Scientific Research Publishing

Retraction Notice

Title of retracted article:	**Coupling numerical simulation and field experiment to optimize vegetation arrangement for pleasant outdoor wind environment in residential district**
Author(s):	Bo Hong, Fang Chen, Peng Ren
* Corresponding author.	Email: hongbo@nwsuaf.edu.cn
Journal:	Journal of Environmental Protection (JEP)
Year:	2015
Volume:	6
Number:	4
Pages (from - to):	374 – 387
DOI (to PDF):	http://.doi.org/10.4236/jep.2015.64037
Paper ID at SCIRP:	6702619
Article page:	https://www.scirp.org/journal/PaperInformation.aspx?PaperID=55836
Retraction date:	2019-05-10

Retraction initiative (multiple responses allowed; mark with **X**):

X All authors
☐ Some of the authors:
☐ Editor with hints from
- ○ Journal owner (publisher)
- ○ Institution:
- ○ Reader:
- ○ Other:

Retraction type (multiple responses allowed):

X Unreliable findings
○ Lab error ○ Inconsistent data **X** Analytical error ○ Biased interpretation
○ Other:
☐ Irreproducible results
☐ Failure to disclose a major competing interest likely to influence interpretations or recommendations
☐ Unethical research

☐ Fraud
○ Data fabrication ○ Fake publication ○ Other:
☐ Plagiarism ☐ Self plagiarism ☐ Overlap ☐ Redundant publication *
☐ Copyright infringement ☐ Other legal concern:

☐ Editorial reasons
○ Handling error ○ Unreliable review(s) ○ Decision error ○ Other:

☐ Other:

Results of publication (only one response allowed):

☐ are still valid.
X were found to be overall invalid.

Author's conduct (only one response allowed):

☐ honest error
☐ academic misconduct
X none (not applicable in this case – e.g. in case of editorial reasons)

* Also called duplicate or repetitive publication. Definition: "Publishing or attempting to publish substantially the same work more than once."

History
Expression of Concern:
☐ yes, date: yyyy-mm-dd
X no

Correction:
☐ yes, date: yyyy-mm-dd
X no

Comment:

The paper does not meet the standards of "Journal of Environmental Protection".

This article has been retracted to straighten the academic record. In making this decision the Editorial Board follows COPE's Retraction Guidelines. Aim is to promote the circulation of scientific research by offering an ideal research publication platform with due consideration of internationally accepted standards on publication ethics. The Editorial Board would like to extend its sincere apologies for any inconvenience this retraction may have caused.

Editor guiding this retraction: Prof. Qingren Wang (EiC of JEP)

Journal of Environmental Protection, 2015, 6, 374-387
Published Online April 2015 in SciRes. http://www.scirp.org/journal/jep
http://dx.doi.org/10.4236/jep.2015.64037

Coupling Numerical Simulation and Field Experiment to Optimize Vegetation Arrangement for Pleasant Outdoor Wind Environment in Residential District

Bo Hong*, **Fang Chen**, **Peng Ren**

College of Landscape Architecture and Arts, Northwest A & F University, Yangling, China
Email: *hongbo@nwsuaf.edu.cn

Received 27 March 2015; accepted 20 April 2015; published 21 April 2015

Abstract

Combining with field experiment in Ivy Town residential area, numerical simulation of the influences of vegetation on outdoor wind environment with SPOTE (Simulation Platform for Outdoor Thermal Environment) was carried out for comparison in the study. The conclusions were drawn as follows: 1) the wind velocity with and without vegetation was compared both in winter and summer; the simulation result would help us determine which vegetation to plant in green space; 2) after supplanting the status deciduous vegetation into evergreen one, the actual wind velocity increased to a much extent in areas with adjusting vegetation than areas with status vegetation, with an increase by 64.7% in winter; 3) by adjusting arrangement and types of vegetation in the regions where the wind environment was unpleasant for pedestrian thermal comfort both in winter and summer, the pedestrian-level wind velocity could be obviously improved through the simulation and comparison.

Keywords

Outdoor Wind Environment, Numerical Simulation, Field Experiment, Vegetation, Optimum Design

1. Introduction

The urban microclimate as represented by the Urban Heat Island (UHI) phenomenon accompanying urbaniza-

*Corresponding author.

How to cite this paper: Hong, B., Chen, F. and Ren, P. (2015) Coupling Numerical Simulation and Field Experiment to Optimize Vegetation Arrangement for Pleasant Outdoor Wind Environment in Residential District. *Journal of Environmental Protection*, **6**, 374-387. http://dx.doi.org/10.4236/jep.2015.64037

tion has become markedly worse in recent years in Beijing. One of the intensities of urban heat island of Beijing that has gradually increased is the loss of vegetative cover in urban areas [1]. In order to reduce the UHI effects, various mitigating measures have been proposed. The most commonly applied measures include tree planting [2]. However, the monetary benefits of urban trees are difficult to qualify because these trees can provide numerous benefits, such as improving thermal environment, reducing community noise and air pollution problems, enhancing biodiversity and meliorating aesthetics [3] [4]. Thus, residential green space, which is one of urban reforestation styles, is of interest, and the greening and beautification of residential quarter has become one of the main concerns of residents [5].

Wind environment is one of the most important factors to be considered in UHI study as it has significant influence on UHI effect and outdoor thermal comfort [6]. The conventional urban wind environment assessment methods only took into consideration on improving the outdoor thermal environment by changing the arrangement of the building and building coverage ratio for a given background [7]. However, from engineering point of view, the existence of tree covered ground surface is one of the most essential factors to be considered in urban design, and using vegetation to improve a residential area's microclimate has been investigated by a few researches [8] [9]. It has been found on average that about 80% of the cooling effect in hot and humid climate regions is contributed by vegetation shading [10] [11]. In addition, vegetation would decrease the upstream wind velocity obviously [12].

Despite the import influence of vegetation for thermal environment in residential areas, the current vegetation design only considers visual requirements, and the current Chinese National Residential Greening Norms and Beijing Residential Greening Norms have no quantitative measures for planting to create comfortable thermal environment [13], and the arrangements of vegetation are actually often made empirically from the varying standpoints of conventional planning concepts for landscape design. Furthermore, a typical problem for residential quarters in Beijing is that hot summer and cold winter are impacted by monsoon climate, and the outdoor thermal environment has various problems in both summer and winter respectively [14]. Although some researchers have been conducted into the effect of landscape on wind environment in residential area [12], few reports have systematically quantified the relationship between vegetation and wind environment in residential areas in terms of quantitatively optimal design of vegetation to create a pleasant outdoor thermal environment.

