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UNDERSTANDING THE DISPERSION OF MATERIAL FROM A BUILDING IN CHANGING METEOROLOGICAL CONDITIONS

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Abstract: If a hazardous material is released from inside a building it not only poses an immediate risk to the occupants of that building, but also to the population in the surrounding area. Accurate estimation of the extent of these hazards is critical to defining cordons and assessing the impact on the local population. Hazard prediction generally focuses on how the meteorological conditions affect outdoor dispersion, but in the case of naturally ventilated buildings, the meteorology may have a considerable impact on both the rate and location from which material is exhausted from the building. This study aimed to assess the impact that changes in meteorology could have on the release of material from naturally ventilated buildings, and the impact this had on the predicted downwind hazard. This was achieved through modelling, by linking indoor and outdoor models to simulate the downwind hazard from indoor releases as the meteorology shifted over a four hour period. The approach involved using the CONTAM system to model the indoor transport, while the outdoor transport and dispersion was simulated using both the HPAC and QUIC codes. Assessment of the results suggested that the location and amount of material exhausted from the building and subsequent downwind dispersal, produces a wide variety in predicted hazard footprints. This highlights the importance of understanding the indoor environment and how the material might exhaust when making downwind hazard assessments.

Key words: *Indoor-outdoor,urban dispersion, naturally ventilated.*

INTRODUCTION

If a hazardous material is released from inside a building it not only poses an immediate risk to the occupants of that building, but also to the population in the surrounding area. Following a release in a room, material is transported through the building and out into the external atmosphere through doors, windows, fans and other leakage points. In a mechanically ventilated building the rate that material leaks out is governed by the air handling system, which controls the air exchange rate and internal temperatures. This typically leads to a well-defined source that makes assessment of the external hazard easier. However, in a naturally ventilated building the transport of material is primarily governed by the external meteorological conditions, and how these translate into wind pressures on the external faces of the building and indoor-outdoor temperature differences. As the meteorology is constantly varying, this makes accurate prediction of the downwind hazard much more difficult.

The aim of this paper is to show the impact that a changing meteorology can have on the source terms created by indoor releases in naturally ventilated buildings and the subsequent downwind hazards. The study also compared how the exposure predicted downwind of the building would be affected by the choice of outdoor dispersion model.

TEST CASE

The test case was based on data from a trial that was conducted within an old school complex. The complex was approximately 2 km square and had a rural aspect. No live agent or tracer releases were made during this trial, although the detailed building survey data and high quality meteorology and indoor temperatures measurements provide data for detailed simulation. Two buildings from the trial site were selected for the modelling study; a single story residential property and a warehouse. Trial data from two consecutive days, with observations made between 8 am and 12 pm local time were abstracted for the modelling study. The meteorological information consisted of measurements at 1 second intervals of wind speed, wind direction, temperature, humidity, solar radiation and precipitation taken at the centre of the trial site.

METHOD

Indoor Models

The building survey data was used to construct indoor models of the test case building using the the National Institute of Standards and Technology, US (NIST - US) CONTAM v3.2 multizone modelling system (Dols et al., 2016). The fidelity of the models was set at room level, with smaller zones, such as cupboards, being subsumed into the appropriate rooms. The leakage areas required to define the flow linkages between zones for doors, windows and hatches were based on values given in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook Library (ASH, 2001). Figure 1 illustrates the CONTAM models produced for the test case buildings.

