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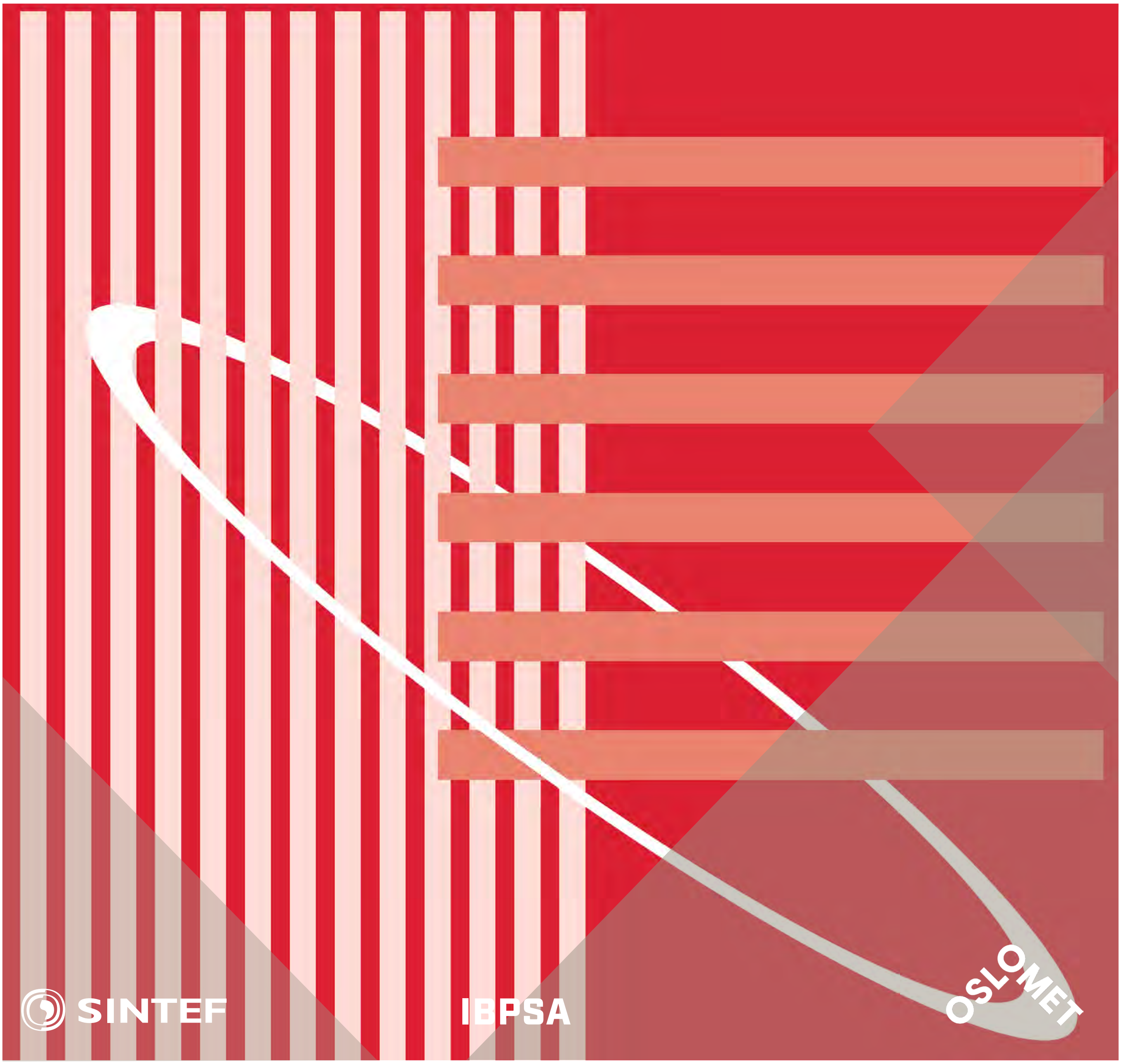

SINTEF Proceedings

Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

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Simulation Study on the Influence of the Urban Street Intersection Greening on Ventilation Performance

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Nomenclature

PFR(purging flow rate)

NEV(net escape velocity)

LOR(Land occupation rate)

GC(Green coverage)

GVR(Greening volume ratio)

