CFD Methodology for Air Quality Assessment

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1 INTRODUCTION

The 'Air Quality Positive (AQP) approach' is a process of identifying and implementing measures on new developments in London to demonstrate how benefits to local air quality are maximised, and how pollution exposure is minimised [1]. To achieve the AQP target, new developments are pushed beyond compliance with Air Quality Neutral benchmarks and the requirements of the typical air quality assessment.

Dispersion models (i.e., ADMS) are widely used for air quality assessments in support of planning applications. These models are continuously being developed and also used early in the design process to help describe the existing air quality environment within and around the development site [1]. However, dispersion models often struggle to accurately predict the interaction of complex-built environments and local effects on wind microclimate and pollutant concentrations.

During the design process, more advanced prediction tools (i.e., Computational Fluid Dynamics (CFD) or wind tunnel) are needed to quantify the air quality impact of different design options, highlight constraints and opportunities, and inform on how to progress to more detailed design stages. This is especially applicable in the case of larger, complex developments, or tall buildings, which can have major impacts on the local microclimate [1].

This paper describes a methodology to implement the Technical Guidance [2] to advanced prediction tools (i.e., CFD) for modelling air quality impact during the design process, supporting the AQP approach of a real-world case study (125 & 130 London Wall, City of London).

2 METHODOLOGY

2.1 Road vehicle emissions

The Emission Factors Toolkit EFT is published by Defra to allow users to calculate road vehicle emission rates for NO_x, PM_{10}, $PM_{2.5}$ and CO_2 for a specified year, road type, vehicle speed and fleet composition. The toolkit is implemented in several dispersion models and updated yearly.

Table 1, Example of EFT Road emission input.

Road ID	Road Type	AADT	%HDV	Speed (kph)	N° hours	Link (km)
London Wall	London Central	18332	3	20	24	0.7

EFT 2019 was used to calculate the NO_x emissions from light and heavy-duty vehicles on the road network surrounding the application site (Table 1). The annual average daily traffic (AADT) and traffic percentage of heavy-duty vehicles were obtained for each road link [3]. To evaluate the air quality impact of the proposed development, the number of proposed trips generated by the development was added to the AADT and a growth factor was applied for the future opening year [2].

The toolkit calculates the road emissions (g/s) using standard vehicle emission factors, which are converted into hourly or daily NO_x emissions. The values are divided by the volume of the road source created in the CFD model to obtain the volume emission rate (i.e., g/m^3). Road sources were created as closed volumes extending over the road links between 0.2m and 1.5m from the ground [2], and the scalar emission rate was set for each source.

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2.2 Assumptions

A steady-state Reynolds-Averaged Navier-Stokes (RANS) model was implemented in the CFD package OpenFOAM version 7.0. Pollutant concentrations were obtained by solving the transport equation of a non-buoyant passive scalar. The study was limited to the prediction of NO_2 concentrations and thermal stratification effects on turbulent diffusion were assumed negligible compared to advection mechanisms. Following this approach, the prediction of the scalar concentrations is based on the accurate prediction of the wind microclimate.

2.3 Wind Microclimate Assessment

The wind assessment was conducted according to the City of London Guidelines [4].
The CFD wind assessment specifically assumed:

1. Surrounding (context) buildings within at least 400m from the site.
2. Future consented schemes in the surroundings within 300m from the site boundary.
3. No landscape features smaller than 8m.
4. 36 equally spaced wind directions.
5. Maximum cell size near critical locations of 0.3m or lower.
6. Minimum 10 cells across street canyons.
7. k-ω SST turbulence model.

The inflow velocity profile was assumed logarithmic with the equivalent roughness height (z_0) specified at 0.7m (City terrain, ESDU 84011). The remaining inflow characteristics relating to turbulence followed ESDU 01008.
The meteorological data used for the assessment relate to the Weibull parameters specified in [4] - Annex A: Wind climate properties. A reference height of 120m was used (i.e., Scale Factor = 1.0).