Combining field experimental tests with numerical studies by Simulation Platform for Outdoor Thermal Environment (SPOTE) [15], this study investigated the optimal design of vegetation to develop the optimal design method for a pleasant outdoor thermal environment, and the optimal design of vegetation was examined for improved ventilation in summer whilst checking any flow of cold wind in winter by means of the optimal design method presented in this research.

2. Methodology

2.1. Research Method

Figure 1 shows the flow of the optimal vegetation design system for improving wind environment in residential areas using numerical modeling and field experiment. As presented by the author, this optimum design system was composed of the following four stages: Initially, an optimization problem was established by the designer;

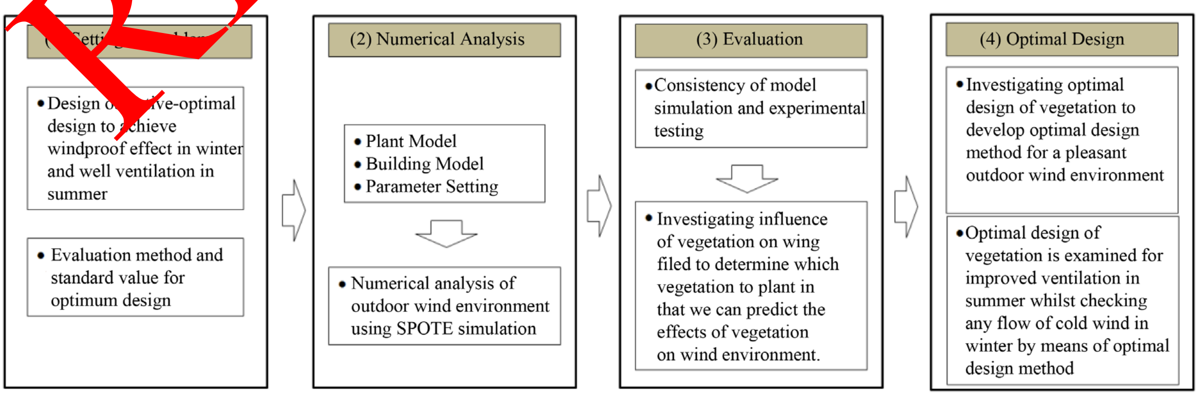


Figure 1. The schematics of the optimal design for vegetation arrangement.

next, numerical analysis was performed on the outdoor wind environment using SPOTE simulation; thirdly, by consistency of model simulation and experimental testing, the influences of different vegetation on wind environment were investigated. Finally, the optimum solution candidates and the optimum process were examined. Hence, as the first step, the design objective and evaluation method were determined in these stage. In the second stage, models including plants and buildings were used to analyze the outdoor environment. In the third stage, in order to investigate influence of different vegetation on wind filed, numerical simulations were carried out to determine which vegetation to plant in green space in that we can predict the effects of vegetation on wind environment. In the fourth stage, optimal design of vegetation was examined for improved ventilation in summer whilst checking any flow of cold wind in winter. Thus far, the optimal vegetation design for comfortable wind environment was carried out.

2.2. Field Experiment

Ivy town residential area is located at northeast part of Chaoyang district, Beijing (Figure 2). With an area of 6.38 million square meters, buildings are distributed in rows. The vegetation in the green space between buildings is presented the following characteristics: 1) Trees are low with a height no more than [illegible] m; 2) The smaller number of evergreen trees are planted in the green space. This is suitable for comparison research, for it can better reflect the impact of vegetation on wind environment by numerical simulation.

Portable weather stations were used in this study to measure the parameters including wind velocity (measurement accuracy: 0.1 m/s, measurement range: 0 - 70 m/s, measurement error: ±(0.3% + 3% of reading) m/s) and wind direction (measurement accuracy: 1˚, measurement range: 0˚ - 360˚, measurement error: ±3˚), as well as air temperature and humidity.

With consideration of attenuation effect of vegetation on wind velocity and the location of concentrated open activity areas for residents, a total of 8 measuring points were installed for studying the impact of air flow on the daily activities of local residents. Meanwhile, the attenuation effect of different vegetation types and arrangement on wind velocity could also be investigated (Figure 3).

Testing time was May 19, 2011, and dominant wind direction was SW with 3 - 4 m/s velocity. Measurement parameters included wind velocity, wind direction and temperature with a 1 minute sample frequency. The values were taken for several times with the average value obtained in the stable wind field.

2.3. Numerical Simulation Study

In order to compare results of experiment with that of simulation, models should be built based on the actual en-

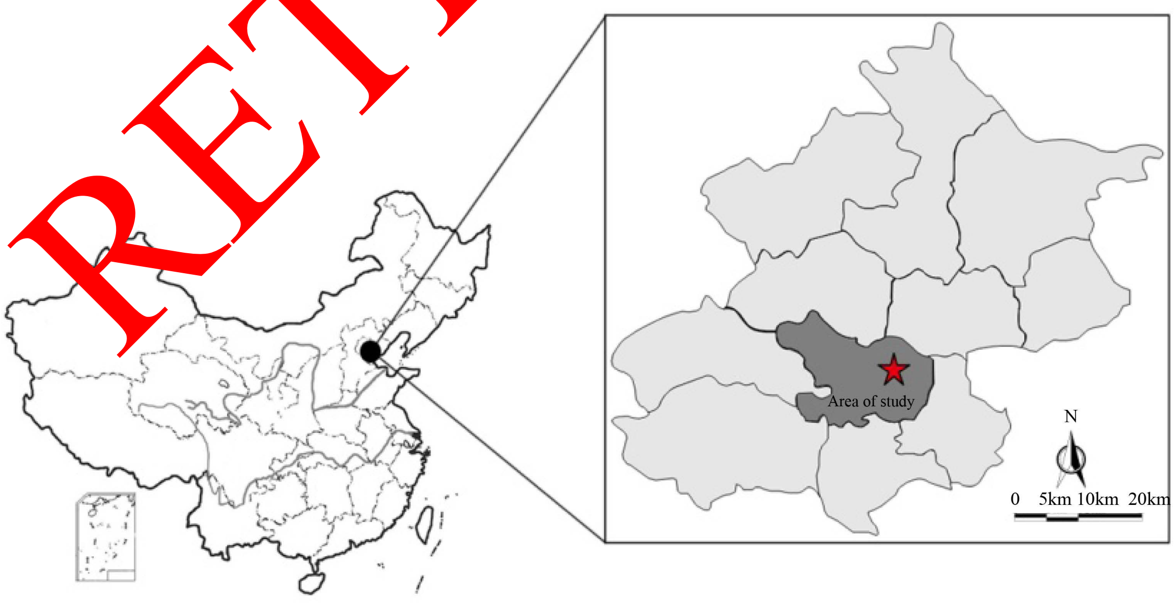


Figure 2. Location of the area of study.

