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**MODELLING OF WIND COMFORT FOR PEDESTRIANS IN URBAN
OUTDOOR SPACES**

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Abstract

The following work focuses on the importance of aerodynamic comfort in urban spaces for urban planning and city sustainability. The PSWIFT model is used to simulate meteorological conditions, particularly wind, while considering urban factors such as topography and buildings. The main objective is to establish wind comfort for pedestrians, by analysing the wind data provided by the PSWIFT model and determining the frequency with which a comfort threshold is exceeded in urban spaces.

Key words: *PSWIFT, neighbourhood scale, wind comfort criterion*

Introduction

The study of pedestrian aerodynamic comfort in urban outdoor spaces is crucial for urban planning. It directly impacts city dwellers' well-being and satisfaction, influencing the liveability of urban spaces. Predicting wind behaviour can ensure outdoor spaces are safe and comfortable, particularly in areas with high wind speeds. Comfortable outdoor spaces indirectly promote active transportation, contributing to city sustainability by reducing reliance on motorized transport. Studying wind comfort is not only about enhancing quality of life but also about fostering sustainable, resilient cities for the future.

The airflow in urban environments is highly complex due to the interaction between wind and the built environment. The urban boundary layer is structured into several sublayers (Oke et al., 2017), including the roughness sublayer and the inertial sublayer, which reflect the influence of buildings and trees on wind dynamics. These layers are shaped by both mechanical turbulence, caused by surface roughness, and thermal effects, due to urban heat flux. Within the urban canopy layer, wind behaviour is dominated by localized phenomena like roof and corner vortices, wake or recirculation zones. Being able to model these microscale and local-scale airflow patterns is essential for assessing pedestrian wind comfort.

The 3D diagnostic flow model PSWIFT can be used to study these phenomena. PSWIFT is developed in collaboration between SUEZ Aria Technologies and CEA. Simulations are performed from the mesoscale to the microscale, where buildings are explicitly represented (Tinarelli et al., 2013; Armand et al., 2021). PMSS can handle huge urban areas thanks to highly efficient parallelization (Oldrini et al., 2019; 2021). It aims to provide results close to the accuracy of CFD models with significantly faster computation times. Over the past years, the PSWIFT model has undergone significant improvements, including adjustment of the flow to respect mass conservation by accounting for topography and obstacles, estimation of turbulent quantities according to Monin-Obukhov theory, and calculation of velocity fluctuations due to background and obstacle-generated turbulence. These developments have been extensively validated, and partly presented at Harmo conference (Ribstein et al., 2024, 2025).

The present work reviews the current literature to establish a criterion of wind comfort for pedestrians in urban outdoor spaces. This is a wind speed threshold that characterizes an upper limit for a pedestrian stationary area, e.g. café terrace. Statistics on wind fields computed by PSWIFT over a year on an hourly basis are produced, which would be cost-prohibitive with a full CFD model. The wind discomfort frequency is computed and analysed. It corresponds to the percentage of time during which the comfort threshold is exceeded during that year while considering the activities practiced in the study area. Thus, high frequencies of threshold exceedance can be allowed locally in pedestrian movement areas, while stationary areas warrant special attention.

Method

A wind comfort criterion can be established in different ways, integrating different definitions of the thresholds for the perception of discomfort by users of outdoor spaces. In France, the Centre Scientifique et Technique du Bâtiment (CSTB) has determined a wind speed threshold value (Delpéch *et al.*, 2005) equal to 3.6 m/s (about 13 km/h), characterizing an upper limit of comfort for pedestrian stationary activity. The calculation of this threshold is essentially based on the Beaufort scale, which ranks the wind speeds measured at 2 meters from the ground according to their visible effects on the environment and the feeling. This is a scale measuring comfort at “average” wind speeds, not gusts. It would be possible to model gusts as wind fluctuations and thus use PSWIFT’s turbulence diagnostics. For the moment, we have not had any requests on this point.

Thanks to PSWIFT model’s short CPU time, the methodology consists in simulating wind flow in 3D over the study area over a long period, e.g. hour by hour for a selected year. Statistics on wind fields computed by PSWIFT are then produced, which would be cost-prohibitive with a full CFD model.

