Wind Field Simulation Tools Assist in Conducting Heritage Impact Assessments

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ABSTRACT:
Urban development, with its evolving streetscapes and new constructions, can significantly impact historically significant districts. To mitigate adverse effects, governments often implement Development Control Plans (DCPs) and mandate Heritage Impact Assessments (HIAs). However, the resulting changes to local wind environments and pedestrian comfort are frequently overlooked. Comfortable climatic conditions are crucial for enhancing the visitor experience at heritage sites, thereby boosting the economic contribution of cultural heritage. This study investigates this issue using Taiwan's Control Yuan as a case study. Referencing the Dutch NEN 8100 wind comfort standard, we employed computational fluid dynamics (CFD) software (WindperfectDX®) to analyze potential impacts. First, a 3D model of the site was created in SketchUp® . We then developed three distinct architectural proposals for a new building and simulated the resulting wind field for each design. The analysis focused on how each proposal altered wind speeds and turbulence around the historic building and adjacent roads.
Our results showed varied outcomes: one design slightly increased wind speeds, while another maintained stable conditions. Notably, designs with sharp edges generated higher turbulence, whereas those with rounded corners reduced it. These findings underscore that the microclimatic impact of new developments on historical environments cannot be ignored. Therefore, a more careful and comprehensive evaluation of architectural design is essential during the planning stages to preserve the integrity and accessibility of our shared heritage.

1. Introduction

Driven by existing conditions and limitations such as economic development, population growth, and limited land area, various emerging developments are springing up throughout cities like bamboo shoots after spring rain. Against this backdrop, the coordination and integration between newly developed buildings and existing historical buildings is particularly important. The "Environmental Planning and Assessment Act" enacted by New South Wales (NSW), Australia in 1979 stipulates in detail the relevant matters and principles that should be followed in the environmental planning of each Local Government Area (LGA) throughout NSW. Development Control Plans (DCPs) are formulated as reference procedures, bases, and principles for effective development control and management. Developers should respond to the contents of the DCPs by conducting a Heritage Impact Assessment (HIA).

The configuration, height, and building volume of new buildings can all influence the wind field in urban environments, with particularly significant and important impacts on surrounding historical buildings and environments. Therefore, careful evaluation should be conducted during the design phase of new buildings. Jianlei Niu et al. (2015) believe that urban design techniques such as building volume retraction and changes in building configuration can promote street ventilation capabilities, effectively alleviate the sense of oppression brought by high-rise building clusters, and improve pedestrian safety and environmental comfort. Ting Yu-Ting's (2017) research on the relationship between building volume retraction height and building volume retraction depth scale suggests that if future planning aims to improve the pedestrian wind environment and low-rise area wind environment, it should be oriented towards a smaller building volume retraction scale. If the goal is to improve the high-rise area and overall urban wind environment, the building volume design should be oriented towards a larger building tower retraction depth but a smaller building podium height. It can be seen that the influence between building volume configuration and wind field is closely related and should be one of the important analysis objects of this study.

In addition to architectural design, the impact of trees on urban air quality is complex and depends on multiple factors, including wind direction, the leaf area density of trees, and their location. According to research by Riccardo Buccolieri, Antoine P.R. Jeanjean, Elisa Gatto, and Roland J. Leigh, the study primarily explores the effects of trees on ventilation, nitrogen oxides (NOx), and PM2.5 concentrations in the street environment of Marylebone Road in central London. The research employs computational fluid dynamics (CFD) simulations and considers the impact of trees with varying leaf area densities on air quality. In the case of Marylebone Road, trees can reduce pollution under parallel wind conditions, while they may increase localized pollution under perpendicular wind conditions. The study also emphasizes the need to evaluate the impact of trees on air quality in specific contexts, noting that there is currently no universal solution.

As public awareness and authorities' emphasis on the comfort of wind environments in public spaces have increased, along with a growing understanding of the concept, and as high-rise buildings in cities have rapidly proliferated, the standards for wind comfort have remained chaotic and inconsistent. Recognizing the necessity of establishing a wind comfort assessment guideline, the Netherlands Standardization Institute (NEN) convened meetings with local authorities, architects, urban planners, developers, and scientists to discuss and confirm the need for a wind comfort evaluation standard. In close collaboration with eight Dutch cities, three wind tunnel laboratories, and numerous other stakeholders, NEN launched a wind comfort assessment project, resulting in the creation of the new standard, NEN8100.

