Influence of Vegetation System on Outdoor Wind Environment of a Nursing Home

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Abstract. With the rapid growth of aging population in China, researchers have paid more attention to the aging planning and architectural design of elderly community. As the particularity of elderly people, they have higher demand on the comfort and safety of the outdoor wind environment, and the outdoor vegetation system has a great contribution on improving outdoor wind environment which has been proved. In this study, the influence of vegetation system on outdoor wind environment in extreme weather of a nursing home has been quantitatively investigated according to CFD methods. The parameters related to the wind environment including average wind velocity and its distribution has been calculated. Results showed that vegetation system could improve the outdoor wind environment significantly, especially planting shrub and grass. After planting deciduous and evergreen arbors, shrub and grass, the average wind velocities of all the living and activity regions decreased below to 1.5m/s, and area proportion of the regions with low wind velocity increased up to 75%.

1. Introduction
The aging population in China has been reached 25.4 million and account for 18.1% of the total population in the end of 2019. Together with the continuously decreasing of the new-born population, the problem of aging is becoming serious [1]. Moreover, with the increasing demand of the high quality living environment proposed by the elderly people, the living environment design for elderly people’s residential facilities has been investigated widely. As an important component of the living environment, researches for improving the outdoor environment have been increasing continuously in recent years due to the main space for elderly people’s fitness activities and social communications [2-3]. The good or bad of outdoor wind environment quality directly affected not only the exercising or living environment comfort of elderly people but also the safety of the elderly people especially near high-rise buildings. Without the need for varying building structure, vegetation system design has been proved to be the best method to improve the outdoor wind environment of the existed building groups. Argiro [4] investigated the benefits of vegetation system on urban environment, results showed that it could greatly improve the urban microclimate and mitigate the heat island effect as well. Hong [5] studied the influence of vegetation on outdoor wind environment in residential district by both simulation and experimental methods, results showed that the wind environment of residential district could be improved considerably by adjusting vegetation arrangement and types. Liu [6] investigated the winter microclimate of the garden in one nursing home. It indicated that the average leaf area index of the vegetation system had a strong influence on the winter microclimate, and deciduous trees such as eucalyptus, hedgehog, thorn, sea otter, ginkgo were recommended. In this paper, a nursing home located in Dezhou, northern China has been chosen as the research object, and the effect of the vegetation system on the outdoor wind environment has been evaluated according to...
CFD methods. The wind velocity contours at the pedestrian height (1.5m) of the nursing home’s outdoor environment in each season has been simulated. And the average wind velocity and its distribution of living and activity regions were calculated to quantify the effect of each vegetation system’s factor. Based on these results, the vegetation system design suggestions has been proposed.

2. Modeling methodology

2.1. Model establishment

The nursing home investigated in this paper is located in Dezhou, Shandong Province and its building area is 69000m$^2$ with 300m in north-south direction and 230m in east-west direction as shown in Figure 1. The nursing home is separated into two parts by a east-west direction internal road. Public care center and living service center are located in the north side, and the living and activity region is located in the south side including five residential zones named Liangyi garden, Jinghe garden, Tingfang garden, Wenmei garden and Wangchun garden respectively with Chinese meaning of living a long and healthy life and two activity squares. The outdoor wind environment of the living and activity regions are the focus of this paper.

![Figure 1. Aerial view of the nursing home](image1)

A computational domain of 900m (east-west direction) $\times$ 690m (north-south direction) $\times$ 132m (height) has been established which were all 3 times of the space of the nursing home. The dense structured grids with an resolution value of 1m $\times$ 1m $\times$ 0.5m were used in the nursing home area, and the sparse structured grids with an resolution value of 2m $\times$ 2m $\times$ 1m were used in other areas as shown in Figure 2. The total grids number reached 49,087,280, which was suitable to the present simulation.

![Figure 2. Simulation grids formation](image2)

2.2. Fluid model

Considering both the accuracy and efficiency of the simulation, the standard k-ε turbulence model has been used to simulate the air flow of the outdoor environment. The boundary condition of the inlet was set as constant wind velocity. The wind velocity under different height ($H$) was calculated by $V = V_0 (H/H_0)^n$ (where $V_0$ was the wind velocity of the reference height, reference height $H_0$ was set as 10m, and the roughness coefficient $n$ was set as 0.16 as the recommendation value of suburbs). Boundary condition of outlet was set as free outlet, and the boundary condition of the computational domain top was set as free sliding plane.

