INFLUENCE OF BUILDING TOPOGRAPHY AROUND HIGH-SPEED RAILWAY FOUNDATION ON WIND ENVIRONMENT AND THERMAL COMFORT

by

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The influence of the surrounding building topography of the Datong-Xi'an high-speed railway foundation on the wind environment and the thermal comfort is studied, especially the outdoor wind environment and indoor air-flow organization of the surrounding buildings are analyzed numerically, and the building terrain and the indoor temperature and the wind's speed distribution are systematically evaluated. The results show that the surrounding terrain of the roadbed has a significant effect on the wind environment of the site, affecting the natural ventilation in summer and wind-proof and energy-saving in winter. The terrain surrounding of the building in summer reduces the wind speed by 30.5%, and it increases in winter by 31.6%; the wind speed in the indoor personnel activity area of the building around the roadbed is less than 0.35 m/s, leading to a comfortable body feeling.

Key words: *high railway roadbed, wind environment, thermal comfort, surrounding terrain, T-test*

Introduction

With the continuous development of railway construction, the terrain surrounding the roadbed has a greater impact on the wind environment of the site, which the wind speed changes seasonally, making the indoor air temperature field and the speed field around the roadbed unevenly distributed, thereby affecting the comfort of the indoor environment. The terrain around the roadbed affects the summer nature ventilation remarkably and wind-proof and energy-saving in winter. This phenomenon has attracted much attention in the academic world and building industry, and it has now become a hot research topic. The deterioration of the wind environment of the building terrain around the roadbed affects not only people's health and normal life, but also energy consumption for heating and air conditioning in buildings [1, 2]. It is a known fact that an excessive wind speed affects the safety and comfort of pedestrians [1]. On the other hand, a too-small wind speed is not conducive to the diffusion of pollutants in the air. Sun *et al.* [3] used the numerical software CFD to simulate the wind environment of the residential area and analyzed the relationship between the building layout and the wind field. Li *et al.* [4] used the CFD to study the outdoor wind environment of a school's comprehensive teaching building numerically and discussed the wind environment of

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the outdoor pedestrian area and activity area as well as the pressure distribution of building units. Liu *et al.* [5] aimed at the correlation between the surrounding wind environment of high-rise buildings and the shape of the podium, site and other factors, rationally designed the shape of the podium and planned the site to optimize the surrounding terrain and wind environment. Gu *et al.* [6] used CFD to perform numerical simulation analysis of the wind load and the wind environment of the Olympic Park Tennis Centre Stadium. Lu *et al.* [7] studied the practical engineering application of the wind environment simulation in urban planning and single building design, and proposed the simulation method of the coarse and fine grid without considering the influence of surrounding buildings on the target buildings. Zhu *et al.* [8] proposed that the simulation of the wind environment before the construction of the project can avoid the shortcomings of space planning and wind field distribution and can reduce construction costs and unsafe factors. Zeng *et al.* [9] used MATLAB software to study the influence of air temperature, clothing thermal resistance, air relative humidity, and air-flow rate on predicted mean vote (PMV) indicators in non-air-conditioned residential buildings in winter and summer. Shang *et al.* [10] used AIRPAK software to study the indoor temperature field, the velocity field and PMV-PPD (predicted percentage dissatisfied – PPD) index results under two air supply modes of displacement ventilation and side air supply in an office in summer. Pourshaghaghy *et al.* [11] used test methods to study the performance and thermal comfort of an international hospital air conditioning system. Homod *et al.* [12] proposed a method that can be used to effectively control the thermal comfort in heating, ventilation and air-conditioning systems, which is of great significance to study the outdoor wind environment and the indoor air-flow organization. He [13] suggested an analytical method to identify the thermal instability, and Liu, *et al.* [14] pointed out the importance of the thermal oscillation in thermal comfort for cocoons, and Tian and Liu [15] characteristic set algorithm can be used for theoretical analysis.

In recent years, many scholars have conducted in-depth studies on the correlation among the outdoor wind environment conditions of buildings, building shapes, construction sites and other factors, and on the evaluation methods of the outdoor wind environment as well. However, there were few research reports on the natural ventilation in summer and wind-proof and energy-saving in winter on the surrounding building terrain of the high-speed railway section. This paper considers the interference influence of the surrounding building terrain of the Datong-Xi'an high-speed railway roadbed on the wind environment of a hospital building located in the site, and it focuses on the building's indoor temperature and the speed distribution, which are studied numerically and verified the T-test method in mathematical statistics.

Building model and meshing

Physical model

In this paper, we take a hospital construction project as an example, where the surrounding building terrain of the Datong-Xi'an high-speed railway roadbed is located on the site. The hospital building is mainly composed mainly of the outpatient medical technology building, the ward building, and the logistics support and comprehensive supporting building.

