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Effect of Underground Space Development on the Outdoor Thermal Environment in a Residential Area

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Abstract: The outdoor thermal environment of the underground parking system of a residential area in Nanjing, China is simulated using ENVI-met software for three planning schemes in which underground space is not used, partly used, and fully used. The scale of underground space development is found to affect the outdoor thermal environment. The quality of the outdoor thermal environment is best when the underground space is fully used. Compared with the situation where underground space is not used, the partial use of underground space reduces the wind speed by up to 0.09 m/s, reduces the air temperature by up to 0.5 °C, and increases the relative humidity by up to 3%, whereas the full use of underground space decreases the wind speed by up to 0.33 m/s, reduces the air temperature by up to 1.1 °C, and increases the relative humidity by up to 5%. The use of underground space is shown to improve the ecological environment of the residential area and enhance the quality of the outdoor thermal environment.

1. Introduction

The rapid development of the economy and urbanization in China have adversely affected the natural ecosystem and outdoor thermal environment in China. The most representative phenomenon is the urban heat island effect. The urban heat island effect directly affects people's daily and work lives and is more obvious in residential areas [1]. Realizing humanized living conditions is currently a main challenge facing urban engineers.

Underground spaces are increasingly being developed in residential areas, with functions that have low requirements for natural light and heat being transferred underground so as to create more land for greening and waterscapes and thus improve the environment.

In a study on improving the environment by developing underground spaces in residential areas, Golang and Ojima [2] presented design ideas and principles in terms of the psychology and thermal properties of underground living. Peng [3] considered the development of underground spaces as an effective way of realizing green residential areas. However, the cited studies emphasized the effectiveness of developing underground spaces only in terms of improving the environment, which is a macroscopic analysis. There has been little quantitative analysis. In our previous study [4], we employed computational fluid dynamics to simulate the outdoor thermal environment of residential areas for two plans, one of which included underground space development and the other did not. That study did not consider the effect of the development scale on the outdoor thermal environment.

The present study takes the underground parking system of a residential area in Nanjing, China as the research object. The simulation software ENVI-met is used to investigate the effect of the scale of



underground space development on the outdoor thermal environment for three planning schemes in which underground space is not used, partly used and fully used.

2 .Case Study

2.1 Research Tool: Envi-met

Envi-met comprises five sub-models and can be used to simulate effectively the change in the outdoor microclimate [5]. We previously verified the applicability of the software through field experiments. More details on ENVI-met are given in the literature [6].

2.2 Research Project

This paper takes a residential underground parking system as the research object. The residential area is located in the east of the city of Nanjing in Jiangsu Province, China. The planning area is 87,000 m², the overall floorage area is 233,000 m² and the floor area ratio is 2.6. The community has eight high-rise residences and 960 families. The actual scheme has fully developed underground parking and is referred to as scheme C in this paper. To study the effect of the scale of underground space development on the outdoor thermal environment, we consider two other schemes having the same building layout and landscaping design, namely schemes A and B, which are based on Standards and Guidelines of Construction of the Building's Equipped Parking-lot in Nanjing (2015 Amendments), as shown in Figure 1(a) and 1(b). In Figure 1, scheme A has ground-level parking for 126 vehicles; scheme B has partly underground parking and partly ground-level parking for 90 vehicles; and scheme C has underground parking. Twelve monitoring points are set as shown in Figure 1(c) to study the effect of the scale of the development of underground space on the outdoor thermal environment. This study used meteorological data recorded at the Nanjing base station and provided by the Dedicated Meteorological Data Set for Building Thermal Environment Analysis in China. The study site is located at 32° N, 118°48' E and 7.1 m above sea level. The input simulation parameters are given in Table 1.

