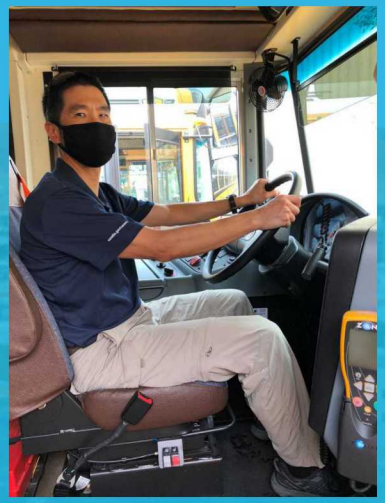
SAND2020-10614PE

Modeling Airborne Exposure Risk Factors in School Buses



PRESENTED BY

Clifford K. Ho, Ph.D. ckho@sandia.gov

Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Objectives

- Understand most important factors that impact exposure risks if there is a sick child on the bus
  - E.g., source/receptor location, ventilation conditions
- Identify scenarios that reduce risk of exposure
  - E.g., number and location of open windows

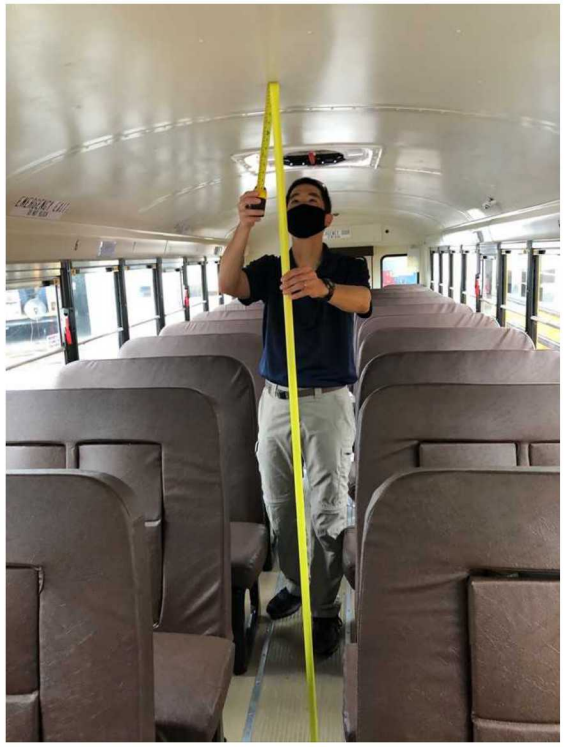
Tasks

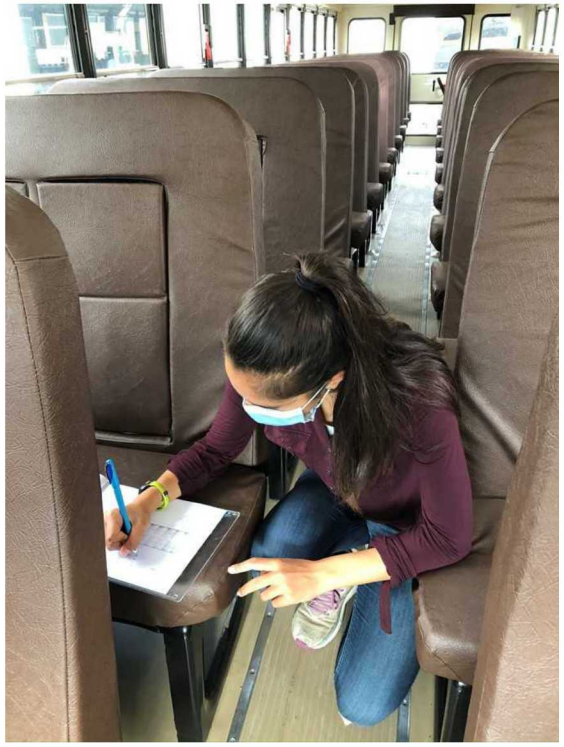
- Characterization and Testing
  - Albuquerque Public Schools Public (APS) Transportation Center
  - Measure dimensions of school buses
  - Measure transient temperatures and air speeds with heater and A/C on
  - If modeling warrants, perform additional testing of aerosol or tracer dispersion in a moving bus
- Modeling
  - Develop model(s) of APS school bus(es)
  - Evaluate ventilation scenarios
    - Heater on/off, window(s) open/closed, emergency hatch open/closed
    - Source term: Exhalation from one child (front, middle, back)
    - **Notes**
      - Current APS protocol is 2 kids per seat (max is 3 kids per seat)
      - Plexiglass barriers are NOT allowed (DOT regulations)

Characterization and Testing

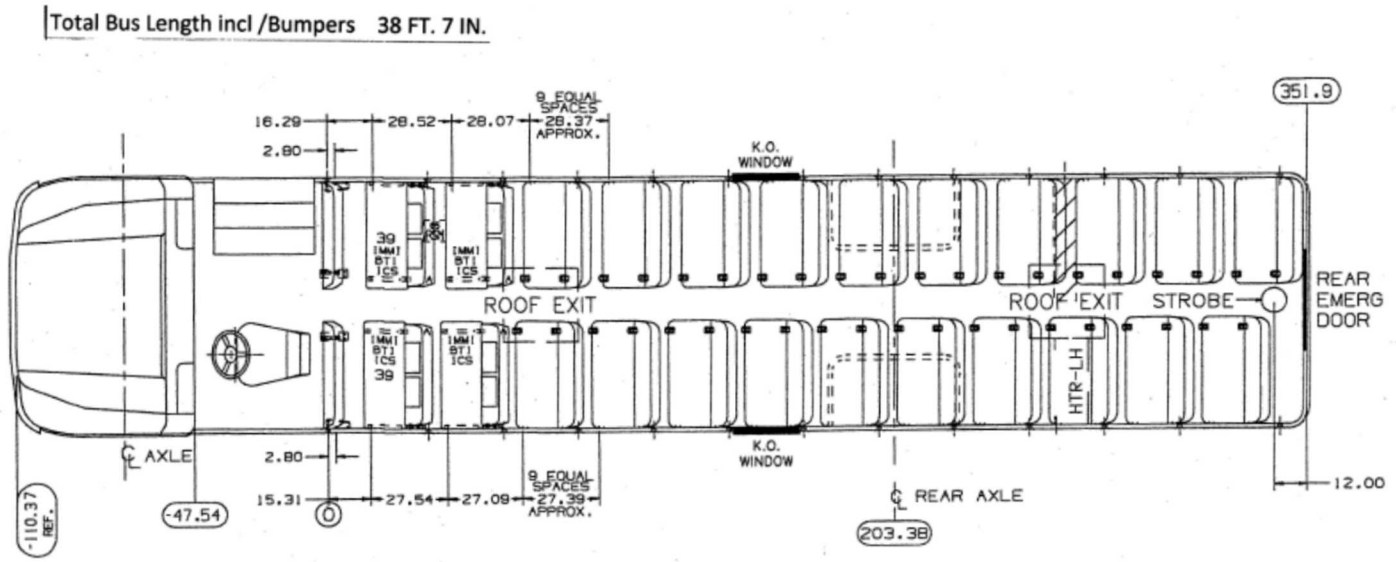
Characterization and Testing

- Visited Albuquerque Public Schools Transportation Center on July 27, 2020
  - Measured interior dimensions of two buses
    - 72-passenger IC CE series bus (#84) with 13 rows
    - 48-passenger IC CE series bus (#150) with 8 rows
  - Measured air speeds and temperatures inside closed, unoccupied buses during ventilation scenarios for model validation
    - Heating in 72-passenger bus
    - Air conditioning in 48-passenger bus

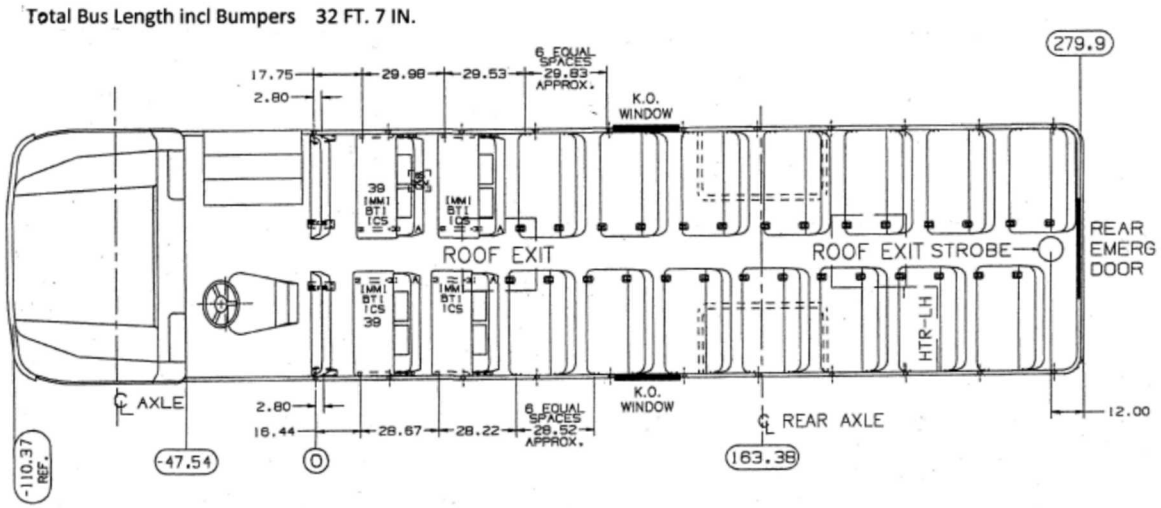




Bus Types – IC CE Series



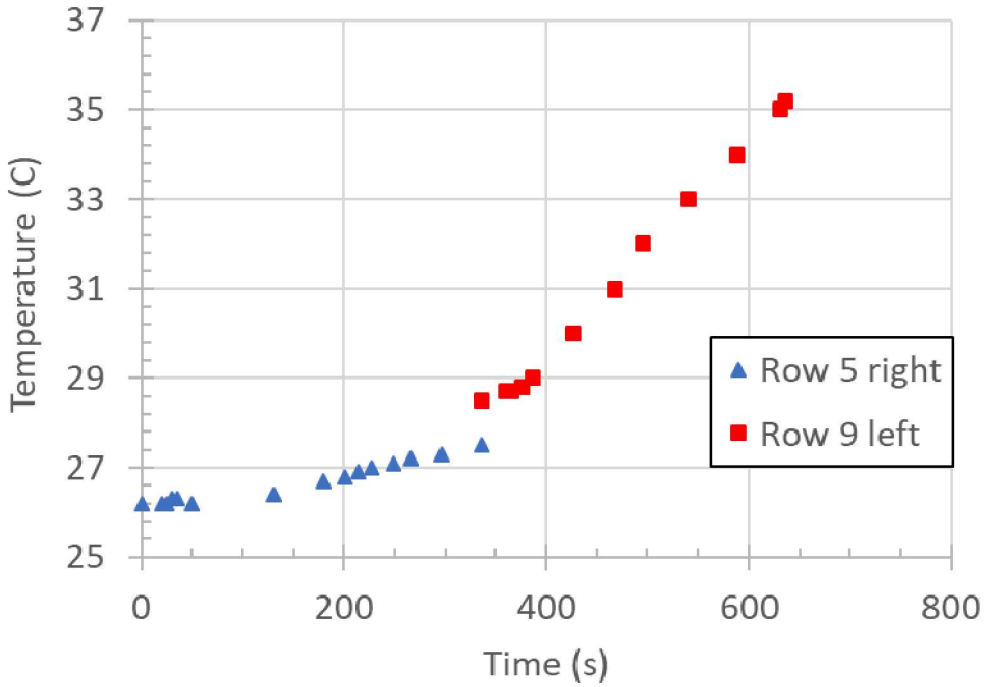
72 passenger bus (12 rows)