NEN8100 establishes five levels of wind comfort standards, labeled A to E, which are further evaluated based on three degrees: Good, Moderate, and Poor. This study references the NEN8100 proposed by Yaxing Du and Cheuk Ming Mak (2017) while also compiling other wind comfort assessment standards, as follows:

Table 1. Related wind comfort assessment standards

Standard	Evaluation Parameters	Evaluation Standard Comparison				
		Long Sitting	Short Sitting	Strolling	Fast Walking	Dangerous
Isyumov &Davenport （1975）	Beaufort scale	3	4	5	6	8
Lawson （1978）		2	3	4	5	non
Melbourne （1978）	Peak gust wind velocity	<10 m/s	<13 m/s	<16 m/s	non	>23 m/s
Soligo （1998）	Wind velocity	<2.5 m/s	2.5 m/s −3.89 m/s	3.89 m/s −5 m/s	>5 m/s	≥14.44 m/s
NEN8100 （2006）	Wind velocity	5 m/s				15 m/s
		A	B	C	D	

2. Method

Site and Sampling

The former site of the Taipei City Council is located at the intersection of Section 1, Zhongxiao West Road, and Section 1, Zhongshan South Road in Taipei City. The primary buildings surrounding the site are sampled from six main structures along both sides of Zhongshan South Road and the street trees. The western and southern sides of the site are adjacent to the Chung Sheng Building (CS) and the National Taiwan University Children's Hospital (CH), respectively. The northern side faces the Central Building (CB) across Zhongxiao West Road, while the eastern side is opposite the Control Yuan (CY) and the Executive Yuan (EY) across Zhongshan South Road. Among these, both the Control Yuan and the Executive Yuan are designated national historic monuments. The Control Yuan, built in 1915, is an example of late Renaissance Revival architecture; the Jinan Church, constructed in 1916, resembles a Victorian-era rural brick church; and the Executive Yuan, completed in 1940, is a representative of Taiwan's modernist architectural style from the late Japanese colonial period.

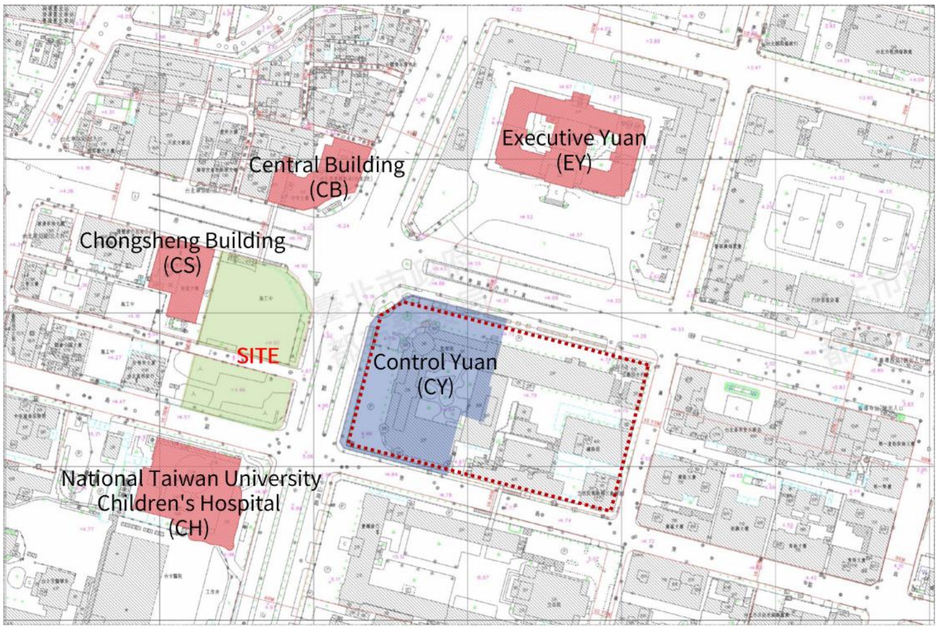

Figure 1. Case sudy location map and the 5 nearing buildings.

