Nursing Home Wind Environment Evaluation in Northern China - A Case Study in Dezhou

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Abstract. As the rapid development of institution-based care for the elderly people, the nursing home’s outdoor wind environment research has become an important topic including wind potential evaluation as well as wind comfort analysis. In this study, the wind environment of a nursing home located in Dezhou, northern China has been evaluated quantitatively according to CFD methods. The parameters related to the wind environment including average wind velocity, wind velocity variation range and area proportion of shadow wind, comfort wind and risky wind regions has been calculated. Results showed the annual average wind velocity of the nursing home’s outdoor environment was 1.69m/s and its variation range was 40.41%. The area proportions of shadow wind, comfort wind and risky wind regions were 23.00%, 75.35% and 1.65%. This indicated that the wind environment optimization of the nursing home should be focused on decreasing the shadow wind regions and dismiss the risky wind regions, and relative optimization suggestions were proposed.

1. Introduction
The problem of the aging population in China is becoming serious due to the continuous increasing of the elderly people which has been reached 25.4million and account for 18.1% of the total population in the end of 2019[1]. Otherwise, with the increasing demand of the high quality care service proposed by the elderly people, the disadvantages of the traditional home-based care mode emerge gradually, and more and more elderly people tend to choose institution-based care mode because of better medical facilities, experienced nursing assistants and same age friends. As the outdoor environment of the nursing home is the main space for elderly people’s fitness activities and social communications, the outdoor environment design directly affects the physical and mental health of the elderly people resulting in an increasing investigations related to the nursing home outdoor environment design in recent year [2-3]. The wind environment evaluation is an important component of the outdoor environment because it not only affects the excising and living environment comfort of elderly people but also the safety of the pedestrians especially near high-rise buildings as well as sustainable development of the green buildings[4-5]. In this paper, a nursing home located in Dezhou, northern China has been chosen as the research object, and the wind environment of the nursing home has been evaluated according to CFD methods in order to discover the existing problems of the wind environment. The wind velocity distribution of the nursing home’s outdoor environment in each season were simulated, and the annual wind environment has been quantitatively evaluated by area proportions of the shadow wind, comfort wind and risky wind regions which were divided according to the wind velocity. Based on these results, the regions with poor wind environment were identified clearly and the optimization suggestions has been also proposed.
2. Modeling methodology

2.1. Model establishment
The aerial view of the nursing home is shown in Figure 1. The nursing home is adjacent to No. 12 Wei Street in north and Meijiao Road in east covering an area of 69000 m$^2$ with 300m in north-south direction and 230m in east-west direction. There are public care center and a living service center planed in the northern side of the nursing home, and the elderly people’s residential zone is planned in the southern side. There are five group apartments in the residential which are named Liangyi garden, Jinghe garden, Tingfang garden, Wenmei garden and Wangchun garden respectively with Chinese meaning of living a long and healthy life.

Figure 1. Aerial view of the nursing home

The length, width and height of computational domain were all set as 3 times of the nursing home space, which was 900m, 690m and 132m respectively. The dense structured grids were used in the nursing home building area with a resolution value of 1m × 1m × 0.5m, and the sparse structured grids were used in other areas with a resolution value of 2m × 2m × 1m 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

2.2. Mathematical 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, and the coefficients setting is shown in Table.1. Since the height of the computational domain was only 132m, which the air in this height could be considered as incompressible fluid, 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[6]). Boundary condition of outlet was set as free outlet, and the boundary condition of the computational domain top was set as free sliding plane.

| Table 1. Coefficients setting of standard k-ε turbulence model |
|-------------------|------------------|----------------|-------------------|------------------|--------------|--------------|
| $C_\mu$ | $C_{\epsilon 1}$ | $C_{\epsilon 2}$ | $C_{\epsilon 3}$ | $C_{\epsilon 4}$ | $\alpha_k$ | $\sigma_\epsilon$ |
| 0.09 | 1.44 | 1.92 | -1.0 | -0.33 | 1.0 | 1.22 |

3. Simulation conditions

3.1. Season division
The method of the season division in this paper was according to the related standard QX/T 152-2012[7]. If the average temperature was above or below 10℃ for 5 consecutive days, the first day of this 5
consecutive days was defined as the start of spring or winter. If the average temperature was above or below 22°C for 5 consecutive days, the first day was defined as the start of summer or autumn. After analyzing the daily meteorological data of Dezhou in 2019, the season division was confirmed as shown in Table 2. According to the standard related to wind environment evaluation (GB/T 50378-2019[6]), the wind environment of spring and autumn are considered as one season for evaluating in this paper due to the close environmental temperature.

