SHELTER MODELS FOR CONSEQUENCE ANALYSIS AND RISK ASSESSMENT OF CO_2 PIPELINES

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Presentation content

- Requirement for a shelter model
- Description of models developed
  - Analytical model
  - Computational Fluid Dynamics (CFD) model
- Model validation – single room
- Sensitivity study
- Effect of partitions and half height clouds
- Conclusions and recommendations

What is the CCS transportation challenge?

To transport anthropogenic CO_2 of varying composition from multiple capture sites (power plant and industrial) to multiple storage sites in a safe, reliable and efficient manner in compliance with appropriate design standards and regulatory requirements.

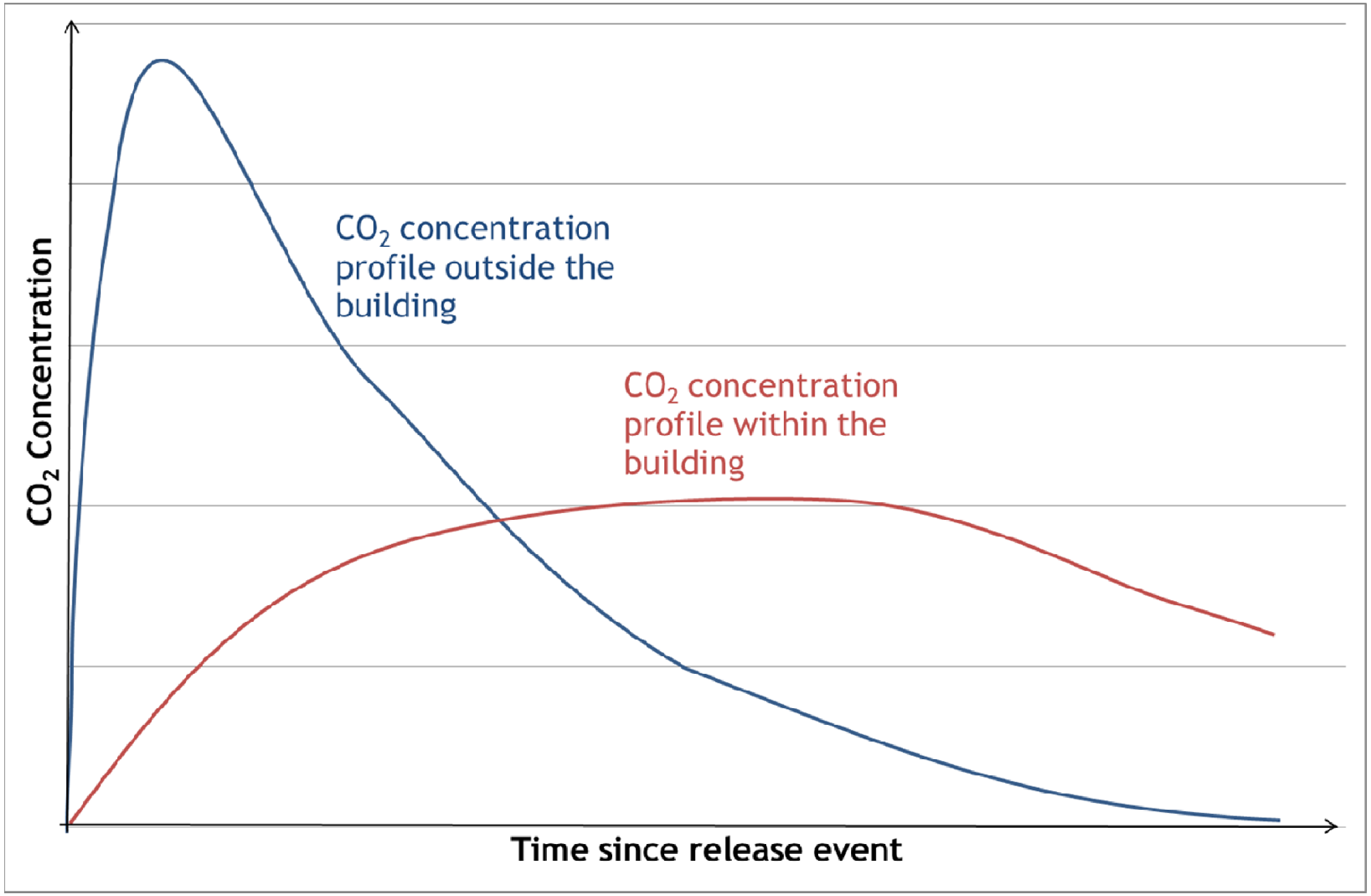
Consequences of CO_2 pipeline failure

- CO_2 is not explosive or inflammable like natural gas and is odourless.
- CO_2 is denser than air and might accumulate in depressions or valleys.
- CO_2 is toxic and above concentrations of ~10% can have long term effects or cause fatality.