Figure 3. On-site field measurement points, the local reference weather station on the top of the building (A8).

vironment including proper vegetation and building model. In this study, SPOTE, consisting of an air model, vegetation model, underlying surface model and a general radiation calculation model, was chosen for numerical simulation, and coupled calculation of radiation, convection, conduction and air flow were carried out considering vegetation influences. The details of sub-models of SPOTE are introduced as below.

2.3.1. Air Model

A standard *k*-ε model is employed by applying extra terms in the flow, momentum, and energy equations for the aerodynamic effects of vegetation. The drag force of vegetation canopy is presented with a term F_i added in the *i* component of momentum equation as well as F_k and F_ε added into the transport equations of turbulent energy (k) and energy dissipation rate (ε), respectively, for denoting the effects on turbulent flow field. F_i, F_k, and F_ε are derived by applying the spatial average to the basic equations.

$$F_i = -\frac{1}{2} C_d \eta a \langle u_i \rangle \sqrt{\langle u_i \rangle^2} \tag{1}$$

$$F_k = \langle u_i \rangle F_i - 4 C_d \eta a \sqrt{\langle u_i \rangle^2} k \tag{2}$$

$$F_\varepsilon = \frac{\varepsilon}{k} \left(C_{p\varepsilon 1} \langle u_i \rangle F_k - C_{p\varepsilon 2} 4 C_d \eta a \sqrt{\langle u_i \rangle^2} k \right) \tag{3}$$

where C_d is the drag coefficient; η is the green coverage ratio, and a is the leaf area density [$m^2 \cdot m^{-3}$]. By comparing the numerical results with field measurements, the model coefficients $C_{p\varepsilon 1}$ and $C_{p\varepsilon 2}$ are respectively defined as 1.8 and 0.6 [16].

Moreover, the functions of vegetation on temperature and humidity are applied using the following equation:

$$\frac{\partial \langle \theta \rangle}{\partial t} + \langle u_j \rangle \frac{\partial \langle \theta \rangle}{\partial x_j} = \frac{\partial}{\partial x_i} \left(\alpha \frac{\partial \langle \theta \rangle}{\partial x_i} + \frac{\nu_t}{\sigma_\theta} \frac{\partial \langle \theta \rangle}{\partial x_i} \right) + \frac{1}{\rho c_p} 2 LAI \alpha_c \left(\langle \theta \rangle - \langle \theta_p \rangle \right) \tag{4}$$

$$\frac{\partial\langle d_a\rangle}{\partial t}+\langle u_j\rangle\frac{\partial\langle d_a\rangle}{\partial x_j}=\frac{\partial}{\partial x_i}\left(D\frac{\partial\langle d_a\rangle}{\partial x_i}+\frac{\nu_t}{\sigma_w}\frac{\partial\langle d_a\rangle}{\partial x_i}\right)+\frac{1}{\rho\Lambda}2LAI\alpha_w\left(\langle d_a\rangle-\langle d_{a,p}\rangle\right) \tag{5}$$

where θ is the air temperature [K]; α is the convection coefficient for heat exchange [W·(m^{-2}·K^{-1})]; ρ is radiation absorptivity; C_p is the air heat capacity at constant pressure [J·(kg·K)$^{-1}$]; θ_p is the temperature of leaves [K]; d_a is the absolute humidity of air [kg·kg^{-1}]; D is the diameter of leaves [m]; LAI is the leaf area index; Λ is the latent heat of vaporization of water [J·kg^{-1}], and α_c [W·(m^{-2}·K^{-1})]and α_w [kg·(m^{-2}·s^{-1}·kPa^{-1})] are the convective coefficients for heat and mass exchange, respectively.

2.3.2. Heat Balance for Vegetation

The surface temperature of vegetation canopy and the complex radiation process of the vegetation canopy are calculated with the heat balance equations as follows.

$$\varphi_{rad,SR}+\varphi_{rad,LR}+\varphi_{conv,p-a}+\varphi_{trans,p-a}=0 \tag{6}$$

$$\varphi_{conv,p-a}=2\alpha_c\left(\theta_p-\theta\right) \tag{7}$$

$$\begin{cases}\alpha_c=\rho C_p/r_a\\ r_a=A\left(D/W\right)^{0.5}\end{cases} \tag{8}$$

$$\varphi_{trans,p-a}=2a\frac{0.625\Lambda\rho}{c_p p\left(r_a+r_i\right)}\Delta p_{p-a}=2a\alpha_w\left(d_{a,p}-d_a\right) \tag{9}$$

where $\varphi_{rad,SR}$ is the short-wave solar radiation intensity absorbed by leaves [W·m^{-2}]; $\varphi_{rad,LR}$ is the long-wave heat radiation absorbed by leaves [W·m^{-2}]; $\varphi_{conv,p-a}$ is the sensible convective heat transfer between leaves and air in the vegetation canopy [W·m^{-2}]; $\varphi_{tran,p-a}$ is the heat exchange of leaves transpiration [W·m^{-2}]; A is the surface area of leaves [m^2]; W is the air velocity at leaf surface [m·s^{-1}]; (r_a+r_i) is total resistance in transpiration [m·s^{-1}] [17]; p is atmospheric transmittance.

The transportation of radiation including solar and long-wave radiation among vegetation canopy and around surfaces is calculated with a generalized radiation simulation system using the Monte-Carlo method, in which the non-transparent objects and half-transparent objects are processed with 2D and 3D basic units respectively for calculating the decay of emitted trajectory [15]. Considering the symmetrization rule of radiation for the calculation of DEA (Direct Exchange Area), TEA (Total Exchange Area) can be obtained by Geb-Hart method [18]. So, the radiative heat transportation from one grid to another in a grey space can be easily computed. The short wave (solar radiation) and long wave radiant fluxes incident to the plant canopy are calculated with a decay exponential function respectively as exp(–*lka*), where *k* is the absorption coefficient for long-wave and short wave and *l* is the length by which radiant flux passes through the plant canopy.