| Season | Spring   | Summer   | Autumn   | Winter   |
|--------|----------|----------|----------|----------|
| Duration | Mar. 14-May 13 | May 14-Sep. 14 | Sep.15-Nov.16 | Nov.16-Mar. 13 |

3.2. Time distribution characteristic of elderly people’s outdoor activities
In order to accurately evaluate the wind environment of the nursing home, the time distribution characteristic of local elderly people’s outdoor activities has been investigated according to the questionnaire and the results has been showed in Figure 3. It showed that the variation of time distribution of different seasons was limited, and was mainly concentrated in two time periods, one was from 6:00am to 12:00am, the other was from 2:00pm to 8:00pm. Therefore, only the wind environment of these two time periods (total 12 hours) in each season has been evaluated.

![Figure 3. Time distribution characteristic of elderly people’s outdoor activities](image)

3.3. Simulation condition setting
According to the meteorological data, the wind rose distribution of each season has obtained as shown in Figure 4, and the static wind was defined as the wind velocity was below 0.1m/s. Results showed that both the wind direction and wind velocity distributions of each season were similar, the main wind
directions were all east, followed by south-east and south, and the main wind velocity ranged from 1m/s to 3m/s. The average wind velocity during elderly people outdoor activities (6:00 am - 12:00am & 2:00pm - 8:00pm) of each wind direction in each season was listed in Table 3, and a total of 24 simulation conditions has been set.

| Wind direction | N  | NE | E  | SE | S  | SW | W  | NW |
|----------------|----|----|----|----|----|----|----|----|
| Simulation condition No. | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
| Wind average velocity(m/s) | 2.31 | 2.44 | 3.37 | 2.76 | 3.35 | 3.18 | 3.00 | 3.31 |
| Proportion(%) | 2.28 | 4.23 | 25.34 | 16.47 | 17.81 | 9.95 | 12.77 | 7.39 |

### Table 3: Wind direction and average velocity of each simulation condition

#### Spring and Autumn

| Simulation condition No. | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|--------------------------|----|----|----|----|----|----|----|----|
| Wind average velocity(m/s) | 1.83 | 2.38 | 2.80 | 2.67 | 3.17 | 2.75 | 3.17 | 2.94 |
| Proportion(%) | 3.09 | 3.56 | 23.45 | 18.28 | 18.21 | 9.27 | 11.96 | 10.22 |

#### Summer

| Simulation condition No. | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|--------------------------|----|----|----|----|----|----|----|----|
| Wind average velocity(m/s) | 2.22 | 2.58 | 2.67 | 2.55 | 2.84 | 2.87 | 2.56 | 2.70 |
| Proportion(%) | 2.64 | 4.84 | 24.93 | 15.88 | 15.31 | 11.11 | 12.61 | 8.69 |

### 4. Results and discussion

In this part, the wind environment of the nursing home in each season has been discussed. The wind velocity distribution in the pedestrian height (1.5m) of each wind direction was first given. The average wind velocity and its variation range (standard deviation/average) were also calculated. Moreover, according to the wind velocity distribution, the outdoor environment has been divided into 3 types, which were shadow wind, comfort wind and risky wind regions. The shadow wind region was defined as the region where the wind velocity was lower than 1.0m/s, which against the diffusion of air pollutants and easily produced a stifling feeling to the elderly people, especially in summer. Considering the elderly people’s physiological characteristics, cold and heat intolerant, the comfort wind region was defined as the region where the wind velocity was higher than 1.0m/s but lower than 3.3m/s[8]. The risky wind region was the region with wind velocity above 3.3m/s, the high velocity would cause respiratory and digestive diseases as well as cold and fever due to the rapid sweat evaporation, and also falling object hazards. All the area proportion of these three regions has been given, and the higher percentage of the comfort wind region and more narrow wind velocity variation range implied a better wind environment.

#### 4.1. Wind environment evaluation in each season

The average wind velocity in different wind directions in spring and autumn is shown in Figure 5. It could be seen that the shadow wind region often appeared in public care center and living service center in the northern side of the nursing home, and also appeared in group apartments of Wangchun(zone ①), Jinghe(zone ②), and Tingfang gardens(zone ④). Besides, the distribution of the shadow wind region was much wider in the conditions with south-north direction wind than other conditions, this was because that all the buildings in the nursing home were south-facing, which defended and weakened the wind with south-north direction. The risky wind region often appeared in the passages with east-west direction, such as the passages between building No.2 and No.3, No.11 and No.12, No.13 and No.14, which was because of the acceleration effect when the wind flowed through...
adjacent tall buildings. The distribution of the risky wind region was wider in the conditions with east-west direction wind, but fortunately, the risky wind region was rare in the five group apartments zones.