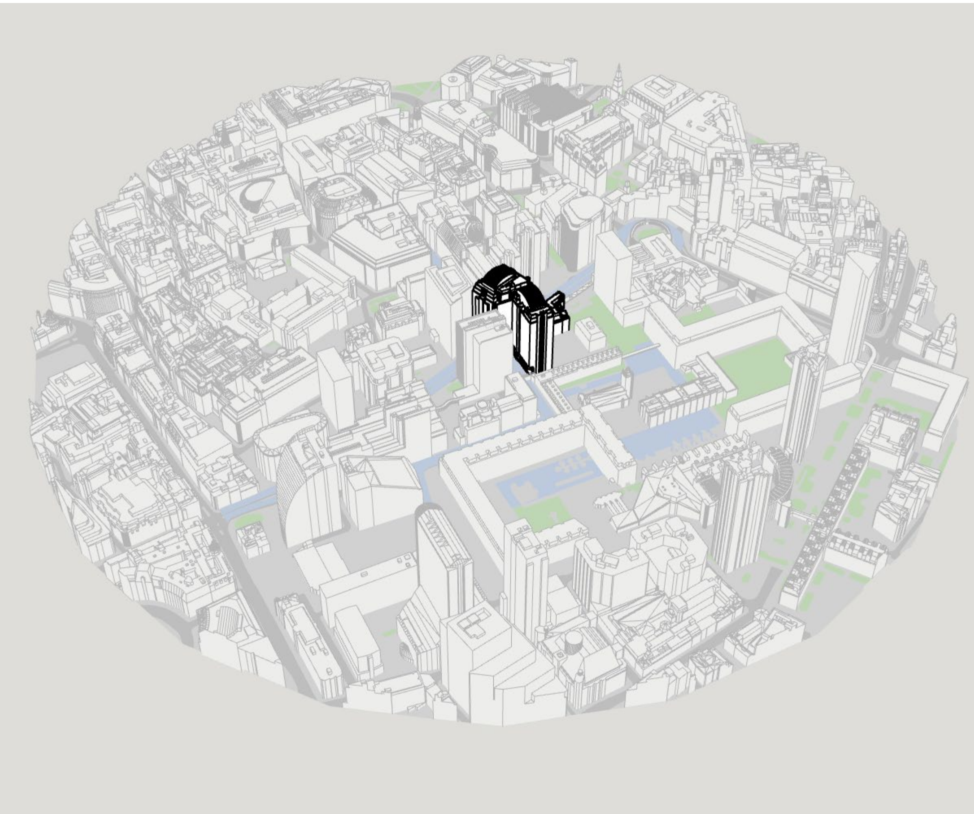

Figure 1, 3D model used for the CFD wind and dispersion assessment.

2.4 Post Processing

The total NO_x concentrations were obtained from the CFD simulations of momentum and transport equations from all road sources and for each of the 36 wind directions. The EFT toolkit 'NO_x-NO_2-calculator' was used to convert NO_x to NO_2 concentrations using the fraction emission at the future opening year in the City of London. Simulated NO_2 concentrations were then 'combined' for all wind

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directions using the probability function of the Weibull distribution. The 'estimated' background concentration was added to the simulated NO_2 scalar field [2]. Finally, simulated NO_2 concentrations were 'calibrated' using an adjustment factor obtained from a linear fitting interpolation of the NO_2 measurements from nearby diffusion tubes and automatic stations (Table 3).

Table 2, Background NO_2 concentration and fraction emission.

Local Authority	**Background NO_2 concentration**	**Fraction NO_x emitted from local road vehicles as NO_2**
City of London	29.8	0.236

Table 3, Local NO2 measurements used for calibration.

Diffusion tube	**Annual Mean concentration (µg/m³) of NO_2 (2019)**
London Wall	52
Museum of London	55
Brewers Hall Gardens	42

3 RESULTS

The Air Quality Strategy [5] provides the policy framework for local air quality management and assessment in the UK. The policy sets out air quality objectives for key pollutants, which are designed to protect human health and the environment. The annual mean objective for NO_2 is 40µg/m³ and this value was used as the threshold concentration for 2D and 3D contour plots.

Figure 2 shows NO_2 concentrations at the pedestrian level (1.5m from the ground) in the proximity of the site and within the passageway. During the design stage, the contour plot was used to identify areas of potential air quality risk at the ground level, helping the design of entrances, sitting areas and outdoor amenity spaces.