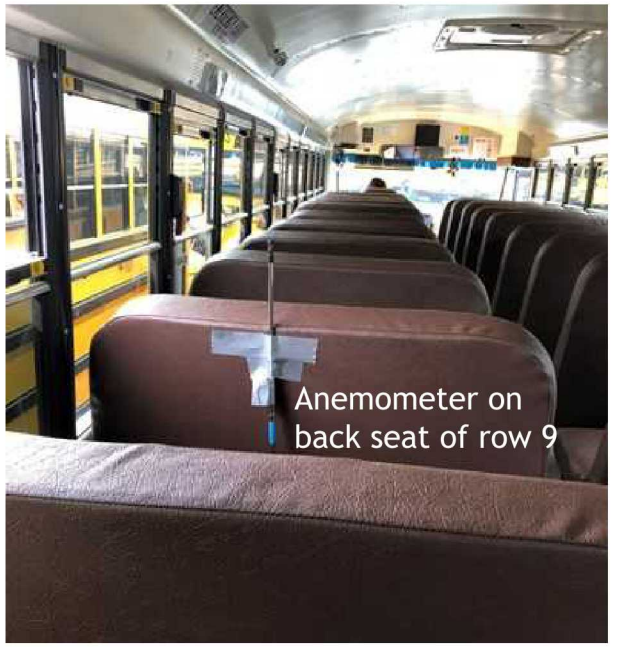
48 passenger bus (8 rows; a bit smaller than the one shown)

Characterization and Testing

- 72-passenger bus heating (unoccupied)
  - Heater located under row 9 (left seat)
  - Measured temperature and air speed at two locations
  - ~5 minutes at each location

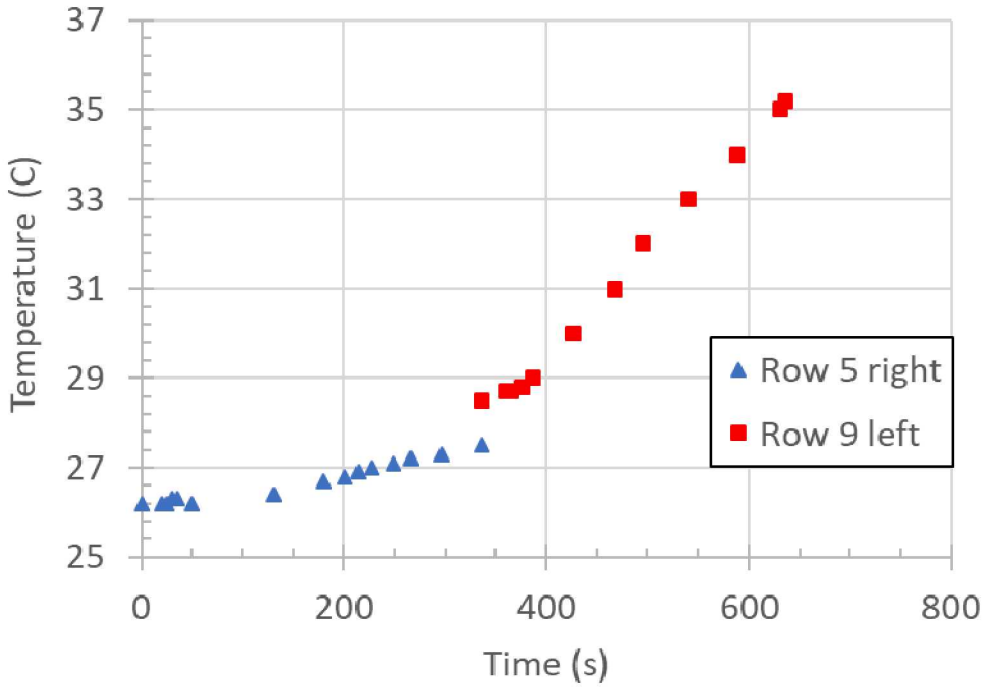


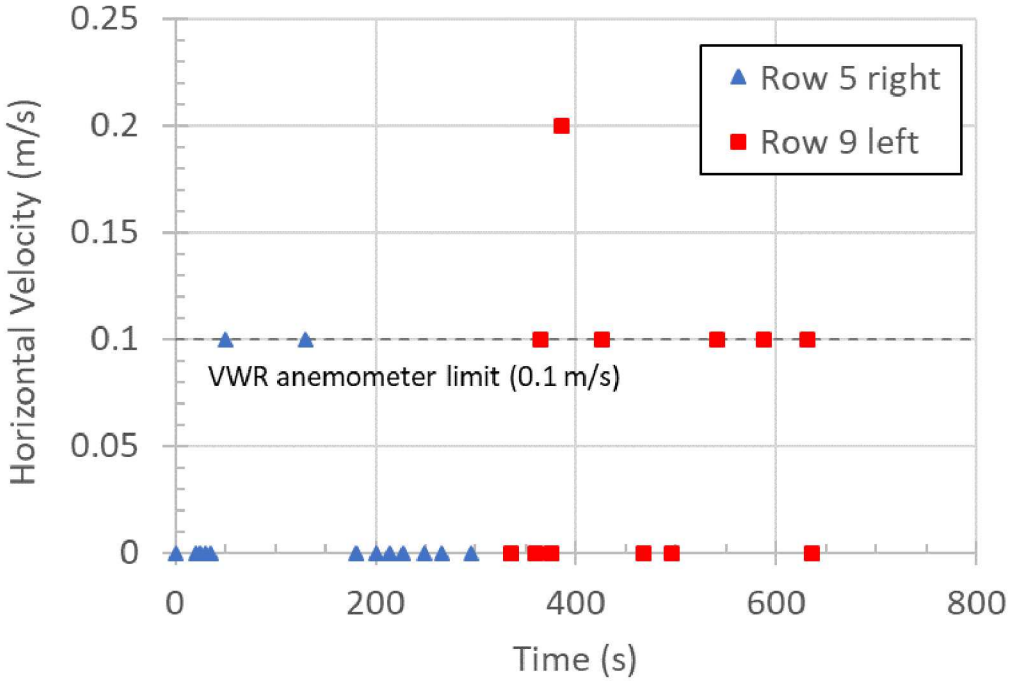
Anemometer on back seat of row 5 (right seat)



Characterization and Testing

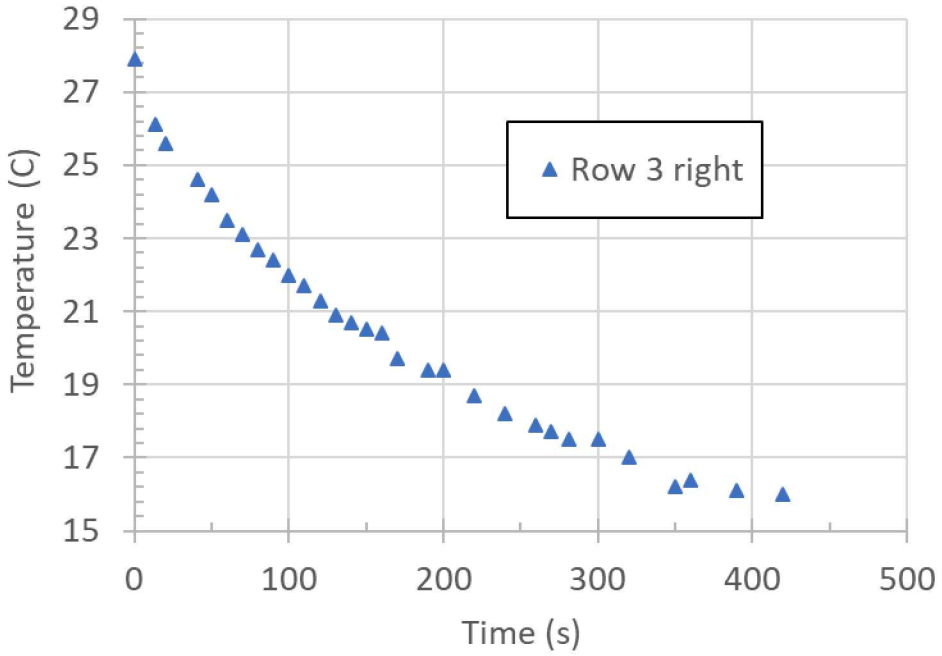
- 72-passenger bus heating (unoccupied)
  - Heater located under row 9 (left seat)
  - Measured temperature and air speed at two locations
  - ~5 minutes at each location





Characterization and Testing

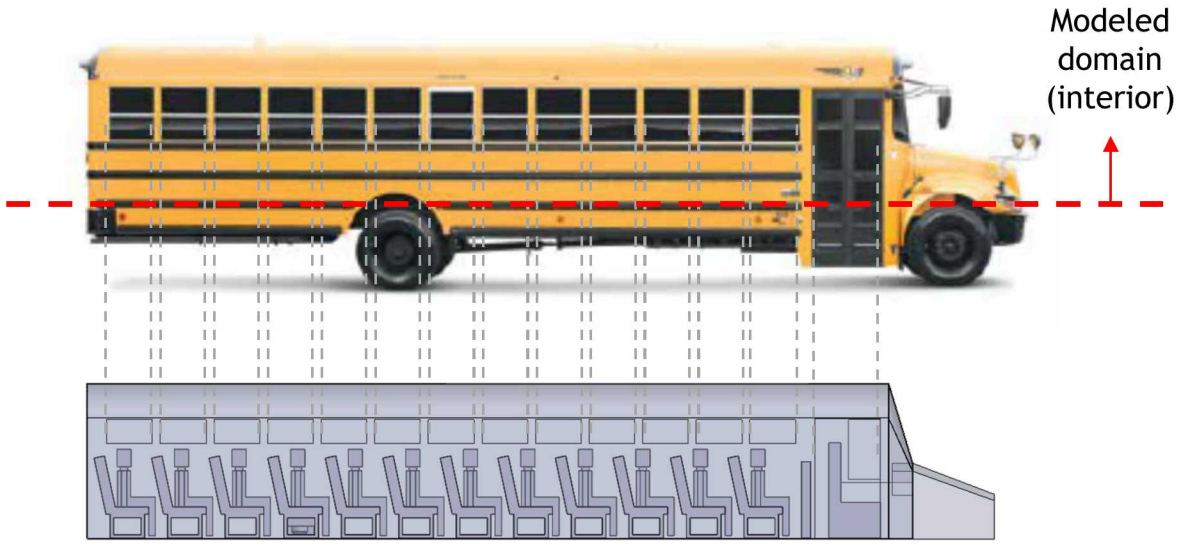
- 48-passenger bus (8 rows) (unoccupied)
  - A/C cooling using front vents (x3) and back vents (x4)
  - Measured temperature and air speed on back of right seat at row 3



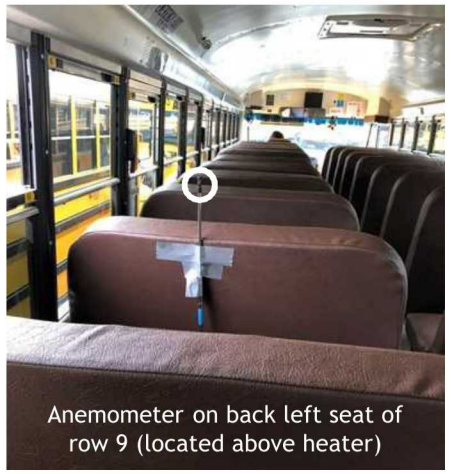
Modeling of School Buses

Modeling of School Buses

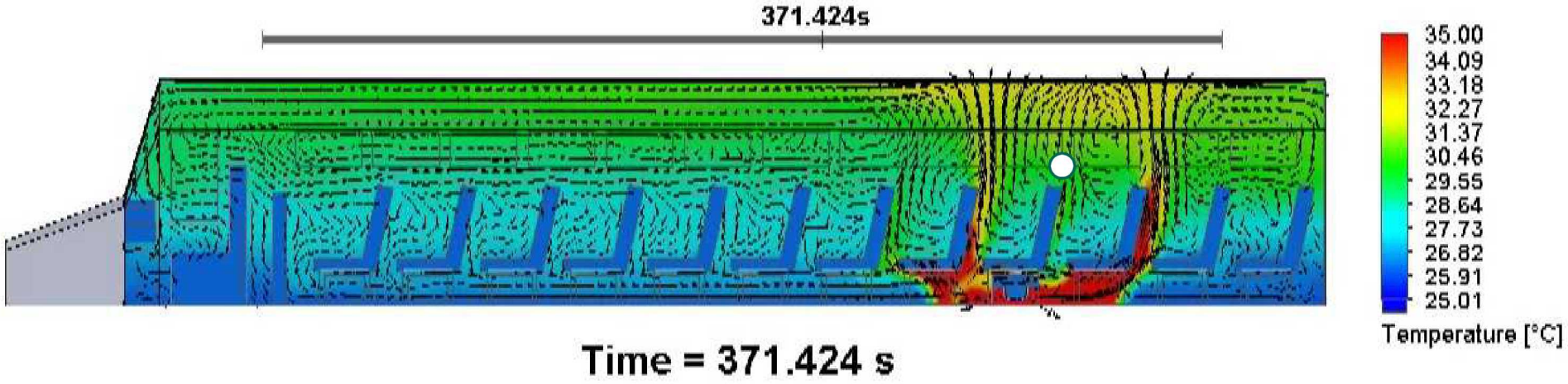
- Bus type and configuration
  - IC CE Series 72-passenger bus (#84)
- Ventilation scenarios
  - Heater on/off
  - Window(s) open/closed
  - Emergency hatch (top) open/closed
- Source
  - Simulate expelled pathogen plume from one “infected” student
    - Located in front, middle, or back of bus
- Outcomes
  - Simulate relative exposure risks as a function of time and location for different scenarios