2.3.3. Underlying Surface Model

The underlying surface model is created using the following equations:

$$q_{nswr}+q_{nlwr}+q_{lat}+q_{conv}=\frac{\lambda}{\rho c}\frac{\partial T_s}{\partial z}\bigg|_{z=0} \tag{10}$$

$$\frac{\partial T_s}{\partial t}=\frac{\lambda}{\rho c}\frac{\partial^2 T_s}{\partial z^2} \tag{11}$$

where q_{nswr} is the direct diffused reflective solar heat gained from the canopy and underlying surfaces [W·m^{-2}]; q_{nlwr} is the net long-wave radiation from the earth's surface to the sky, building exterior surface and vegetation canopy [W·m^{-2}]; q_{conv} is the convective heat exchange [W·m^{-2}], $q_{conv}=\alpha_c\left(T_s-T_a\right)$, $\alpha_c=\rho c_p/r_c$ for soil surface, and $\alpha_c=4.4V+3.58$ for wall and roof; q_{lat} is latent heat [W·m^{-2}], q_{lat} equals zero for wall; T_s is the temperature of the solid underlying layers; T_{s0} represents the soil temperature at −2 m and indoor air-conditioning temperature for wall [K]; z is the normal direction, which is vertically downward for soil and perpendicular to the building envelope surfaces and from exterior surface to indoor space.

Because the thermal inertia of all underlying surfaces is very large, a 24 h iterative computation and an implicit expression difference method are utilized respectively in this sub-model.

2.4. Numerical Simulation Study

The present authors carried out a series of numerical studies to examine the accuracy of simulation of wind field using SPOTE [19]. In order to further verify the accuracy of numerical modeling in the study site, field measurement data combining with incoming air velocity and numerical simulation were carried out with SPOTE.

Parameters adopted in this numerical modeling were as follows: vegetation was divided into the following four categories according to height, leaf density and effects on pedestrian. Typical vegetation and final leaf area index for each kind of vegetation are listed in **Table 1**. The standard k-ε turbulence model and incoming gradient wind are regarded as boundary conditions. Other simulation settings were implemented with the AIJ guidance [20]. The average wind velocity of each point was calculated and compared with the experimental data.

The measured data were consistent well with the simulation results, especially well for the wind direction of each measuring point (**Figure 4**). Through comparison of the deviation between wind velocity in simulation and experiment, it is discovered that the deviation between experimental and simulation results ranges from 2.35% to 15.12% (**Table 2**). The following factors should be comprehensively considered: the deviation between vegetation model and actual experiment, errors caused by instrumental measurement and systematic errors. With all these factors considered, it could be concluded that simulated values represent well with those measured in actual experiment.

Table 1. Vegetation Classification[a].

Kind	Vegetation classification	Main vegetation	Leaf area index	
A	Evergreen arbors	*Cedrus deodara*	2.32 (S)	2.32 (W)
B	Deciduous arbors	*Ailanthus altissima*	3.68 (S)	1.22 (W)
C	Evergreen shrubs	*Sabina cv.Henanbai*	1.69 (S)	1.69 (W)
D	Deciduous shrubs	*Syringa oblata*	2.59 (S)	0.86 (W)

[a]A type of vegetation canopy has the height of 4 m, and is 1m from the ground; B type of vegetation canopy has the height of 3 m, and is 2 m from the ground; C type of vegetation canopy has the height of 2 m, and is 1.5 m from the ground; D type of vegetation canopy has the height of 2 m, and is 0.5 m from the ground. S and W represent summer and winter respectively.

Table 2. Comparison of wind velocity between experiment and simulation.

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7
Wind velocity in simulation	0.87	1.27	0.83	1.12	1.25	0.89	1.01
Wind velocity in experiment	1.09	1.12	0.85	1.08	1.29	0.83	1.19
Error	11.00%	11.81%	2.35%	3.57%	3.10%	6.74%	15.12%

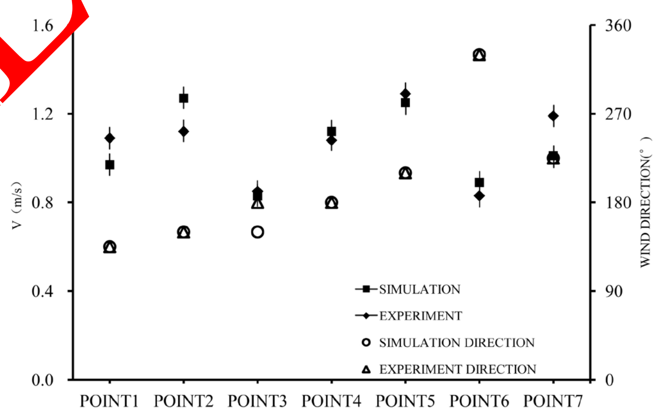


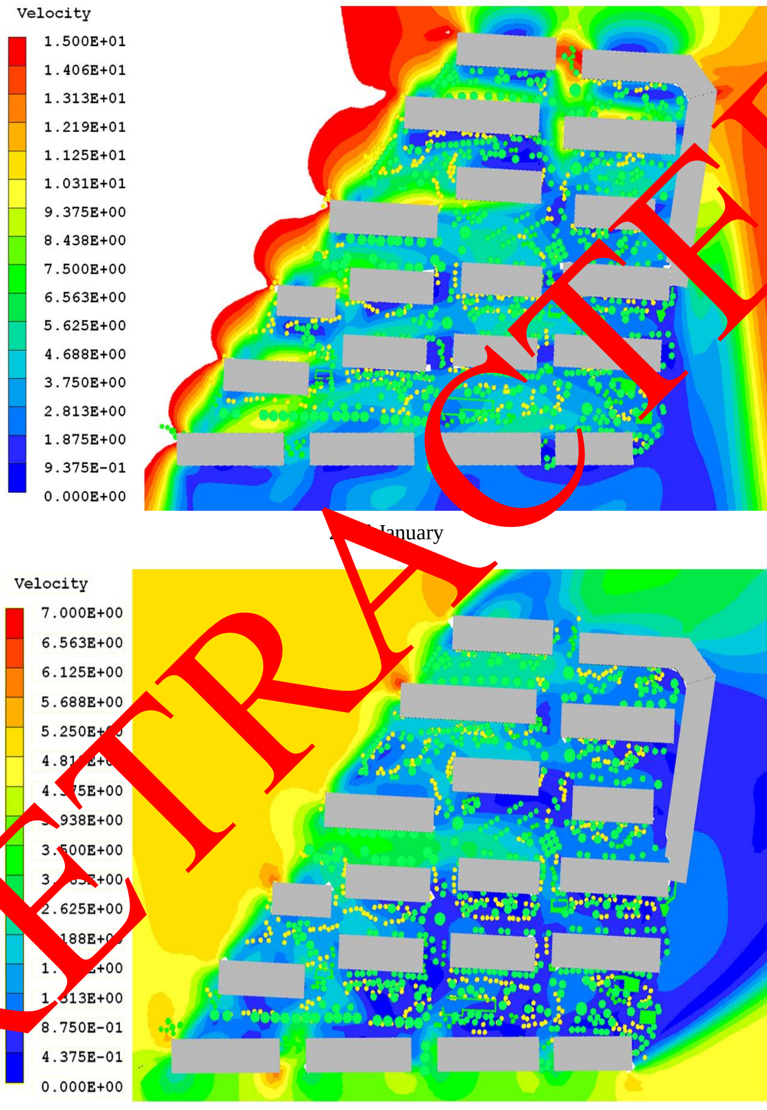
Figure 4. Comparison of wind velocity and direction between experiment and simulation[b]. [b]The right ordinate represents wind direction, with 0˚ standing for the north, 90˚ standing for the east, 180˚ for the south, 270˚ for the west and 360˚ for the north.