Firstly, the T-test method is used to analyze the changes in the building wind environment around the roadbed and the impact of building types and geographic locations on the energy consumption level of public buildings is discussed. Secondly, according to the statistical data of the energy consumption monitoring platform of the building projects around the roadbed, targeted energy conservation supervision, construction of public building energy consumption data index system, and analysis strategies for public building energy consumption in hot summer and cold winter areas are proposed. The hospital building model of the site surrounding the roadbed is shown in fig. 1. Figure 2 shows the layout plan of the hospital building in the surrounding area of the roadbed.

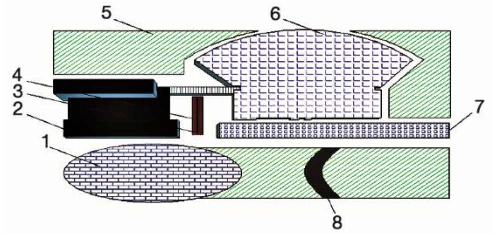

Figure 1. Hospital building model of the site surrounding the roadbed; *1 – comprehensive supporting building, 2 – emergency, outpatient medical technology, surgical clinic, etc., 3 – pedestrian passage center line, 4 – pedestrian passage, 5 – green belt, 6 – outpatient building, 7 – ward building, 8 – pedestrian passage*

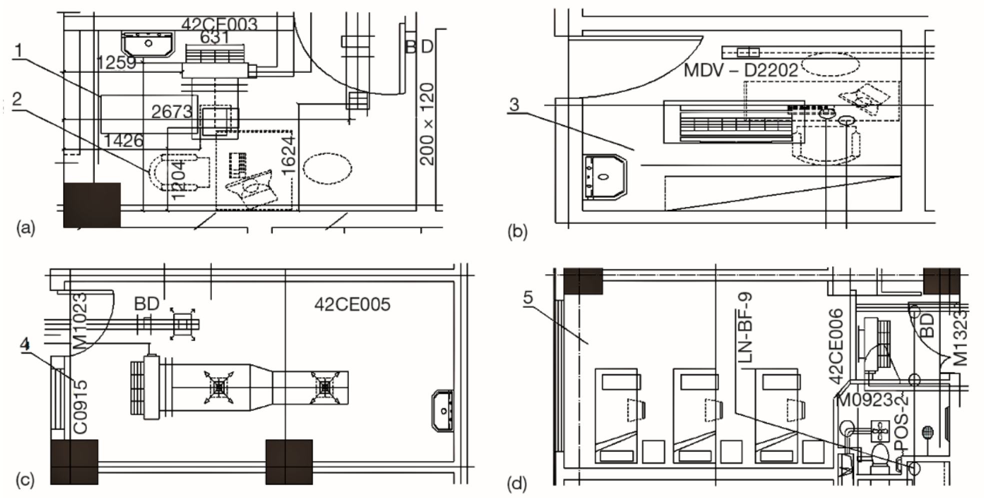

Figure 2. The layout plan of the hospital building around the roadbed; *1 – outpatient medical technical room, 2 – emergency room, 3 – surgical clinic, 4 – comprehensive supporting building, 5 – ward building*

Model simplification and parameter setting

In order to simplify the problem, the following simplifications and assumptions are made. The indoor air-flows at a low speed, and it is an incompressible fluid and conforms to Boussinesq hypothesis, that is the fluid density only affects the buoyancy force. The heat transfer process is a constant heat flow. Assuming that the flow has a high turbulent Reynolds number and the turbulent viscosity of the fluid is isotropic.

Initial conditions are: the working pressure is 101325 Pa, the air supply temperature is 18 ℃, the human body power is 105 W, the minimum fresh air input ratio in clinic and ward is set to be 20 m^3 per hour, the indoor temperatures in winter and summer are 23 ℃, 26 ℃, respectively.

The boundary conditions are: the corresponding temperature and speed conditions are given according to the simulation conditions.

Theoretical analysis

The air-flow of the ventilation and the air-conditioning system is a steady flow of incompressible fluid, which satisfies the laws of conservation of mass, momentum, and energy. Using a standard model, the continuity equation, the momentum equation, k-ε equation, and the energy equation are simultaneously used as the calculation equations. The control equations for the gas-flow in the entire model space are:

$$\mathrm{div}(\rho \bar{u} \phi) = \mathrm{div}(\Gamma_\phi \mathrm{grad}\phi) + S_\phi \tag{1}$$

where ϕ, Γ_ϕ, and S_ϕ are the general variable, the generalized diffusion coefficient, and the generalized source term, respectively, and shown in tab. 1. The empirical constants in the k-ε model are given in tab. 2.