2.3. Plant model

In this paper, the vegetation system included deciduous and evergreen arbors, shrub and grass. Due to the leaf area index (LAI) and drag coefficient of the plants directly affected the flow field around the plants, the variation of the LAI and drag coefficient of each plant in different season has been listed in Table 1 [7].
Table 1. LAI and drag coefficient of each plant

| Species           | Season        | LAI (m²/m³) | Drag coefficient |
|-------------------|---------------|-------------|-----------------|
| Deciduous arbor   | Spring & Autumn | 1.0         | 0.5             |
|                   | Summer        | 4.0         | 0.8             |
|                   | Winter        | 0.0625      | 0.01            |
| Evergreen arbor   | Whole year    | 12          | 0.8             |
| Shrub             | Whole year    | 4.0         | 0.8             |
| Grass             | Whole year    | 4.0         | 0.8             |

The simplified 3-D model of each plant and its planting design are shown in Figure 3. There were two kinds of deciduous arbors, one was 10m high planted around the edges of nursing home, the other was 6m high planted along both side of the internal road, both of the deciduous arbors’ planting intervals were 6m. The evergreen arbors were 10m high and were planted at the open space located in the south-east side of the nursing home, and the space between the residential zones. Moreover, the evergreen arbors were not planted in rows with constant interval, but planted irregularly in order to create characteristic green landscape. The crown size of both the deciduous and evergreen arbors were 5m×5m. The height of the shrub was 1.0m and its width was also 1.0m, which were planted around the residential zones. The grass was 0.2m height and were planted in the region between each residential zones.

Figure 3. 3-D model of each plant and its planting design

3. Simulation conditions
In this paper, the effect of vegetation system on outdoor wind environment was discussed separately according to different seasons. The season was divided according to QX/T 152-2012 [8] after analyzing the daily meteorological data of Dezhou in 2020. In addition, considering elderly people’s outdoor activities always concentrated in two time periods of 6:00am to 12:00am and 2:00pm to 8:00pm, only the outdoor wind environment of these two time periods (total 12 hours) in each season has been evaluated. According to the meteorological data of wind velocity, the 90% fractile of each season were 4.1m/s, 3.1m/s, 2.8m/s and 3.0m/s. The time with velocity higher than 90% fractile was extracted and defined
as extremely weather. The wind direction distribution of these extremely weather has been listed in Table 2. Results showed that except for summer, the major wind direction was all east direction.

### Table 2. Wind direction distribution of extremely conditions

|       | N   | NE  | E   | SE  | S   | SW  | W   | NW  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|
| Spring| 1.09%| 0.00%| 41.30% | 9.78%| 23.91% | 7.61% | 7.61% | 8.70% |
| Summer| 0.56%| 2.81%| 21.91% | 8.99%| 25.84% | 7.87% | 16.85% | 15.17% |
| Autumn| 0.00%| 2.06%| 37.11% | 3.09%| 9.28% | 11.34% | 19.59% | 17.53% |
| Winter| 0.57%| 3.41%| 28.98% | 8.52%| 17.05% | 14.77% | 16.48% | 10.23% |

The average wind velocity, temperature, relative humidity and air pressure of each major wind direction condition were calculated, and four simulation conditions represented different seasons were confirmed as shown in Table 3.

### Table 3. Simulation conditions in this paper

| Wind direction | Wind velocity | Temperature | Relative humidity | Air pressure |
|----------------|---------------|-------------|-------------------|--------------|
| Condition 1(Spring) | East | 5.4 m/s | 14.9 °C | 35% | 101,240 Pa |
| Condition 2(Summer) | South | 3.7 m/s | 29.6 °C | 41% | 100,120 Pa |
| Condition 3(Autumn) | East | 3.6 m/s | 16.7 °C | 61% | 102,200 Pa |
| Condition 4(Winter) | East | 3.6 m/s | 1.9 °C | 44% | 102,890 Pa |

### 4. Results and discussion

In this part, the effects of vegetation system on outdoor wind environment under each season’s extremely weather have been discussed in detail, and the effects of deciduous arbor, evergreen arbor, shrub and grass were discussed respectively. The wind velocity contours at the pedestrian height (1.5m) of outdoor environment in each season were given. And the average wind velocity and its distribution of living region and activity regions were calculated to quantify the effect of each vegetation system’s factor. Considering the elderly people’s physiological characteristics, cold and heat intolerant, the average wind velocity at the pedestrian height of the living and activity regions should not be higher than 1.5m/s, and this limit was used to evaluate the quality of the outdoor wind environment.

#### 4.1. Effects of deciduous arbor

As mentioned above, the deciduous arbors were planting around the edges of the nursing home as shown in Figure 3. The wind velocity contours before and after planting deciduous arbors in different seasons is shown in Figure 4. It could be seen that the area with lower wind velocity (blue area) increased obviously, especially in zone ②, zone ④ and the square I. The variations of the average wind velocity and its distribution of each region is shown in Figure 5. It could be found that, except for winter, planting deciduous arbor has contribution to improve the wind environment of both living and activity regions, and the most contribution was obtained in spring with an average velocity decreasing rate of 30.51% and 24.55% for living and activity regions, respectively. For the living region, the effect of deciduous arbor on decreasing the wind velocity was most obvious in the zone ④ with an average decreasing rate of 40.14%. For the activity region, the average decreasing rate of square I was the highest, which was 27.65%. The obvious effect of deciduous arbor on improving the outdoor wind environment was attributed to the east major wind direction in spring and autumn, and the two rows of deciduous arbor planted in east edge of the nursing home played a key role in decreasing the velocity of the east wind. The limited influence in winter was because of the defoliation of the deciduous arbor weakened the wind defending effect due to the lower LAI and drag coefficient values. Moreover, compare to other seasons, the outdoor wind environment in summer was the best.
this was mainly because of the major wind direction in summer was south, and more and taller building block defended the wind flow and decreased the wind velocity effectively.