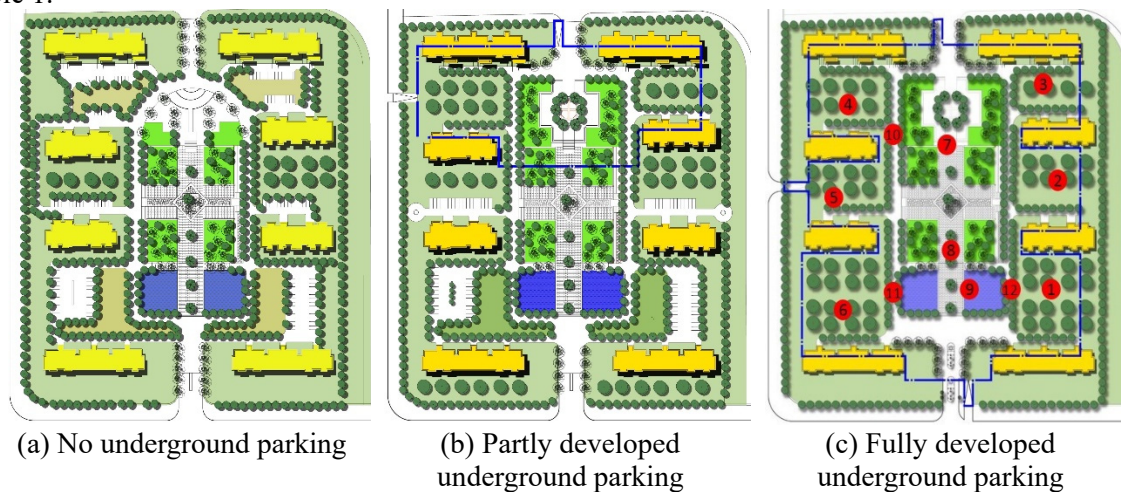


Fig. 1 Three planning schemes

Table 1. Inputs of simulation

Typical Meteorological Day	Relative Humidity (%)	Wind Velocity (m/s)	Wind Direction (degree)	Initial Atmospheric Temperature (K)	Outdoor Atmospheric Pressure (Pa)	Initial Time	Total Simulation Time (h)
6.23 (Summer)	80	2.4	157.5	294.95	100250	6:00	12

3. Results and Analysis of the Case Study

3.1 Comparative Analysis of the Wind Environment

Figure 2 presents fields of the wind environment 1.5 m above the ground at 15:00 on a typical summer's day for the three schemes. Overall, the distribution of the wind speed is similar in the community areas among the three schemes. The northern and southern gateways form a north–south air duct, with high-rise buildings either side of the entrances of the two gateways producing a narrow-pipe effect that increases the wind speed. In the areas above the underground space developments, plants block the spread of airflow and reduce the wind speed.