Table 1. Control equation variables, diffusion coefficients and source terms

Equation	ϕ	Diffusion coefficients, Γ_ϕ	Source terms, S_ϕ
Continuity equation	1	0	0
X-direction momentum equation	μ	$\mu_{\mathrm{eff}} = \mu + \mu_t$	$-\frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left(\mu_{\mathrm{eff}} \frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu_{\mathrm{eff}} \frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial z}\left(\mu_{\mathrm{eff}} \frac{\partial w}{\partial x}\right)$
Y-direction momentum equation	v	$\mu_{\mathrm{eff}} = \mu + \mu_t$	$-\frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left(\mu_{\mathrm{eff}} \frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial y}\left(\mu_{\mathrm{eff}} \frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu_{\mathrm{eff}} \frac{\partial w}{\partial y}\right)$
Turbulence energy equation	k	$\mu = \frac{\mu_t}{\sigma_k}$	$G_k - \rho\varepsilon$
Turbulent energy dissipation equation	ε	$\mu = \frac{\mu_t}{\sigma_\varepsilon}$	$\frac{\varepsilon}{k}(C_{1\varepsilon} - C_{2\varepsilon}\rho\varepsilon)$
Energy equation	T	$\frac{\mu}{P_r} + \frac{\mu_t}{\sigma_T}$	0

where:

$$\mu_{\mathrm{eff}} = \mu + \mu_t, \quad \mu_t = \frac{\rho C_\mu k^2}{\varepsilon} \tag{2}$$

Table 2. Standard k-ε model parameters

C_μ	$C_{1\varepsilon}$	$C_{2\varepsilon}$	σ_k	σ_ε	σ_T
0.09	1.44	1.92	1.0	1.3	1.0

Calculation results and analysis

Numerical simulation

The hospital clinics in the surrounding areas of the roadbed is used as an example for numerical simulation in summer. Since the 3-D display of the calculation results cannot clearly show the distribution of the flow field in the hospital building where the site is located around the roadbed, the following display results are representative sections selected in the simulation to analyze the parameter distribution. The temperature and velocity cloud diagrams of the tuyere section are shown in figs. 3-8, respectively.