The average wind velocity and its variation range, and the area proportions of shadow wind, comfort wind and risky wind regions are given in Table 4. The average wind velocity was 1.81 m/s in spring and autumn, which was in a comfort level. The area proportions of shadow wind, comfort wind and risky wind region were 21.49%, 74.99% and 3.52%. In addition, the best wind environment was obtained in the conditions with southeast wind due to the minimum value of variation range and maximum proportion of comfort wind region. And the wind environment in the conditions with north and south wind were relatively poor.

| Wind environment related parameters in spring and autumn |
|---------------------------------------------------------|
| Av. wind velocity(m/s) | N | NE | E | SE | S | SW | W | NW | Weighted |
|------------------------|---|----|---|----|---|----|---|----|----------|
| Variation range(%)     | 43.40 | 37.42 | 42.10 | 33.14 | 55.60 | 44.44 | 38.70 | 37.82 | 40.76 |
| Shadow wind region(%)  | 36.79 | 19.90 | 16.27 | 12.69 | 29.12 | 18.15 | 14.25 | 13.77 | 21.49 |
| Comfort wind region(%) | 63.21 | 80.10 | 76.79 | 87.31 | 66.33 | 77.92 | 83.57 | 82.37 | 74.99 |
| Risky wind region(%)   | 0.00 | 0.00 | 6.95 | 0.00 | 4.55 | 3.93 | 2.18 | 3.83 | 3.52 |

Figure 5. Wind velocity distribution in spring and autumn

Figure 6. Wind velocity distribution in summer
The wind velocity distribution under different wind direction in summer is shown in Figure 6, which was similar to the results of spring and autumn. The calculation results of the wind environment related parameters are given in Table 5. The average wind velocity was 1.69 m/s in summer, which was also in a comfort level. The area proportions of shadow wind, comfort wind and risky wind region were 22.46%, 76.40% and 1.13%. In addition, the best wind environment was obtained in the conditions with northeast wind. And the wind environment in the condition with north was the poorest.

**Table 5. Wind environment related parameters in summer**

|                | N  | NE | E  | SE | S  | SW | W  | NW | Weighted |
|----------------|----|----|----|----|----|----|----|----|----------|
| Av. wind velocity(m/s) | 0.98 | 1.68 | 1.81 | 1.68 | 1.50 | 1.61 | 2.13 | 1.86 | 1.69     |
| Variation range(%)    | 42.30 | 33.10 | 41.87 | 33.38 | 54.73 | 44.08 | 38.87 | 37.29 | 40.92    |
| Shadow wind region(%) | 53.70 | 13.70 | 20.58 | 14.22 | 31.62 | 22.47 | 12.82 | 15.26 | 22.46    |
| Comfort wind region(%)| 46.30 | 86.30 | 79.12 | 85.78 | 65.68 | 76.79 | 83.64 | 83.93 | 76.40    |
| Risky wind region(%)  | 0.00 | 0.00 | 0.29 | 0.00 | 2.69 | 0.75 | 3.54 | 0.78 | 1.13     |

The wind velocity distribution under different wind direction in winter is shown in Figure 7, which was similar to the results of spring, autumn and summer. The calculation results of the wind environment related parameters are given in Table 6. The average wind velocity was 1.56 m/s in winter, which was also in a comfort level. The area proportions of shadow wind, comfort wind and risky wind region were 25.16%, 74.63% and 0.21%. In addition, the best wind environment was obtained in the conditions with southeast wind. And the wind environment in the conditions with north and south were the poorest.

**Table 6. Wind environment related parameters in winter**

|                | N  | NE | E  | SE | S  | SW | W  | NW | Weighted |
|----------------|----|----|----|----|----|----|----|----|----------|
| Av. wind velocity(m/s) | 1.18 | 1.59 | 1.74 | 1.61 | 1.37 | 1.68 | 1.76 | 1.71 | 1.56     |
| Variation range(%)    | 43.40 | 37.76 | 41.23 | 33.14 | 53.61 | 44.23 | 36.62 | 37.16 | 39.49    |
| Shadow wind region(%) | 39.55 | 17.76 | 20.58 | 15.03 | 37.60 | 21.01 | 16.95 | 17.56 | 25.16    |
| Comfort wind region(%)| 60.45 | 82.14 | 79.38 | 84.97 | 62.31 | 77.82 | 83.05 | 81.85 | 74.63    |
| Risky wind region(%)  | 0.00 | 0.10 | 0.03 | 0.00 | 0.10 | 1.17 | 0.00 | 0.58 | 0.21     |