![Wind velocity contours before and after planting deciduous arbors](image1)

**Figure 4.** Wind velocity contours before and after planting deciduous arbors

![Average wind velocity and its distribution before and after planting deciduous arbors](image2)

**Figure 5.** Average wind velocity and its distribution before and after planting deciduous arbors

### 4.2. Effects of evergreen arbor

Although almost all the average wind velocities of living and activity regions had a great deceasing rate after planting deciduous arbor, there were still many regions were not up to the standard (≤1.5 m/s), especially for the winter conditions. In particular, the wind velocities in living region such as zone ④ and zone ⑤ and in activity region such as square II were much higher than 1.5 m/s due to lots of open spaces existed among the residential zones. So some evergreen arbors are planted to fill these open spaces to achieve the wind defending effect. And there was no defoliation problem for evergreen arbors, so the wind defending effect still worked in winter.

The wind velocity contours and variations of average wind velocity and its distribution of each region before and after planting evergreen arbors in different seasons are shown in Figure 6 and Figure 7. It could be seen that, unlike deciduous arbor, planting evergreen arbor has contribution to improve the wind environment of both living and activity regions for all the seasons, and the most contribution was obtained in winter with an average velocity decreasing rate of 22.23% and 19.23% for living and activity regions, respectively. For the living region, the effect of evergreen arbor on decreasing the
wind velocity was still most obvious in the zone ④ with an average decreasing rate of 31.80%. For the activity region, the average decreasing rate of square I was still the highest, which was 31.12%. After planting the evergreen arbors, the average wind velocities of almost all the regions were up to the standard (≤1.5m/s) except for zone ⑤ and square II. Moreover, the results showed that planting deciduous and evergreen arbors had very limited effect on reducing the wind velocity in square II region.

**Figure 6.** Wind velocity contours before and after planting evergreen arbors

**Figure 7.** Average wind velocity and its distribution before and after planting evergreen arbors

### 4.3. Effects of shrub and grass

To solve the wind environment problem of residential zone ⑤ and square II, shrub and grass were planted. Due to the large LAI and drag coefficient values of shrub and grass, it helped to decelerate the wind propagation, especially the wind velocity decreasing in the low height space. Considering to the specific advantages of the shrub and grass, the shrub was planted around the edges of each residential zone and the grass was planted in the square II and the neighbor regions. In other to further improve the outdoor wind environment of residential zone ⑤, and weakened the wind acceleration effect of wind passage between residential zone ④ and ⑤, both shrub and grass was planted in this space. The wind velocity contours and variations of average wind velocity and its distribution of each region
before and after planting shrub and grass in different seasons are shown in Figure 8 and Figure 9. It could be seen that, the wind environment of zone 5 and square II improved obviously. The average wind velocity of zone 5 and square II decreased sharply with average values of 45.50% and 45.13%, respectively. And after planting shrub and grass, all the regions’ average wind velocity was below 1.5m/s, which were all up to the standard. Except for the obvious improvement in zone 5 and square II, the environment of other residential zones and square I were also improved, especially for residential zone 1 with an average decreasing rate of 55.10%.

![Figure 8. Wind velocity contours before and after planting shrub and grass](image)

To sum up, the effects of vegetation system including deciduous arbor, evergreen arbor, shrub and grass on outdoor wind environment improvement is shown in Figure 10. After planting all kinds of vegetation, the average wind velocities of living and activity regions decreased to 1.00m/s (0.88~1.11m/s) and 0.89m/s (0.78~1.01m/s), and the area proportion of the regions with low wind velocity increased to 82.40% (75.07%~93.46%) and 89.75% (84.75%~94.12%). Results showed that the greatest contribution on improving outdoor wind environment was obtained by planting shrub and grass for both living and activity regions, and the contributions of planting deciduous and evergreen arbors were close.

![Figure 9. Average wind velocity and its distribution before and after shrub and grass](image)
5. Conclusion
In this paper, the effects of vegetation system on improving the outdoor wind environment of a nursing home located in Dezhou has been discussed according to CFD methods, some conclusions can be reached as the following.
1. The effects of deciduous and evergreen arbors on improving the outdoor wind environment was mainly attributed to the defending effect due to the high leaf area index and drag coefficient. However, the effect of deciduous arbor was very limited in winter due to the obvious decreasing in leaf area index and drag coefficient caused by defoliation.
2. The effects of shrub and grass mainly affected the wind velocity in the low height space, and could help to decelerate the wind propagation. And the shrub and grass were suggested to plant around the edges of residential zones, wind passage and open space. .
3. The comparison results showed that the greatest contribution on improving outdoor wind environment was obtained by planting shrub and grass, and the contributions of planting deciduous and evergreen arbors were close.

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