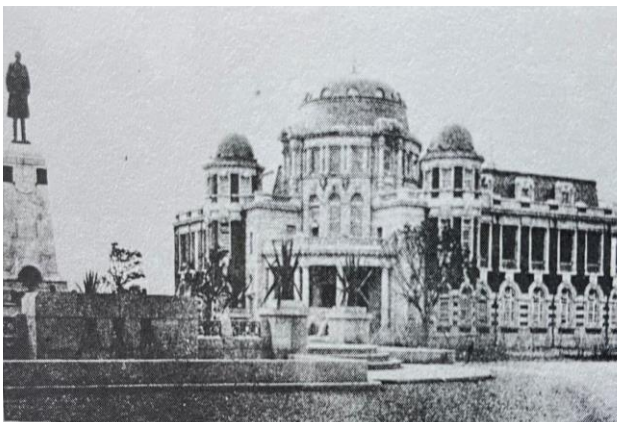

Figure 2. Image of The Control Yuan (CY)

Figure 3. Main entrance of The Control Yuan (CY)

The configuration and height of buildings, as well as street width, can all influence wind flow in the urban environment. Therefore, careful assessment is necessary during the architectural design stage. By applying urban design strategies—such as setting back building masses or altering building layouts—ventilation along streets can be improved, pressure caused by dense high-rise clusters can be relieved, and both pedestrian safety and environmental comfort can be enhanced. Outdoor thermal comfort is significantly affected by changes in wind speed.

This study references the research of Zhou Huiyu (2018) and utilizes the computational fluid dynamics (CFD) simulation software—WindperfectDX®—as a numerical analysis method for evaluating wind field environments. It is an effective 3D thermal flow analysis software compatible with BIM and GIS, with application scopes including wind analysis, air conditioning and ventilation analysis, natural ventilation analysis, thermal radiation analysis, heat conduction analysis, and electromechanical systems, offering high analytical precision. In this study, prior to running the simulation software, SketchUp® was first used to construct the street layout, vegetation such as trees, existing buildings, historical landmarks, and other environmental conditions within the study area. Additionally, models of three different architectural design proposals were created and subsequently imported into the wind field simulation software WindperfectDX® for execution.

The 3D model is imported into the wind field simulation software WindperfectDX® for further simulation analysis. The main process of the wind field simulation analysis includes: 1. Model construction, 2. Simulation import and execution, 3. Mesh division, 4. Parameter and condition settings, 5. Obtaining results, 6. Analyzing results.

Based on the known conditions and current situation mentioned earlier, this study utilizes SketchUp® to construct a 3D environmental model. The completed 3D model is divided into three scenarios: "Empty lot proposal," " Building layout proposal A," and "Building layout proposal B."

Table 2. The three building scenario

Empty lot proposal	Building layout proposal A	Building layout proposal B
		

Figure 4. 3D Model of the Site

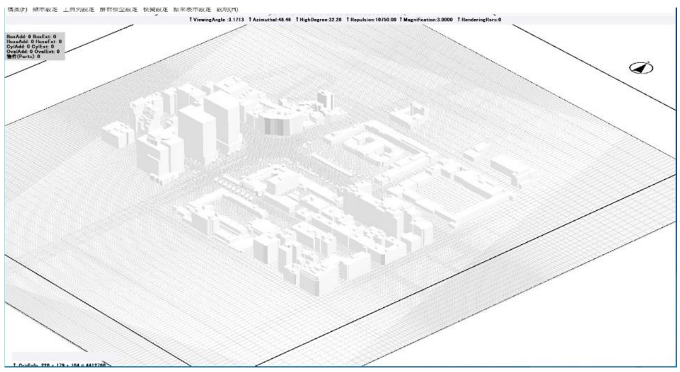

Figure 5. Diagram of 3D model import

The 3D model that has been constructed is first converted into an STL file and then imported into WindperfectDX® for simulation. (figure 5)

This study concentrates the mesh count at the intersections of east-west and north-south roads, using 1 million grids as the simulation mesh count to enhance simulation accuracy.