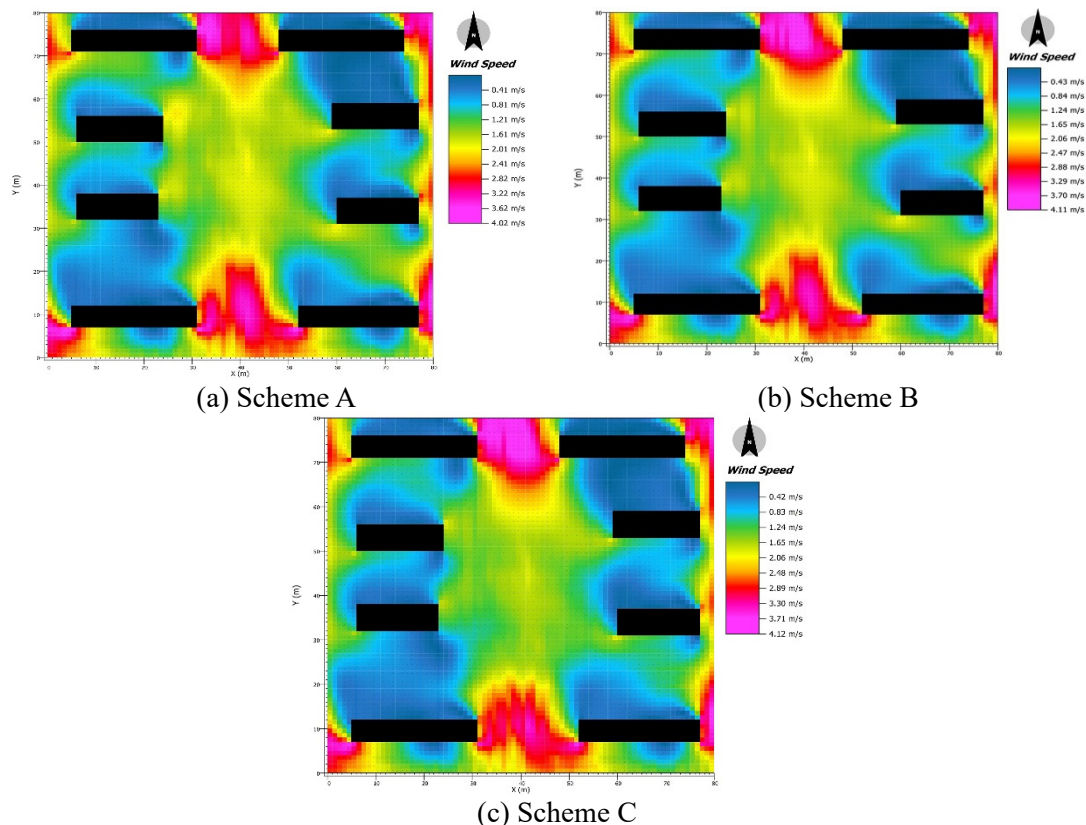


Fig. 2. Wind-speed cloud atlases of the three planning schemes on a typical summer's day

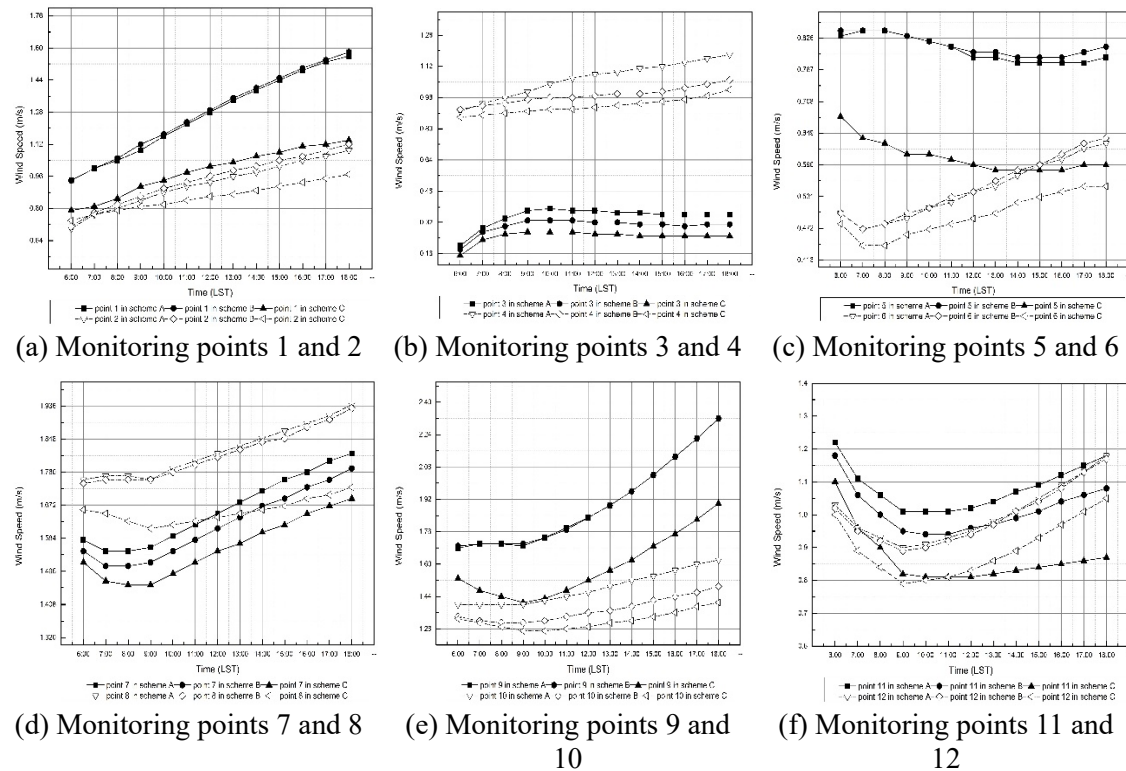


Fig. 3 Hourly wind speed curves at monitoring points for the three planning schemes