Therefore

- Need to be able to calculate CO_2 concentrations around a failure in order to define separation distances from pipelines using a Quantitative Risk Assessment approach.
- Requires a pragmatic infiltration model to predict effect CO_2 exposure on humans in buildings.

Consequences of CO_2 pipeline failure

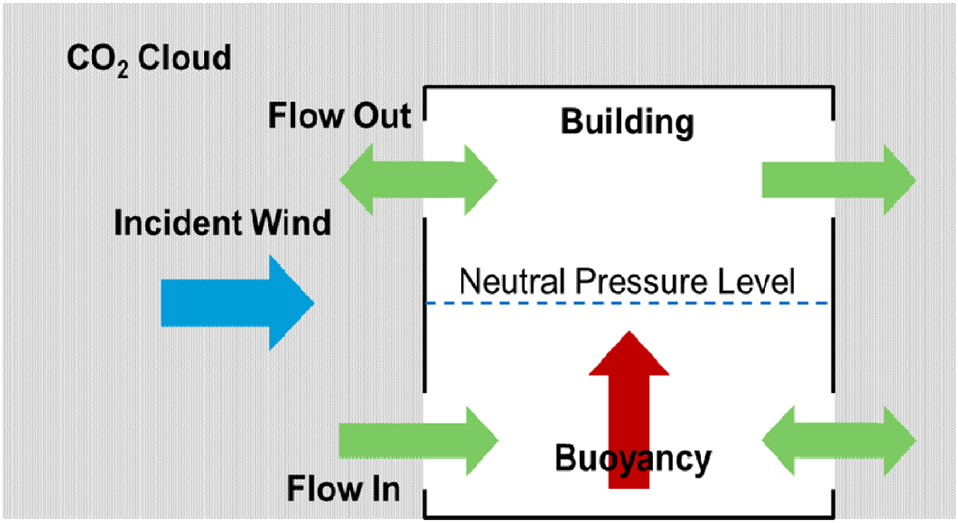


Analytical model description

- Based on the principles of natural building ventilation (Etheridge and Sandberg, 1996).
- Model described in outline in Lyons *et al* 2015 and in detail in future publications
- Considers wind driven and buoyancy driven air flow.

Assumptions:

- o Initial concentration of CO_2 in building is same as atmosphere.
- o Building is engulfed in a cloud of CO_2 following a release