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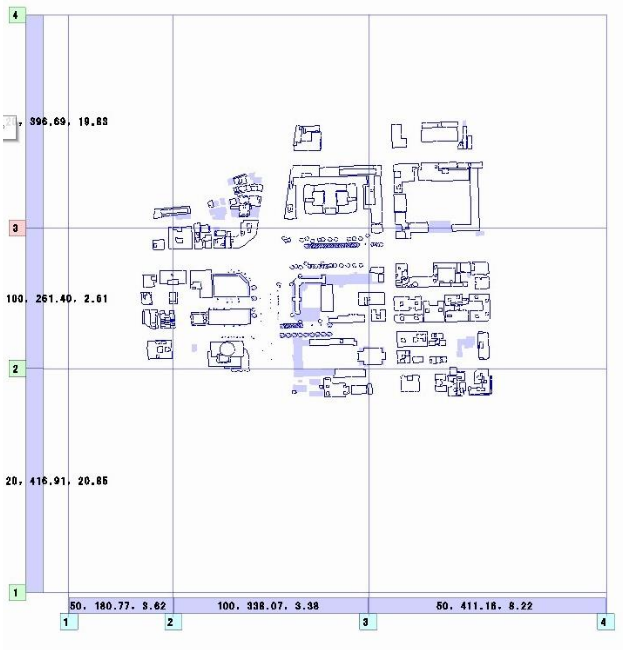

Figure 6. File import software interface

The study utilizes the built-in wind direction and speed settings for Taipei City within the software as parameters, with a reference wind speed of approximately 2.45 m/s and the prevailing wind direction in Taipei City being easterly. Additionally, condition A is used as the regional setting for the urban wind field simulation, and the simulation duration is set to 300 seconds, after which the calculation can be executed.

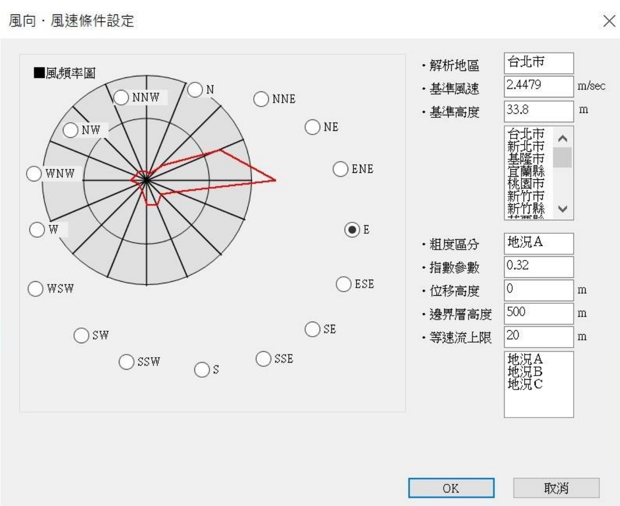

Figure 7. Parameter setting of WindperfectDX

3. Results

In the case of the " Empty lot proposal (Perspective View of Empty lot proposal Simulation Results, Figure 7), the wind field in the site and surrounding area (highlighted in the red box) shows that the wind speed on the north-south road (R1) to the east of the site is 0.4 m/s, while the wind speed on the sidewalk (R1a) is 0.6 m/s. On the east-west road (R2) north of the Control Yuan, the wind speed increases, with the highest speed reaching 3.6 m/s, and the wind speed on the sidewalk (R2a) ranging from 1.4 to 2.0 m/s.

In the case of Building layout proposal A (Figure 8), the wind field in the site (A-Site) and surrounding area (highlighted in the red box) shows a contraction of airflow in the middle road of the site (A-R3) with a wind speed of 2.8 m/s. The wind speed on the north-south road (A-R1) to the east of the site increases from 0.4 m/s to 1.2 m/s, and the wind speed on the sidewalk (A-R1a) is 0.8 m/s. The wind speed on the east-west road (A-R2) north of the Control Yuan decreases to 3.2 m/s, with the wind speed on the sidewalk (A-R2a) ranging from 1.4 to 2.4 m/s.

In the case of building layout proposal B (Figure 9), the wind field in the site (B-Site) and surrounding area (highlighted in the red box) also shows a contraction of airflow in the middle road of the site (B-R3) with a wind speed of 2.8 m/s. The wind speed on the north-south road (B-R1) to the east of the site remains between 0.6 and 1.2 m/s, and the wind speed on the sidewalk (B-R1a) is 0.8 m/s. The wind speed on the east-west road (B-R2) north of the Control Yuan remains between 2.0 and 3.4 m/s, and the wind speed on the sidewalk (B-R2a) ranges from 1.4 to 2.4 m/s.