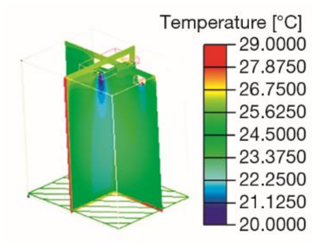

Figure 3. Temperature cloud map of the tuyere section

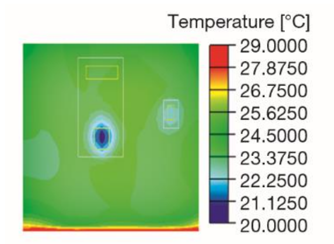

Figure 4. Temperature cloud map of *z* = 1.5 m

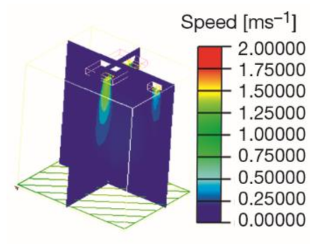

Figure 5. Speed cloud map of the tuyere section

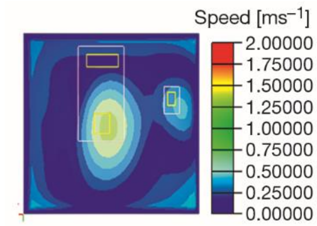

Figure 6. The *z* = 1.5 m velocity cloud map

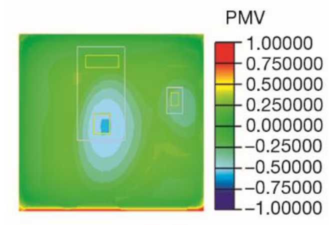

Figure 7. The *z* = 1.5 m PMV cloud map

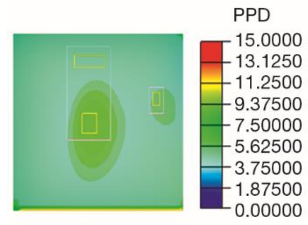

Figure 8. The *z* = 1.5 m PPD cloud map

According to figs. 3-8, except for the low temperature near the air outlet, the temperature distribution in the staff activity area in the clinic is good, and the minimum blowing temperature in the staff activity area is about 24 °C. The average temperature in the clinic is about 25 ℃, and the effective blowing temperature is less than 1.1 ℃, which was set within the specified range when the average wind speed is 0.1 m/s. Therefore, under this air-flow organization condition, the temperature of the air-conditioned area meets the requirements of human comfort. According to figs. 5 and 6, it can be seen that the air is sent out from the air supply port, mixed with the indoor air, and then discharged through the air return port. The air-flow in the air-conditioned room is in the shape of a free jet near the incident air outlet, and it decreases with the speed of the jet center. At the tail of the jet, the speed is 0.25 m/s. The small vortex in the working area forms a reflux area. Both the up-supply and up-return methods could form a good air-flow organization, and the wind speed in the human activity area is less than 0.35 m/s, and the indoor personnel-in-most area has no obvious blowing feeling. According to figs. 7 and 8, it can be seen that the PMV index of the staff in the clinic is around –0.2, the PPD of most areas is less than 10%, there is no obvious blowing sensation, the body feels comfortable, meeting the design parameter requirements of the thermal environment.

Result analysis

The related software was used to simulate the flow field distribution in the clinic building of the hospital on the surrounding site of the roadbed in summer, and the flow field distribution (temperature and wind speed changes) in the clinic could be seen directly. The simulation showed that the wind speed, temperature, and thermal comfort index of the human body in the clinic all met the requirements of comfort air conditioning, and met the requirements of the thermal comfort model PMV-PPD index parameters of the *Green Building Evaluation Standard*. The PMV index of the staff in the immediate room was around –0.2, and the

PPD of most areas was less than 10%. The body felt comfortable and met the design parameter requirements of the thermal environment.

Evaluation and inspection of building outdoor wind environment

The T-test theory

Set the random variable $Y = X_1 - X_2$, where X_1 and X_2 are the sample population, all obey the normal distribution $N(u_1, \sigma_1^2), N(u_2, \sigma_2^2)$. Randomly draw samples (X_{11}, X_{12}, …, X_{1N}) and (X_{21}, X_{22}, …, X_{2N}), test u_1 and u_2 to see whether there was a significant difference between them, and then form a sample T-test problem.

Evaluation and inspection

The T-test method was adopted. The topography, terrain, and landform surrounding the building were considered. The topography, terrain, and topography around the building were not considered. Analyzing the changes in the building wind environment around the roadbed and discussing the impact of building types and geographic locations on the energy consumption of public buildings. Effect of terrain surrounding the buildings on the wind speed change (summer and winter) was shown in fig. 9.

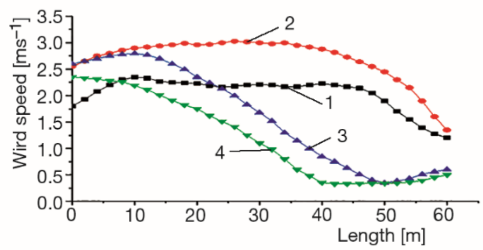

Figure 9. Wind speed change of the terrain around the building (summer/winter); *1 – considering surrounding building terrain (summer), 2 – not considering surrounding building terrain (summer), 3 - considering surrounding building terrain (winter), 4 – not considering surrounding building terrain (winter)*

According to fig. 9, the surrounding terrain of the building had a significant impact on the wind environment of the site, affecting natural ventilation in summer and wind-proof and energy-saving in winter, which was not conducive to the quality of the outdoor wind environment. In the actual green building review, the impact on the outdoor wind environment cannot be ignored. Under the average wind speed of the dominant wind direction in summer, considering the surrounding terrain of the building, the wind speed value at the pedestrian passage (1.5 m height) would decrease overall, and the effect was obvious. However, under the average wind speed of the dominant wind direction in winter, considering the surrounding terrain of the building, the wind speed value at the pedestrian passage (1.5 m height) had an increasing trend, and the influence was more significant. Evaluation and inspection results showed that the T-test probability in summer was less than the significant level of 0.05, and the surrounding terrain of the building had a significant impact on the wind environment of the site, and the average overall wind speed was reduced by 30.5%. The T-test probability in winter was less than the significant level of 0.05. The surrounding terrain of the building had a significant impact on the wind environment of the site, and the average overall wind speed had increased by 31.6%.

Conclusion

The surrounding terrain of the building has a significant effect on the wind environment of the site, affecting natural ventilation in summer and wind-proof and energy-saving in winter.

In summer, when the surrounding terrain of the building is considered, the average overall wind speed of the site reduces by 30.5%, and in winter, the average overall wind speed of the site increases by 31.6%. The wind speed in the indoor personnel activity area of the building surrounding the roadbed is less than 0.35 m/s. There is no obvious blowing sensation, comfortable body feeling, and the air-flow distribution characteristic air diffusion performance index reaches 90%.

The simulation shows that the building's indoor wind speed, temperature, and human thermal comfort index all meet the requirements of comfort air conditioning and meet the requirements of the thermal comfort model (PMV-PPD index parameters) for the *Green Building Evaluation Standards*.

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