**16th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
8-11 September 2014, Varna, Bulgaria**

COMBINED OUTDOOR-INDOOR DISPERSION MODELLING IN URBAN AREAS

Herring S[1], England J[2], Lingard B[1], Parker S[1]

Dstl Porton Down, Salisbury, Wiltshire, SP4 0JQ[1]
Riskaware Limited, Colston Tower, Colston Street, Bristol, BS1 4XE[2]

Corresponding author: Steven Herring, sjherring@dstl.gov.uk

Abstract: Extensive research has been conducted in order to develop tools for modelling the dispersion of hazardous materials in urban areas, and predicting the resulting outdoor hazard. However, only limited work has been conducted to extend the capability of such tools to predict the hazard to people resulting either from the infiltration of material into, or exfiltration of material from, buildings. To address this problem Dstl is developing a combined outdoor-indoor dispersion modelling capability called the Urban Sub-System (USS) for integration into the US Defense Threat Reduction Agency's Hazard Prediction and Assessment Capability (HPAC). The principal feature of the USS is that it provides a software framework that enables a range of indoor and outdoor dispersion models to be coupled in a flexible manner at run-time. The aim of the USS is to provide solutions based upon prioritising either time or accuracy requirements to meet the needs of different users, from first-responders to decision makers, planners and scientists conducting pre- and post-event investigations. An overview of the current development work and the implications of test case simulation results obtained from different indoor models and prototyping user interface options for the further development of the USS is presented.

Key words: *urban, dispersion modelling, indoor dispersion, outdoor dispersion*

BACKGROUND

Extensive research has been conducted to develop emergency response tools to predict the effects on people in the outdoor environment from releases of hazardous materials in urban areas. However, despite the fact that most of the population in developed countries typically spend ninety percent of their time indoors, only limited work has been conducted to further develop such tools to predict the hazard to the population resulting from the infiltration of material into buildings. Current hazard prediction tools also have limited capability to predict how material exfiltrates from a building into the outdoor environment following an indoor release. These are significant limitations, firstly because the tools are unable to provide emergency responders and decision makers with any direct indication of whether people should shelter-in-place inside buildings or evacuate, and secondly because the tools are unable to predict the time evolutions of indoor and outdoor hazards following indoor releases. The latter is important because the limited exchange of air between the indoor and outdoor environments may lead to the hazard extending over a considerably longer time than for an outdoor release. These gaps mean that at present the evaluation of indoor-outdoor effects relies upon using manual estimation methods or manually coupling multiple models together, neither of which is satisfactory for emergency response. For example, if a scenario involves a release inside a building followed by the exfiltration of material, it is not clear how an analyst should define the indoor source in the outdoor dispersion model.

To address these limitations and provide a greatly enhanced level of situational awareness to decision makers Dstl prototyped a proof-of-principle Urban Sub-System (USS) for the US Defense Threat Reduction Agency (DTRA) in 2011. This prototype implemented a flexible software framework that enabled a range of indoor and outdoor dispersion models to be coupled at run-time which was integrated in the DTRA Hazard Prediction and Assessment Capability (HPAC) (Herring *et al.*, 2012). The current work is further developing the prototype USS to meet DTRA's requirement for a capability that may be deployed as part of HPAC.

AIM

The aim of the USS is to provide an enhanced modelling capability to support decision making and response to releases of hazardous material in urban environments. Moreover, this capability is required to provide solutions based upon prioritising either time or accuracy requirements to meet the needs of Basic and Advanced users, from first-responders to scientists conducting pre- or post-event investigations.

DEVELOPMENT APPROACH

At present the DTRA HPAC code incorporates three outdoor dispersion models that can model urban dispersion at three levels of fidelity. These comprise: the building resolving MicroSwift/Spray (MSS) Lagrangian particle dispersion code for modelling dispersion close to the source; the building aware Urban Dispersion Model (UDM) which is a Gaussian puff model that uses empirical relationships and building data to predict urban dispersion; and the Second Order Integrated Puff (SCIPUFF) Gaussian puff model which has a simple urban canopy model. HPAC also includes a range of source term and effects models to provide a single comprehensive emergency response tool. Given the complexity of the HPAC code, the approach taken to developing the prototype USS was to insert it in place of UDM. This imposed certain restrictions on linking the USS to the Second-order Integrated Puff (SCIPUFF) and MicroSwift/Spray (MSS) outdoor models, but has enabled the development to be conducted within the urban component codebase of HPAC that Dstl is responsible for.