Abstract

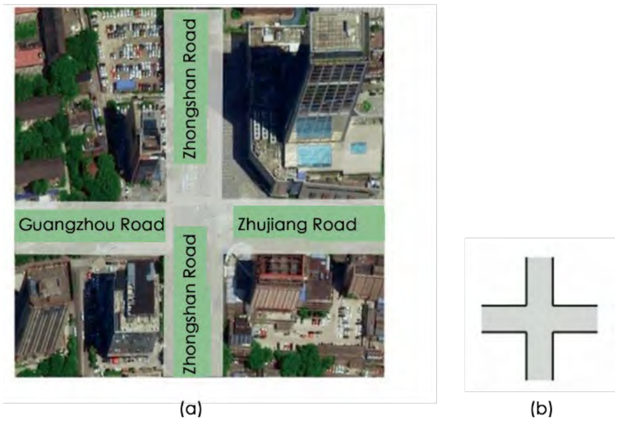
This article hopes to explore the impact of single-row shrubs, single-row trees, and double-row trees on the ventilation performance of street intersections. By simplifying the shape of intersections, ideal models can be built. Use the model and numerical simulation software FLUENT of the cross street intersection to simulate the airflow and pollutant distribution of the intersection, the wind direction is 0 ° and 45 °. Mainly analyzed the pollutant cloud maps of the three height parts (0.5 m, 1.5 m and 5 m), and compared the average speed, average concentration and maximum concentration of the vertical height intersection area, and studied the streets in different directions of green intersections under different wind directions Impact. According to the simulation results of wind speed and pollutant distribution, find the internal flow field and pollutant diffusion law at the intersection of the intersection, and use the ventilation index to compare the greening layout of the intersection and the intersection, especially the ventilation effect of the pedestrian activity space at the bottom. This article hopes to obtain a greening form based on street intersections that focus on urban ventilation and are beneficial to the diffusion of pollutants.

Introduction

At present, many studies have shown that the intersections of urban streets are the most polluted areas of automobile exhaust (Ahmad K, Khare M, Chaudhry K K, 2005). The air quality in this area is poor, and the air index is easily exceeded, especially the high CO content, which seriously harms human health (Hlavinka M W, 1988). The impact of greening on street air quality is controversial. On the one hand, people think that the greening of street canyons is usually a part of the urban landscape strategy, which has an aesthetic value of appreciation, but also has the functions of evaporative cooling, adjusting humidity, improving local microclimate, and avoiding direct sunlight (Chen et al., 2014; Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013; GILL, HANDLEY, ENNOS, & PAULEIT, 2007; Rui, Buccolieri, Gao, Ding, & Shen, 2018; Rui, Buccolieri, Gao, Gatto, & Ding, 2019). On the other hand, more and more studies have found that plants have the ability to remove pollutants, and plants have the ability to purify air by filtering pollutants. Plant leaves absorb gaseous pollutants through stomata, while particulate matter is removed from the air by depositing on leaves and branches (Bealey et al., 2007; McDonald et al., 2007; NowakCrane & Stevens, 2006; Tallis, Taylor, Sinnett, & Freer-Smith, 2011).

Methods

Urban street intersections usually take many forms according to the structure, traffic and commercial building forms of urban streets. According to the number of branches, there are different types of three-way, four-way intersections, roundabouts, etc. The research object selected in this paper is a typical four-way intersection. Figure 1a shows a sketch of four-way in the city of Nanjing (China); based on this, idealized intersection is established (Figure 1b).



(a) (b)

Figure 1. a) Sketch of the types of four-way intersection in Nanjing, China; b) idealized intersection chosen as study case.

In summary, this article sets up three groups of single greening cases. As shown in Figure 2, a single row of shrubs is arranged in the center of the street, two rows of shrubs are arranged on both sides of the street, and two rows of trees are arranged in the street. The green layout and green indicators in this example are shown in Table

1. Table 1 details the green form and related green indicators used in this article. Occupancy rate represents the area of street land occupied by greening. Since trees only occupy a part of the trunk, this part of the area is negligible.

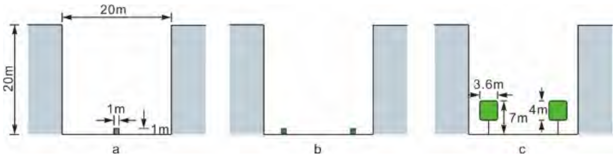


Figure2. Shrub and tree layout Case

Table 1. Greening layout and greening index

	Plant type	Greening pattern	LOR (%)	GC (%)	GVR (%)
a	Shrub[a]	A row of bushes lined up in the middle of the street	3.9	3.9	0.2
b	Shrub	Double rows of shrubs on both sides of the street between motorized and non-motorized lanes	7.8	7.8	0.4
c	Arbor[b]	Double row arbors, arranged on both sides of the street, between motor vehicles and non motor vehicles	0.0	28	5.6

Note: a). In this paper, the height of shrub is 1m, and the density of leaf area is $2m^2/m^3$. b). In this paper, the height of arbor is 7m, the height of crown is 3-7m, and the density of leaf area is $1m^2/m^3$.

The overall model is 460 m long and 460 m wide (Figure 3). The main body of the model (indicated as Case in the figure) is composed of 40 m x 40 m building blocks. In the case of a street canyon with an aspect ratio (W / H) of 1, the street width is 20 m and the building height is 20 m. To consider the influence of surrounding buildings, two rows of buildings are added at the intersection.

