

Predicting the Dispersion Consequences of Gaseous Releases from a Research Facility in an Urban Environment

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Extended Abstract

Introduction

This paper describes the outcome of a CFD simulation study to investigate the air flow patterns around a university research facility located on an urban campus, and in particular to predict the dispersion consequences of gaseous emissions from roof-mounted stacks. These emissions are the air and fume-cupboard extracts from laboratories; they will be diluted prior to discharge, but will need to be vented to atmosphere in a thoughtful and considerate manner as they may contain noxious or odorous components.

As part of a major campus redevelopment project, a very large new university block is being constructed opposite; surrounding streets are to be pedestrianised; and the two-storey research building is to be refurbished by addition of an extra floor and new roof-top plant room. Air extracted from the laboratories is to be vented to atmosphere from two stacks located on top of the roof-level plant room, rather than being released via the louvered sides of the plant room as at present. Accordingly, as part of the submission process for planning approval, a CFD model was constructed and exercised, to determine the sensitivity of the effluent plume trajectory to local ambient conditions and to the release configuration from the stacks.

Methodology

The domain of solution, 216 m. by 243m. by 68m. high, encompassed the research building and its neighboring buildings for about two blocks in each direction. As there were no pre-existing CAD models of the buildings to import, the blockage effect of the buildings within the domain was represented by use of PHOENICS VR library objects, with some bespoke objects created for specific building or roof elements.

A Cartesian grid was used, comprising 500,00 cells arranged in a non-uniform manner so as to capture adequately the principal features of the geometry and the flow pattern anticipated.

Thermal effects (buoyancy) were represented in the model. The effect would be smaller in summer than in winter, as the ambient temperature is closer to the effluent release temperature.

The enhancement of mixing due to the effects of turbulence was represented by use of an enhanced variant of the established K-epsilon model.

The variables for which conservation equations were solved were:

- longitudinal momentum;
- lateral momentum;
- vertical momentum;
- pressure (mass continuity);
- total concentration of effluent in air/effluent mixture;
- mixture temperature/enthalpy; and
- turbulence representation parameters, namely turbulence kinetic energy and turbulence energy dissipation rate.

The total concentration of effluent gas in the mixture was used as a concentration marker variable, to track the dispersion consequences of the released material, enabling graphic depiction of the extent and position of the plume-core envelope.

Qualitative Assumptions

The main assumptions underlying the release simulations were:

- The predominant wind direction was from the South West in summer, and the North East in winter. The wind speeds selected were 0.5m/s (still wind); 2.5 m/s (light breeze); and 8 m/s (stiff breeze). A power-law vertical velocity profile was specified.
- Typical external air temperatures were taken as 5°C for winter and 28°C for summer.
- To create a “worst case” scenario, the emissions leaving the stacks were considered to be undiluted, with no account taken of the high levels of air change rate flushing through the facility.
- The stack efflux velocity was limited to 15 m/s, it being recognized that noise regeneration is likely above this value.
- The discharge temperature was taken as 24°C throughout the year.
- In the absence of any guideline for a threshold level for olfactory detection of the emissions, the acceptable criterion was taken as a ten-thousand-fold dilution of the effluent from the stack. This value (one hundred parts per million by mass) has been used for tracking the dispersion extent of the “plume core envelope”.
- Finally, to reduce further the size of the effluent plume core, the effect of a discharge dilution arrangement was predicted. Based on the venturi concept, this device would entrain surrounding ambient air into the exhaust stack air stream to offer an immediate dilution factor of up to 60%.

Qualitative Assumptions

The workscope for this case study comprised 25 simulations performed in four stages.

The first stage encompassed model construction and testing, followed by an initial scoping study based on the “as planned” geometry. The objective was to determine whether the proposed refurbishment would provide adequate dilution / dispersion of effluent releases under various wind conditions. The scoping study involved three wind speeds, five wind directions, and two seasonal temperature conditions, to find the worst case conditions.

The second stage looked at the “masterly inactivity option”, comparing the results for the “as was” (i.e. pre-upgrade) geometry under worst case release conditions. These predictions highlighted the changes to airflow patterns and effluent plume trajectories which would result from the large new construction projects nearby, emphasizing the need for the planned refurbishment.

The predictions from the first two stages showed that whilst the proposed new arrangements were an improvement over the old, they fell short of the required criterion under certain wind vector conditions. It was therefore decided to investigate using a venturi stack device to dilute the effluent at the point of release using entrained ambient air.

Accordingly the third stage of the study involved creation of a two-dimensional axi-symmetric model of such a device, using a body-fitted coordinate system. This was then applied in a parametric study of the various venturi stack design parameters, to identify the sort of performance enhancement which might be attained subject to local design constraints.

The fourth stage revisited the previous worst case conditions to determine whether the environmental impact criterion could be met following fitment of such a stack dilution device

Quality of the Results

The presentation includes plume trajectory plots, ground-level concentration footprints and vector plots depicting ground-level flow patterns for six of the simulations in the case study, namely:

- Ø “Pre-refurbishment” geometry; wind 0.5 m/s from NNE in winter
- Ø “Pre-refurbishment” geometry; wind 8.0 m/s from SW in summer
- Ø “As planned” geometry; wind 0.5 m/s from NNE in winter
- Ø “As planned” geometry; wind 8.0 m/s from SW in summer
- Ø “As planned” geometry with venturi discharge stacks; wind 0.5 m/s from NNE in winter
- Ø “As planned” geometry with venturi discharge stacks; wind 0.5 m/s from SW in summer

These plots are augmented by plots from the venturi stack design exercise in Stage 3.

The outcome of the simulations can be summarized as follows:

- As might be expected, the plume trajectories at higher wind speeds were flatter than their low-wind counterparts, and dispersed more rapidly
- At lower wind speeds the core envelope was more erect at the point of release; in the winter case, this was assisted by a contribution from buoyancy-driven uplift.
- The large buildings being constructed on the opposite side of the street will considerably alter the ambient air flow patterns in the vicinity of the discharge locations on the research building. This could seriously impair plume dispersion under certain wind conditions using the existing discharge arrangements.
- The modified discharge arrangements proposed for the refurbished building would be a considerable improvement; under still conditions in winter, they reduced street-level concentrations by two orders of magnitude.
- Under worst case wind conditions in winter, the street level concentrations were still above the $1:10^4$ acceptable dilution criterion
- Under worst case wind conditions in summer, the plume core just failed to clear roof and upper storey regions of adjacent downwind buildings, where there would be openable window
- Incorporation of a venturi-type entrainment/dilution device at the stack outlet can reduce the environmental impact to acceptable levels with a minimum visual impact.

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As the research building is located in close proximity to neighboring buildings and dwellings, and the previous discharge arrangements were known to cause an environmental nuisance under certain ambient conditions, it was hoped the outcome of the case study would lead to significant improvements in this regard.

In applying the CFD models, the objectives were to predict the changes to the existing discharge consequences which would arise from refurbishment and the adjacent building works, and to establish whether the discharges would meet currently accepted criteria. If not, the models could be used to help designers assess the effect of modifications in an iterative process aimed at minimizing the likely environmental impact of the release subject to aesthetic (e.g. visual) constraints.

These project objectives have been successfully attained. The predictions of the model are physically credible, and indicate that even if the critical concentration used here is an overestimate by a factor of up to 100 times (e.g. a 100:1 dilution prior to discharge), the emissions from the basement stack releases represent a substantial improvement on the existing arrangements, and meet exposure criteria which have been accepted at similar research establishments.

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