3. Comparisons and Analysis

The date for numerical simulation was selected as 22nd January and 19th May, and the wind directions were set as N and SSW, with the wind velocities as 7.0 m/s and 4.0 m/s at the height of 21 m respectively.

3.1. Comparison of Simulations with and without Vegetation

The simulations with and without vegetation were performed (**Figure 5**). And the wind velocity with and without vegetation were compared independently.



19th May

Figure 5. Simulation with vegetation.

Defining minus = $V_{[\text{with vegetation}]}/V_{[\text{without vegetation}]}$, the data of simulations with and without vegetation were compared (**Figure 6**), analysis for the wind environment at pedestrian level was carried out.

By the comparison of simulation data with and without vegetation, the actual wind velocity increased to a much less extent in areas with vegetation than areas without vegetation, the ratio of region with decreased wind velocity was 61% and 60.2% in summer and winter respectively, while regions with excessively large wind velocity increased obviously, due to the wind-induced effect of vegetation (**Table 3**). It is strongly in-

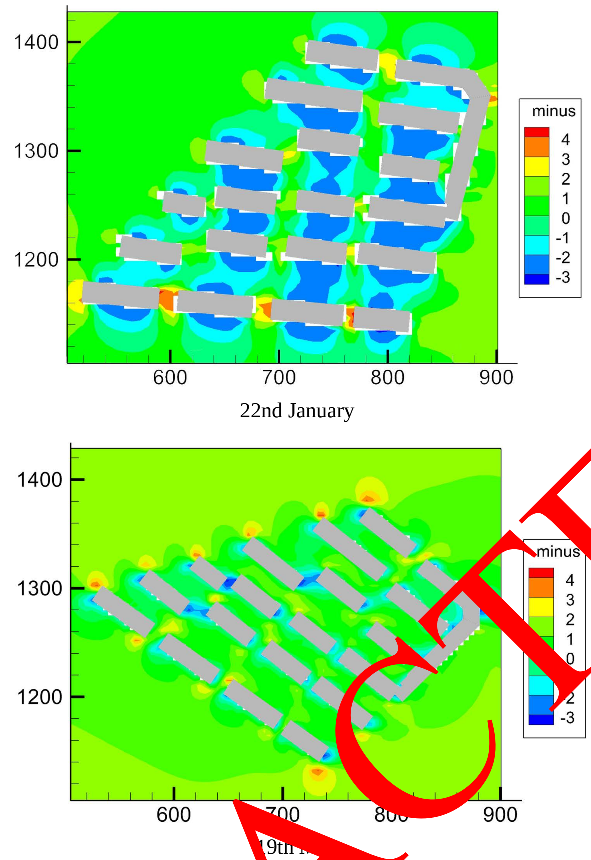


Figure 6. Distribution of minus in simulation.

Table 3. Comparison of simulations data with and without vegetation.

		Max ratio of wind velocity	Min ratio of wind velocity	Region with increased wind velocity	Region with decreased wind velocity
With plants Without plants	Summer	0.95	3.2	35.0%	61.0%
	Winter	0.95	0.47	35.8%	60.2%

dicated that vegetation plays a significantly active role in improving wind environment.

3.2. Comparison of Simulations by Adjusting the Types of Vegetation

The status vegetation in green space between buildings was mostly deciduous plants, and evergreen plants composed a proportion no more than 10%. By adjusting the types of vegetation, in other words, supplant the status deciduous plants into evergreen plants, the simulations after adjusting the types of vegetation were performed (**Figure 7**).

Similarity, defining minus = $V_{[adjusting\ vegetation]}/V_{[status\ vegetation]}$, the data of simulations after adjusting the types of vegetation were compared (**Figure 8**), analysis for the wind environment at pedestrian level was carried out.

After supplanting the status deciduous plants into evergreen ones, the actual wind velocity increased to a much extent in areas with adjusting vegetation than area with status vegetation, and the ratio of region with increased wind velocity reaches almost 69.1% and 64.7% in summer and winter respectively, while regions with excessively large wind velocity increased obviously in winter, due to the wind-induced effect of vegetation (**Table 4**). It may be indicated that with all evergreen vegetation planted in the green space between buildings would not improve the wind environment of residential areas, especially in winter. Therefore, the overall evergreen vegetation may exert potential negative impact on building sunshine in winter [21].