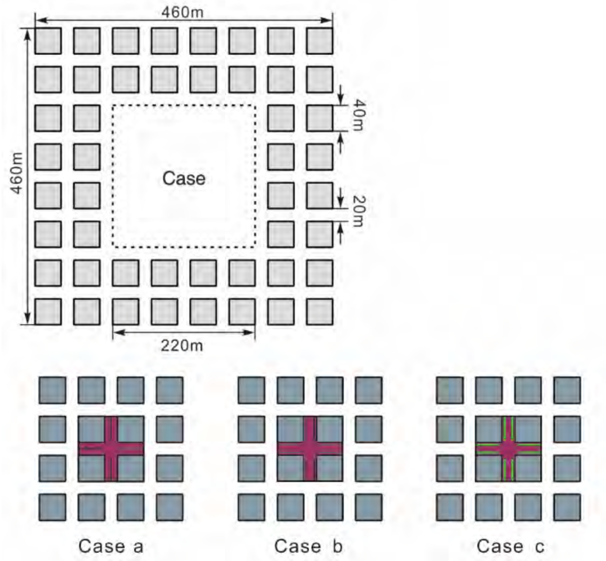


Figure3. Sketch of the model considered in the CFD simulations

In the case simulation, the wind direction is 0 ° and 45 °. In Figure 4, taking 0 ° as an example, the calculation domain and boundary conditions used in the CFD simulation are shown.

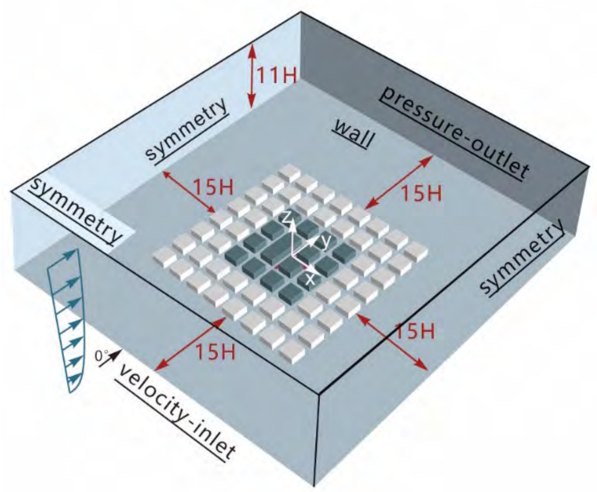


Figure4. Computational domain and boundary conditions used in CFD simulations for 0°

These simulations were performed using ANSYS fluent 16.0. And we choose a standard k-ε model to close the turbulence equation. At present, many scholars have adopted the k-ε standard to study the ventilation and pollutant diffusion of urban streets, and the results are within the acceptable range.

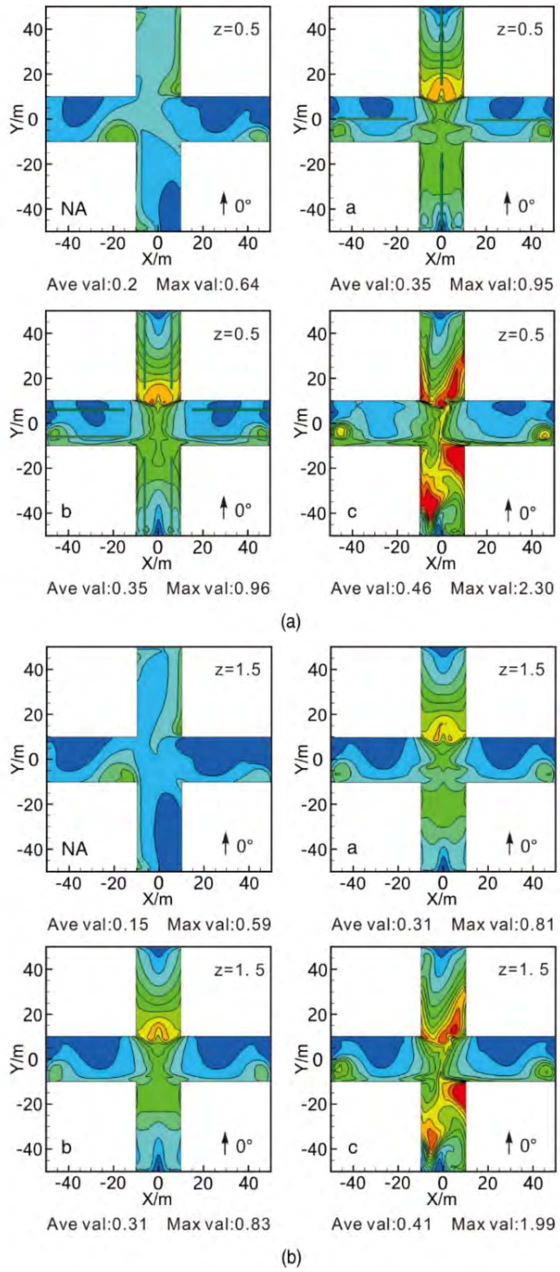
In all the cases considered, the convergence criteria were met after about 3500 iterations using a mesh size of approximately 2460000 cells. The mesh size were selected based on the results of the mesh independent tests. The minimum grid in the intersection area is 0.025 h, i.e. 0.4 m.