Figure 3 compares hourly wind speed curves of the 12 monitoring points for the three planning schemes. The average wind speeds recorded at monitoring points 3 and 4 are respectively 0.05 and 0.09 m/s lower in scheme B than in scheme A. The wind speeds recorded at monitoring points 1–6, inside the area of underground exploitation, are lowest for scheme C, with the average wind speeds being 0.28, 0.06, 0.1, 0.14, 0.2, and 0.05 m/s lower than those in scheme A, respectively. These results show that as the scale of the underground space development increases, the greater abundance of plants strongly affects the wind environment.

At monitoring points 7–12, outside the area of underground exploitation, the wind speed is again lowest for scheme C, with the average wind speeds being 0.1, 0.16, 0.33, 0.16, 0.22, and 0.11 m/s lower than those in scheme A, respectively. These results indicate that the change in the surface also affects the wind environment outside the area of underground space development.

3.2 Comparative Analysis of Air Temperature

Figure 4 presents fields of the air temperature 1.5 m above the ground at 15:00 on a typical summer's day for the three schemes. The air temperature decreases from high to low in the order of plan A, plan B, and plan C; i.e., the air temperature drops with an increase in the scale of underground space development.

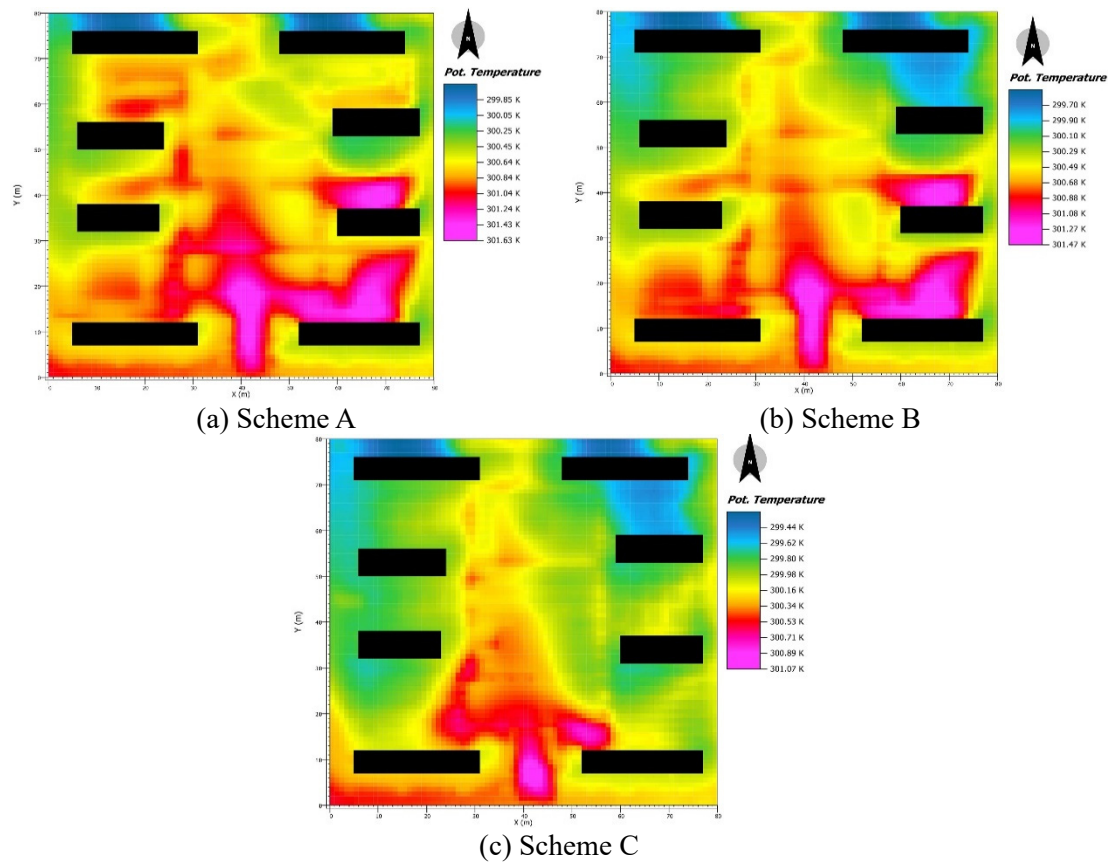


Fig. 4 Air temperature cloud atlases of the three planning schemes on a typical summer's day

