Impact of Land Use/Land Cover on the Microclimate of Elementary School Blocks: A Case Study of Kurosaki Area

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高齢者や児童の健康状態は、その狭い生活圏に固有な日照や気温、風の強さなど、いわゆる微気候の影響を受けやすい。そこで北九州市黒崎地区の４学区について、建築密度、緑地率、道路舗装率、天空率を調べ、比較検討した。

Abstract

As the global climate continues to warm, climate and environmental changes brought about by urbanization have become the focus of attention. Land use/land cover plays an increasingly important role in changes in outdoor physical environments. In addition, changes in urban climate are more harmful to vulnerable groups, especially for senior citizens and young children. However, few studies have focused on microclimate change around elementary schools. This research took four elementary schools in the Kurosaki area as examples. According to the land use/land cover data, the peripheral types of schools were divided into four categories: commerce, high green areas, residences, and public places. Through field measurement and ENVI-met simulation, this study tried to make clear the land use/land cover impact on the microclimate around elementary schools based on the urban block as the research scale. The results indicated that the measured air temperature trends of schools in different categories were significant differences. Also, the microclimate around the elementary school was closely related to building density, green plot ratio, impervious ground surface fraction, and sky view factor. The findings of the research provide a reference for the design of the environment around the elementary school and the overall urban planning.

Keywords land use/land cover; elementary school, ENVI-met, microclimate

1. Introduction

Rapid urbanization has been undergoing all over the world since the second half of the 20th century. According to the National Census in 2015, the total population of Japan was about 127 million and the urbanization rate of Japan was approximately 93%[1)]. Cities have become the main settlements of humans. Previous research has demonstrated the impact of urban microclimates on outdoor human comfort, the energy consumption of buildings, and the spread of air pollutants. Air temperature (Ta) and wind speed are the two most representative microclimate parameters[2)]. High temperatures sometimes induce serious health problems such as heatstroke, cardiovascular diseases, and even death, especially for senior citizens and very young children[3)]. Airborne transmission is an important way of transmitting influenza viruses and respiratory syncytial viruses[4)].

Land use/land cover (LU/LC) has become a critical driver of urban microclimate formation at the microscale. The increase of artificial surfaces and the density and layout of buildings have direct impacts on the microclimate. In previous studies, four commonly used parameters in urban planning and architecture of building density (BD), green plot ratio (GnPR), impervious ground surface fraction (PAVE), and sky view fraction (SVF) were used to characterize urban morphology[5)]. Reducing BD has a more significant influence on mitigating the urban heat island effect and can reduce the temperature rise and length of time of the heat island effect by approximately 30%[6]. Urban green infrastructure, such as parks, street trees, and green roofs, are often suggested for urban planners to adjust the urban microclimate[7].

Despite the extensive research on microclimate in open spaces, most research objects are main streets, residential quarters, and parks. School is the main place where children learn. As children spend most of their time at school, it is crucial to provide students with a healthy and comfortable learning environment. Physical, visual, and auditory comfort conditions required for learning and the energy consumption of school buildings have always been the focus of research. However, little attention has been paid to the microclimate around elementary schools.

For these purposes, we used the research method that combines field measurement and ENVI-met software numerical simulation. This study aimed to bridge these gaps by assessing the microclimate performance of urban morphology at the block scale by considering different elementary school block types. Finally, it revealed the relative importance of LU/LC to the elementary school blocks with an objective to formulate optimum design strategies for improving the outdoor thermal environment of elementary school blocks. The research results arising from this study provide valuable insights for informing future elementary school block-scale designs.

2. Methodology

2.1. Study area

This study was carried out in Kurosaki (33°51'N, 130°45'E), located in Kitakyushu City, Japan. It has a Pacific Ocean side climate. June to September were the hottest months, the average air temperature is 22.7–27.8 °C. Most of the Kurosaki area is an urbanization promotion area, and the area around Hobashira Mountain is an urbanization control area. The land use on the north and south sides of Kurosaki also shows obvious differences, as shown in Fig. 1.

Four elementary schools (Kurosaki Chuo Elementary school [C1], Hikino Elementary School [R1], Kurogahata Elementary School [G1], Hagiwara Elementary School [P1]) had been selected to conduct field measurements 24 h per day from August 1 to August 31, 2012. C1 is in commercial zone, R1 is in Category I residential zone, and G1 and P1 are in Category I mid/high-rise oriented residential zone. The elementary school facilities include school buildings, gymnasiums, swimming pools, and playgrounds.