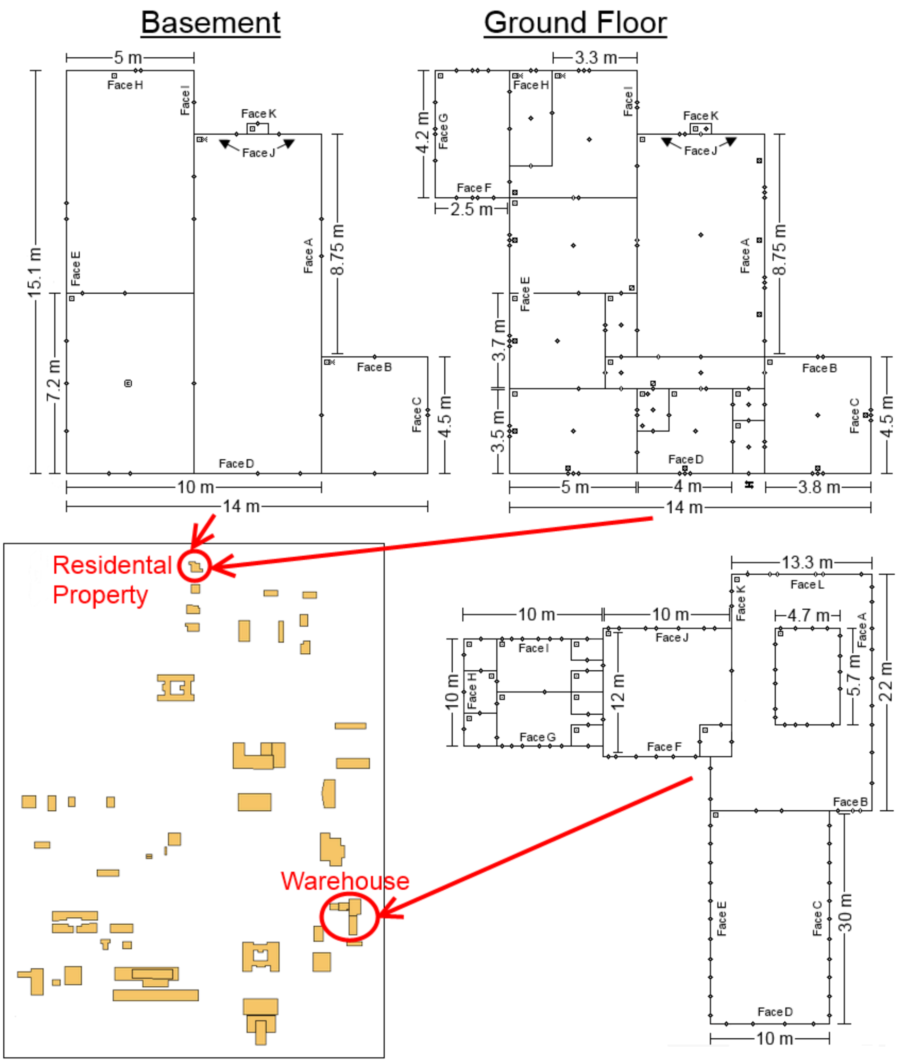

Figure 1. Imaging showing the building layout of the trials site (bottom left) and the CONTAM model representation of the residential property (top) and warehouse (bottom right).

Building Surface Pressures

The time-varying building surface pressure inputs required to drive the CONTAM indoor models were created by using the Quick Urban Industrial Complex code (Pardyjak et al., 2007). The external pressure field around the trials building was created using the QUIC pressure model and a simple box representation of the buildings on the site. This was then applied to the CONTAM model at the external node locatios. These predictions were based on averaging the observed meteorological data over 5 minute intervals.

Internal Temperature Schedules
The indoor temperature data was used to create CONTAM temperature schedules for both buildings for the two trial days. If a room did not have a temperature sensor, or the sensor reading was faulty, the closest appropriate value was assumed.

Outdoor Hazard Prediction
Outdoor hazard predictions were produced using the Hazard Assessment and Prediction Capability (HPAC) v6.3 and the Quick Urban Industrial Complex (QUIC) model v5.86. HPAC uses a fast running guassian puff model to predict urban dispersion, whereas QUIC combines a wind field solver (to estimate the flow around building) and a lagrangian puff model to simulate the atmospheric transport. For the QUIC approach, CONTAM was run independently and the exhausted material manually inputted as continuous sources at the external locations on the buildings surface. For each simulation a 2km by 2km concentration grid (at 2m resolution) was produced for comparison.

RESULTS AND DISCUSSION
The results consisted of time series data for the mass of agent exhausted from the buildings and the external concentration fields resulting from the releases. Both the mass exhausted and concentration grids were output at 5 minute intervals for the trial periods for both days. The external concentration results from HPAC and QUIC were turned into contour images on similar scales for comparison. Space constraints prevent presentation of all but a few interesting results.