To correctly assess the feeling of (dis)comfort, the wind discomfort frequency is computed and analysed. It corresponds to the percentage of time during which the comfort threshold of 3.6 m/s is exceeded during the study period while considering the activities practiced in the study area. Thus, it is possible to allow high exceedance frequencies locally if the area in question is a walking area or sidewalks. Conversely, special attention is paid if the area corresponds to terraces or playgrounds. *Table 1* (Faure *et al.*, 2009) shows the maximum comfort threshold exceedance (discomfort frequency) considered permissible for different categories of activities.

Table 1: maximum discomfort frequencies according to activities (Faure *et al.*, 2009)

| Activities | Examples | Maximum discomfort frequencies (as a percentage of annual time) |
|---|---|--|
| Prolonged stationary station | Café terrace, open-air theatre, swimming pool | A few percent |
| Short-term stationary station | Public garden, playground, shopping street | 5% |
| Normal walking | Walkway, pedestrian crossing, building entrance | 10% |
| Fast walking or outdoor sport practice | Car park, sidewalk of avenues, sports field | 20% |

Implementation

The 3D wind simulations are based on the PSWIFT model from the PMSS (Parallel Micro Swift Spray) chain present in the GIS-embedded AirAdvanced® Map desktop software (formerly ARIA Impact 3D and ARIA City). PSWIFT makes it possible to simulate small-scale wind flow in the presence of obstacles, with much lower CPU time than full CFD solutions.

The workflow for determining wind comfort and discomfort areas is the following:

- *Preparation of the configuration and input data of PSWIFT:* Land use, buildings, topography and meteorological data are gathered over a sufficiently long period of time (usually one year) and at a sufficiently high frequency (usually an hourly basis) to produce statistics. In order to be as realistic as possible, a past year is modelled, and PSWIFT uses observations from nearby weather stations as input data, such as open data from METAR stations.
- *Wind flow simulation:* The PSWIFT calculation engine simulates the wind flow in 3D over the study area, hour by hour for the selected year, which represents 8,760 to 8,784 simulated weather conditions.
- *Calculation of wind statistics:* From the PSWIFT results providing the hour-by-hour wind fields, the following statistics can be computed at each point of the field of study over the year, or over a chosen season:
 - o Average wind speed
 - o Frequency of exceedance of the 3.6 m/s threshold speed.
- *Map visualization of results:* Maps illustrate the computed statistics. Their analysis makes it possible to identify areas of aerodynamic discomfort. It is also possible to plot wind streamlines,

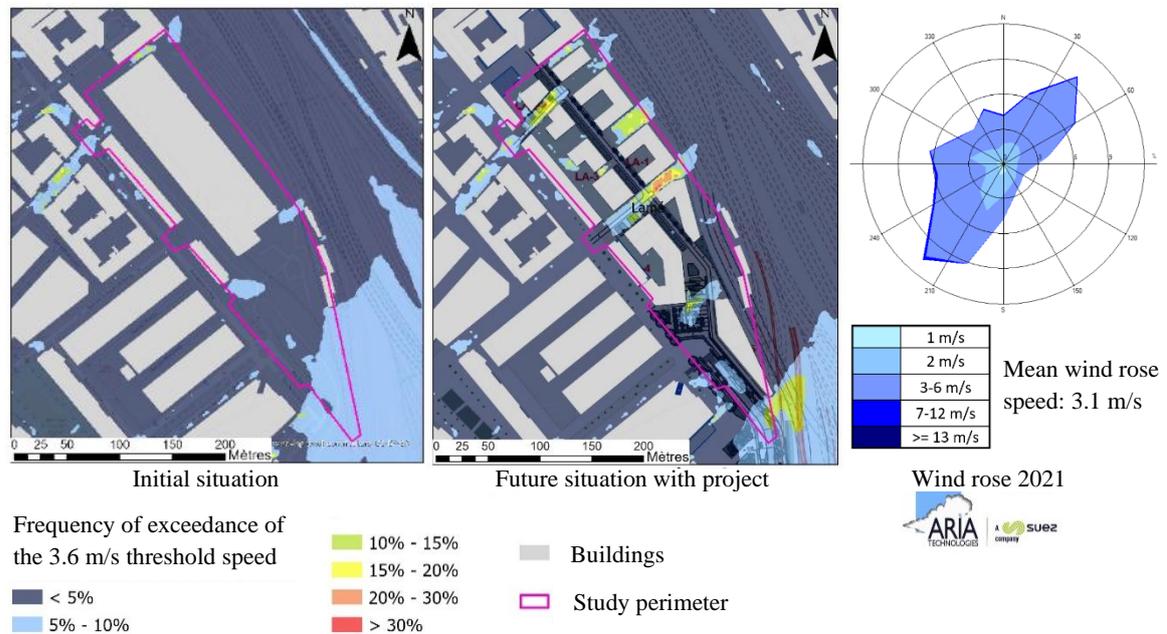
particularly for the dominant directions of the wind rose, to highlight and explain the occurrence of some aerodynamic effects, such as recirculation phenomena in the wake of buildings.