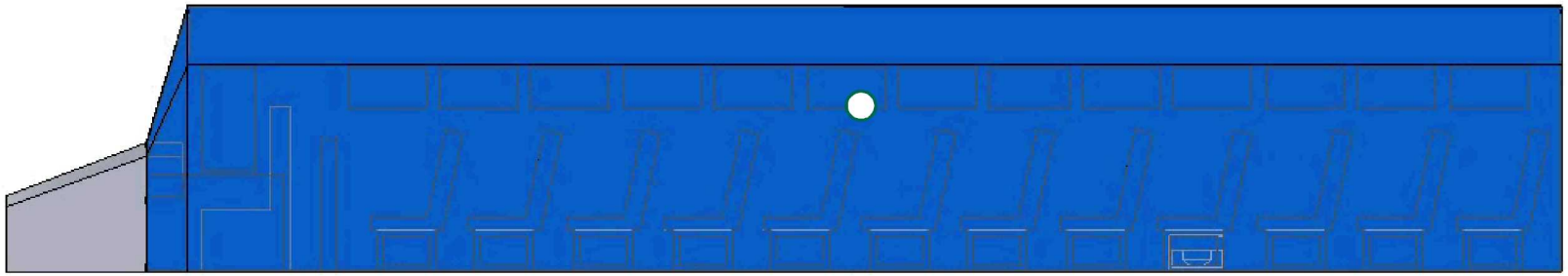
Modeling Heating of Bus



Cut plane through left row

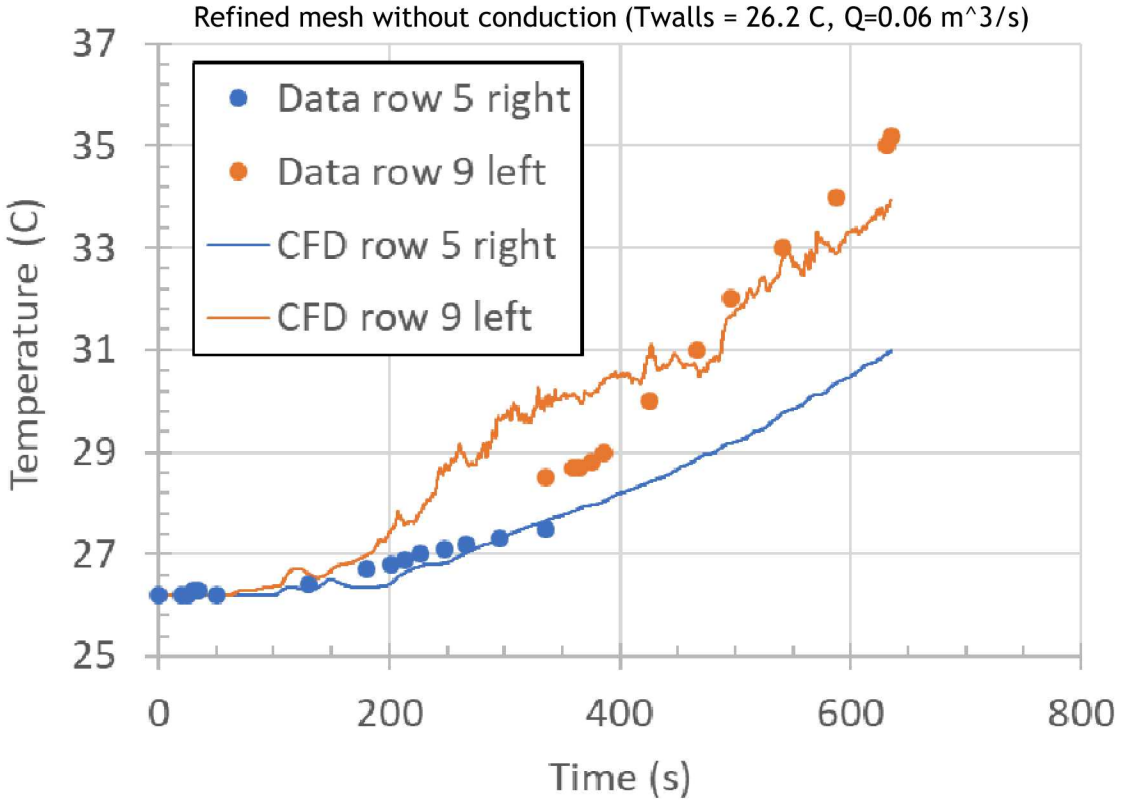


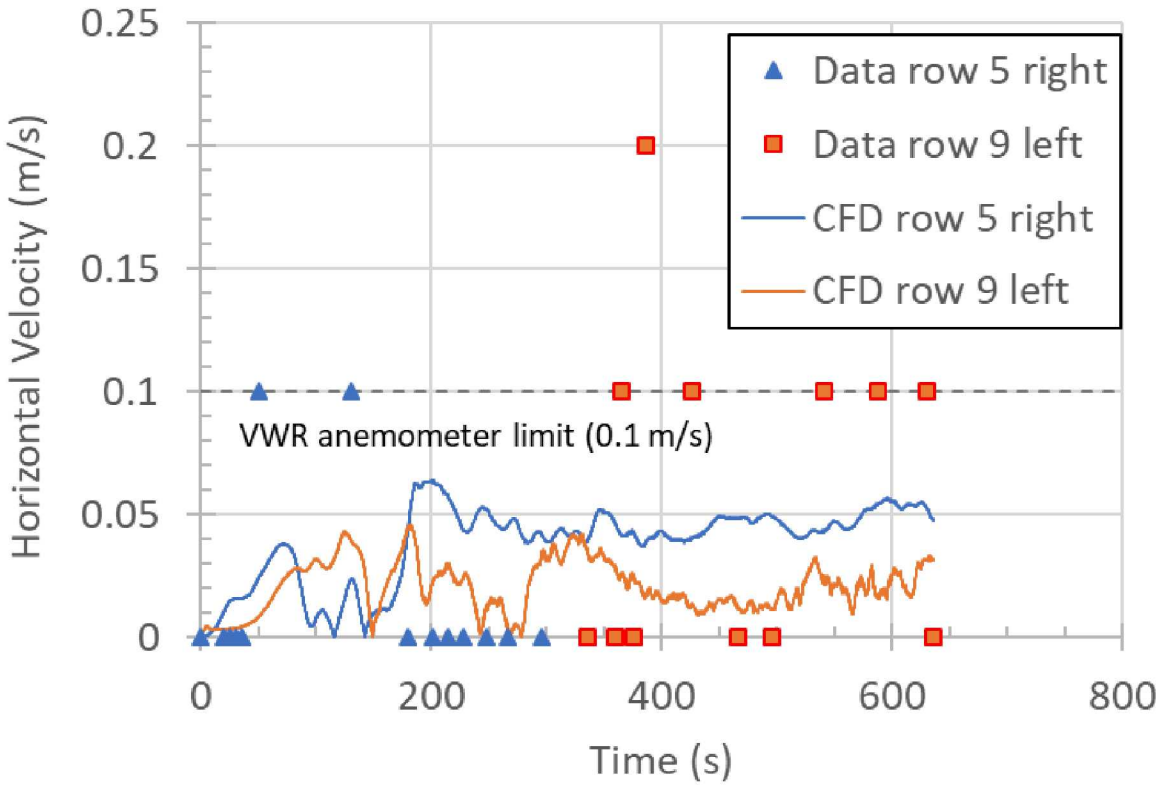
Cut plane through right row



Heater air flow recirculation = 0.0661 m^3/s (640 cfm or ~6 Air Changes per Hour); T_{heater} ramps from 26 C to 60 C in 636 s