The need to enable simulations to be carried out based on prioritising accuracy or time, means that a key requirement of the USS is to enable a wide range of outdoor and indoor models to be used within a single architecture. This has been achieved by adopting a dependency injection approach. This means that the USS consists primarily of software components which manage the transfer of information within the modelling system and the required interfaces to the various models to be used (e.g. indoor and outdoor dispersion models). When the USS is executed the indoor and outdoor models to be used are selected by choosing a ‘boot-strapper’ option. The USS manager then causes the required model wrappers to be used to set up the simulation. This approach provides a high degree of modelling chain flexibility and enables models to be used in a plug-and-play manner.

The prototype USS demonstrated the capability to couple outdoor and indoor simulations based on using UDM and single and multi-zone indoor models. Single zone models used the Building Infiltration Model (BIM) while the use of both COMIS and CONTAM multi-zone models was demonstrated. In addition, the use of the Quick Urban Industrial Complex (QUIC) model to provide building pressure inputs for indoor models was demonstrated. The current project is refining and extending the modelling capabilities of the prototype code based on parallel activities that are addressing:

- Enhancement of the modelling capabilities;
- Indoor-outdoor model integration issues;
- User interface functionality;
- Code testing and verification.

ENHANCEMENT OF MODELLING CAPABILITIES

While the prototype USS enabled coupled simulations to be conducted using UDM, the BIM single zone model and COMIS and CONTAM multi-zone indoor models, current developments are focused on the use of BIM and CONTAM models. This is because COMIS is no longer supported, whereas the National Institute for Standards and Technology (NIST) are funding on-going development of CONTAM.

When using CONTAM models, the pressure boundary conditions may be defined by incorporating pressure coefficient data into the model and providing a wind speed at a reference height, or by providing building surface pressure differences. In the first case care must be taken to ensure that appropriate wind speed profile data is available and that the correct value is used. In the second case care must be taken to allow for the hydrostatic pressure variation that is accounted for in CONTAM, which for tall buildings may be considerably greater than the building surface pressure differences. If building surface pressures are taken from the QUIC urban windfield solver, for example, then no correction is required as it does not account for variations in hydrostatic pressure. The USS has been developed to enable either the wind speed or wind pressure input options to be used.

In addition to the wind pressures the other major driver on the air flows through a naturally ventilated building is the difference between the indoor and outdoor temperatures. This temperature difference drives the stack effect and typically produces an upwards flow through the building for warmer interiors. The effect is greatest in tall buildings but may be significant in buildings with even a modest number of floors. This means that it is important to be able to set appropriate temperatures in indoor models used in the USS. If indoor models are pre-prepared for use by the USS, then the subtle room-to-room variations in temperature that occur in reality may be represented. However, providing the facility to do this rapidly in the USS for very complex multi-zone models was assessed to be very difficult. The approach currently adopted therefore, has been to provide the facility for the user to be able to apply a global indoor temperature to all zones of all indoor models if they do not wish to use the indoor model default values, or to be able to edit the indoor temperature used in individual BIMs.

A factor that was not recognised in the prototype USS was that while in most UK cities there are very few buildings with underground floors, underground levels are commonplace in some US cities for example. Unfortunately, geometric data for underground floors is not readily obtained, in the way that the basic building external geometry may be, so the facility has been provided to enable underground volumes to be added to BIM models where these are known.

INDOOR-OUTDOOR MODEL INTEGRATION ISSUES

From a software engineering perspective it is a relatively straightforward exercise to couple indoor and outdoor dispersion models together. However, this raises important questions regarding the accuracy with which indoor models are defined, the fidelity with which information should be transferred between indoor and outdoor models and the accuracy of the resulting outputs. A critical part of work undertaken therefore has been to explore these issues through simulating indoor and outdoor release scenarios in real urban areas using models with varying levels of fidelity. These simulations have been based on two distinctly different buildings in quite different cities to enable a wide range of questions to be examined to inform the development of the USS.

The first building considered was a large office block in the central business district of Oklahoma City that was used in the Joint Urban 2003 experiment, while the second was an end-of-terrace residential building in the area used for the DAPPLE experiment in the centre of London. The large office block has more than 250 rooms spread over 14 floors above ground, a basement and sub-basement and a ventilation system that is divided into 3 sub-systems serving floors 8-14, 2-7, and floor 1, the underground and sub-basement levels. The residential building has four floors that are considered to be divided into five-room, naturally ventilated flats. Both buildings have simple rectangular footprints. The difference in the building complexities can be appreciated by comparing the CONTAM model floor plans shown in Figures 1a and 1b.