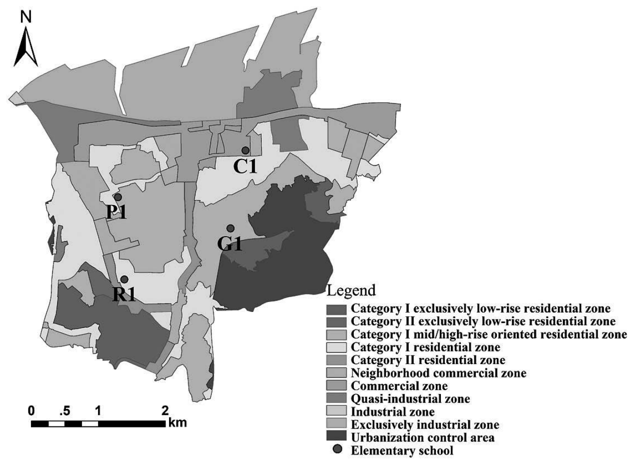

Fig. 1. Land use zones in Kurosaki

This study took the school block as the research scale. The 300 m scope centered on the elementary school was used as the study area, as shown in Fig. 2. According to the LU/LC database of Kitakyushu 2012, the peripheral type of 4 schools were divided into the following four categories: commerce, high green area, residence, and public place. Table 1 summarizes the morphological parameters of each school block. Due to the C1 containing large-volume or high-rise buildings, BD and PAVE were the highest among all the study areas, and GnPR was the lowest. The situation of G1 was the opposite of that of C1. The BD and PAVE were the lowest, and GnPR was the highest. The vegetation was dense, especially the tall trees. At the same time, the tree canopy played a role in blocking the sky and reducing the SVF of the area. R1 is mainly middle- and low-rise residences, and the PAVE value was higher. P1 is surrounded by a middle school and parks, and the GnPR was slightly higher than that of R1.

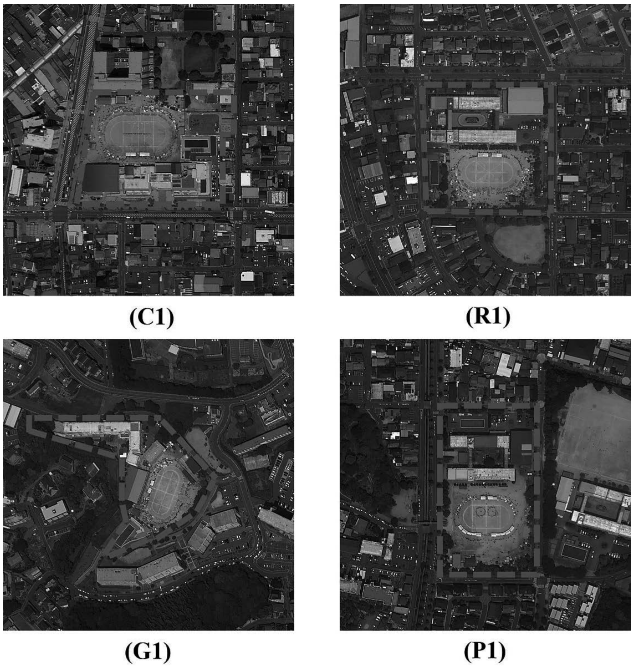

Fig. 2. Spatial characteristics of 4 elementary school blocks.

(Source: Google Earth)

Table 1. Urban morphology characteristics around 4 schools.

Study	C1	R1	G1	P1
Peripheral type	Commerce	Residence	High green area	Public place
BD	33.19%	23.60%	13.54%	20.33%
GnPR	5.55%	17.52%	47.36%	20.74%
PAVE	78.44%	67.09%	45.77%	58.46%
SVF	0.47	0.46	0.33	0.41

2.2. *Field measurement*

A louver box was placed at each elementary school, the underlying surface of these observation points is soil. To monitor the air temperature at the pedestrian level, the temperature sensor Platinum resistance thermometer Pt100 and data recording device DATAMARK LS-3300PtV were taken at 1.5 m above the ground, as shown in Fig. 3. The air temperature measurements were performed every minute. The reference thermometer was used for calibration before measurement to avoid measurement errors.