Table 2. Measured Wind Speed Results for the Site Environment

Site	Result		
	Empty lot proposal	Building layout proposal A	Building layout proposal B
Site	0.4 – 1.2 m/s	0.4 – 1.6 m/s	0.4 – 2.0 m/s
CY	0.4 – 2.0 m/s	0.6 – 2.4 m/s	0.4 – 1.0 m/s
CR	1.0 – 2.2 m/s	0.6 – 1.6 m/s	0.6 – 1.6 m/s
R1	0.4 m/s	0.6 – 1.2 m/s	0.6 – 1.2 m/s
R1a	0.6 m/s	0.8 m/s	0.8 m/s
R2	2.0 – 3.6 m/s	2.0 – 3.2 m/s	2.0 – 3.4 m/s
R2a	1.4 – 2.0 m/s	1.4 – 2.4 m/s	1.4 – 2.4 m/s
R3	1.2 m/s	2.8 m/s	2.8 m/s

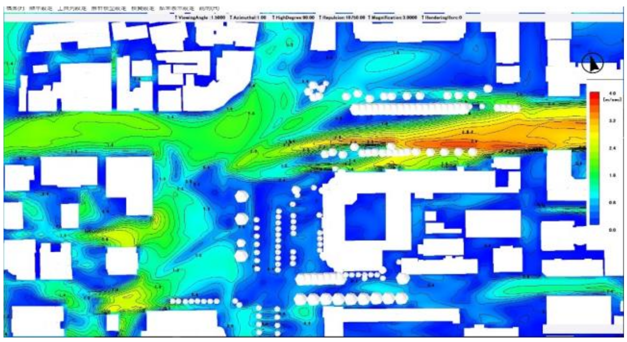

Figure 8. Result of empty lot proposal

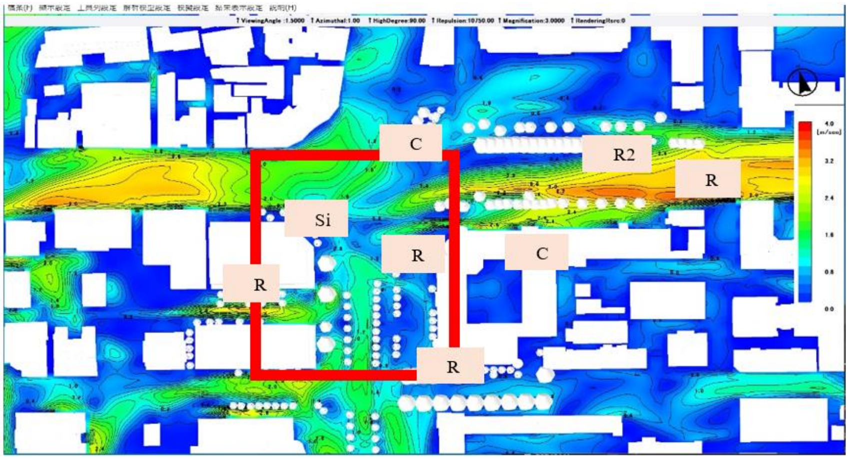

Figure 9. Result of building layout proposal A

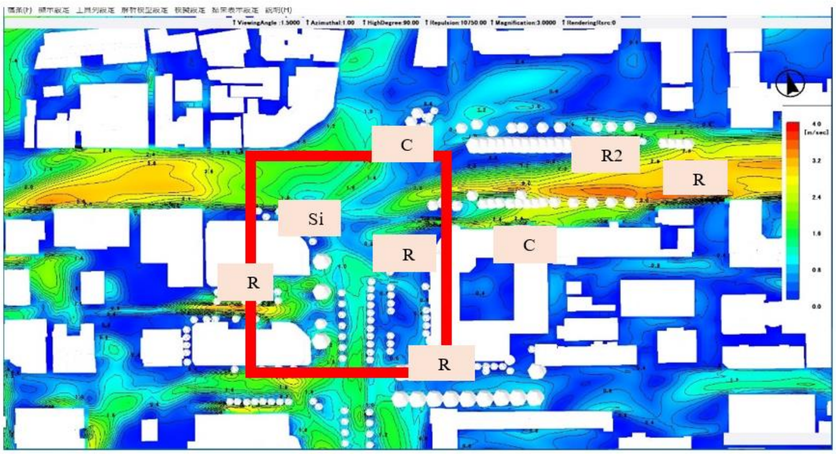

Figure 10. Result of building layout proposal B

Wind Field Classification: All three architectural schemes fall within wind field classifications suitable for both prolonged sitting and short-term sitting.

Wind Speed Variation: Proposal A exhibits a slight upward trend in wind speed, while Proposal B maintains relatively stable wind speed with no significant changes.

Turbulence Intensity: Influenced by the exterior design of the buildings, particularly the shape of the edges; analysis results indicate that sharp corners increase turbulence intensity, whereas rounded corners help reduce turbulence intensity, creating a more comfortable wind field environment.

Building Spacing: It is recommended to increase the distance between buildings to help mitigate the valley wind effect.

Based on the research analysis results, Proposal B better aligns with the recommended outcomes, demonstrating superior wind field performance. Additionally, according to Chen Pin-ying’s (2019) study, the presence of low-rise buildings in front of high-rise structures tends to generate stronger turbulence. Therefore, it is advisable to assess the impact of new high-rise buildings on surrounding historical sites and the environment, evaluate the wind field effects of the height of new buildings in relation to adjacent low-rise structures, and utilize software tools for simulation.

4. Conclusions

A comfortable climatic condition encourages visitors to spend more time at these historical sites, allowing for a deeper experience and learning opportunity, while also enhancing the contribution of cultural heritage to the local economy and social activities. Therefore, the impact of nearby new development projects on the environment of historical sites cannot be overlooked. During the design and planning stages, it is essential to carefully assess the potential effects and the risk of disrupting the original environmental experience. This preservation philosophy extends beyond merely conserving cultural heritage themselves; more importantly, it aims to provide the public with an environment conducive to learning, appreciating, and enjoying the legacy of historical culture.
