moonen et al. (2012). Therefore, tall buildings and towers are exposed to stronger winds due to their height and cause downward turbulence at the ground level, also known as the down dash effect [17].

The scenarios with an open courtyard (Scenario 1 and 2) had lower average wind speeds compared to those with a closed courtyard (Scenario 3, 4 and 5). The wind flow pattern with a closed courtyard is similar to that with a building without courtyard, in contrast to an open courtyard that can affect wind movement due to the shape of the opening and its orientation to the wind direction. When a U-shaped building has its back towards the direction of the wind, the effect will be the same as with a building without courtyard. Conversely, when a U-shaped building faces the direction of the wind, the airflow in the U shape will increase the wind speed.

Figure 5. Effect of urban block typology on wind speed in Bandung.

Figure 6. 3D view of wind flow pattern around isolated tall buildings. (Adapted from Moonen et al, 2012).
3.5. Effect of Urban Block Typology on Solar Radiation

The average solar radiation in 24 hours was 244.94 W/m². The highest solar radiation was 908.82 W/m² precisely at 12.00 o’clock. The simulation showed the existence of an equinox phenomenon, where there is no shade from the building because the sun is in a 90° perpendicular position. The existing scenario had a high BCR (74.56%), while the low FAR (2.2) creates a horizontal building skyline that receives more radiation (rad = 282.39 W/m²). Scenario 2 has a low BCR (40%) and a high FAR (5.6), creating a vertical building skyline and causing less solar radiation (rad = 250.73 W/m²).

![Figure 7](image)

**Figure 7.** Effect of urban block typology on direct solar radiation in Bandung.

This analysis is in line with the previous statement, that the FAR affects the height of the building and creates shadow from the building, which causes those areas to receive less solar radiation. Scenario 3 with a hybrid block configuration consisting of a podium building, a closed courtyard and a wide tower building causes the area to receive lower radiation values compared to the other configurations. A building with a tower configuration that surrounds a courtyard is highly favorable for reducing incoming solar radiation [18].

4. Conclusion

This study investigated the impact of urban block typology and building intensity on the performance of microclimate parameters. It was revealed that the BCR has a correlation with relative humidity and wind speed. If the BCR is increased, the relative humidity and wind speed will be reduced. The FAR has a correlation with air temperature, relative humidity, and solar radiation. If the FAR is increased, the relative humidity increases significantly and the air temperature and solar radiation decrease. The FAR has a more significant influence on the microclimate parameters than the BCR. The BCR affects horizontal surfaces more, while the FAR affects vertical surfaces more. Scenario 3 has the most optimum microclimate parameter performance with a hybrid block consisting of a podium, a tower and a courtyard. A closed courtyard configuration has the effect of lowering air temperature, lower solar radiation, and lower wind speed compared to an open courtyard, but has higher relative
humidity and wind speed. A tower has an effect on the wind speed around the building, causing a down dash effect towards the ground level of tall buildings.

5. References

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