The case simulation condition setting in this article has been compared with the urban wind environment simulation and the porous plant simulation, and is compared with the case of the Japanese Architecture Society (AIJ). Relevant wind tunnel test models and experimental data can be obtained on the official website of the Architectural Society of Japan (AIJ Guideline for Practical Applications of CFD to Pedestriau Wind Environment around Buildings).

This article uses the purging flow rate (PFR) and net escape velocity (NEV). PFR is one of the most important indicators for determining the effectiveness of local ventilation. It can be considered as an indicator for studying the efficiency of local ventilation and refers to the air flow required to effectively remove air pollutants outside the area (KatoIto & Murakami, 2003).

Results

The concentration of pollutants at intersections with height of 0.5 m, 1.5 m and 5 m is shown in Figure 5 when there are no plants（Case NA） and Case a, b and c with plants. At 0.5 m, 1.5 m and 5 m sections, the concentration of pollutants decreased sequentially. Case NA-0 pollutant concentration is mainly concentrated on the downstream of the Y-axis street and the downwind side of the X-axis street. The flow velocity and pollutant concentration distribution of each height of a-0 are relatively symmetrical. The concentration of pollutants in the streets in the Y-axis direction has been significantly increased, especially at the entrance of the downstream streets, the accumulated pollutants in the upstream are blocked by the downstream shrubs. So that the concentration of pollutants in this area is obviously increased. The high concentration of pollution in this area may have an adverse effect on human health. It is noteworthy that the highest concentrations at 0.5 m, 1.5 m, and 5 m can reach respectively, 0.95 g/m^3, 0.81 g/m^3 and 0.57 g/m^3. The average concentration and distribution of Case b-0 are basically the same as Case a-0, and there is no obvious change. Due to the barrier effect of the forest canopy on ventilation, the concentration of Case c-0 pollutants at all heights increased significantly, especially on both sides of the Y-axis street and the center of the intersection. The average concentration of each section can reach 0.46 g/m^3, 0.41 g/m^3 and 0.26 g/m^3, and the maximum concentration can reach 2.30 g/m^3, 1.99 g/m^3 and 0.83 g/m^3, respectively.



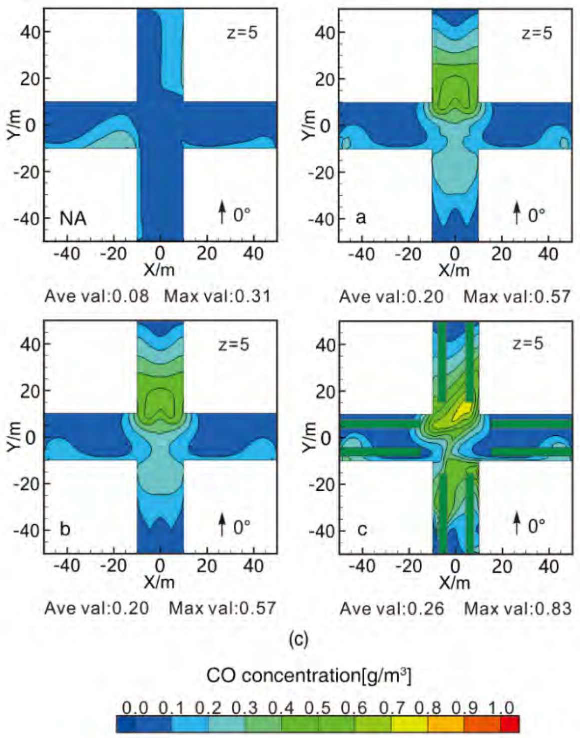
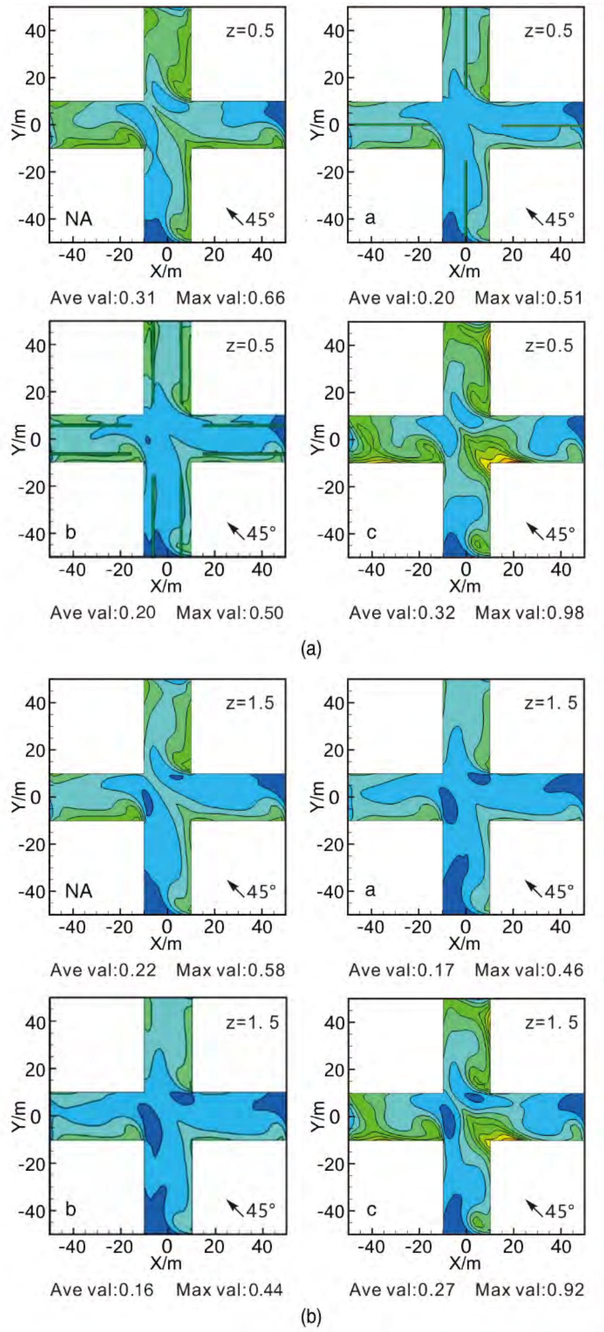