In this work, days with clear, calm, and sunny weather conditions were most appropriate for microclimate analysis. Affected by humid air currents and typhoons, there were many rainy days during the field measurement period. The sunshine time and precipitation data from the Yahata Weather Station were used to filter out typical days. The sampling framework for filtering typical days consisted of a daily precipitation of 0.0 mm and a sunshine rate of 50% or more. Based on these criteria, 13 typical days in August were selected.

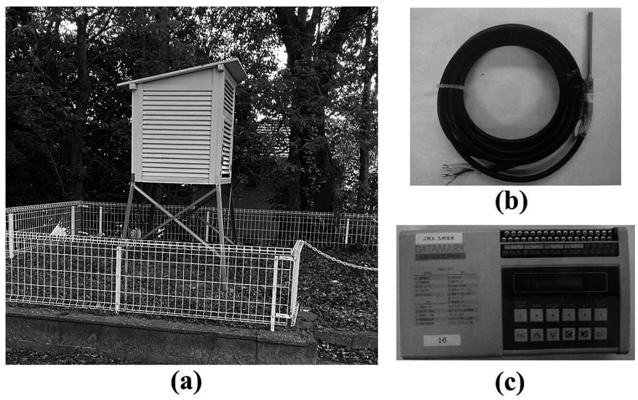

Fig. 3. Measurement tools.

2.3. *ENVI-met simulation*

In this study, numerical simulations were conducted using ENVI-met software. The model area was 300 m × 300 m × 90 m with 150 × 150 × 30 three-dimensional grids, the horizontal and vertical grid resolutions were 2 m and 3 m respectively. The plant and soil database, and building properties were obtained from Google Earth satellite images (captured on May 26, 2012), LU/LC data (2012 Kitakyushu), and field measurements at four sites. The simulated date was selected as a typical summer day on August 18, 2012, from 00:00 to 24:00. To avoid the influence of the initialization (24 h), numerical simulations were conducted for August 17, 2012. Table 2 shows the input configuration to the simulation model. The initial air temperature in the atmosphere was 302.2 K. The initial wind speed was 1.4 m/s, and the wind direction was 202.5°.

Table 2. Input configuration used in simulation with ENVI-met.

Parameter	Input value
Start Date	August 17, 2012
Start Time	00:00
Total Simulation Time	48 h
Wind Speed in 10 m height	1.4 m/s
Wind Direction (0: N, 180: S)	202.5°
Initial Temperature of Atmosphere	302.2 K
Relative Humidity in 2 m	78.59%
Special Humidity at model top	7.0 g/kg

This study selected the coefficient of determination (R^2) and the root mean square error (RMSE) to evaluate the validity of the ENVI-met model. The RMSE calculation is shown in Equation (1).

$$RMSE = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (\mathrm{Ta}_i - \widehat{\mathrm{Ta}}_i)^2} \quad (1)$$

where n is the number of measurements, Ta_i is the measurement, and $\widehat{\mathrm{Ta}}_i$ is the simulation

3. Results and discussion

3.1. Model validation

The ENVI-met model was validated considering the hourly measured and predicted Ta of each elementary school. Fig. 4 shows the scatter diagram of the measured and simulated Ta values. The R^2 value ranged from 0.93 to 0.98, and the RMSE value ranged from 0.50 °C to 1.22 °C. Overall, a strong agreement was found between the simulated and the measured Ta. And the ENVI-met model can accurately simulate the outdoor microclimate environment of elementary school blocks.