**Figure 7. Wind velocity distribution in winter**
4.2. Annual wind environment evaluation and optimization suggestions

The annual results of the wind environment related parameters are summarized in Table 7. It can be seen from the table that the average wind velocity in spring and autumn are higher than that in summer and winter, for all the seasons, the average wind velocities were in the comfort level with an annual value of 1.69m/s. The wind velocity variation range in each season was closed with an annual value of 40.41%. The area proportion of shadow wind region in winter was the highest which reached 25.16%, and the annual value was 23.00%. The area proportion of comfort wind region in summer was the highest which reached 76.40%, and the annual value was 75.35%. The area proportion of risky wind region in spring and autumn was the highest which reached 3.52%, and the annual value was 1.65%. Based on the analysis, the wind environment optimization of the nursing home should focus on the decrease of the shadow wind region area proportion. Besides, some typical risky wind regions should also be modified. The optimization of the shadow wind and risky regions would also narrow the wind velocity variation range simultaneously.

Table 7. Seasonal and annual wind environment related parameters

|                  | Spring & Autumn | Summer  | Winter | Annual |
|------------------|-----------------|---------|--------|--------|
| Av. wind velocity(m/s) | 1.81            | 1.69    | 1.56   | 1.69   |
| Variation range(%)    | 40.76           | 40.92   | 39.49  | 40.41  |
| Shadow wind region(%) | 21.49           | 22.46   | 25.16  | 23.00  |
| Comfort wind region(%) | 74.99           | 76.40   | 74.63  | 75.35  |
| Risky wind region(%) | 3.52            | 1.13    | 0.21   | 1.65   |

Figure 8 shows the main wind shadow and wind risky regions based on the wind velocity distribution of each season. It could seen that the wind shadow region was mainly appeared in the public care center and living service center. Because of the mechanical ventilation would be adopted to solve the ventilation problem of the patios in building No.1 and No.11, the main optimization should be focused on the structure of building 5. The suggestion was changing building 5 structure from “I” to “T”, or using the space corridor to connect these two parallel buildings in order to avoid the formation of the approximative enclosure space. For the optimization of the wind shadow region between buildings No.8 and No.13, buildings No.9 and No.14, the suggestion was using out of place layout style rather than symmetrical layout style. For the wind shadow region appeared in southern side of the group apartments of zone ①, zone ② and zone ④, the suggestion was enlarging the gap between buildings No.4 and No.7, buildings No.10 and No.16, and buildings No.16 and No.15 in order to increase the air mass flow.

Figure 8. Main wind shadow and wind risky regions
The risky wind region often appeared in the passages with east-west direction, such as the passages between building No.2 and No.3, No.11 and No.12, No.13 and No.14. The optimization suggestions included planting evergreen arbors in the eastern and western side of nursing home to defend the wind with east-west direction, enlarging or dismissing the space between two parallel buildings (buildings No.2, No.3, No.11, No.12, No.13 and No.14) in order to weaken the acceleration effect caused by wind flowing through adjacent tall buildings.

5. Conclusion
In this paper, the wind environment of a nursing home located in Dezhou has been evaluated according to CFD methods in order to discover the existing problems of the wind environment. The wind distribution of the nursing home’s outdoor environment in each season was simulated, and the annual wind environment has been quantitatively evaluated by the average wind velocity and its variation range, moreover, the area proportions of the shadow wind, comfort wind and risky wind regions were also calculated. Based on these results, the conclusions can be reached as the following.
1. The annual average wind velocity of the nursing home’s outdoor environment was 1.69m/s and its variation range was 40.41%. the area proportions of shadow wind, comfort wind and risky wind regions were 23.00%, 75.35% and 1.65%.
2. The wind environment related parameters of different seasons were close and the best wind environment was obtained in summer with the highest comfort wind region area proportion (76.40%). The area proportion of shadow wind region in winter was the highest which reached 25.16%, and the area proportion of risky wind region in spring and autumn was the highest which reached 3.52%.
3. The wind environment optimization of the nursing home should focus on the decrease of the shadow wind region area proportion and the suggestions included changing structure of building 5, using out of place layout style rather than symmetrical layout style of buildings No.8, No.13, No.9 and No.14, and enlarging the gap between buildings No.4 and No.7, buildings No.10 and No.16.
4. Besides, some typical risky wind region should also be modified, and the suggestions included planting evergreen arbors in the eastern and western side of nursing home, enlarging or dismissing the space between two parallel buildings (buildings No.2, No.3, No.11, No.12, No.13 and No.14).

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