Based on the research findings and wind field analysis, the following recommendations are proposed as references for future planning and design to ensure that the impact of new development projects on the surrounding environment of historical sites is minimized:

Architectural Form and Design Adjustments

Refine Building Edge Design: Avoid sharp-edged designs and adopt rounded or streamlined designs instead to reduce turbulence intensity and enhance the comfort of the wind field environment.
Control Building Height: For high-rise buildings near historical sites, consider their turbulence impact on low-rise structures and the surrounding environment, and conduct assessments through wind field simulations.
Optimize Building Spacing: Appropriately increase the distance between buildings to mitigate the valley wind effect, preserving the openness and comfort of the historical environment.

Wind Field Environment Management

Utilize Digital Simulation Technology: Before initiating new development projects, employ software to simulate the wind field environment to ensure that the design scheme does not generate excessive wind speeds or turbulence impacts.
Establish Wind Environment Metrics: Refer to existing wind field assessment standards and develop microclimate adaptation metrics applicable to areas surrounding cultural heritage during the Development Control Plan (DCPs) stage, serving as a basis for future development reviews.
Enhance Greenery and Barriers: Strategically incorporate vegetation, windbreaks, or semi-open shelters to guide airflow, mitigate excessive wind field issues, and create a more comfortable public space.

Regulatory and Policy Adjustments

Strengthen Coordination Between Cultural Heritage and Urban Planning: Establish a cross-departmental collaboration mechanism to more effectively integrate urban design reviews with cultural asset preservation assessments, ensuring that new developments align with the needs of historical environments.
Improve Standards for Wind Field and Sunlight Impact Assessments: Current regulations should incorporate wind field and sunlight shadow analyses as mandatory conditions for reviewing new development projects, minimizing their impact on historical sites and surrounding areas.
Promote a Historical Environment Impact Assessment System (HEIA): Integrate the Heritage Impact Assessment (HIA) approach by including factors such as wind fields, sunlight, and environmental experience into cultural asset preservation planning, enhancing the comprehensiveness and feasibility of evaluations.

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