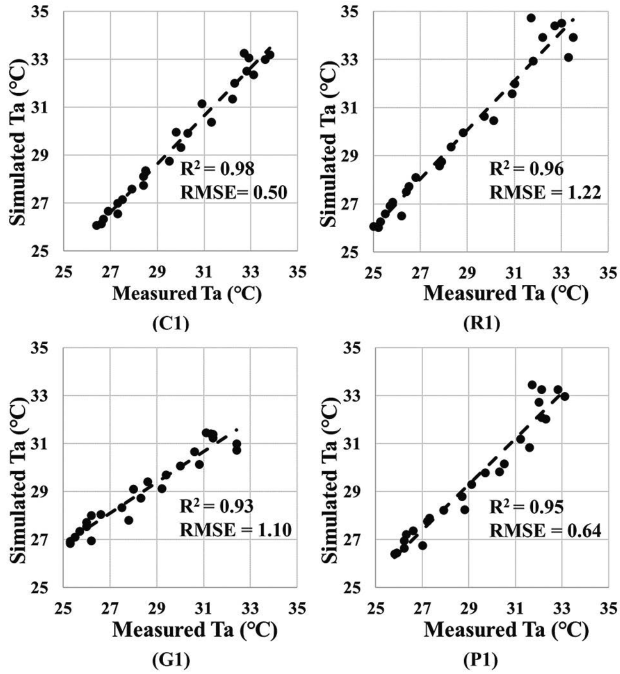

Fig. 4. The comparison between measured and simulated Ta

3.2. Comparative analysis of measured data

The air temperature of 4 elementary schools on typical days during the observation period was compared, as shown in Fig. 5. Ta reached its highest value at approximately 14:00 and approached its lowest value at approximately 06:00.

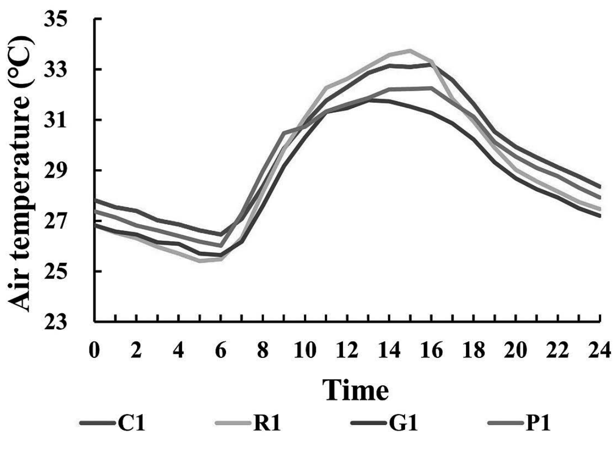

Fig. 5. Comparison between Ta of four schools on typical days

There were obvious differences in air temperature throughout the day between different elementary schools. C1 school is located in the core area of Kurosaki, where the air temperature has been maintained high throughout the day. This was because the Kurosaki station center is basically commercial land, with high building density and a lot of high-rise buildings. The surface cover is mainly asphalt and concrete, and the artificial heat removal of vehicles and the air conditioning equipment of buildings have increased significantly. Therefore, the air temperature raised rapidly during the daytime, and it was difficult to drop significantly at nighttime. The average air temperature was 29.7 °C, which was the highest value among all schools. Because of the existence of large areas of the natural surface in the study area, the air temperature of G1 school remained low throughout the day, even during the hottest period from 14:00 to 15:00. The average air temperature was 28.6 °C. Many middle and low-rise residential buildings and the occupation of the natural surface by the artificial surface made the air temperature of the R1 school increase sharply after sunrise (6:00), even slightly surpassing C1 school between 10:00 and 16:00. At the same time, residential land had low BD and less artificial heat removal, so the heat was easily diffused at night, and the air temperature was low. The average air temperature was 29.2 °C. The air temperature of P1 school fluctuated relatively little throughout the day, with an average air temperature of 29.3 °C.

3.3. *Spatial distribution of air temperature and wind speed*

From the past study, the most uncomfortable microclimate hour is approximately 14:00 in summer. This time is also the time when people are more active.

Based on the 24 h simulation results, the air temperature of 4 study areas at a height of 1.5 m above the ground at 14:00 was generated. Fig. 6 and Fig. 7 show the distribution of air temperature and wind speed.