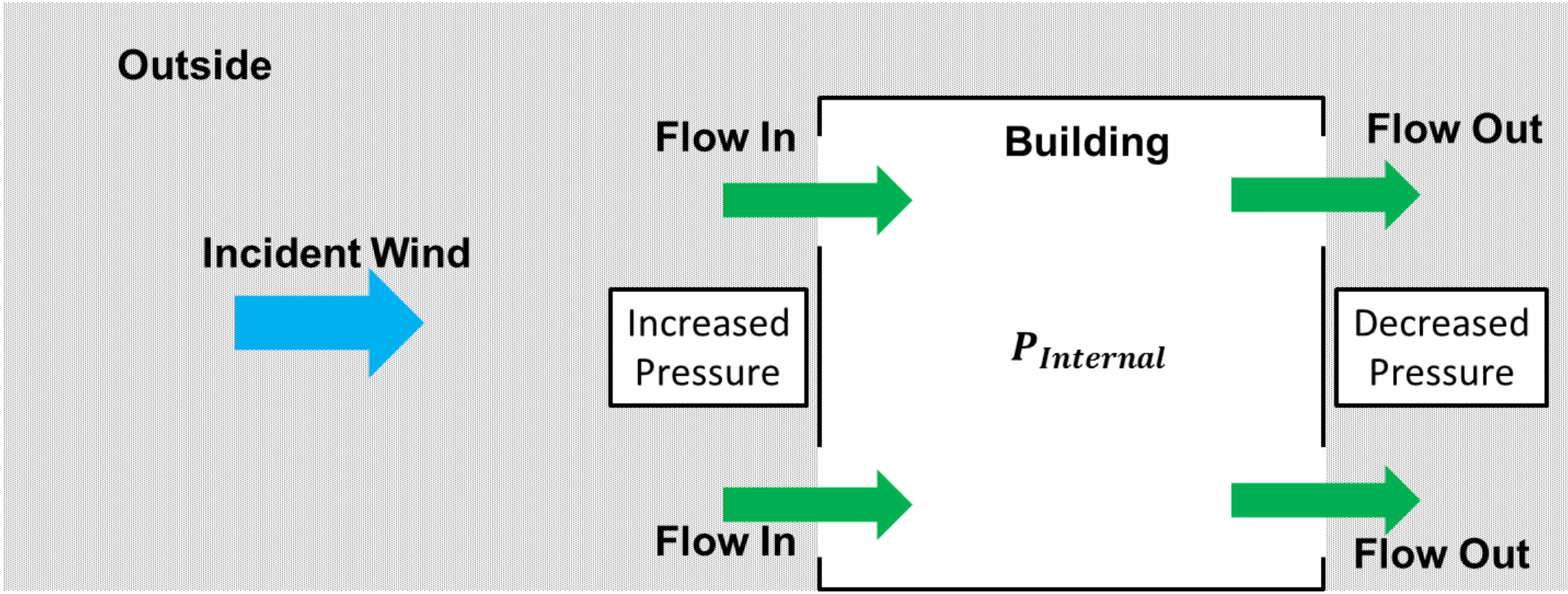


Etheridge, D. W. & Sandberg, M.. 1996. *Building Ventilation: Theory and Measurement*, New York: John Wiley and Sons.

Lyons, CJ, Race, JM, Hopkins, HF & Cleaver, P 2015, Prediction of the consequences of a CO_2 pipeline release on building occupants. in *Hazards 25: Edinburgh International Conference Centre, Edinburgh; United Kingdom; 13 May 2015 through 15 May 2015.* vol. 160, Institution of Chemical Engineers Symposium Series, Red Hook, Hazards 25, Edinburgh, United Kingdom, 13-15 May.

Air flow – wind driven

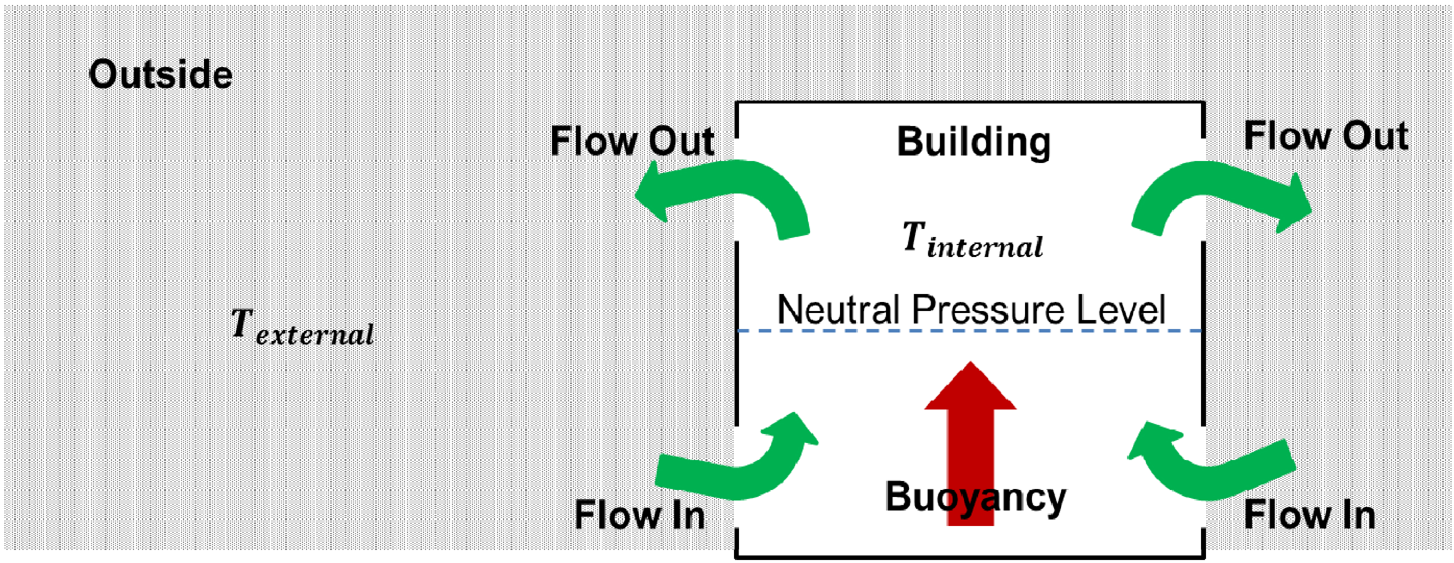
- Wind blowing outside.
- Pressure difference between internal and external environments.
- Air flows from high to low pressure - in at front face, out at rear.
- Air flow straight through building.