Figure 5. Case NA-0, a-0, b-0, c-0 central intersection at the height of 0.5m, 1.5m, 5m

When the wind direction is 45 °, the pollutant concentration drops sequentially at heights of 0.5 m, 1.5 m, and 5 m, as shown in Figure 6. The concentration at 45 ° is slightly higher than that at 0 °. Case NA-45 pollutant concentration is mainly concentrated on the leeward side and corner of the building. At heights of 0.5 m, 1.5 m and 5 m, the maximum concentrations can reach 0.66 g/m^3, 0.58 g/m^3 and 0.35 g/m^3, respectively. The average concentration and maximum concentration of pollutants in each height section of Case a-45 decreased slightly. At 0.5 m, due to the effect of shrubs, the horizontal diffusion of pollutants was blocked, the vertical diffusion capacity of pollutants was increased, and the concentration of pollutants on the windward and leeward surfaces decreased. In the direction of the Y-axis, the concentration of street pollutants increased significantly, especially at the entrance of downstream streets, where the pollutants accumulated upstream and were blocked by the downstream bushes, which significantly increased the concentration of pollutants in the area, and adverse health effects. The two rows of shrubs in Case b-45 can improve the air quality at the intersection, and reduce the average concentration and maximum concentration at each height. The maximum pollutant concentration is mainly distributed around the two rows of shrubs, unlike Case a-45. The concentration of pollutants in the center is low. Due to the influence of the canopy, the pollutant concentration of Case c-45 increased, especially the local pollutant concentration of the two streets in the downstream wind direction and the leeward side of the building in the lower right corner of the figure. The average pollutant concentration at each height was 0.32 g/m^3, 0.27 g/m^3 and 0.12 g/m^3, and the maximum concentration was 0.98 g/m^3, 0.92 g/m^3 and 0.66 g/m^3, respectively.



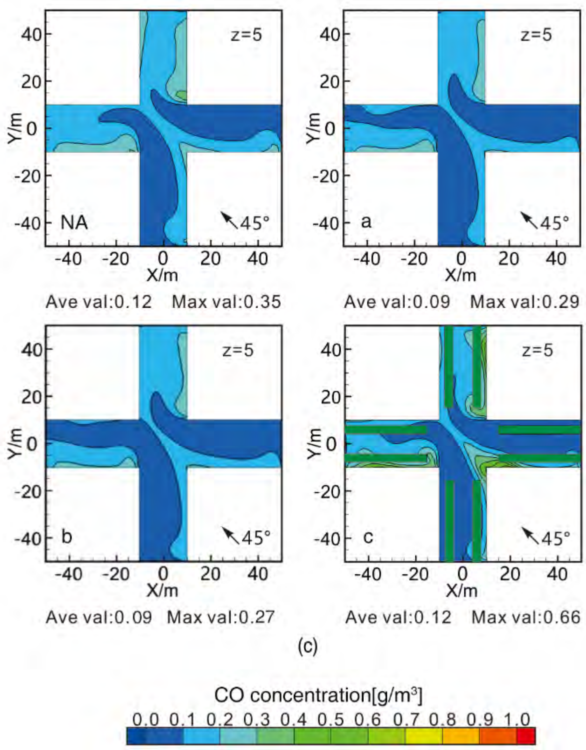


Figure 6. Case NA-45, a-45, b-45, c45 central intersection at the height of 0.5m, 1.5m, 5m

Discussion

As shown in Figure 7, the light histogram shows the average wind speed in Case NA-45 without greening, and the dark histogram shows the average speed in the intersection after different greening is arranged. The average speed of the intersections with plants at different heights is changed. Figure 7a is the comparison of the average wind speed in the height direction of the center intersection Case a-0, Case a-45 and Case NA-0, Case NA-45. Figure 7b comparison of the average wind speed in the height direction of the central intersection of Cases b-0, Cases b-45 and Cases NA-0, Cases NA-45. Figure 7c shows the comparison of the average wind speed in the height direction of the central intersection of Case c-0, Case c-45 and Case NA- 0, Case NA-45. At 0 ° wind direction, compared with Case NA-0, the average wind speed of each height section of each intersection with greening has a significant decrease, especially the section of 1.5 m to 10 m, the average speed drop More than half of them, the speed change is very obvious. At 45 ° wind direction, it can be found that the average velocity in the sections Case a-45 and Case b-45 is increased compared to the case without greening, but the impact of greening is relatively small. Case c-45 due to the effect of greening, the average speed of each height section has been reduced. In addition, it was also found that the average speed and wind speed of the headspace had a very significant drop, which means that the condition of the two rows of trees has a certain effect on the air exchange at the top of the intersection building.

