Three-Dimensional CFD Simulation of Airflow and Contaminant Transport in Complex Buildings

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PAR3D Numerical Model: Existing CFD Capabilities

- 3-D Incompressible Flow with Buoyancy
- Transport of Active & Passive Constituents
- Two-Equation ($k-\varepsilon$) Turbulence Modeling
- Multi-Zone Curvilinear Grids
- Parallel Processing
Eulerian Modeling Approach

- Contaminant concentrations are treated as continuous (transported) functions.

- Computed flow field produces dispersion through advective (convective) transport.

- Computed turbulence field produces dispersion through diffusive transport.

- Boundary & initial conditions determine the local rates of contaminant delivery.
Dispersion in a Hypothetical Five-Room Building with a Connecting Corridor
Building Dimensions in Plan View

Note: All dimensions are in feet.
Ceiling is 8 ft high.
Grid spacing is 1 ft.
5-ROOM BUILDING WITH CORRIDOR

RED  =>  SUPPLY VENTS, 427 CFM EACH
GREEN  =>  RETURN VENTS, 829 CFM EACH
BLUE  =>  RETURN VENTS, 331 CFM EACH
PURPLE  =>  OPEN CORRIDOR EXIT, 769 CFM OUTFLOW
YELLOW  =>  OPEN CONNECTING DOORS

Note: All vents are in the ceiling.
Velocity Vectors 4 ft from Floor and Ceiling
Velocity Magnitude 4 ft from Floor and Ceiling
Contaminant Release Scenario for Five-Room Building:

- Contaminant is introduced impulsively in Room 4 with an initial concentration of unity.

- Contaminant is dispersed throughout the building via the steady-state flow created by a forced-air flow rate of 6400 cubic feet per minute (cfm).

- Contaminant is removed through the return vents and through the open corridor exit.
Concentration (at 2-min intervals) 4 ft from Floor
Contaminant Dispersion in an Existing Two-Story Multi-Room Building
TWO-STOREY BUILDING
LOWER LEVEL
Grid Layout for Plenum

- Supply Vent
- Return Vent
- Exhaust Vent
- VAV Box
TWO- Story Building

Upper Level
Floor Plan
Release Scenario for Two-Story Building

- Contaminant is released impulsively on the second floor.

- The mass released is 600 gm, concentrated initially in a 1-cubic-foot volume centered on the floor of the lobby.

- Contaminant is dispersed through the building by steady-state airflow (22,000 cfm) created by the HVAC system.

- Contaminant passes through the HVAC air handler (with 74% filtration) after which it is transported back to the rooms via the supply vents.
4 FT FROM FLOOR - IMPULSE RELEASE WITH FILTRATION

CONCENTRATION AT 00:00:00

UPPER GROUND LEVEL

LOWER GROUND LEVEL

CONCENTRATION

1.0

0.5

0.0
Advantages of 3-D CFD

• Provides greater local detail than two-dimensional simulations, which may be important for the placement of sensors.

• Best used for dispersion events of short duration (minutes to hours).

• Facilitates the development and study of rapid counter-measures.
Disadvantages of 3-D CFD

• Simulations may require hours (or days) of computer time.

• Input preparation (geometry and boundary conditions) may require months of effort for a multi-story building.

• Uncertainty concerning boundary conditions (and other details) may negate efforts to achieve predictive accuracy.
Practical Needs for 3-D CFD Simulation of Dispersion in Complex Buildings

• Automated translation of building features and dimensions into CFD model input

• Reliable characterization of airflow boundary conditions and other details

• Ready access to multi-processor supercomputers
For related work concerning the practical application of CFD to contaminant dispersion and detection in a building, see the report by J. J. Whicker et al.,

“Placement of Continuous Air Monitors in PF-4 Plutonium Laboratories: Consensus Findings and Recommendations”

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