Simulated vs. Measured Temperature and Air Speed

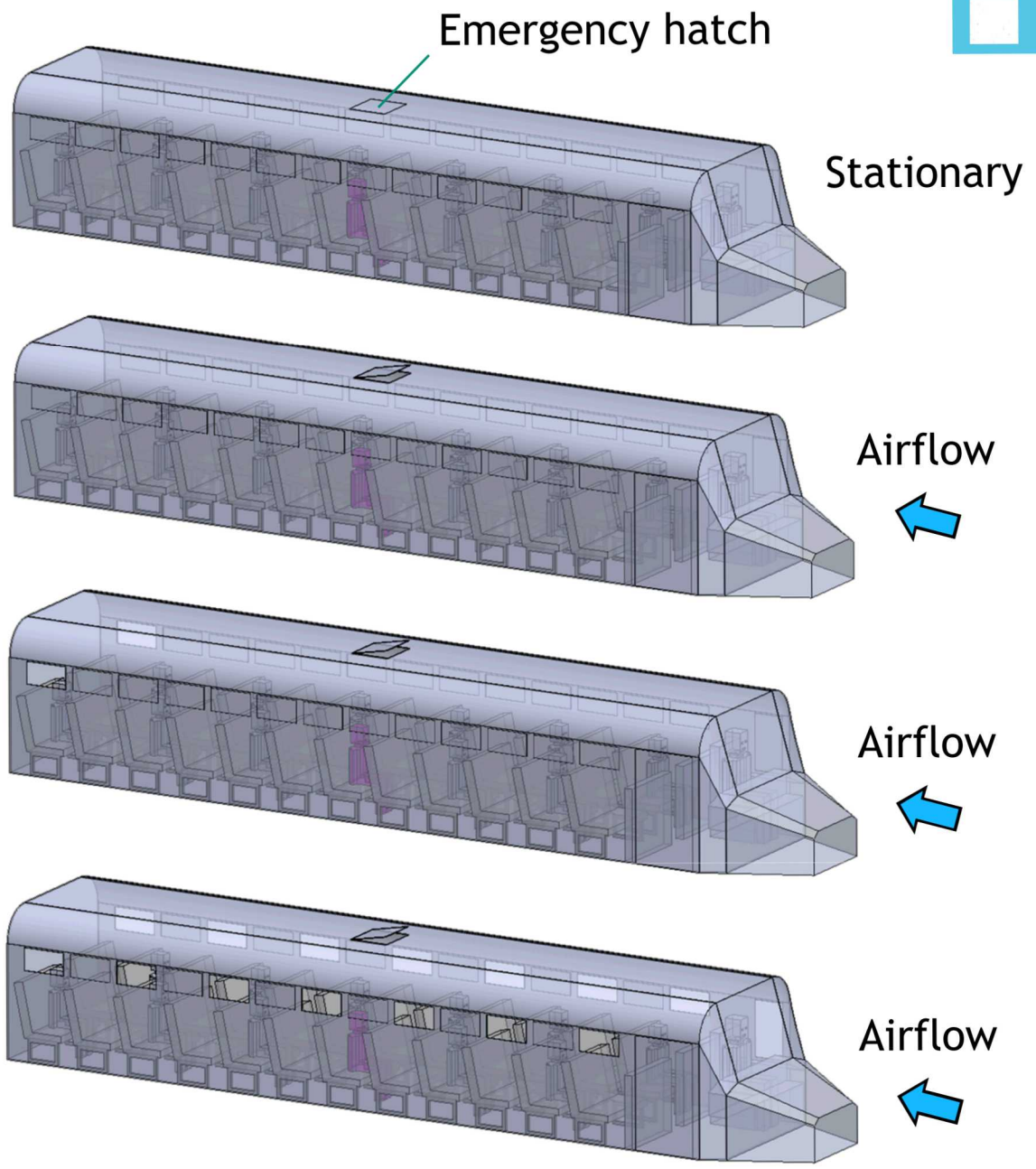




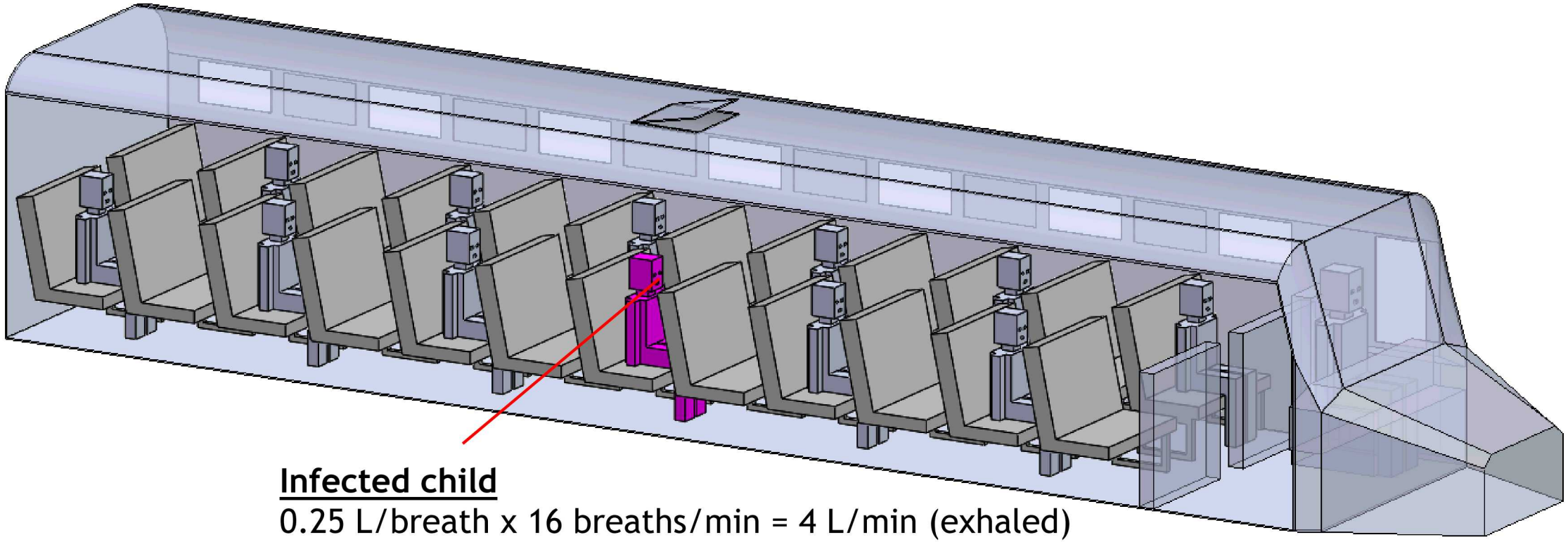
Exposure Modeling

Exposure Modeling Scenarios

- Stationary Bus
  - Heater on/off
  - Pressure openings
    - Door
    - Door, hatch, back windows
    - Door, hatch, every other window
- Moving Bus (10 m/s, ~22 mph)
  - Heater on
  - Airflow openings
    - Hatch
    - Hatch, back windows
    - Hatch, every other window
    - Front and back windows open
    - Front, back, and driver windows open



Boundary Conditions



Infected child
0.25 L/breath x 16 breaths/min = 4 L/min (exhaled)
Pathogen mass fraction = 0.039 (RH=100%, 37 C)

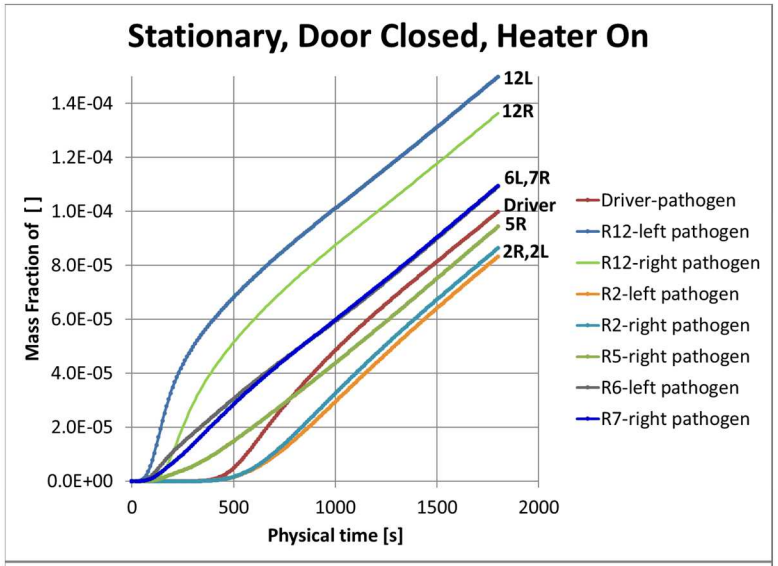
Receptors
- Children: 0.25 L/breath x 16 breaths/min = 4 L/min (inhaled)
- Adult driver: 0.5 L/breath x 16 breaths/min = 8 L/min (inhaled)