Air Flow – buoyancy driven

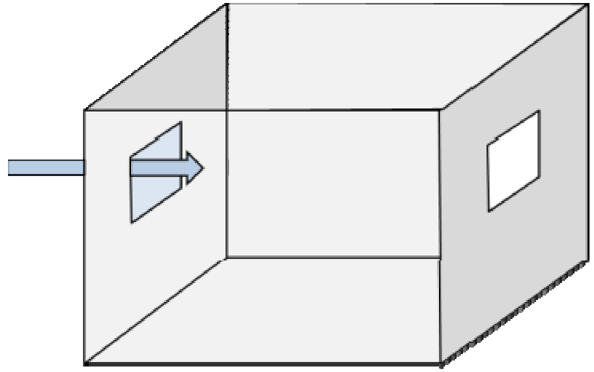
In the absence of a release:

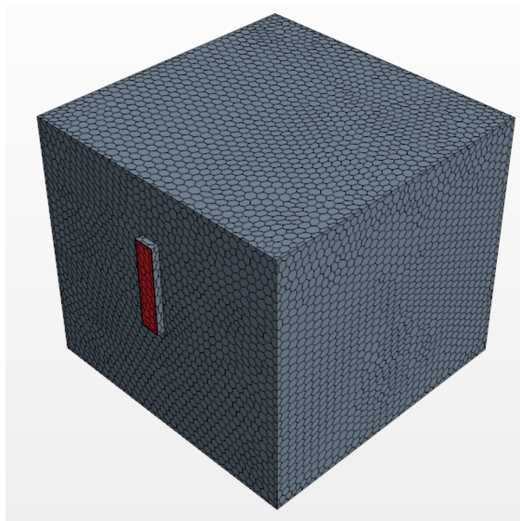
- Increased internal air temperature reduces internal air density.
- Steeper pressure gradient outside the building than inside (as density is greater outside).
- Creates pressure difference across openings at top and bottom of building.
- Warm, less dense air leaves and is replaced by colder more dense air at base, with upward drift of warmer air inside.



CFD model

- Based on conservation equations for mass, momentum, energy and chemical species
- $k - \epsilon$ turbulence model was corrected to incorporate the effect of buoyancy driven flows with low Reynolds number
- Four different models tested - Lag Elipptic Blending (EB) $k - \epsilon$ model gave best results relative to the experimental data
- Meshed using polyhedral mesh within solution domain with a prism layer mesher used to improve the CFD simulation in near-wall regions