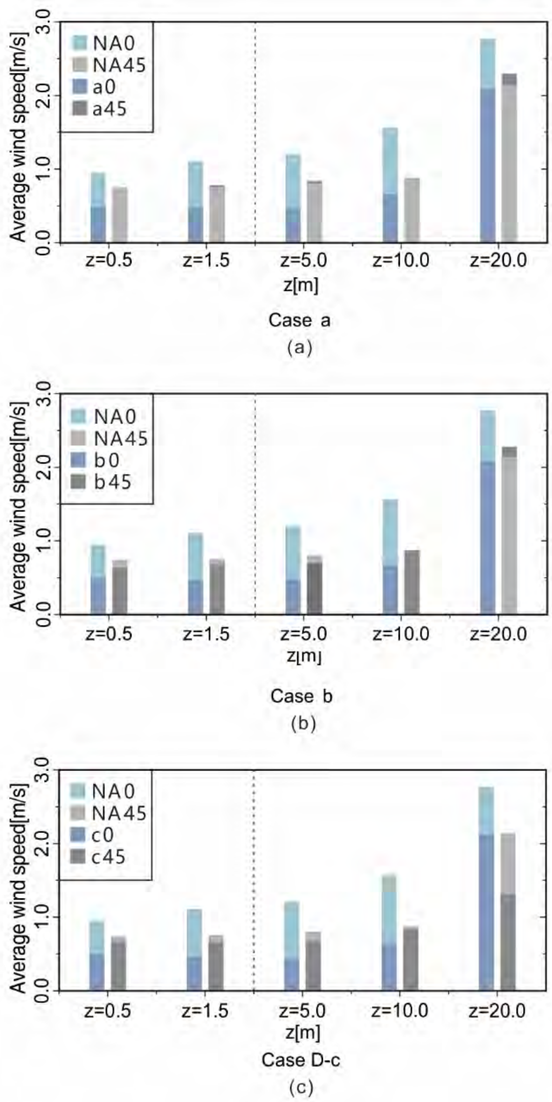
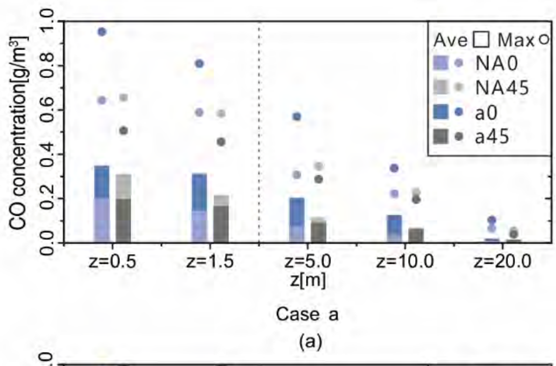
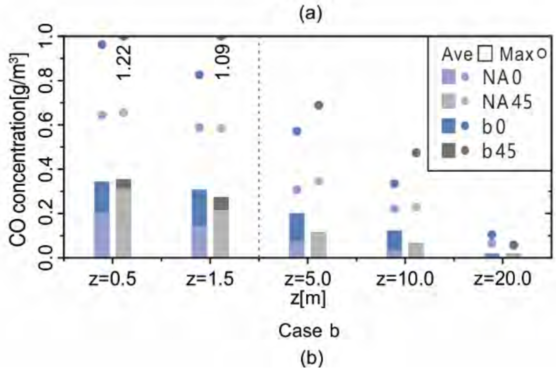


Figure 7. a) Comparison of the average wind speed in the height direction of the central intersection between Case a-0, a-45 and Case NA-0, NA-45; b) comparison of average wind speed in the height direction of Case b-0, b-45 and Case NA-0, NA-45; c) Comparison of average wind speed in the height direction of Case c-0, c-45 and Case NA-0, NA-45

As shown in Figure 8, the light-colored histogram represents the average concentration in Case NA-45 without greening, the light-colored dots represent the maximum concentration, and the dark-colored histogram represents the average in the intersection after different greenings concentration, dark-colored circles indicate the maximum concentration. This series of graphs quantifies the average concentration and the degree of change of the maximum concentration at different heights of intersections containing greenery. Figure 8a is the comparison of the average concentration and the maximum concentration in the height direction of the center intersection Case a-0, Case a-45 and Case NA-0, Case NA-45, Figure 8b shows comparison of the average concentration and the maximum concentration in the height direction of the Case b-0, Case b-45, and Case NA-