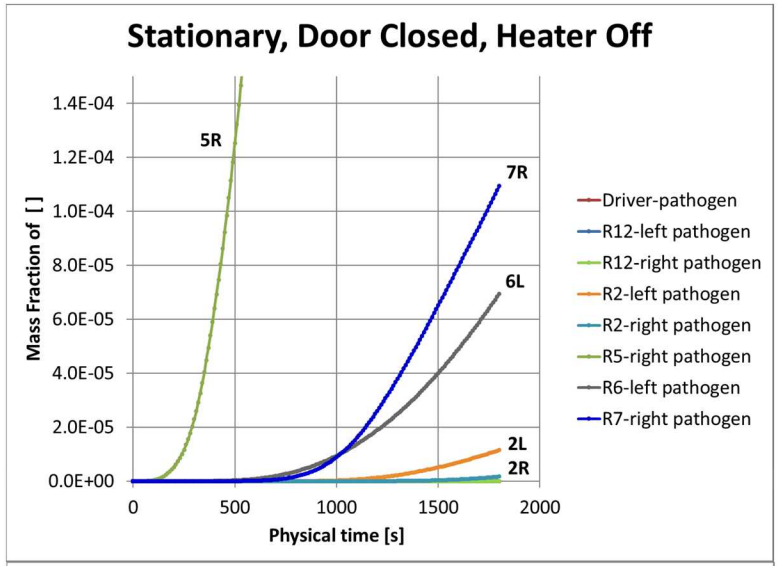
Pathogen Mass Fraction – Stationary Bus

Heater On

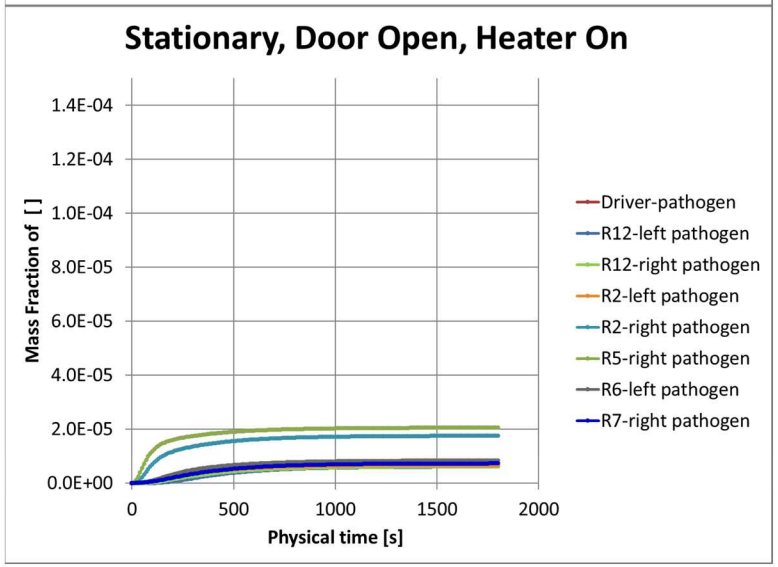
Heater Off

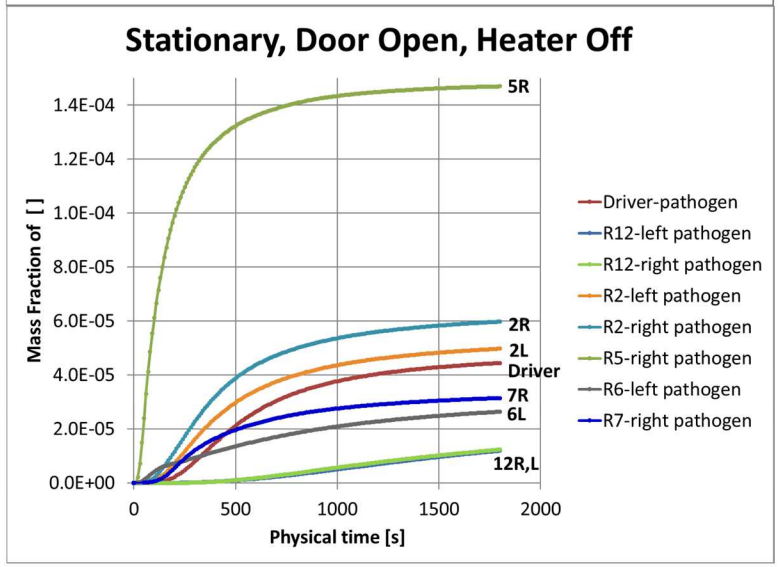
Door Closed





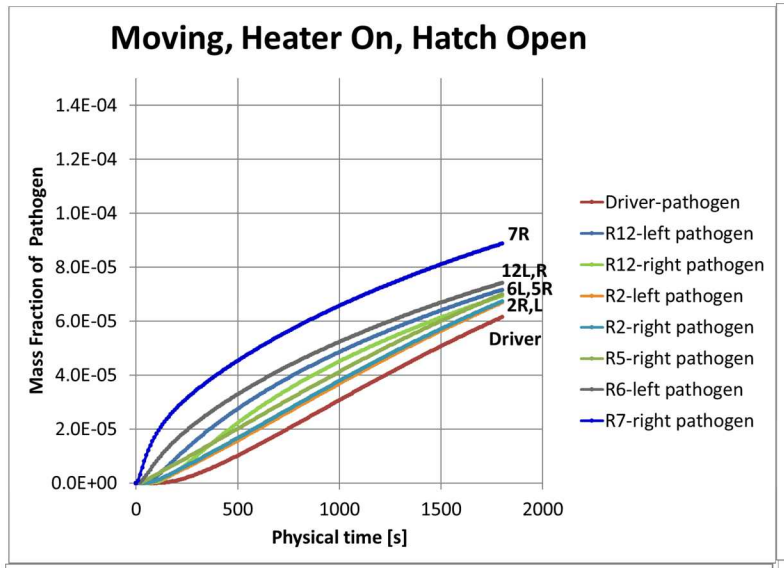
Door Open

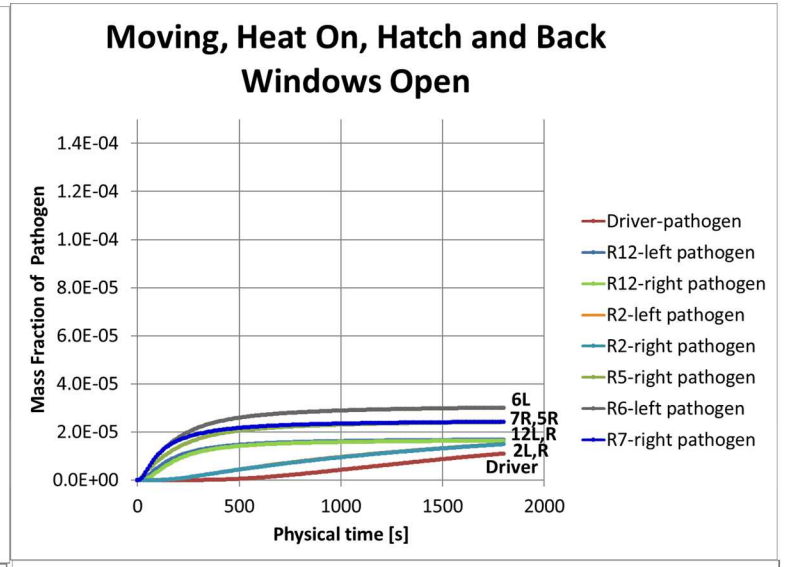


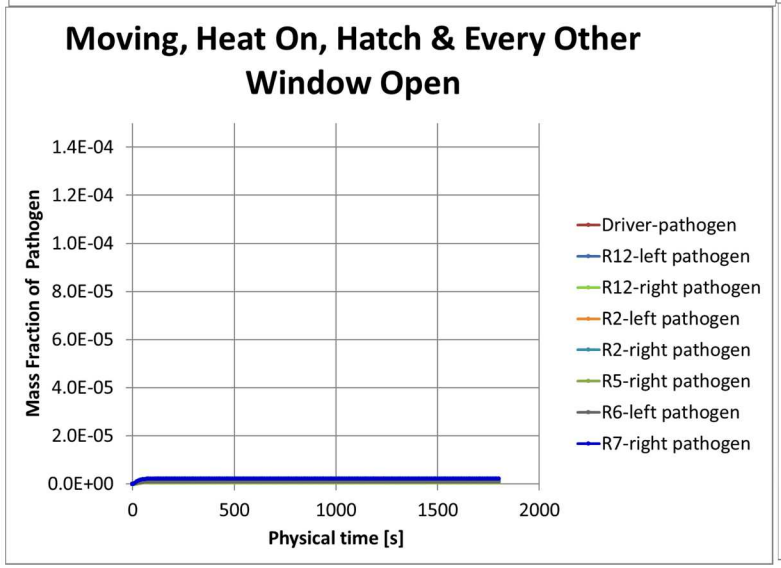


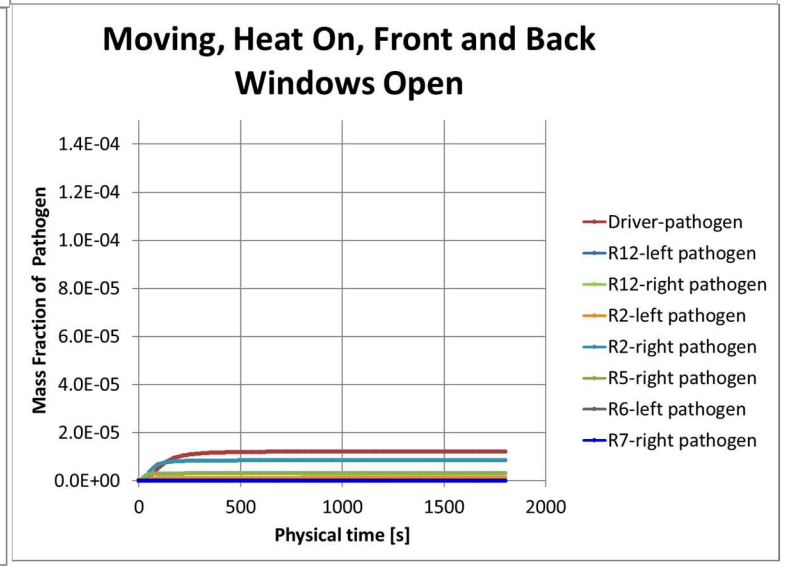
- If heater is on, an open door allows a once-through flow path for pathogens, reducing concentrations
- If heater is off, a closed bus isolates plume near the source, but concentrations increase more rapidly later on (after 15 – 30 min)

Pathogen Mass Fraction – Moving Bus



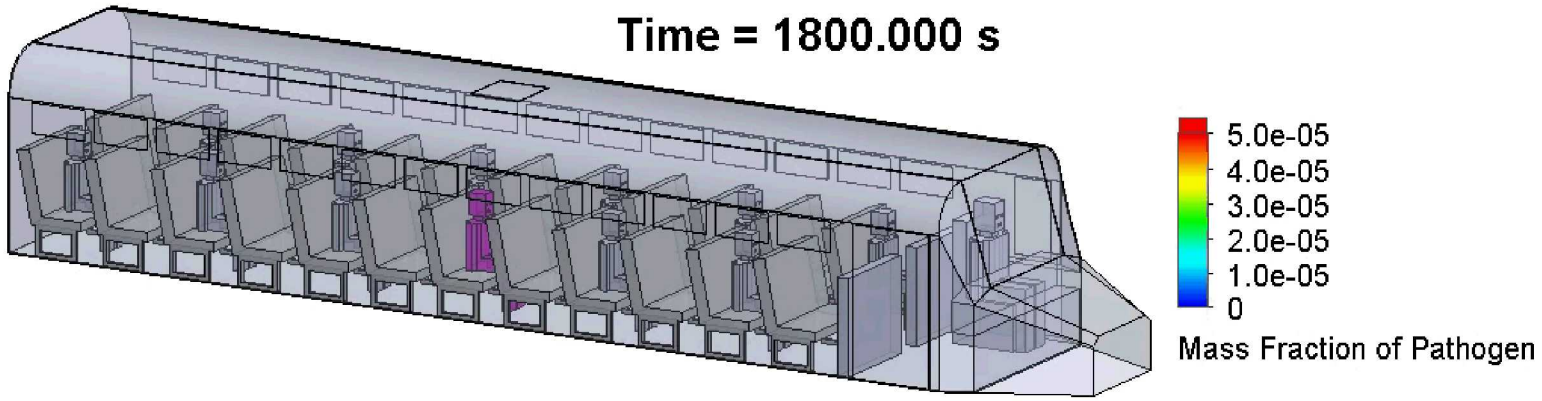


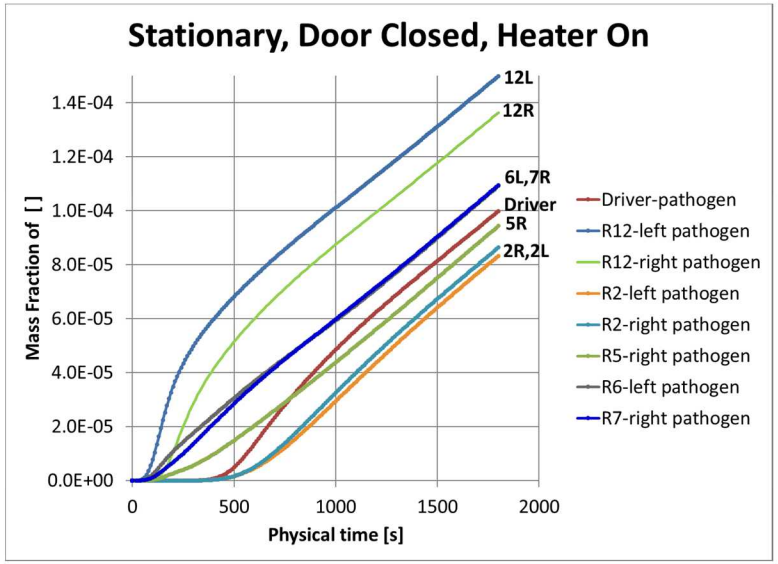


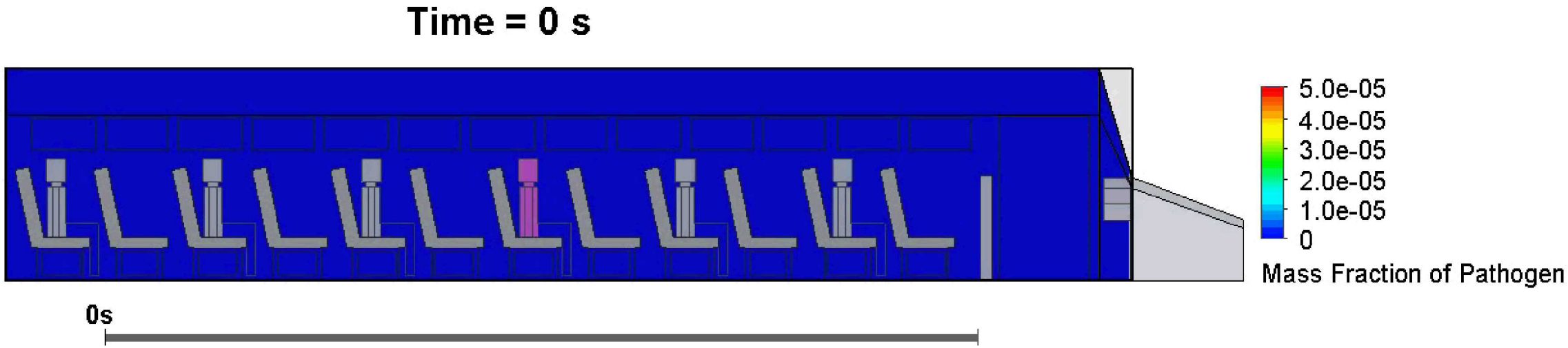


- While moving, having just the hatch open increases pathogen concentrations; need at least two openings for once-through flow