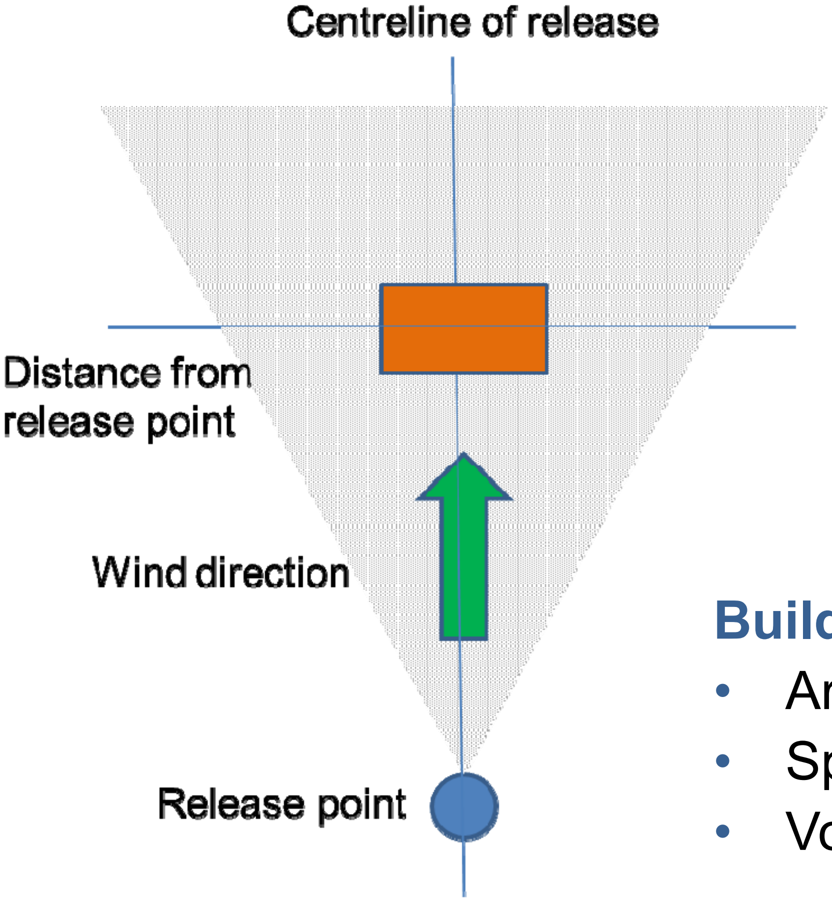




Model input data

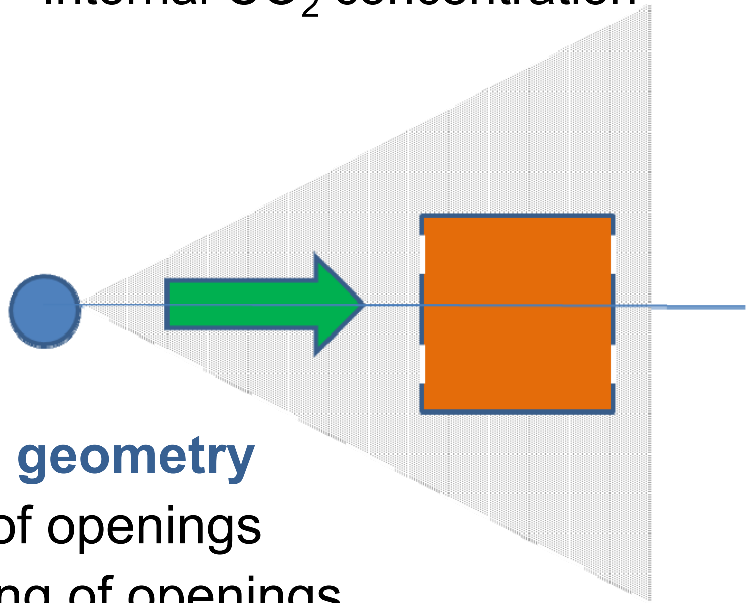
Cloud conditions

- CO_2 concentration profile
- Temperature profile



Atmospheric conditions

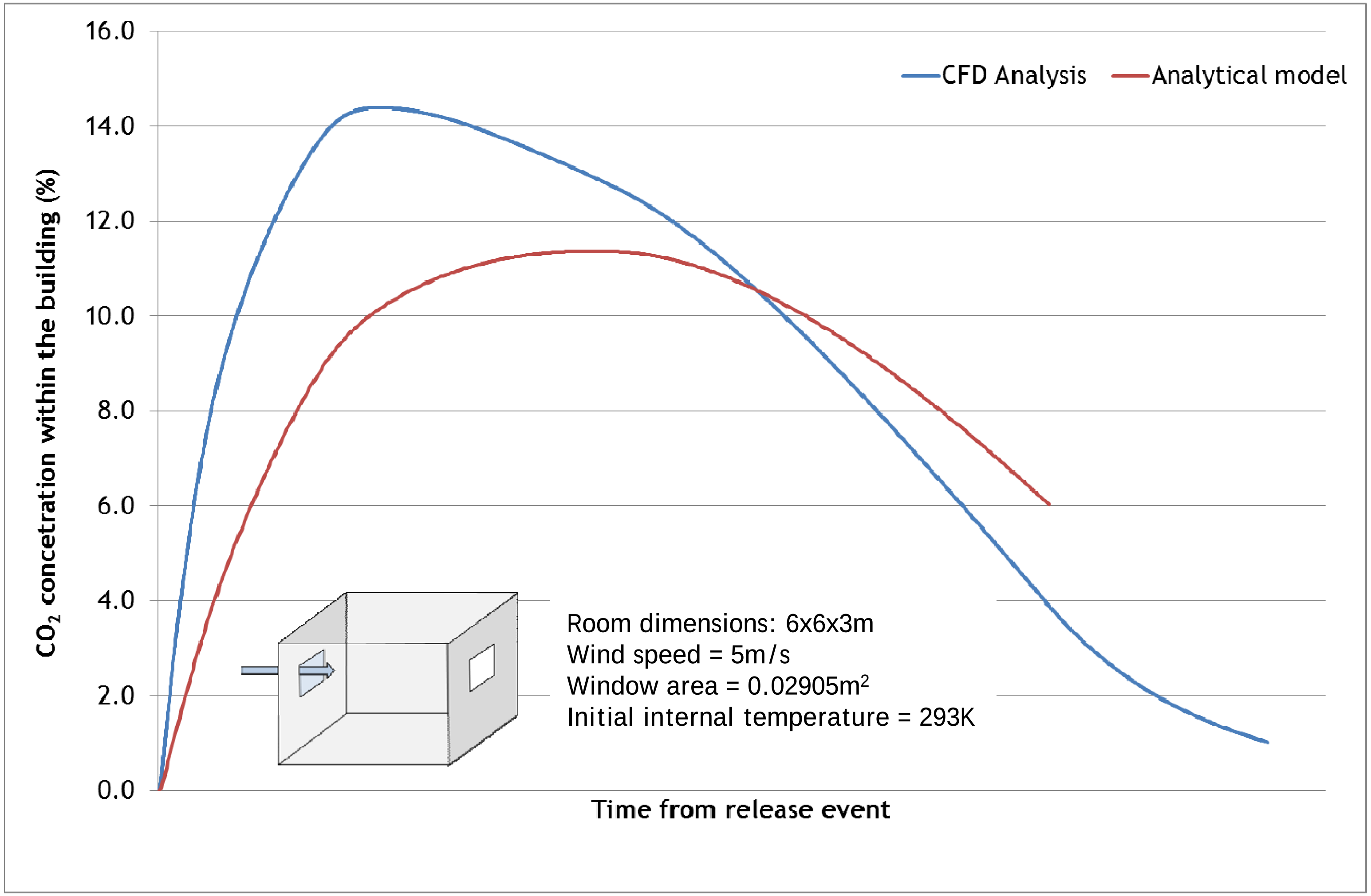
- Wind speed
- Wind incident direction
- Internal temperature
- Internal CO_2 concentration