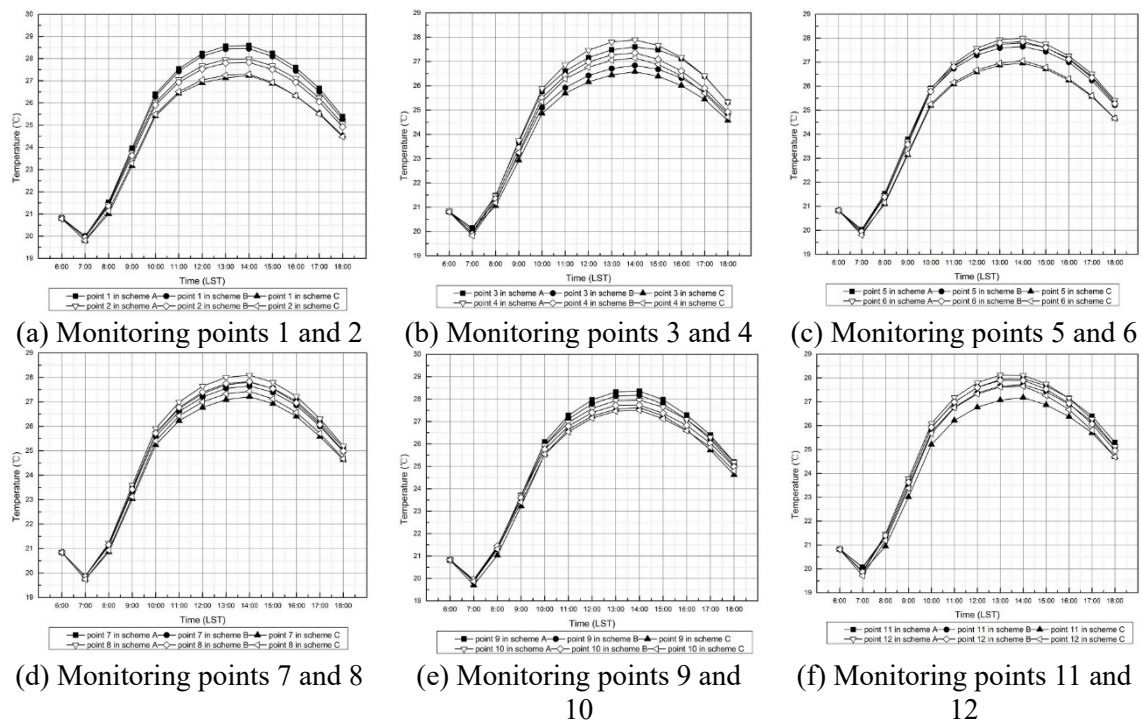


Fig. 5 Hourly air temperature curves of monitoring points for the three planning schemes

Figure 5 compares hourly air temperature curves of the 12 monitoring points for the three planning

schemes. The average air temperatures at monitoring points 3 and 4 in scheme B are respectively 0.5 and 0.4 °C lower than those in scheme A. The air temperatures recorded at monitoring points 1–6 are lowest for scheme C, with the average air temperatures being 1.1, 0.5, 0.8, 0.5, 0.7, and 0.7 °C lower than those in scheme A, respectively. These results show that as the scale of the underground space development increases, the greater abundance of plants strongly affects the air temperature.

The air temperatures recorded at monitoring points 7–12 are respectively 0.1, 0.2, 0.1, 0.2, 0.2, and 0.2 °C lower for scheme B than for scheme A and 0.5, 0.5, 0.5, 0.3, 0.6, and 0.4 °C lower for scheme C than for scheme A. This indicates that the increase in greening due to the development of the underground space blocks solar radiation, and transpiration affects the energy balance around the underground space development and reduces the air temperature.