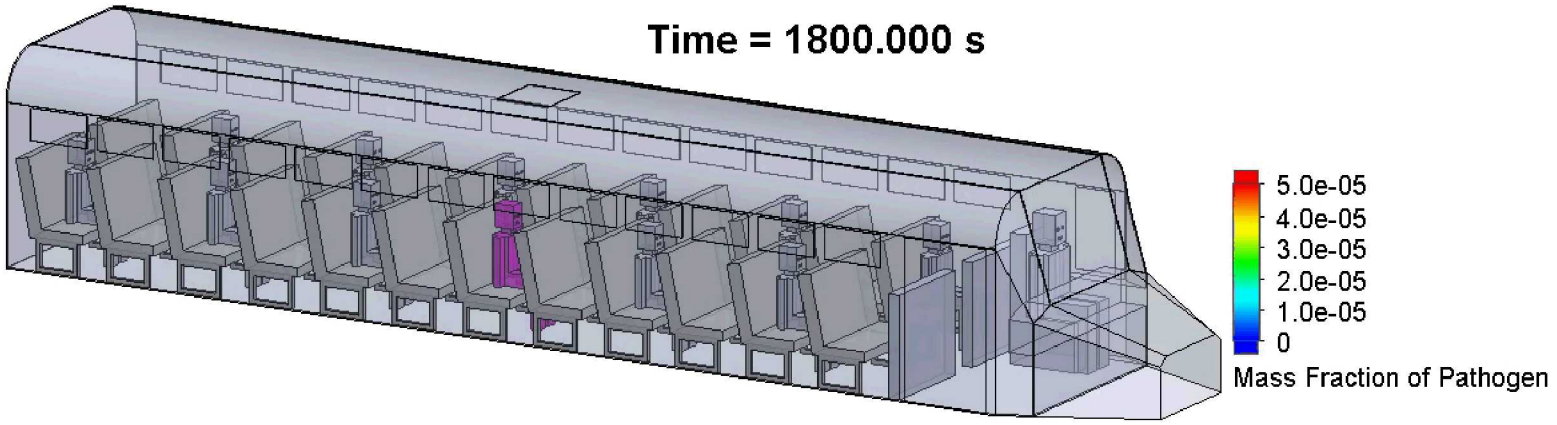
Stationary Bus – Heater On, Door Closed

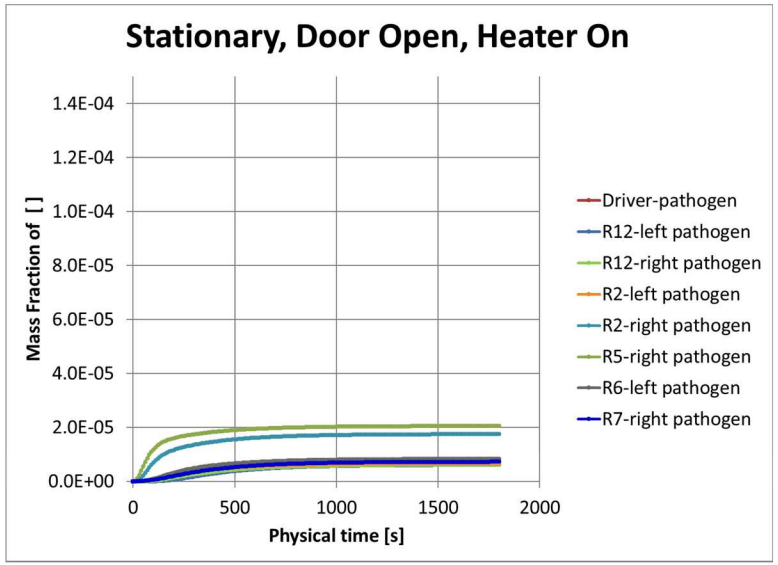


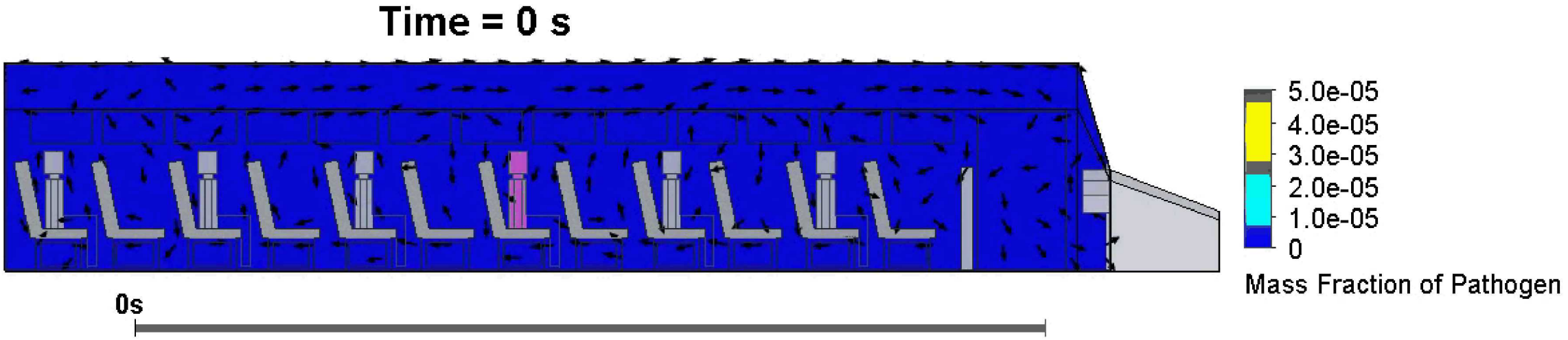




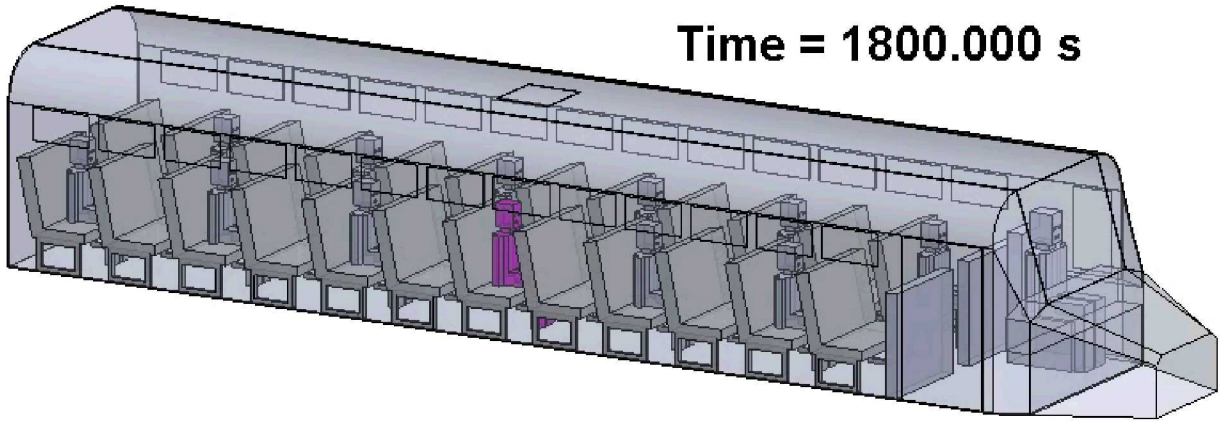
Stationary Bus – Heater On, Door Open

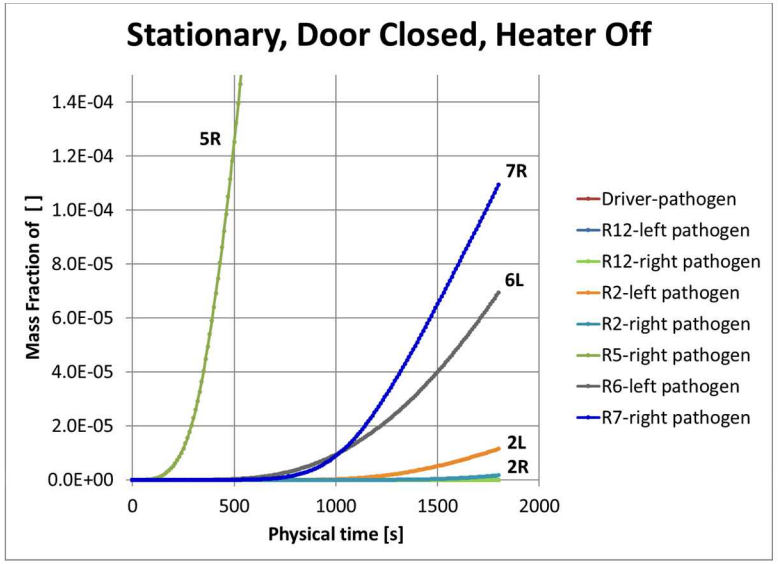


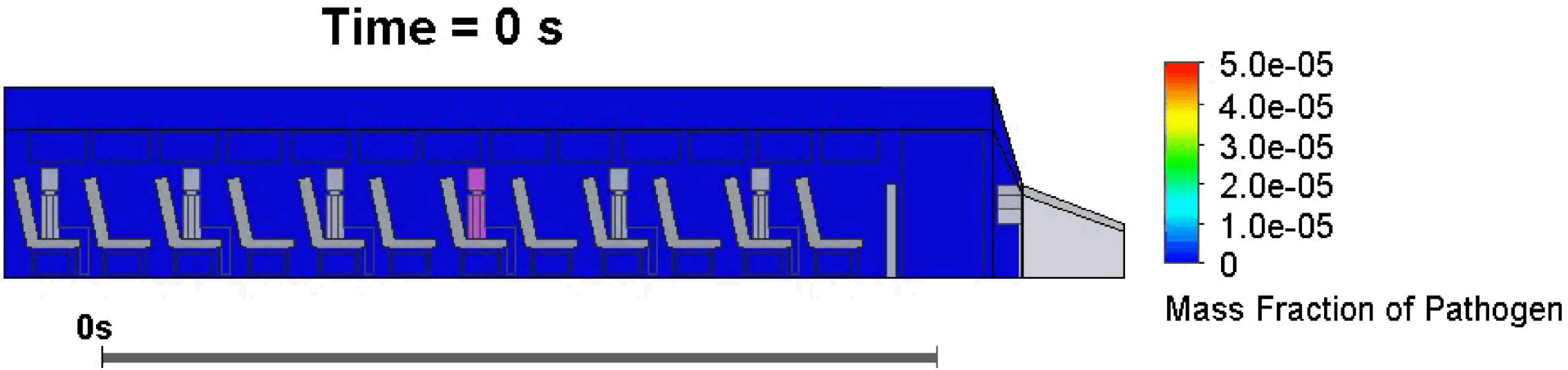




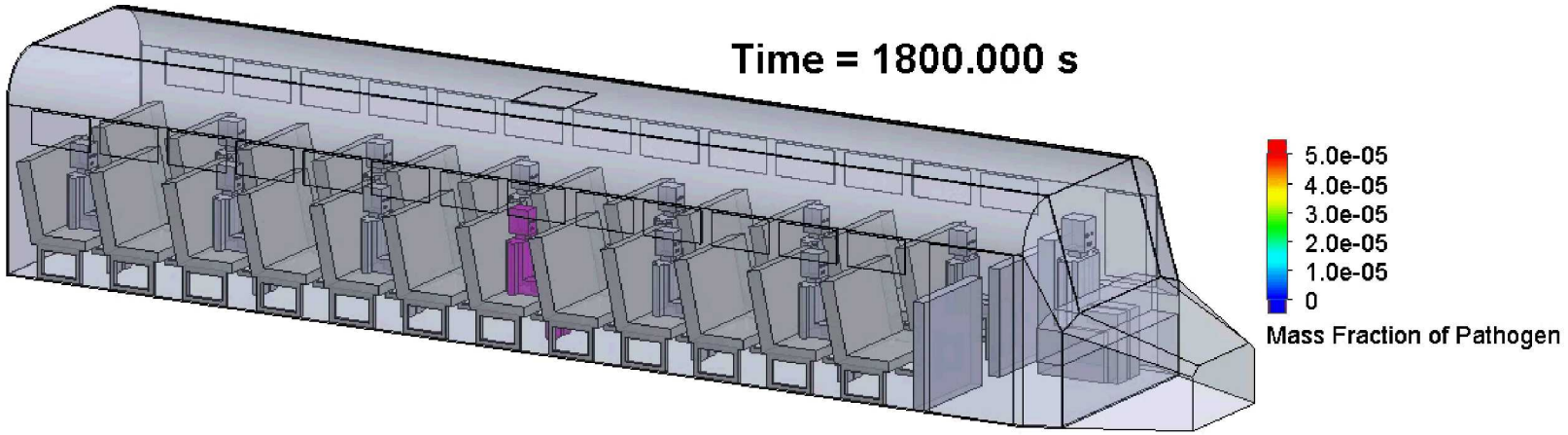
Stationary Bus – Heater Off, Door Closed