Impact of Meteorology on Source
The impact of changing meteorology on the exhaust of material from the buildings was analysed using a state-space analysis technique, developed by Dstl (Parker et al., 2011 and 2014). This technique permits the results to be presented visually as a matrix of the source strength associated with each external node location. Figures 2 and 3 show a state space analysis chart for the residential property and the warehouse over both trial periods. The colours represent the strength of the source, the vertical axis identifies the node location and the bottom axis the evolution of source strength over the time periods. For the residential property (Figure 2) material is shown consistently exhausted at a number of points. This indicates some consistency in the material exhausted into the external environment; however, the variation in colour indicates significant changes in the source strengths over time.

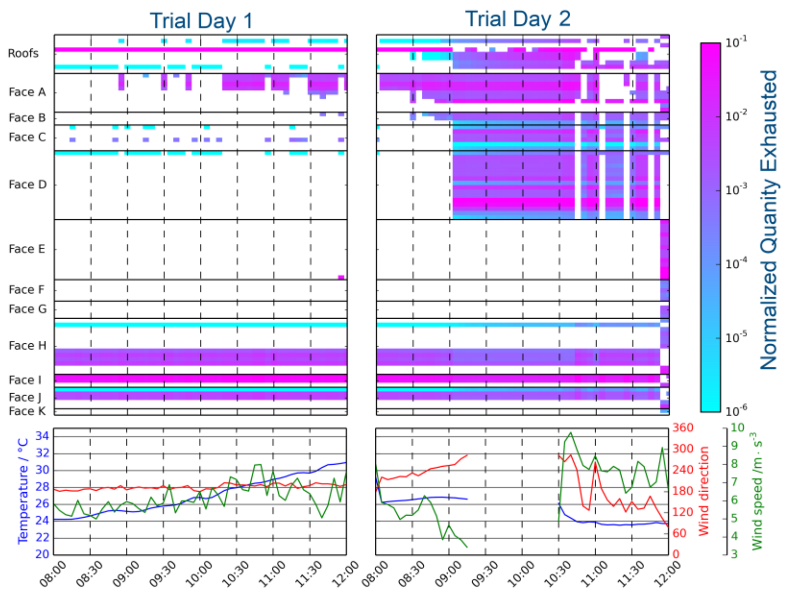

Figure 2. State-space analysis for trial day one (left) and trial day two (right) - residential property

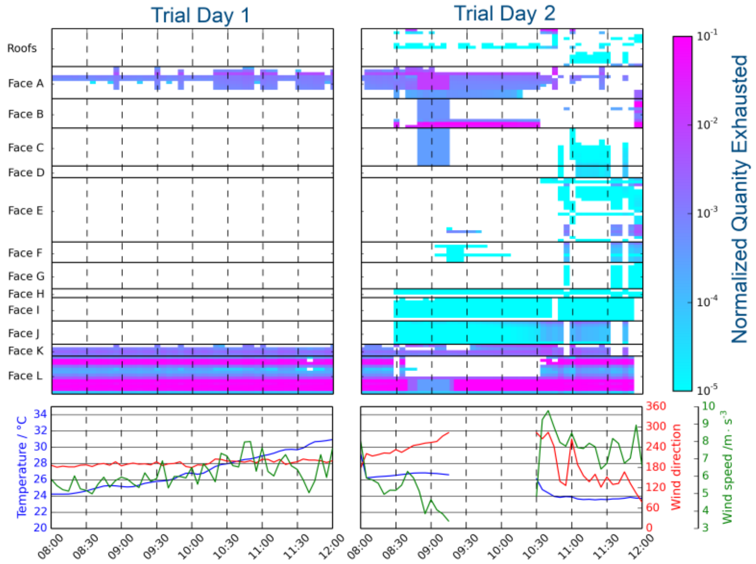

Figure 3. State-space analysis for trial day one (left) and trial day two (right) - warehouse.