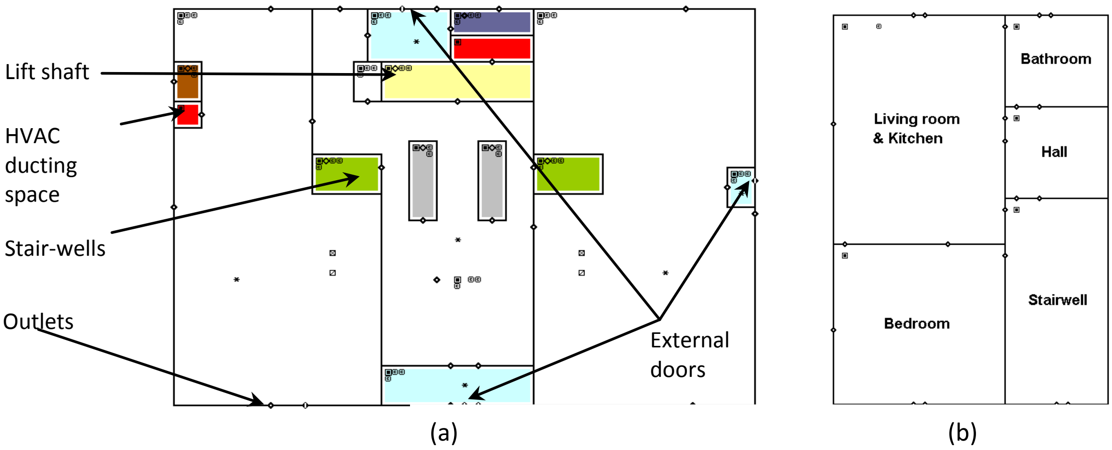

Figure 1. (a) CONTAM floor plans for the ground floors of the large office block and (b) residential building.

Simulation results have been obtained from models of the large office block at three levels of fidelity: room-level detail, floor level detail and ventilation region detail. Constructing these models and conducting the simulations has shown that developing and validating highly detailed indoor models is a difficult and time-consuming process due to the amount of information that is required but may not necessarily be available. This has indicated that complex indoor models should be pre-prepared for use in the USS. The results from the different fidelity models have demonstrated similarities, but also differences.Whether these differences are significant depends upon the question to be answered, and analysis of the results from the models is leading to development of strategy for identifying how real-world geometries may be simplified to minimise fidelity while still giving the appropriate results.

USER INTERFACE FUNCTIONALITY

To fulfil the project aim, it is essential that careful consideration is given to how the user will interact with the system and to the display of outputs, as well as integrating different models into the architecture. Work on the initial prototype revealed issues in assimilating indoor model outputs into the current HPAC output displays which led to misleading plots. Further work has also revealed the potential for confusion when presenting indoor and outdoor information on the standard HPAC ground area plot. Use of the standard HPAC display also requires that all the indoor model volumes are geo-referenced. This is not a problem for the single zone BIMs, but is difficult to achieve when using complex CONTAM models. This is because, not only is extracting the information required from CONTAM difficult, but because there is no need for the volumes within CONTAM models to reflect their true physical locations. Recent work has therefore focused on introducing functionality for interacting with the building data in the Geographic and Environmental Database Information System (GEDIS) and using existing functionality in HPAC to enable the user to rapidly set up the indoor models and view their outputs. This has resulted in prototypes for new output windows for displaying indoor model floor plans and outputs. The geo-referencing has also been limited to identifying those buildings with indoor models in the outdoor display (as shown in Figure 2) and the building external inlet/outlet locations required to link the indoor and outdoor models. This separation of indoor and outdoor displays then enables spatial and temporal indoor model outputs to be displayed for indoor models. An example time series output for a BIM is shown in Figure 2.