The overall Ta of the C1 school was more consistent than that of the R1 school and the P1 school, and the average air temperature of the C1 school was 33.3 °C. High-intensity LU/LC existed around the C1 school. Ta

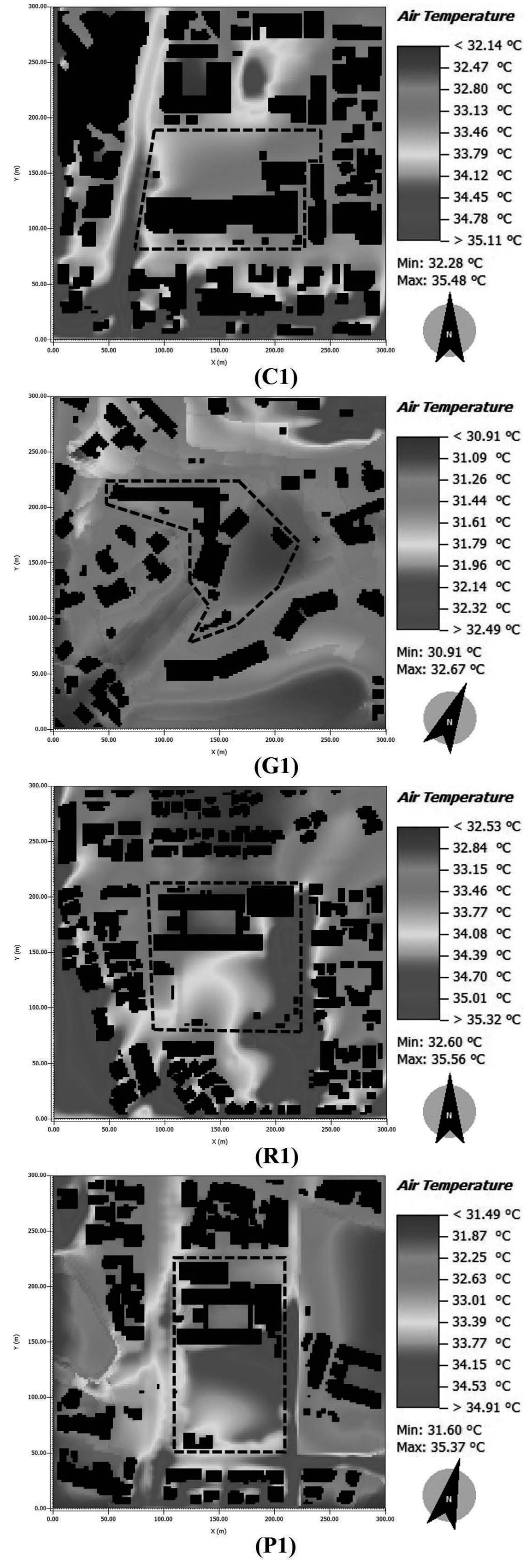

Fig. 6. Distribution of Ta at 14:00 on August 18, 2012.

range of G1 school was not only relatively consistent but also the lowest among all schools. The existence of many natural surfaces around the school provided a good thermal environment for the school and effectively alleviated the rise of school Ta. Therefore, the overall Ta difference of G1 school was the smallest, and the average air temperature was 31.2 °C. The Ta range of R1 school was relatively discrete, with an average air temperature of 34.0 °C, which was higher than that of C1 school. The lack of shelter on many asphalt surfaces of the school and the impact of the park on the south side of the school were the main reasons for the local high Ta in the R1 school. The Ta range of P1 school was relatively more consistent than that of R1 school, and the average Ta of the P1 school was 33.7 °C.

The distribution of Ta followed the wind direction, with a higher Ta on the southeast side of the study area. The Ta in the sandy soil area on the left of the park in C1 was significantly higher than that in the lawn area on the right. The main road was also an area with higher Ta, and the surface is asphalt. The overall average Ta of the G1 school block was the lowest among all school blocks. Affected by the wind speed, the situation in the playground of the school belonged to the area with relatively low Ta, which was opposite to that of other schools. Land shape had a greater impact on Ta; that is, the lower the height of the land, the higher the Ta. In the R1 study area, the arterial roads were also areas with higher Ta. Because the surface is asphalt, the ground vegetation is sparsely covered. In addition, the school playground and the park with a sandy soil surface formed a continuous high Ta area. The P1 school playground and the park where the surface is sandy soil on the left also formed a continuous high Ta area. Building shadows played a role in reducing Ta. Moreover, the height of the middle school on the right was higher than that of the elementary school, the playground Ta dropped by approximately 2 °C.