Building geometry

- Area of openings
- Spacing of openings
- Volume of building

Model comparison – single room totally engulfed



Toxic dose

- A generalised equation for toxic dose of exposure to some contaminant is given by:

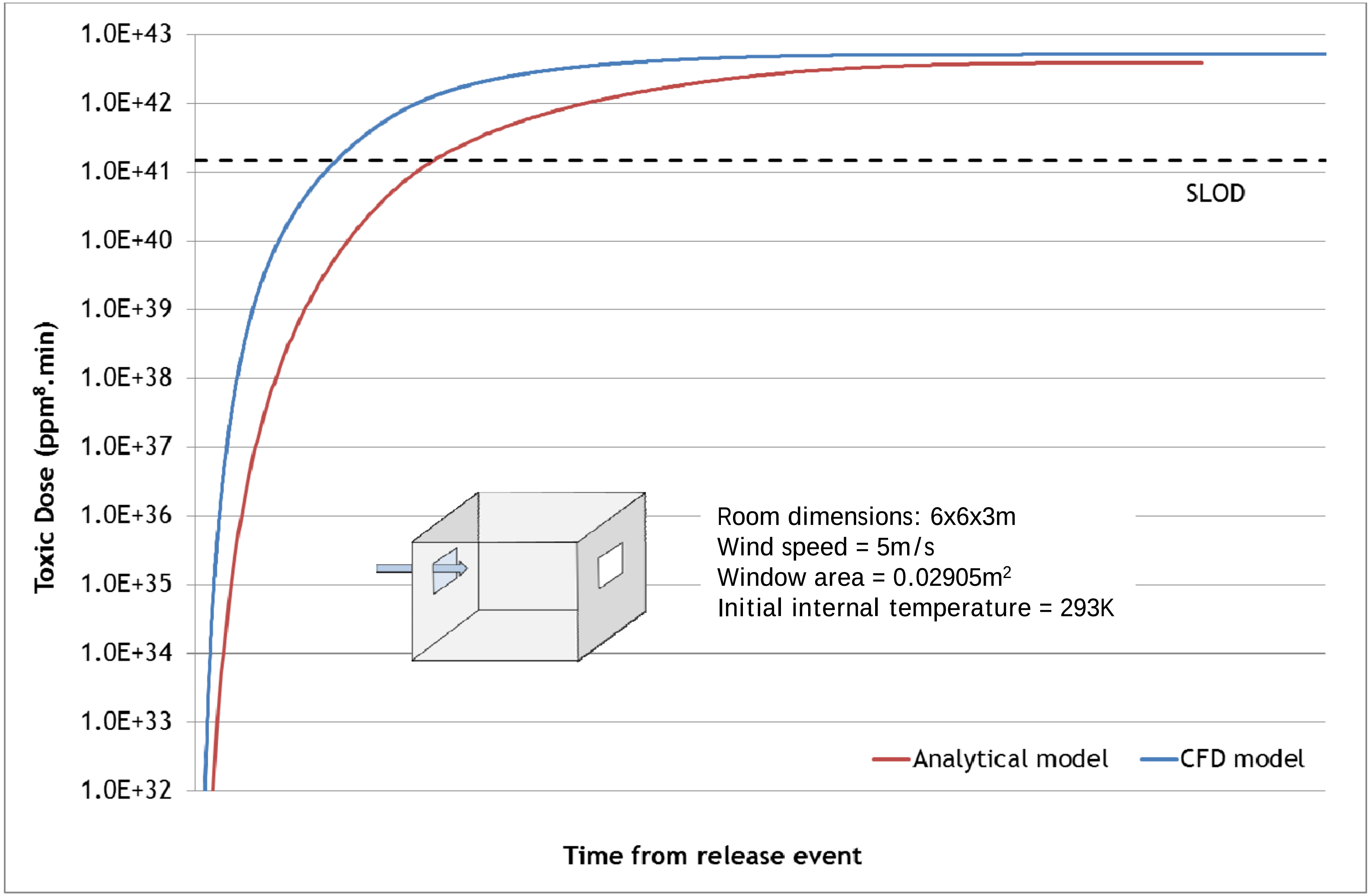
$$D = \int c(t)^n dt$$

Where

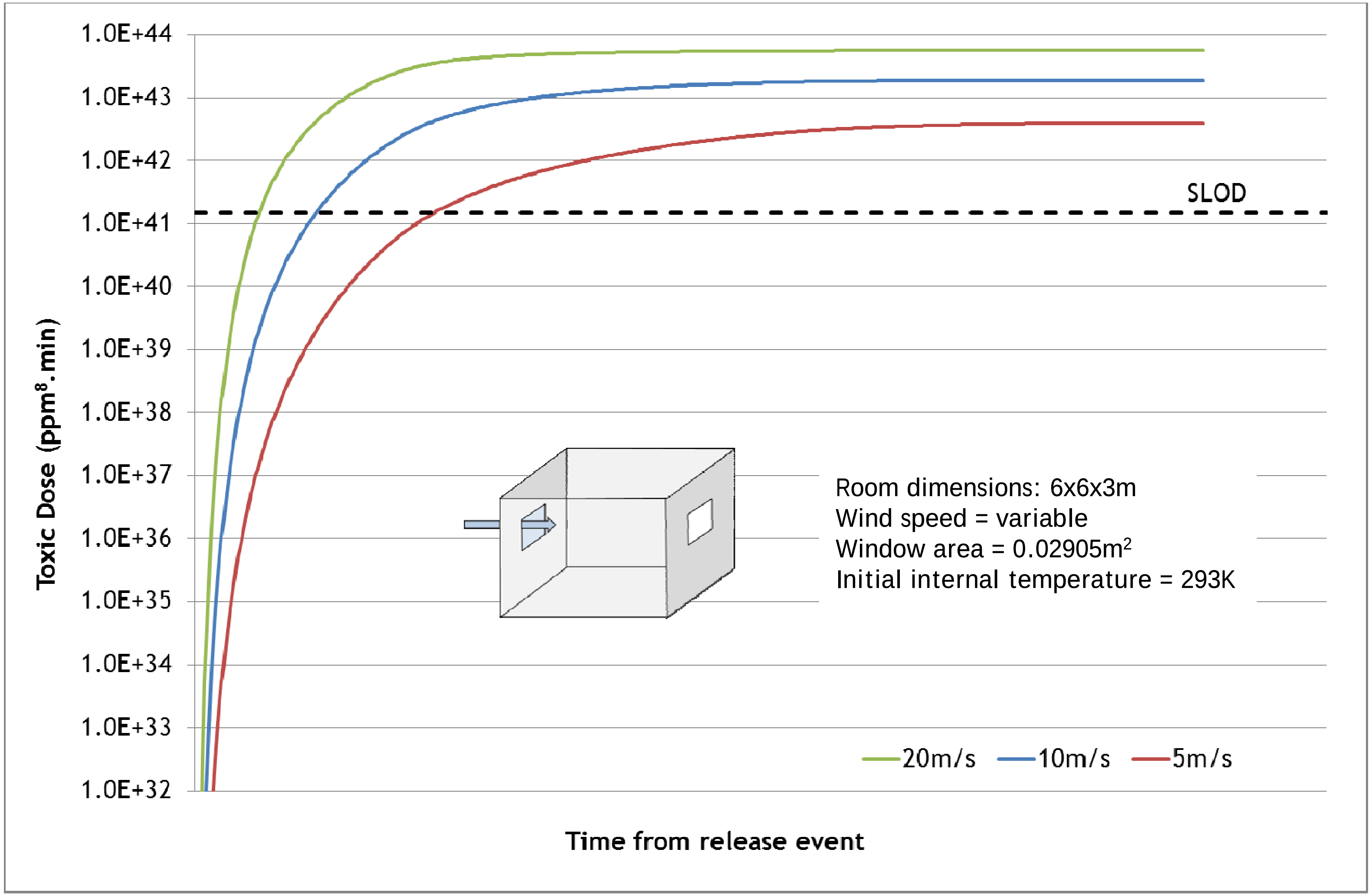
c(t)	the concentration of the contaminant a person is exposed to in parts per million (ppm),
t	the time of the exposure in minutes
n	is the toxic index = 8 for CO_2

- Dangerous Toxic Loads
  - The Specified Level of Toxicity (SLOT). The SLOT dose for CO_2 is 1.5 x 10^{40} ppm^8.min.
  - The Significant Likelihood of Death (SLOD). The SLOD dose for CO_2 is 1.5 x 10^{41} ppm^8.min.