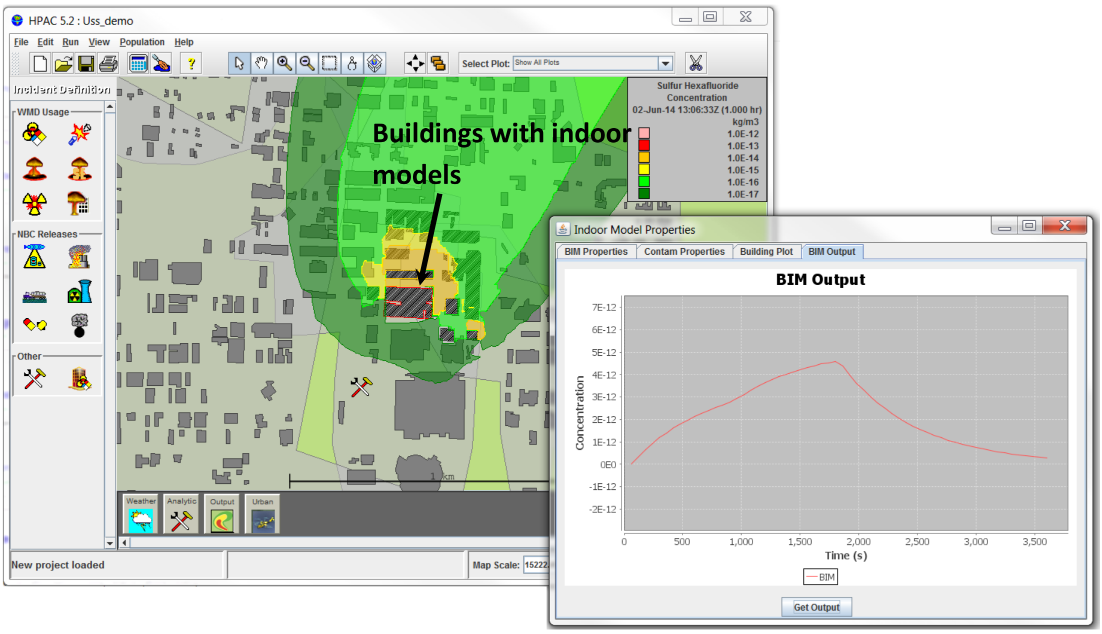

Figure 2. Prototype output display plots showing HPAC outdoor output, and BIM indoor concentration output (inset).

TESTING, VERIFICATION AND VALIDATION

The complexity of the USS and need to ensure that it is fit-for-purpose, imposes the following stringent requirements:

- To verify that the software provides the intended functionality to the user;
- To verify that information is transferred correctly between the models;
- To assess whether the solution provides the capability to meet the use cases within acceptable execution times;
- To assess whether the system provides a satisfactory Man Machine Interface (MMI).

These needs are being met through adopting an incremental approach to software development. The completion of each stage is marked by execution of a test plan that provides for regression testing, but is also being continuously developed to reflect the increasing capabilities of the USS. In addition, the importance of using test case simulations to guide the development of the USS has meant that significant effort has been applied to verify and validate the indoor models used as far as is practicable.

DISCUSSION

At present the use of indoor models in the USS is limited to the domain where UDM is being used as the outdoor dispersion model. This is because in HPAC puffs are passed from UDM to SCIPUFF when they become large compared to the building dimensions, or travel beyond the urban environment. Consequently, when puffs become large in UDM they pass out of the USS as the USS is currently inserted in place of UDM in HPAC. This will be addressed in the future development.

A key part of the further development of the USS is the introduction of the facility to use the MicroSwift/Spray Lagrangian particle dispersion model. It is expected that this will be introduced shortly, and will provide an enhanced capability for conducting coupled indoor-outdoor simulations where near-field effects are important.

The aim of the project is to provide a capability suitable for use by Basic and Advanced users. The work conducted so far has suggested that a Basic user should be able to undertake combined indoor-outdoor modelling using simple single zone indoor models or pre-loaded multizone models. The Advanced user, on the other hand, would have more freedom to use multizone models, and to derive pressure inputs for them from an urban windfield model. While it is desirable to minimise the number of software tools that the modeller has to use, it does not however currently appear desirable to enable the user to construct complex indoor models within the USS, although the facility to undertake limited modifications to library buildings is under consideration.

In order to meet the needs of the Basic user it has been identified that the capability of the BIM model should be enhanced to enable it to be applied in a greater range of scenarios. This will be done by introducing an additional parameter that will enable the effects of building ventilation system and filtration to be accounted for.

CONCLUSIONS

In 2011 Dstl produced a proof-of-principle USS that is now being developed further for transition into the DTRA HPAC. The overall aim of the work is to provide an enhanced modelling capability that meets the needs of both Basic and Advanced users, and to provide them with hazard predictions based on either time or accuracy requirements. To achieve this, the project activities include developing the USS software to enhance the modelling capabilities, conducting simulations and analyses with a range of indoor models to resolve indoor-outdoor model integration issues, prototyping and evaluating user interface options, supported by rigorous testing. The further development activities include the addition of the MSS outdoor model and enhancement of the simple BIM to better support the Basic user.

ACKNOWLEDGEMENTS

The authors would like to thank Mr Rick Fry of the DTRA for supporting this work, NIST and Los Alamos National Laboratory for permission to use the CONTAM and QUIC codes respectively and

Lawrence Berkeley National Laboratory, the National Center for Atmospheric Research and the Naval Surface Warfare Center Dahlgren for supporting the investigation of surface pressures for indoor models.

REFERENCES

Herring, S, Jones R, Bull M, 2012: 'Integrated Outdoor-Indoor Dispersion Modelling of Hazardous Releases in the Urban Environment', 10th UK WES Conference, University of Southampton.