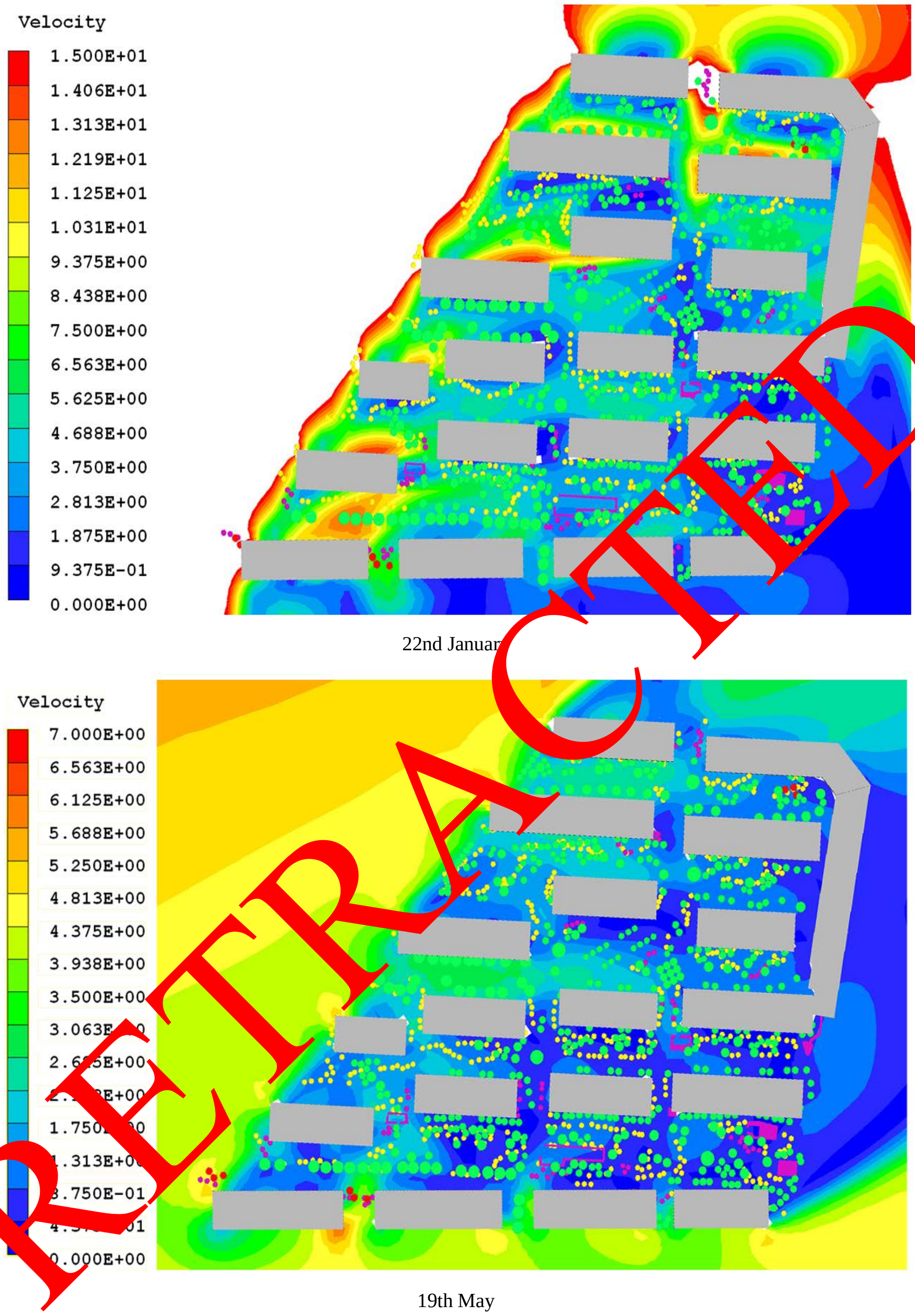


Figure 7. Simulation after adjusting the types of vegetation.

3.3. Comparison Analysis of Conditions by Optimizing Arrangement of Vegetation

Most of heights of tree crown were no more than 3 m, and the vast majority of vegetation was deciduous plants in the study object. When coming wind velocity was too great, the wind environment inside the residential area would be severely affected. Based on the accuracy of simulation of wind field using SPOTE in the study site, appropriate adjustments could be made to mitigate the adverse impact of excessively great wind velocity on pedestrians. By optimizing the vegetation types and arrangement in the residential area, the simulations of wind

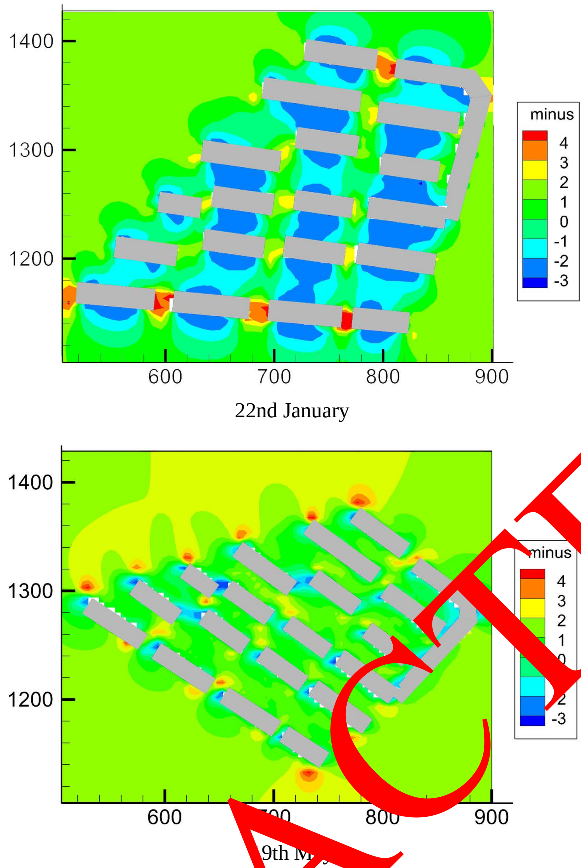


Figure 8. Distribution of minus in simulation.

Table 4. Comparison of simulations data by adjusting the types of vegetation.

		Max ratio of wind velocity	Min ratio of wind velocity	Region with increased wind velocity	Region with decreased wind velocity
Adjusting plants Status plants	Summer	1.08	0.04	69.1%	30.9%
	Winter	1.10	0.86	64.7%	35.3%

field distributions were carried out (**Figure 9**).

In accordance with the definition of minus, the data of simulations after and before optimum arrangement of vegetation were compared independently (**Figure 10**).

After optimization of vegetation on the site, under identical simulation boundary conditions, the wind velocity was decreased, and the ration of region with reduced wind velocity was 71.3% in winter (**Table 5**). It is betrayed that evergreen vegetation, such as *Sabina chinensis* and *Picea asperata*, planted in the west-north side of the residential, with an arrangement of arbor and bush, would effectively block the coming wind velocity and improve the outdoor environment in winter. Moreover, trees planted in the passages between buildings could also reduce the wind velocity.

Although the trade-off between wind environment in summer and winter was insufficient to specify, while the comfortable of outdoor environment in winter was more important for pedestrian's pleasantness in Beijing area (Hong et al., 2011). The optimum arrangement of vegetation was regarded as the optimum design with a reduction of wind velocity by 61.6% in winter (**Table 6**).