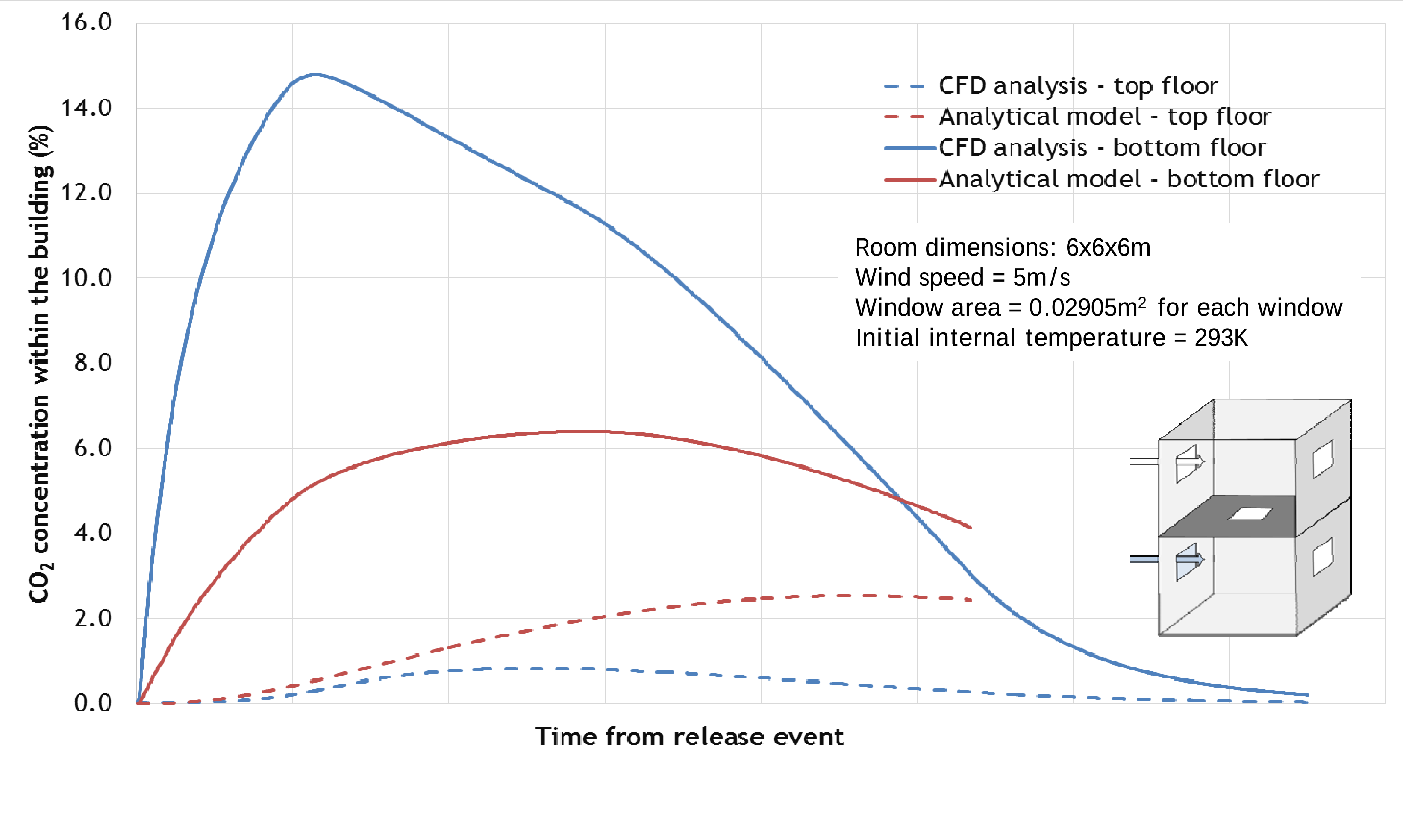
Model comparison – single room totally engulfed



Sensitivity study – wind speed dependence



Partitions and half height clouds



Conclusions

- Two shelter models have been developed as part of this work; an analytical and a CFD model.
- The models compare favourably with experimental test data
- It has been demonstrated that the ability of buildings along a pipeline route to provide shelter can be determined using these models.
- The wind speed has been shown to have the greatest impact on concentration profiles within the building.

Conclusions

- Calculations have been conducted for worst case direction.
- SLOD times would be different (and less severe) for different directions throughout the cloud.
- In conducting a full QRA a failure frequency analysis would be incorporated with these results to calculate the risk at any particular location.
- However, it has been shown that dose received by an individual in a building would not reach the levels of toxicity experienced in shelter were not considered.

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