When we compared the numerical distribution of the four elementary schools, the value of the wind speed of C1 school was relatively consistent. Because of the existence of many high-rise buildings around the school, the wind speed on the campus was more stable. In addition,

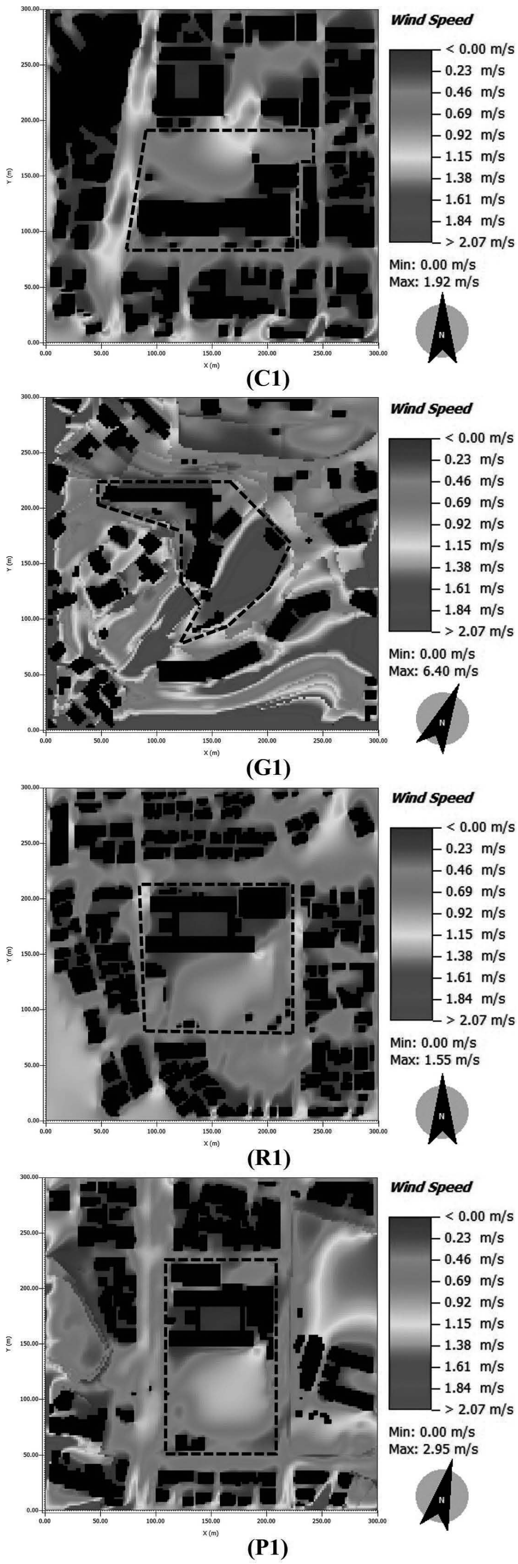

Fig. 7. Distribution of wind speed at 14:00 on August 18, 2012.

the park on the north side of the school increased part of the wind speed of the C1 school. The average wind speed was 0.64 m/s. The overall wind speed of G1 school was the highest among all schools, and the average wind speed was 1.28 m/s. The land height around the campus fluctuated greatly, and less dense buildings on the surface promoted airflow. Furthermore, the obstruction of the teaching building led to local low wind speed, resulting in the difference in the numerical value of wind speed in the school being relatively large. R1 school had less vegetation, and the distribution of wind speed values was scattered, with an average wind speed of 0.56 m/s. When the area around the school is public, the average wind speed of the P1 school was 0.60 m/s.

The channeling effect formed by the main road on the left of the C1 school and the connection between the playground and the park played an important role in optimizing airflow within the school. The wind speed was higher in the open area around the G1 school, and there were fewer low-wind-speed areas in the study area. The playgrounds of the G1 school belonged to areas with higher wind speeds in the study area, which can enhance airflow within the school. The wind paths around the R1 school improved the wind environment of the school. Because of tall trees, parks cannot optimize the wind speed of the campus. The wind path around the P1 school increased the wind speed in the school. In the same environment, the middle school with a higher land height on the right had a higher overall faster airflow than the elementary school.

3.4. *Correlation between school block microclimate and urban morphology*

This study analyzed the relationship between the average air temperature and wind speed of the study area and urban morphology, as shown in Fig. 8.

The BD was positively correlated with the average air temperature of the study area; that is, an increase in BD promoted an increase in Ta ($R^2 = 0.7883$). The average air temperature of the study area had a close positive correlation with PAVE and SVF. The increase in these two parameters deteriorated the Ta in the study area. On the contrary, the average air temperature of the study area had a significant negative correlation with GnPR ($R^2 = 0.9756$), and the increase in the GnPR value effectively reduced the Ta of the study area.