Results

Let's consider as a study case an urban renewal project in a major European capital, involving the demolition and construction of new housing. The aim is to highlight the project's impact on the wind comfort of future users of outdoor spaces (*Figure 1*).

The modelling domain is a 1x1 km area. After verifying the relevance and representativeness of the data in relation to the domain, data from 2021 from a weather station located approximately 4 km from the site are selected. The aim being to model the obstacles that could influence air flows, the buildings are modelled according to their volume, with a resolution of around 3 m in the horizontal plane. With PSWIFT, between 15 and 20 vertical levels are generally defined, distributed between zero and the ceiling of the domain, usually around 200 m high. The vertical grid is refined near the ground in order to accurately describe wind gradients in street canyons. The smallest mesh height is between 1.5 and 2.5 m near the ground, at which the annual or seasonal statistics are computed. In this configuration, PSWIFT computation time for one year of hourly weather data is less than 2 hours on 24 processors.

Figure 1: discomfort frequency before and after the housing construction project



Wind rose analysis shows that the prevailing winds come from the southwest or northeast. This explains why the high frequencies of comfort threshold exceedances tend to occur in streets aligned with this axis. Furthermore, approximately 62% of winds measured at a height of 10 m at the weather station have a speed greater than 3 m/s. However, PSWIFT results show that this rate is much lower at ground level, particularly in open spaces far from buildings. The advantage of PSWIFT is therefore that it includes the structural form of neighbourhood, the street network and the microscale effects of buildings.

Thus, modelling makes it possible to quantify and locate precisely wind discomfort that may arise from the project. Moreover, map visualization makes it understandable for all stakeholders, even non-experts. This leads to contextualized recommendations on building height, layout, and the use of outdoor spaces. In short, it provides a robust assessment that planners can use to organize new urban infrastructure wisely and justify it to the public in a scientific and didactic manner.

Limitations

The wind discomfort estimations tend to be slightly overestimated for two main reasons:

- Trees are not considered by PSWIFT. However, they slow down wind flow at pedestrian level, thereby improving comfort in areas exposed to strong winds.
- The overall aerodynamic drag of the neighbourhood is not modelled as such by PSWIFT, due to CPU constraints. Otherwise, momentum equations would need to be introduced into the model (Oldrini *et al.*, 2014), compromising the ability to compile statistics over a sufficiently long period. Instead, the results only show the cumulative effect of individual buildings. If the studied neighbourhood is relatively isolated from the rest of the city, the drag effect would not be very significant, but it still constitutes a potential source of overestimation of discomfort.

Conclusion

This work highlights the effectiveness of the PSWIFT model in assessing pedestrian wind comfort in urban outdoor spaces by providing high-resolution 3D wind flow simulations over extended temporal periods with reduced computation time. Choosing PSWIFT offers two main advantages:

- a short CPU time;
- a straightforward integration of on-site data (weather, topography, land use and buildings) through the GIS-embedded AirAdvanced® Map desktop software.

The methodology, based on the calculation of wind discomfort frequencies relative to a defined threshold, enables precise identification of discomfort zones. Therefore, it supports the formulation of targeted urban design strategies, such as optimizing building configurations or mitigating wind effects in sensitive areas. Although certain limitations, such as the absence of trees or the simplified treatment of neighbourhood-scale aerodynamic interactions, may lead to a slight overestimation of discomfort, the proposed methodology remains a powerful and accessible tool for anticipating the impacts of urban projects on pedestrian comfort.

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