The state-space analysis for the warehouse (Figure 3) shows a consistent source for trial day one (left image), but varying sources locations for trial day two (right), where the wind direction changes more significantly. The trial day two results differ between the two buildings which indicates the more complex internal structure of the residential building entrains material leading to a consistent set of source locations whereas the open layout of the warehouse alters the source locations to the current wind direction.

The impact the variation in exhaust profile can have on the outdoor hazard can be best shown through an example. Figure 4 shows the outdoor contour plots for the warehouse for 09:15 on trial day one (left and trial day two (right). Looking at Figure 3 in combination with Figure 4 shows how the different range and strength of source points leads to vastly different contour plots. This is an extreme example but can be seen in smaller effects whilst the meteorology changes in terms of wind direction and wind strength.

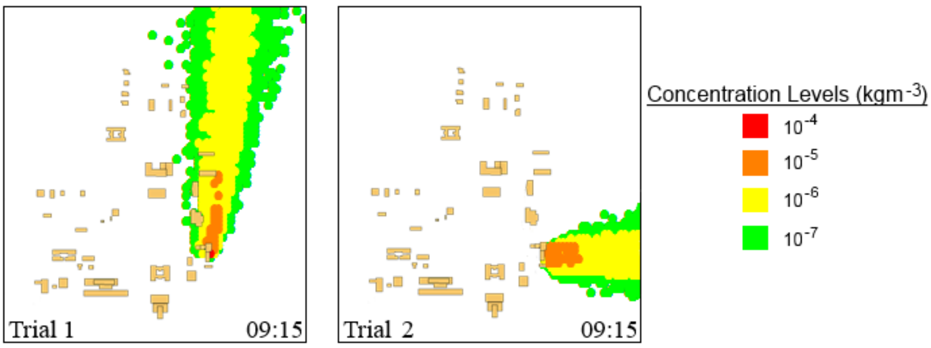

Figure 4. Effect of changes in meteorological conditions on source and predicted plume from warehouse.

Comparison of Outdoor Dispersion Modelling Approaches

The objective of comparing predictions from HPAC and QUIC was not to assess which model was best, but to highlight differences in the resulting outputs which may result in varying interpretations or issuing different advice. Reassuringly both models predicted similar sized hazard areas, but they differed in a number of places

- **differences due to source term handling:** Simulation results for the warehouse building for 09:15 on trials day 2 (Figure 4, right image) showed a much broader plume from QUIC than from HPAC. This was believed to be due to the Gaussian model used in HPAC defining a wake region behind the building, into which it put all the released material, creating a more compact source. The assumptions of wake regions may also have the opposite effect of taking compact point source and spreading the material in to wider wake regions. This may have an impact on the validity of close to source hazard predictions for HPAC.

- **residual hazard after wind shift:** When the wind direction shifts by a large amount in a single time step the QUIC simulations show an amount of low level concentration spread across the domain retained from the previous time step, which is not shown in HPAC. Whether concentration will remain in the domain for 5 minutes is questionable, however, it highlights the advantages in QUICs approach which resolve a wind field based on the current meteorological conditions rather than applying the same meteorology across the domain. More frequent meteorology reading will make the residual material calculations more realistic although this will also have a negative impact on the well mixed assumptions used by the CONTAM model. Further work is required to understand the potential implications of this for defining meteorological inputs and on hazard predictions.

- **secondary wakes/entrainment:** QUIC captures the effect of building wakes in its wind-field computation, whereas the HPAC Gaussian approach models wake regions for isolated buildings in open terrain, or large buildings in urban areas. This can lead to noticeable differences in modelling.

SUMMARY

This study has shown that variations in meteorology can have a large impact on the predicted source term created by indoor releases in naturally ventilated buildings, with changes in wind direction leading to changes in the locations from which material exhausts and the strength of such sources. Furthermore, the extent of these effects and their impact on the subsequent downwind hazard is affected by the complexity of the building. The study has also shown that if the building source is well resolved in space and time then the subsquent downwind hazard prediction may also be affected by the choice of outdoor dispersion model and fidelity of the meteorological inputs. It is therefore recommended that careful consideration is given to representing indoor-outdoor interactions for naturally ventilated buildings in hazard assessment scenarios.

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