The average wind speed of the study area had a close negative correlation with PAVE and SVF. The coefficient of determination R2 was 0.8023 and 0.9638. The BD was negatively correlated with the average wind speed; that is, it increased the value of BD to weaken the average wind speed ($R^2 = 0.6868$). The effect of GnPR on average wind speed was the opposite.

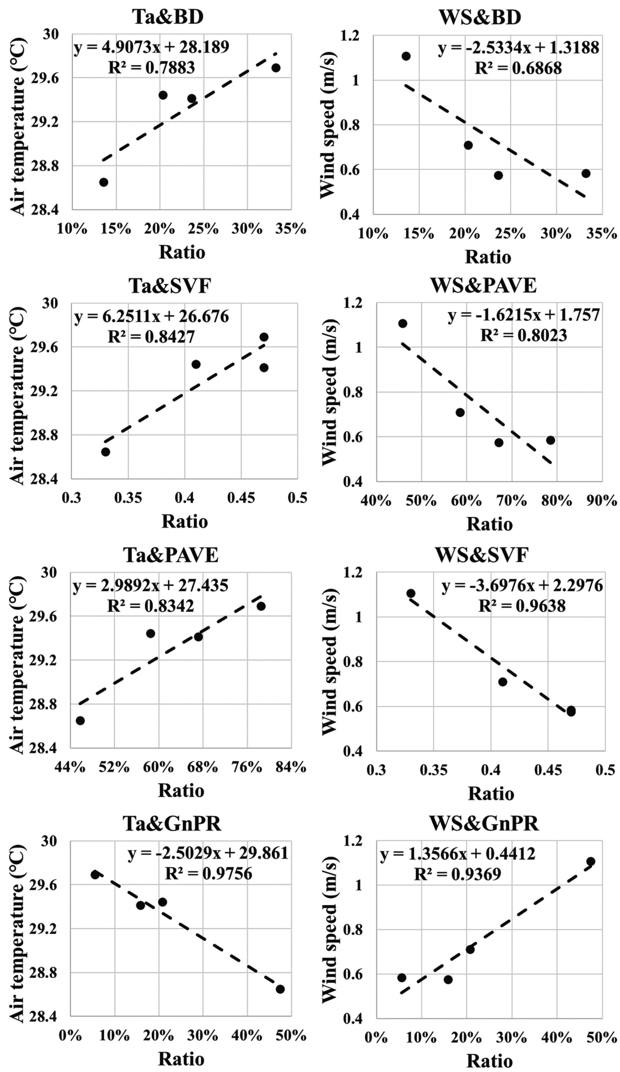

Fig. 8. Relationship between school block microclimate and urban morphology at 14:00 on August 18, 2012.

4. Conclusion

This paper selected 4 elementary schools in Kurosaki, Japan as the research objects. Through field measurement and numerical simulation, the current situation of microclimate around the elementary school was analyzed from the block scale. According to the LU/LC database, the four research areas were divided into four categories. Afterward, validated ENVI-met numerical simulations were carried out to evaluate the microclimate of school blocks. The major conclusions of this study are as follows.

First, based on school blocks with different LU/LC, there were significant differences in air temperature values measured throughout the day in elementary schools, especially between C1 school and G1 school. The difference between the two schools of average air temperature was 1.1 °C.

Second, although BD, GnPR, PAVE, and SVF had different correlations with the microclimate, these four urban morphology parameters were important factors affecting the microclimate of elementary school blocks.

Third, building shadows played an important role in reducing the air temperature. The surface of sandy soil and asphalt caused significant deterioration of local air temperature. On the contrary, vegetation effectively mitigated high air temperature. The land height of the study area affected air temperature.

Finally, the playground was an area with a high wind speed in the school. And the wind path around the school enhanced airflow in schools. Dense buildings and trees dropped down wind speeds. The land shape had a significant impact on the airflow; that is the higher the land height, the higher the wind speed.

Nonetheless, our findings may have some limitations. This study only involved four elementary schools in the Kurosaki area, and the number of cases was small. Subsequent studies should add cases to include all elementary schools in the Kurosaki area.

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