4. Conclusions

Based on comparisons and simulation from this study, the following conclusions could be drawn: 1) through a

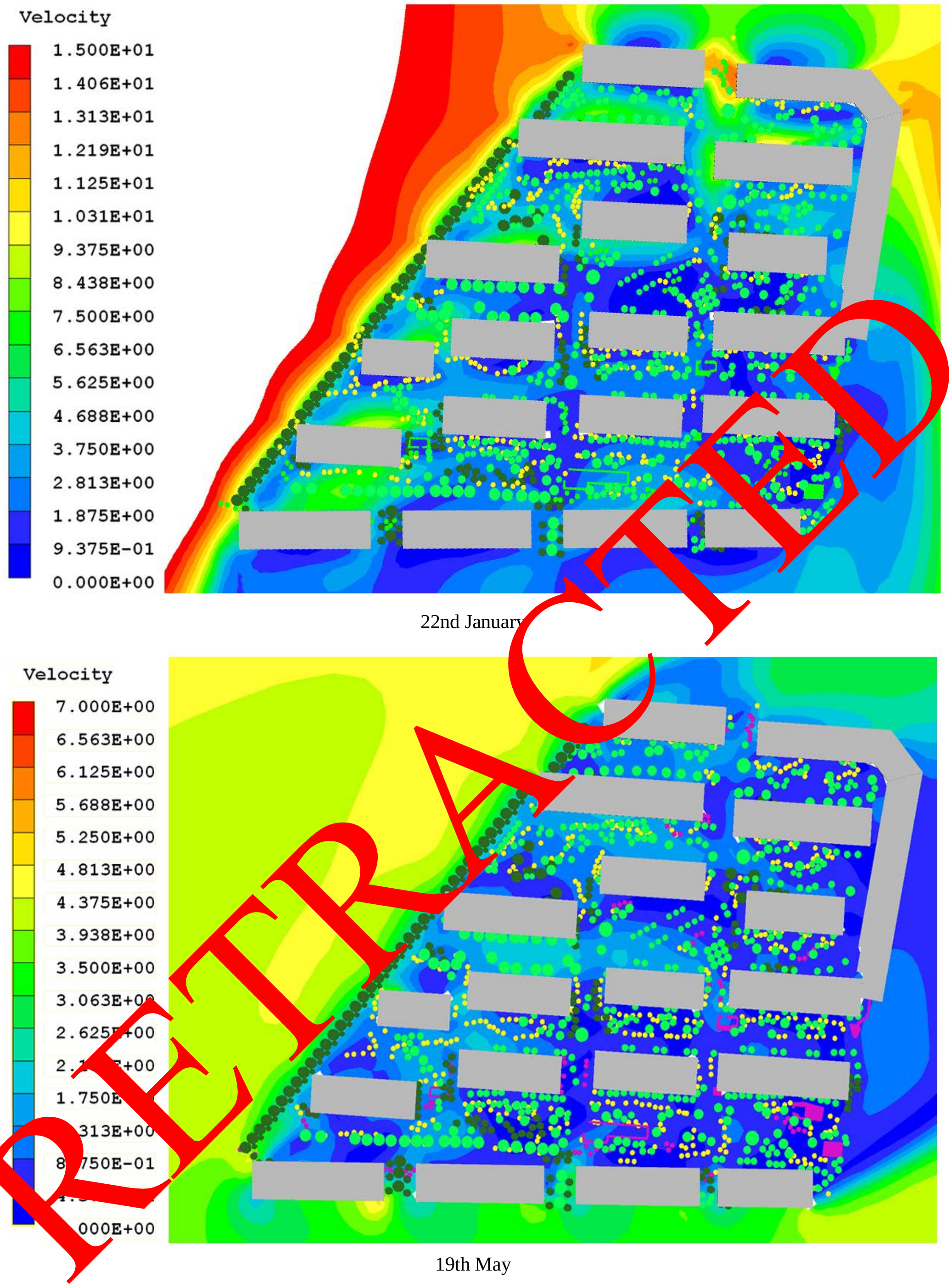


Figure 9. Simulation after optimization.

comparison between experiment and simulation based on SPOTE simulation platform, it could be concluded that simulation results were consistent well with experiment data, and the wind field distribution could be accurately reflected; 2) simulations with and without vegetation are compared to quantitatively show effects of vegetation on wind environment, and the wind velocity was obviously decreased comparing the case with and without vegetation with a good improvement of more than 60%; 3) after supplanting the status deciduous vegetation into evergreen one, the wind velocity increased compared to optimization with status, and the ratio of region with increased wind velocity reached almost 69.1% and 64.7% in summer and winter respectively; 4) by

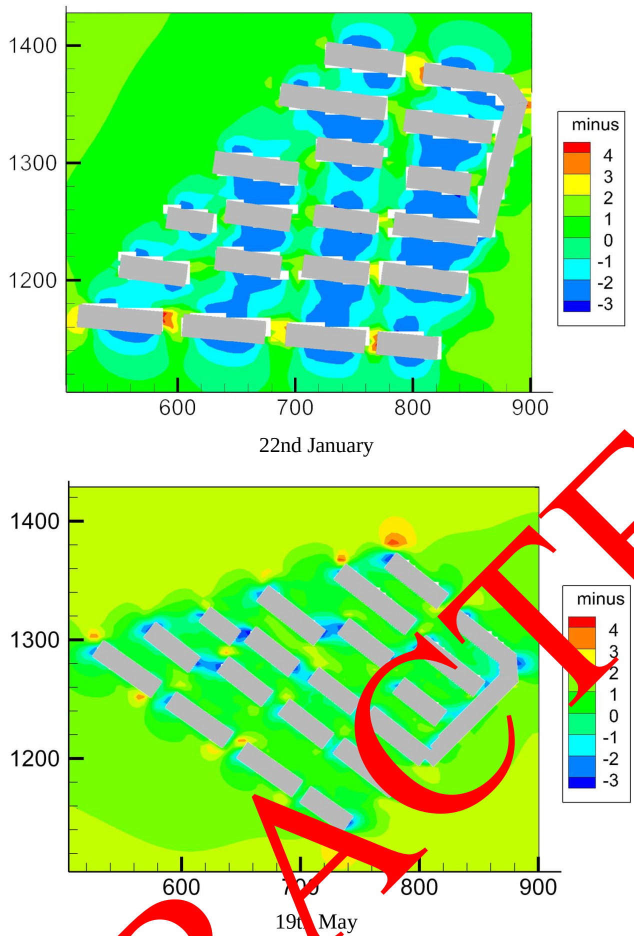


Figure 10. Distribution of minus after optimization.

Table 5. Comparison of simulations data by optimizing vegetation.

		Max ratio of wind velocity	Min ratio of wind velocity	Region with increased wind velocity	Region with decreased wind velocity
After optimization Before optimization	Summer	0.93	2.45	22.2%	73.6%
	Winter	0.81	0.33	24.5%	71.3%

Table 6. Comparison of simulation data before and after optimizing vegetation.

	Region with increased wind velocity	Region with decreased wind velocity	Average wind velocity
Summer	42.5%	55.1%	0.97
Winter	33.2%	61.6%	0.99

adjusting arrangement and types of vegetation in the regions with excessively large wind velocity, the pedestrian-level wind velocity could be obviously improved through the simulation and comparison, and the ration of region with reduced wind velocity was 71.3% in winter.