3.3 Comparative Analysis of Relative Humidity

Figure 6 presents fields of the relative humidity 1.5 m above the ground at 15:00 on a typical summer's day for the three schemes. An increased green area enhances transpiration and evaporation of water from the ground and increases the relative humidity in the area of underground development.

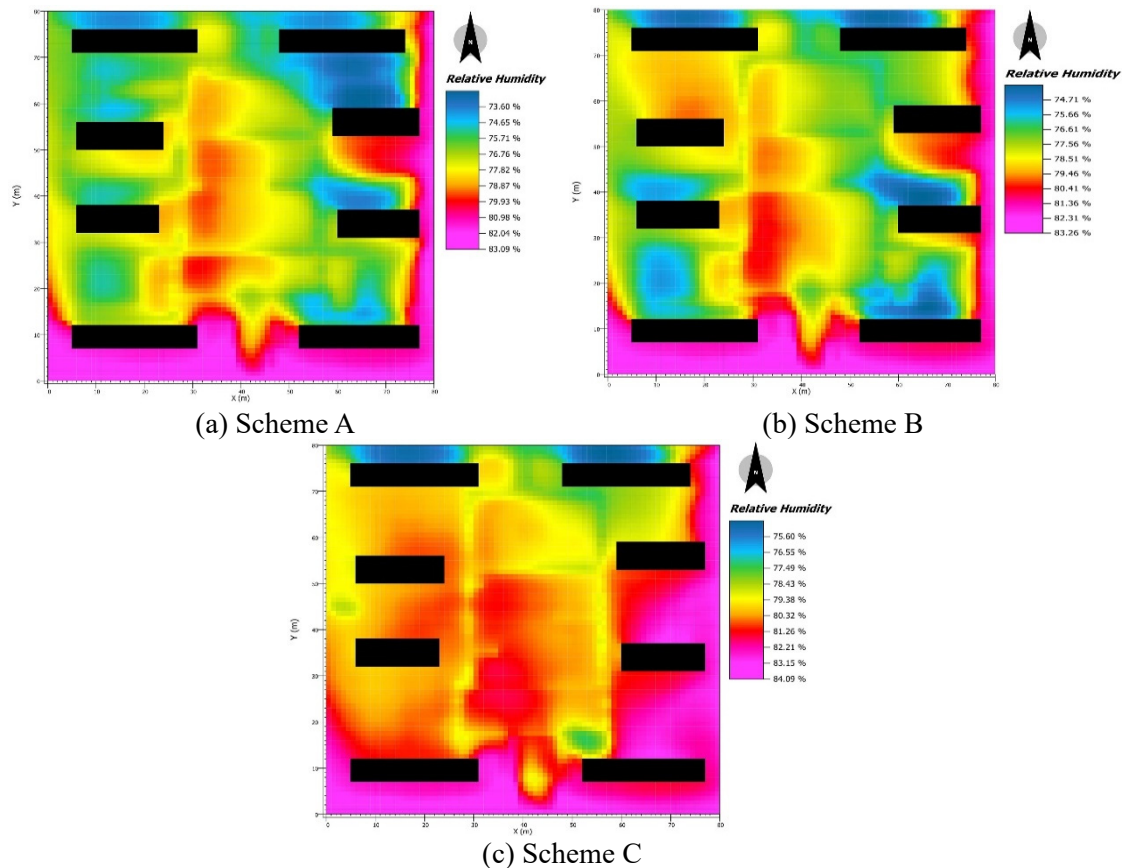


Fig. 6 Relative humidity cloud atlases of the three planning schemes on a typical summer's day

Figure 7 compares hourly relative humidity curves of the monitoring points for the three planning schemes.