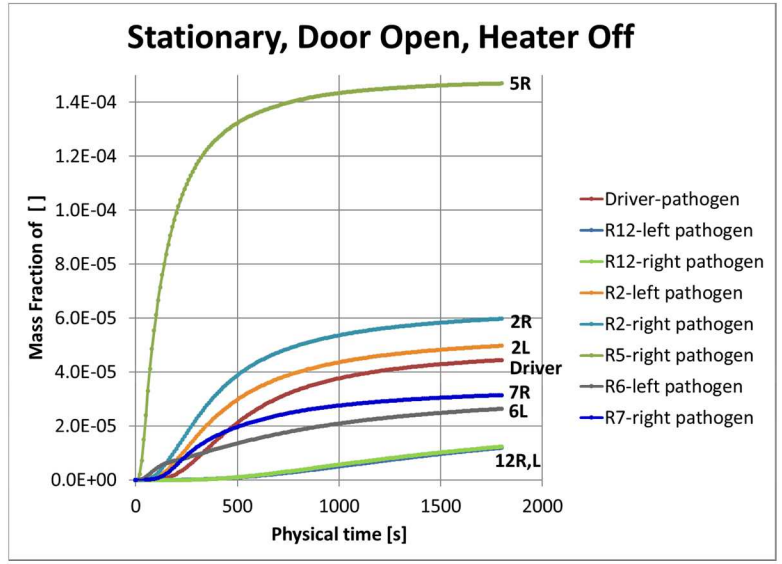


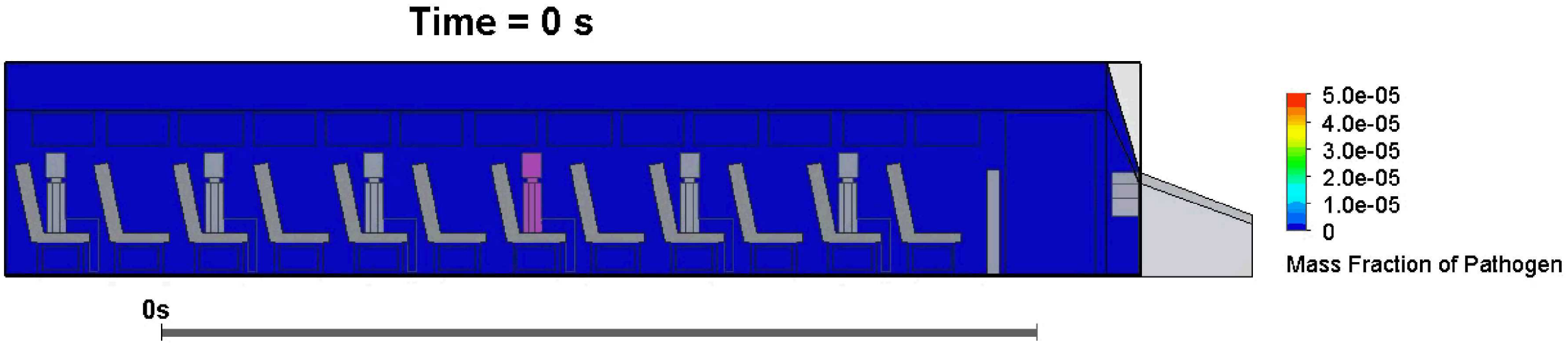




Stationary Bus – Heater Off, Door Open

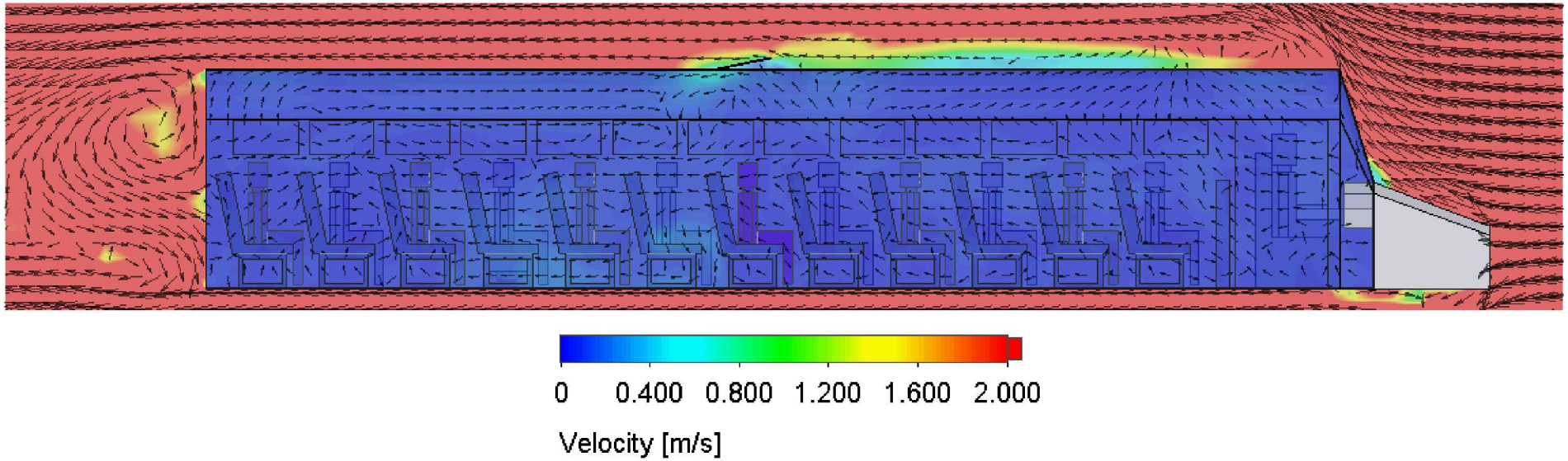




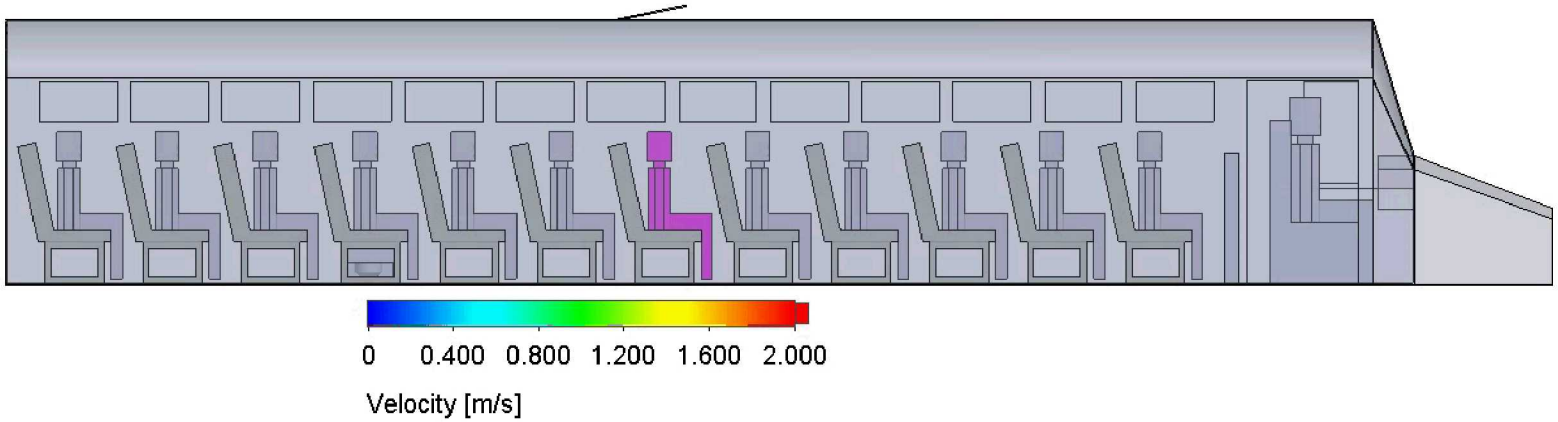


Moving Bus – Hatch Open

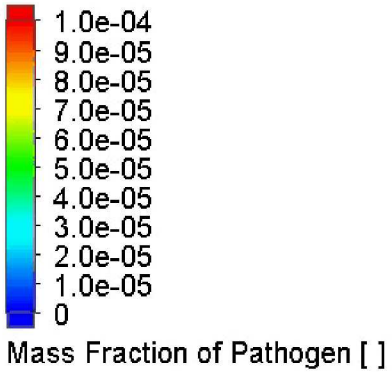
Time = 1800.000 s

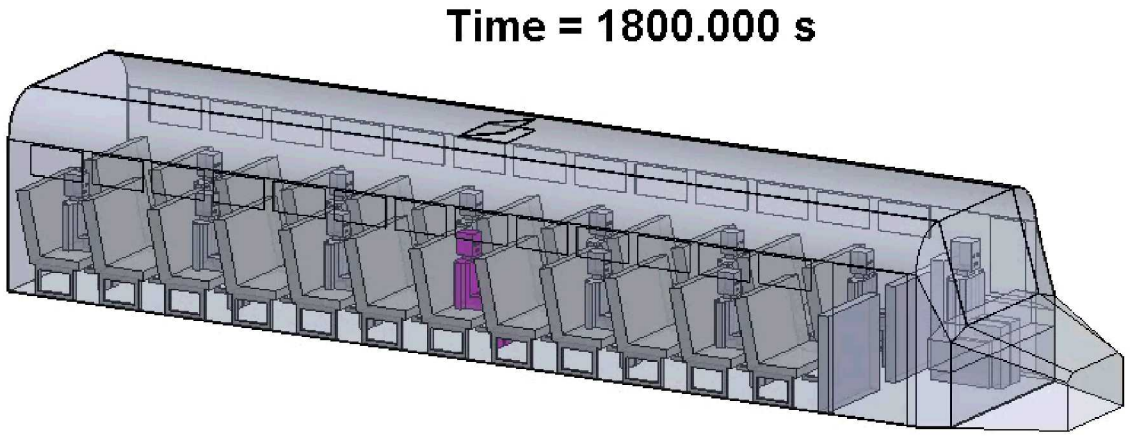


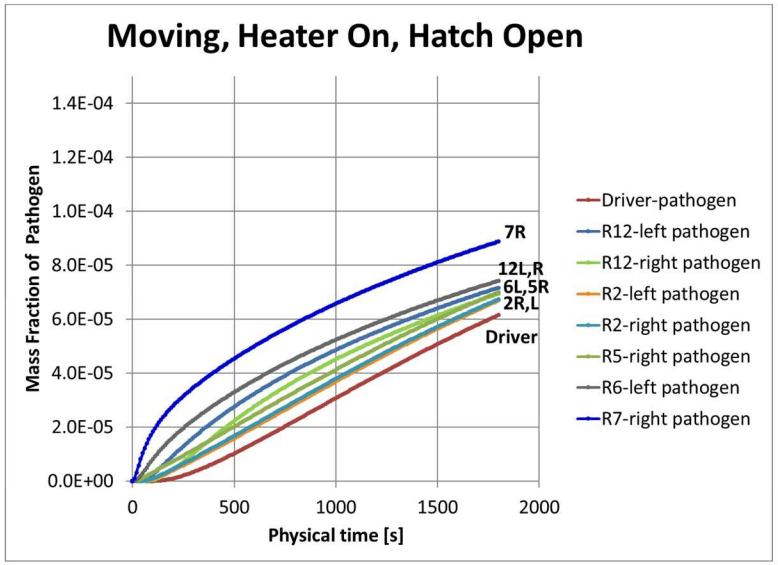
Time = 1800.000 s

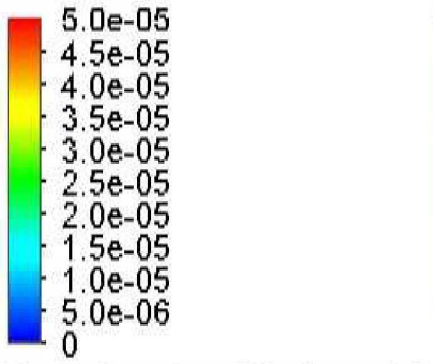


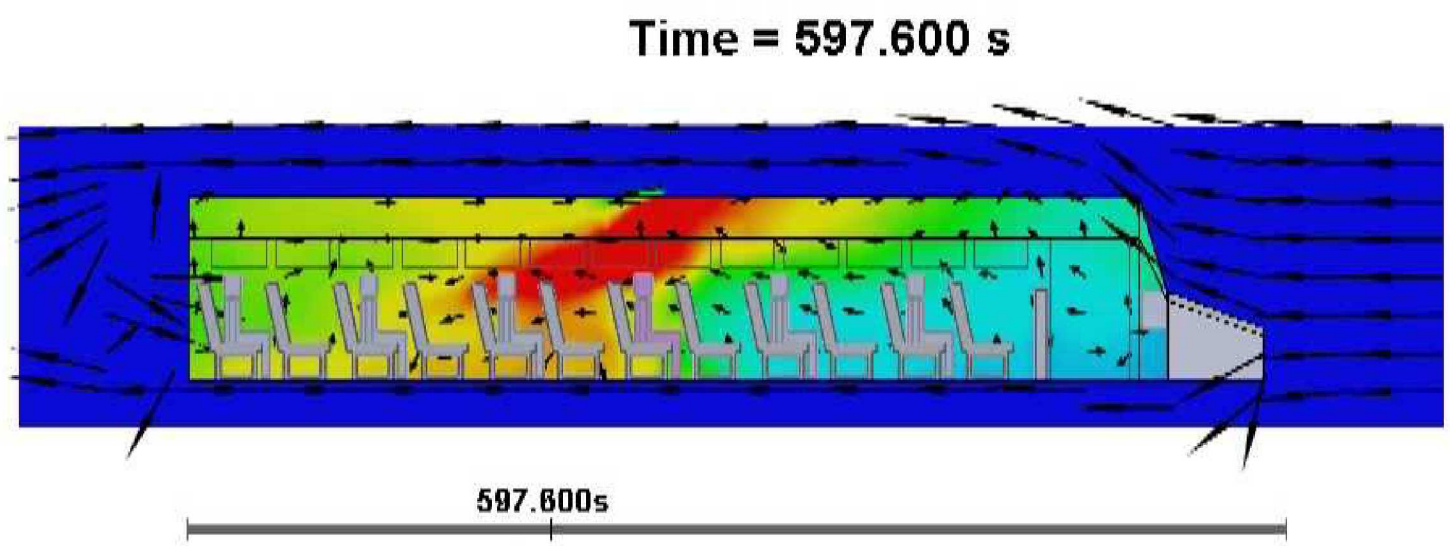