0, Case NA-45. Figure 8c shows the comparison of the average concentration and the maximum concentration in the height direction of the central intersections of Case c-0, Case c-45 and Case NA-0, Case NA-45. At 0 ° wind direction, the average concentration of each height section of each intersection containing plants has a significant increase compared to Case NA-0, especially in Case c-0, the average concentration of each section has been increased. More than half, the concentration change is very obvious. At 45 ° wind direction, it can be found that Case a-45 and Case b-45 have improved the average concentration in the cut surface, and the degree of decrease is most obvious at the cut surface of 0.5 m, which is reduced by nearly 0.3 g/m^3. In Case c-45, due to the action of plants, the average concentration of the bottom of the cut surface has increased, and it has little effect on the central and top areas. On the contrary, the average concentration of Case c-45 decreased slightly at the section of 5 m and 10 m, which was due to the role of the tree canopy to block some upward diffusion pollutants. At 0 ° wind direction, the average concentration of each section of each case increased, especially in Case c-0, which is three times as much as the original, the maximum pollutant concentration at the bottom 0.5 m and 1.5 m reached 2.3 g/m^3 and 1.99 g/m^3, respectively. At 45 ° wind direction, the single-row shrub arrangement in Case a-45 and the double-row shrub arrangement in Case b-45 both reduced the maximum pollutant concentration and had an improved effect on the air quality in the intersection. For Case c-45, greening has a significant impact on the maximum concentration of pollutants in the street, greatly increasing the maximum concentration of pollutants at various heights, especially at 0.5 m and 1.5 m, the maximum concentration of pollutants can reach 2.3 g/m^3 and 1.99 g/m^3.





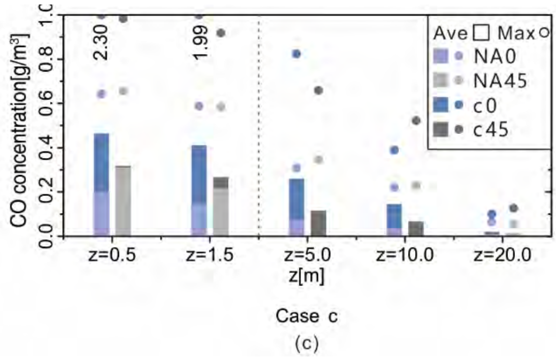


Figure 8. a) Comparison of average concentration and maximum concentration in the height direction of Case a-0, a-45 and Case NA-0, NA-45; b) Comparison of average concentration and maximum concentration in the height direction of Case b-0, b-45 and Case NA-0, NA-45; c) Comparison of average concentration and maximum concentration in the height direction of Case c0, c45 and Case NA-0, NA-45

Figure 9 is based on the Case NA-0 and Case NA-45 without greening, analyzes the extent to which the average speed and average concentration of different areas at the pedestrian height in the intersection are affected by plants. As seen from the velocity and pollutant clouds above, at 0° wind direction, the velocity and pollutant clouds are symmetrically distributed along the Y-axis coordinate, and the velocity in the downstream area is small and the concentration of pollutants is large. At 45° wind direction, the velocity and pollutant clouds are distributed symmetrically along the Y = -X-axis.

It can be found from Figure 9a that when the wind direction is 0 °, the average wind speed in the areas A and B of each case has decreased by at least 25%. In particular, the area A is greatly affected by plants, at least a 60% drop. The difference between the forms of single-row shrubs, double-row shrubs, and double-row trees are small. Shrubs have a relatively large impact on area A, and area B is greatly affected by double-row trees. At 45 ° wind direction, it can be found that area A in Case a-45 and Case b-45 is affected by plants, and the average wind speed has increased. The average wind speed in each area of the remaining cases has decreased, and the highest can be reduced by nearly 40%. When the wind direction is 45 °, the wind speed decreases more obviously in area B due to the influence of plants, especially in the case of double-row trees; the average wind speed in area A is relatively less affected by plants, especially in case a, double-row trees can reduce The average wind speed of nearly 20%.

From Figure 9b, we can find that when the wind direction is 0 °, the plants have a greater influence on the average concentration in the A and B areas. In particular, the average concentration in area A has at least doubled. Relatively speaking, the effect of plant morphological arrangement on concentration is not very obvious. Double-row trees will increase the average pollutant concentration in the area by more than 125%. Due to the effect of shrubs in area B, the average concentration of pollutants increased by about 50%; the effect of double-row trees was more obvious, causing the average concentration of pollutants in the area to increase by about 80%. When the wind direction is 45 °, it can be found that the concentration of pollutants in areas A and B of Cases a-45 and b-45 has decreased, and the air quality in this area of the shrub structure has an improving effect. Both rows of trees increased the average pollutant concentration in areas A and B. The average concentration in area B was relatively significantly affected by plants. Due to the accumulation of more pollutants in the local area near the ground, a larger concentration of pollutants was produced.