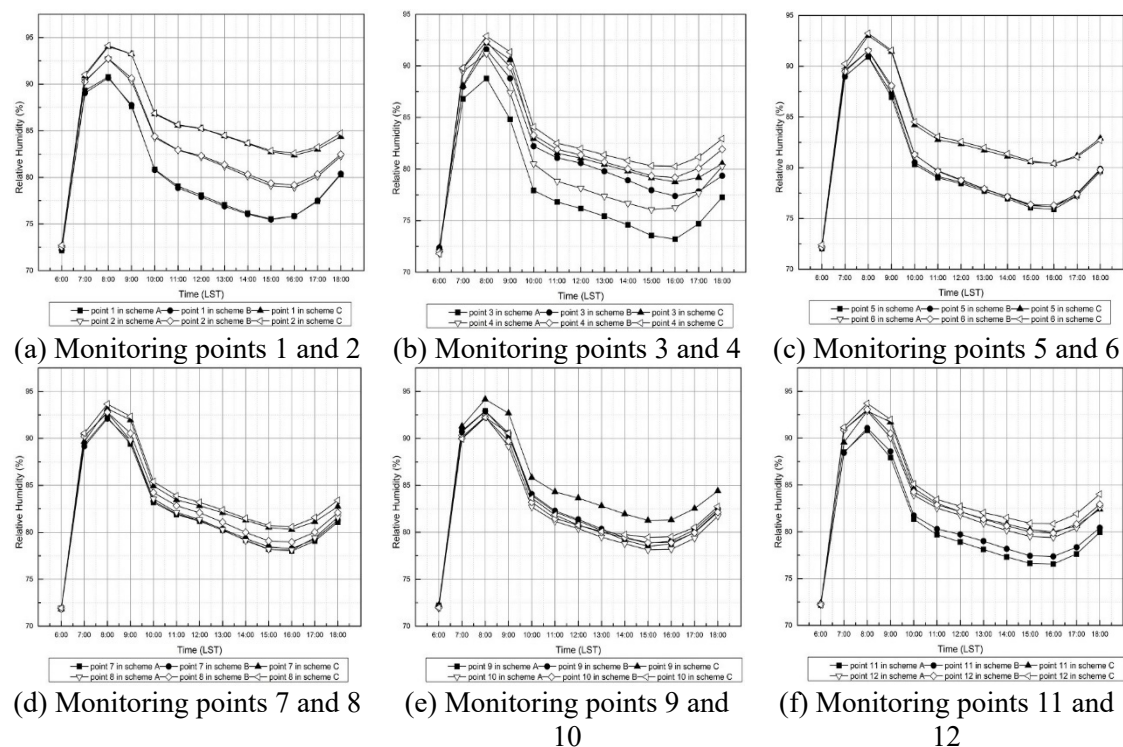


Fig. 7 Hourly relative humidity curves of monitoring points for the three planning schemes

For schemes A and B, monitoring points 1, 2, 5, and 6 are on hard soil and the differences in relative humidity are small. For scheme C, the greater vegetation obviously increases the relative humidity. The average relative humidity is respectively 5%, 3%, 3%, and 3% higher in scheme C than in scheme A, indicating that an increase in green area due to the underground space development increases the relative humidity.

The relative humidity curves are similar at monitoring points 7–12, which are outside the area of underground exploitation, because of the similar ground surfaces.

4. Conclusions

We used the simulation software ENVI-met to quantify the effect of the scale of underground space development on the outdoor thermal environment. The following findings are taken from the results of the study.

First, a change in the ground surface remarkably affects the outdoor thermal environment. Compared with ground-level parking, the development of an underground parking system can make the most of land resources and increase the size of green areas. The increasing greening partially blocks solar radiation. The transpiration of plants reduces the air temperature, improves the outdoor air humidity, and provides a comfortable outdoor thermal environment.

Second, scheme B has wind speeds up to 0.09 m/s lower, air temperatures up to 0.5 °C lower, and relative humidity up to 3% higher than scheme A, while scheme C has wind speeds up to 0.33 m/s lower, air temperatures up to 1.1 °C lower, and relative humidity up to 5% higher than scheme A. The residential green area increases in size with an increase in the scale of underground space development, which effectively improves the quality of the outdoor thermal environment of the residential area.

Residential areas are an important part of the urban landscape, and the development of underground space in residential areas will play a positive role in solving parking problems, enlarging urban green areas, and improving the quality of the urban environment.

Acknowledgments:

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