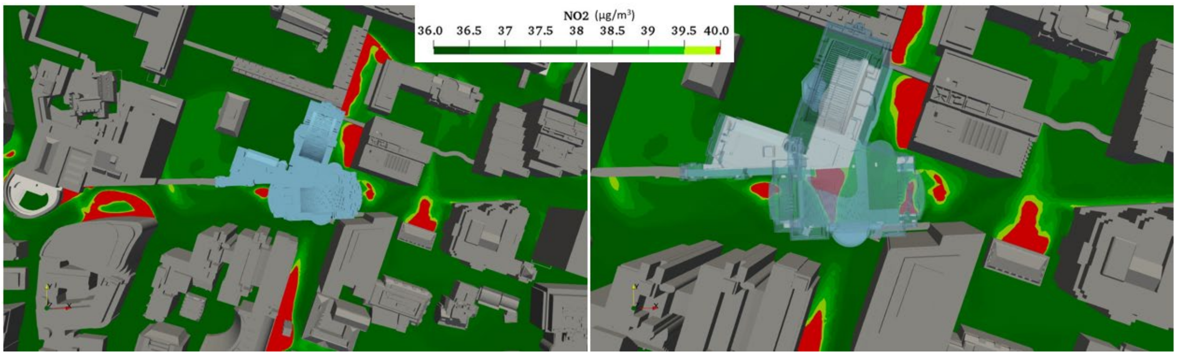

Figure 2, NO_2 mean concentrations at ground level (1.5m from the ground).

Figure 3 shows the 3D contour of the annual NO_2 mean objective (40µg/m³) within and around the proposed development. The impact of large complex buildings on pollution dispersion is visible, particularly in areas of strong wind recirculation and low wind speed where the plume height is significantly increased. On the other hand, air quality improves in areas where ventilation is enhanced by local wind accelerations (i.e., channelling effects, downdraughts, corner separation, etc.). The 3D analysis was used during the design stage to identify dispersion mechanisms near the building facades, particularly over balconies and terraces. Mitigation measures (i.e., solid balustrades and green walls) were also tested by using CFD and integrated into the final design to improve local air quality conditions.

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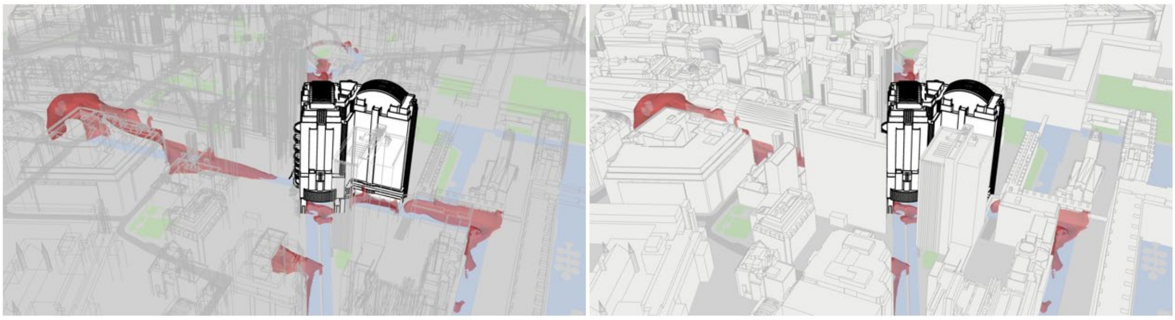

*Figure 3, 3D NO_2 contours (*40µg/m^3) *within and around the site.*

4 CONCLUSIONS

CFD is a valid prediction tool to inform designers how benefits to local air quality are maximised, and how pollution exposure is minimised. CFD is known to predict the interaction of built environments and local effects on wind microclimate and pollutant dispersion more accurately than standard dispersion models, particularly for large, complex developments or tall buildings.

This paper describes a methodology to implement the Technical Guidance [2] into CFD for the key pollutant NO_2. The aim is to expand air quality guidelines to computational tools, which can be used to achieve the Air Quality Positive target and/or be integrated into the standard air quality assessment for new developments in London. The methodology was successfully applied to a real-world case study in the City of London which was granted a planning application. CFD results provided interesting insights and a better understanding of local dispersion mechanisms, which helped the design of the proposed scheme, capturing local benefits to air quality whilst reducing public exposure.

5 AKNOWLEDGEMENT

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