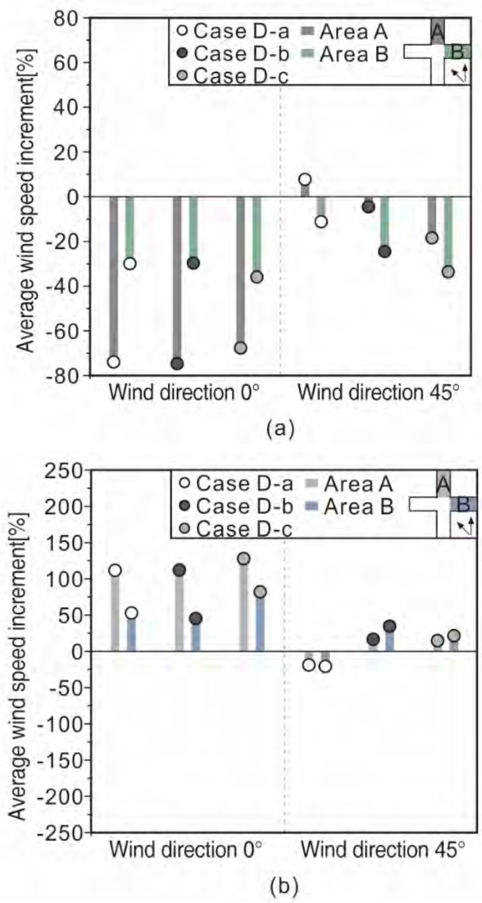


Figure 9. a) Effects of plants on average street speed at different intersections; b) Effects of plants on the average concentration of streets at different intersections.

The ventilation indexes PFR and NEV of Case a, Case b, Case c, and Case NA are shown in Figure 10. When the wind direction is 0 °, in the absence of greening, the ventilation performance below 2 m is good, the ventilation index PFR exceeds 430 m^3/s, and the ventilation index NEV exceeds 0.1 m/s; The ventilation indexes PFR and NEV of Case a-0, Case b-0, Case c-0 have decreased significantly, which means that the ventilation performance of the space area has gradually deteriorated. The PFR of Case a-0 and Case b-0 exceeds 200 m^3/s; The PFR of case C-0 is relatively lower, in contrast, the ventilation performance is poor. From here, we can find that the presence of greening has a greater impact on the ventilation performance of spaces below 2 m at 0 ° wind direction: in the presence of plants, the ventilation performance will be significantly reduced; The effect of the performance is close, and the effect of double-row trees is relatively large. When the wind direction is 45 °, compared with the Case NA-0, the ventilation performance of the Case NA-45 without greening has decreased, the ventilation index PFR is only 280 m^3/s, and the NEV is 0.07 m/s. It can be seen from the figure that when there is a 45 ° wind direction, the ventilation indicators of the Case a-45, Case b-45 and Case c-45 with plants exist are not significantly different from those at 0° wind direction. At 45 ° wind direction, the ventilation indexes PFR and NEV of Case a-45 and Case b-45 are slightly higher than that of Case NA-45, while the ventilation indexes PFR and NEV of Case c-45 are slightly lower than that of Case NA-45. Generally speaking, the influence of plants is relatively small on the intersection with 45 ° wind direction. Single row shrub and double row shrub structure have the ability to improve the ventilation performance, while a double row tree structure will have a negative impact on the space below 2 m in this area.

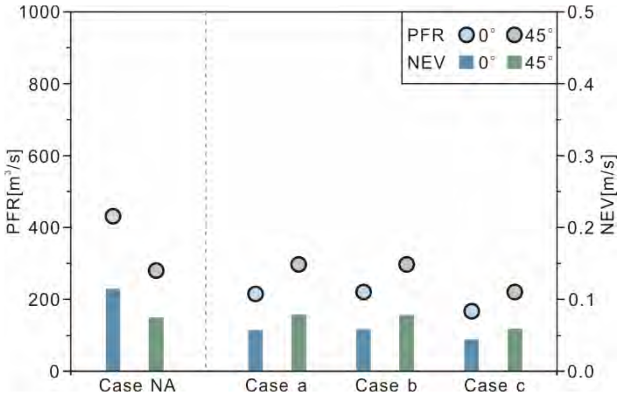


Figure 10. Ventilation index value of Case a, Case b, Case c

Conclusion

This paper focuses on the research task of the influence of greening on the ventilation performance of the cross street intersection, simplifies the shape of the cross street intersection, establishes an ideal intersection model, studies the basic air flow mode and pollutant diffusion situation in the intersection through the numerical simulation method, and compares the ventilation situation of each case through the ventilation index. For the ventilation performance of the pedestrian space area at the bottom of the intersection, the presence of plants has a great impact on the ventilation performance. In the presence of plants, the ventilation performance will be significantly reduced. The impact of single row and double row shrubs on the ventilation performance is similar, especially the impact of double row trees. When the wind direction is 45 °, the influence of plants on the ventilation in the cross street intersection is relatively small, among which the single row and double row shrub structures have the ability to improve the ventilation performance, while the double row tree structure will have a negative impact on the space below 2 m in the area.

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