This study analyzed the impacts of vegetation on outdoor wind environment with the specific wind velocity and direction in the typical winter climate in Beijing, and put forward the optimization method of vegetation arrangement. But the actual climatic conditions in Beijing are worse compared with the daily parameters employed in this simulation. If the prevailing wind direction and velocity change, more numerical simulations should be carried out in the further research. Nevertheless, the results of this study can provide effective guidance for landscape greening to improve the outdoor wind environment in residential district.

Acknowledgements

This research was supported by the Special Fund Programs of Basic Scientific Research of Northwest A & F University (Grant No. 2014YB076) and National Training Programs of Innovation and Entrepreneurship for Undergraduates (Grant No. 201410712049).

References

[1] Taha, H. (1997) Urban Climates and Heat Islands: Albedo, Evapotranspiration and Anthropogenic Heat. *Energy and Buildings*, **25**, 99-103. http://dx.doi.org/10.1016/S0378-7788(96)00999-1

[2] Mochida, A. and Lun, Y.F. (2006) Prediction of Wind Environment and Thermal Comfort at Pedestrian Level in Urban Area. 4*th International Symposium on Numerical Wind Engineering* (*CWE* 2006), Yokohama, July 2006, 33-60.

[3] McPherson, E.G. and Rowntree, R.A. (1993) Energy Conservation Potential of Urban Tree Planting. *Journal of Arboriculture*, **19**, 321-331.

[4] Gong, J.Z., Liu, Y.S., Xia, B.C. and Zhao, G.W. (2009) Urban Ecological Security Assessment and Forecasting, Based on a Cellular Automata Model: A Case Study of Guangzhou, China. *Ecological Modelling*, **220**, 3612-3620. http://dx.doi.org/10.1016/j.ecolmodel.2009.10.018

[5] Li, J. and Sun, P. (2009) Discussion on Beijing Residential Area Greening in New Era. *Journal of Huazhong Agricultural University* (*Social Sciences Edition*), **6**, 96-98.

[6] Chen, H., Ooka, R. and Murakami, S. (2001), Study on Air Quality in Urban Area Using Scale for Ventilation Efficiency. The Effect of Building Shape and Its Arrangement on Ventilation Efficiency in Urban Area. *Annual Technical Meetings of Architectural Institute of Japan*, Japan, 933-934.

[7] Ashie, Y., Murakammi, S. and Morigawa, T. (2002) CFD Analyses on Effects of Wind from Rivers on Outdoor Thermal Environment. Part 2: Control of Thermal Environment Based on Building Layout. *Annual Technical Meetings of Architectural Institute of Japan*, Japan, 881-882.

[8] Ooka, R., Chen, H. and Kato, S. (2008) Study on Optimum Arrangement of Trees for Design of Pleasant Outdoor Environment Using Multi-Objective Genetic Algorithm and Coupled Simulation of Convection, Radiation and Conduction. *Journal of Wind Engineering and Industrial Aerodynamics*, **96**, 1733-1748. http://dx.doi.org/10.1016/j.jweia.2008.02.039

[9] Lin, T.P., Matzarakis, A. and Hwang, R.L. (2010) Shading Effect on Long-Term Outdoor Thermal Comfort. *Building and Environment*, **45**, 213-221. http://dx.doi.org/10.1016/j.buildenv.2009.06.002

[10] Yoshida, S., Murakami, S., Ooka, R., Mochida, A. and Tominaga, Y. (2000) CFD Prediction of Thermal Comfort in Microscale Wind Climate. *The International Symposium on Numerical Wind Engineering* (*CWE* 2000), Birmingham, 27-30.

[11] Shashua-Bar, L. and Hoffman, M. (2000) Vegetation as a Climatic Component in the Design of an Urban Street: An Empirical Model for Predicting the Cooling Effect of Urban Green Areas with Trees. *Energy and Buildings*, **31**, 221-235. http://dx.doi.org/10.1016/S0378-7788(99)00018-3

[12] Feng, N., Ma, [illegible], Lin, B.R. and Zhu, Y.X. (2009) Impact of Landscape on Wind Environment in Residential Area. *Journal of Central South University of Technology*, **16**, 80-83.

[13] Beijing Municipal Bureau of Landscape and Forestry (BMBLF) (2003) Code for Design of Greenland in Resident Areas (Revision). DB11/T-214.

[14] Yao, [illegible] and Huang, L. (2008) Winter Plant-Landscape Design on the Residential Area of Beijing. *Journal of Shanxi Agricultural Science*, **36**, 106-107.

[15] Lin, B.R., Li, X.F., Zhu, Y.X. and Qin, Y.G. (2008) Numerical Simulation Studies of the Different Vegetation Patterns' Effect on Outdoor Pedestrian Thermal Comfort. *Journal of Wind Engineering and Industrial Aerodynamics*, **96**, 1707-1718. http://dx.doi.org/10.1016/j.jweia.2008.02.006

[16] Mochida, A., Tabata, Y., Iwata, T. and Yoshino, H. (2008) Examining Tree Canopy Models for CFD Prediction of Wind Environment at Pedestrian Level. *Journal of Wind Engineering and Industrial Aerodynamics*, **96**, 1667-1677. http://dx.doi.org/10.1016/j.jweia.2008.02.055

[17] Schilling, V. (1991) A Parameterization for Modeling the Meteorological Effects of Tall Forests—A Case Study of a Large Clearing. *Boundary-Layer Meteorology*, **55**, 283-304. http://dx.doi.org/10.1007/BF00122581

[18] Omori, T., Yamaguchi, S. and Taniguchi, H. (1998) Accurate Monte Carlo Simulation of Radiative Heat Transfer with Unstructured Grid Systems. 11*th International Symposium on Transport Phenomena*, 567-573.

[19] Hong, B., Lin, B.R., Wang, B. and Li, S.H. (2012) Optimal Design of Vegetation in Residential District with Numerical Simulation and Field Experiment. *Journal of Central South University*, **19**, 688-695. http://dx.doi.org/10.1007/s11771-012-1058-6

[20] Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M. and Shirasawa, T. (2008) AIJ Guidelines for Practical Application of CFD to Pedestrian Wind Environment around Buildings. *Journal of Wind Engineering and Industrial Aerodynamics*, **96**, 1749-1761. http://dx.doi.org/10.1016/j.jweia.2008.02.058

[21] Hong, B., Lin, B.R., Hu, L.H. and Li, S.H. (2011) Optimal Tree Design for Sunshine and Ventilation in Residential District Using Geometrical Models and Numerical Simulation. *Building Simulation*, **4**, 351-363. http://dx.doi.org/10.1007/s12273-011-0056-1