Moving Bus – Hatch Open



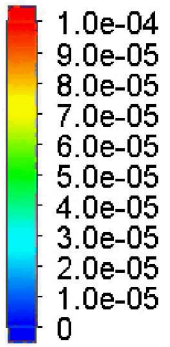


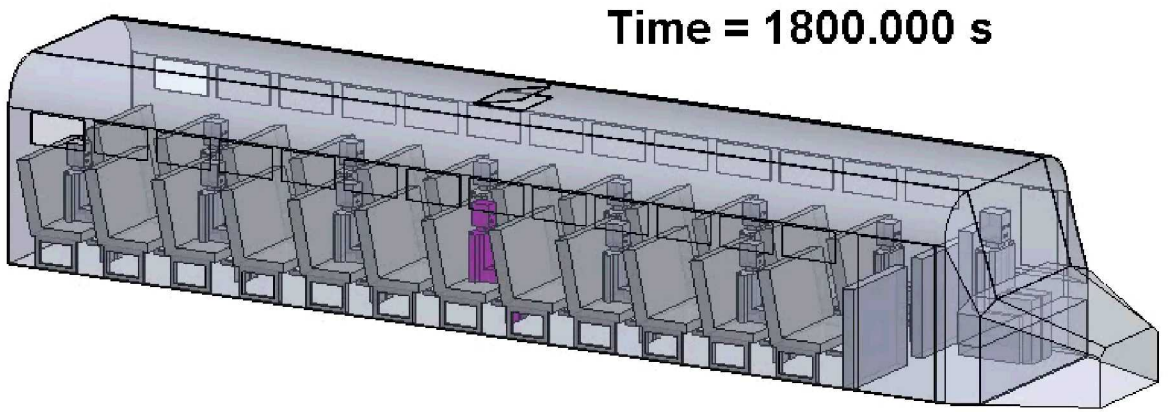


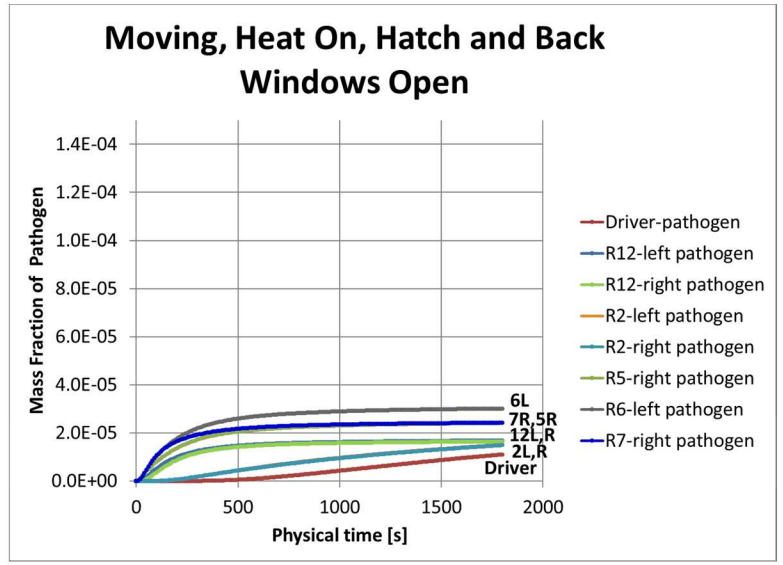


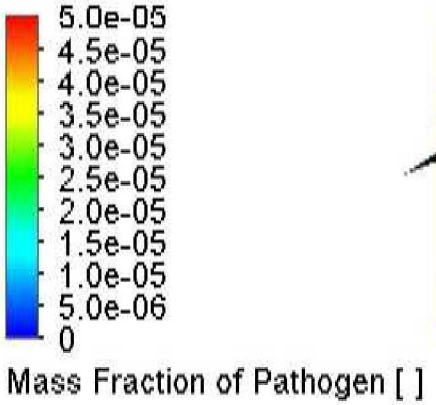


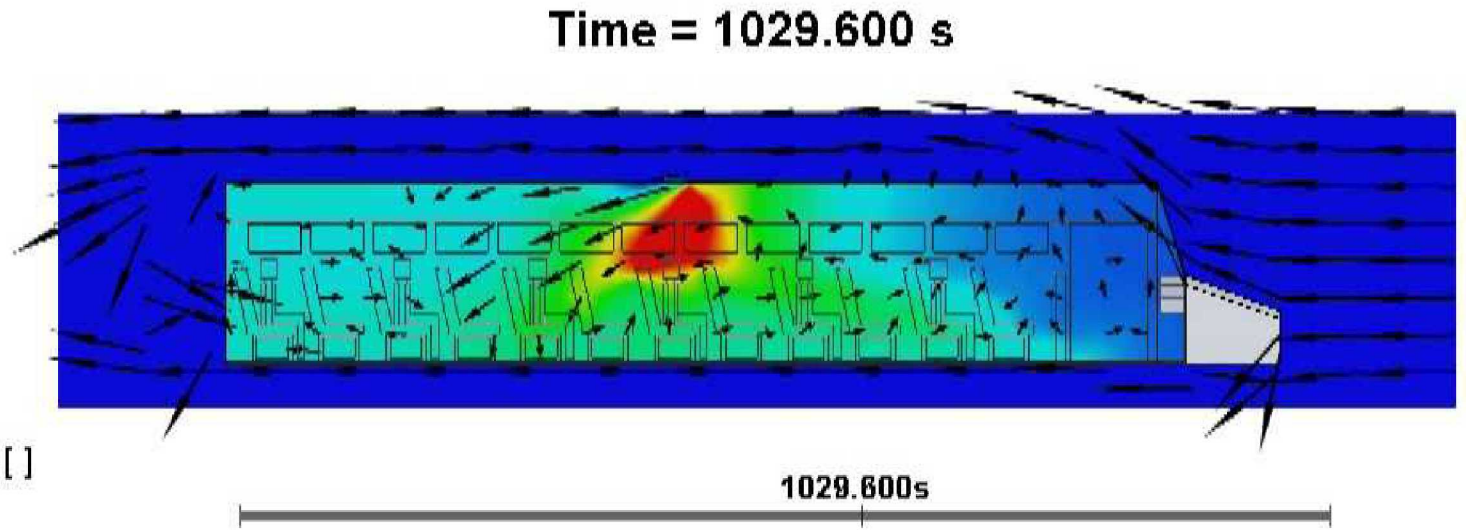
Moving Bus – Hatch and Back Windows Open



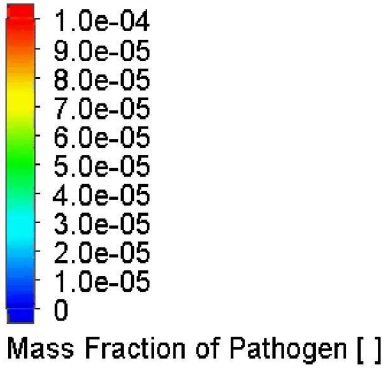


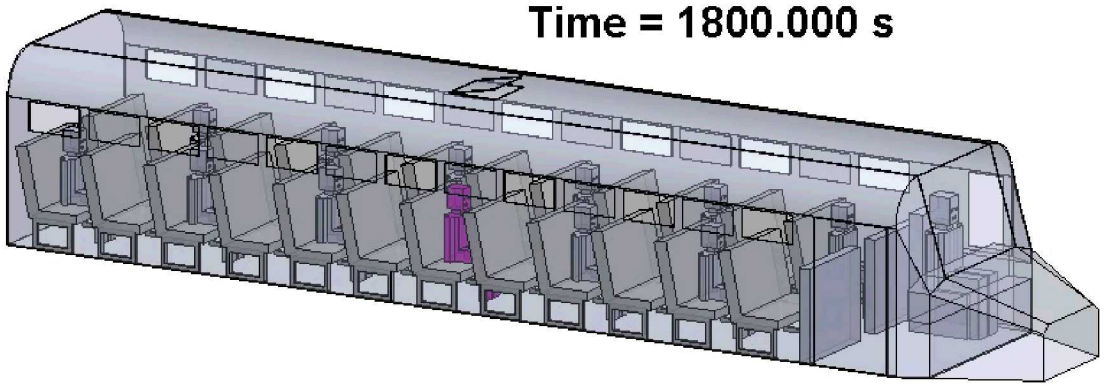


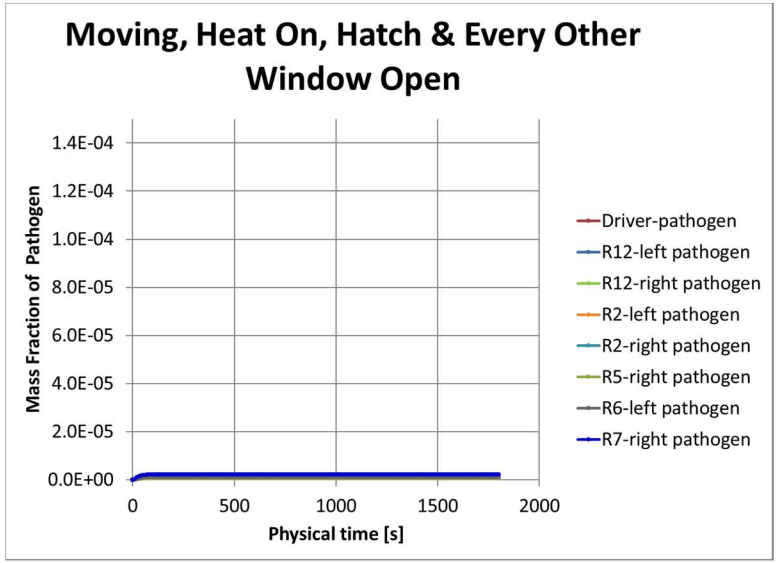


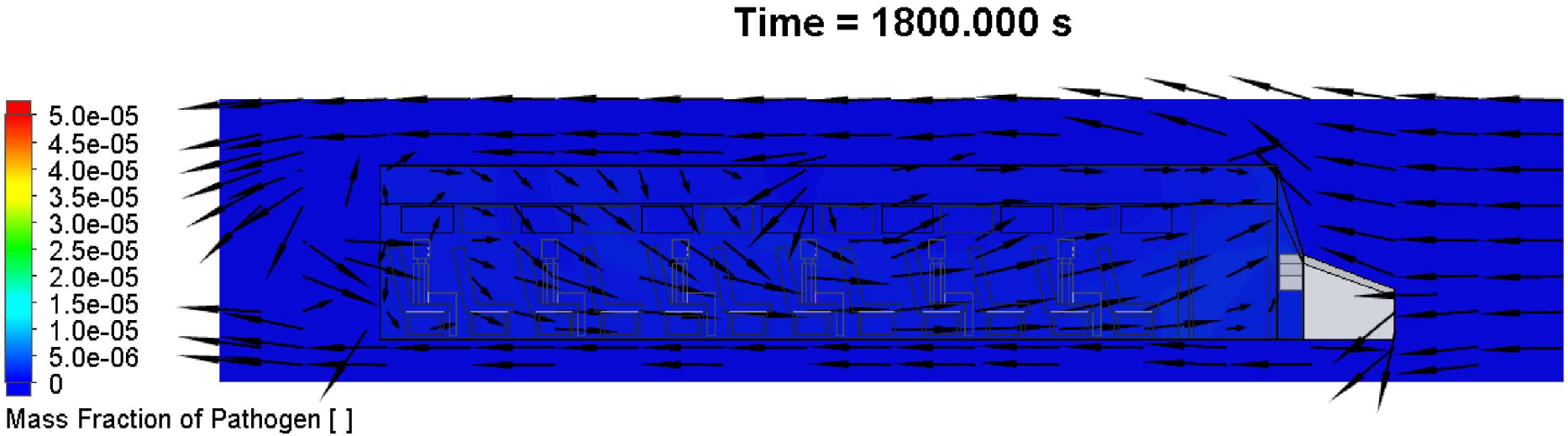


Moving Bus – Hatch and Every Other Window Open

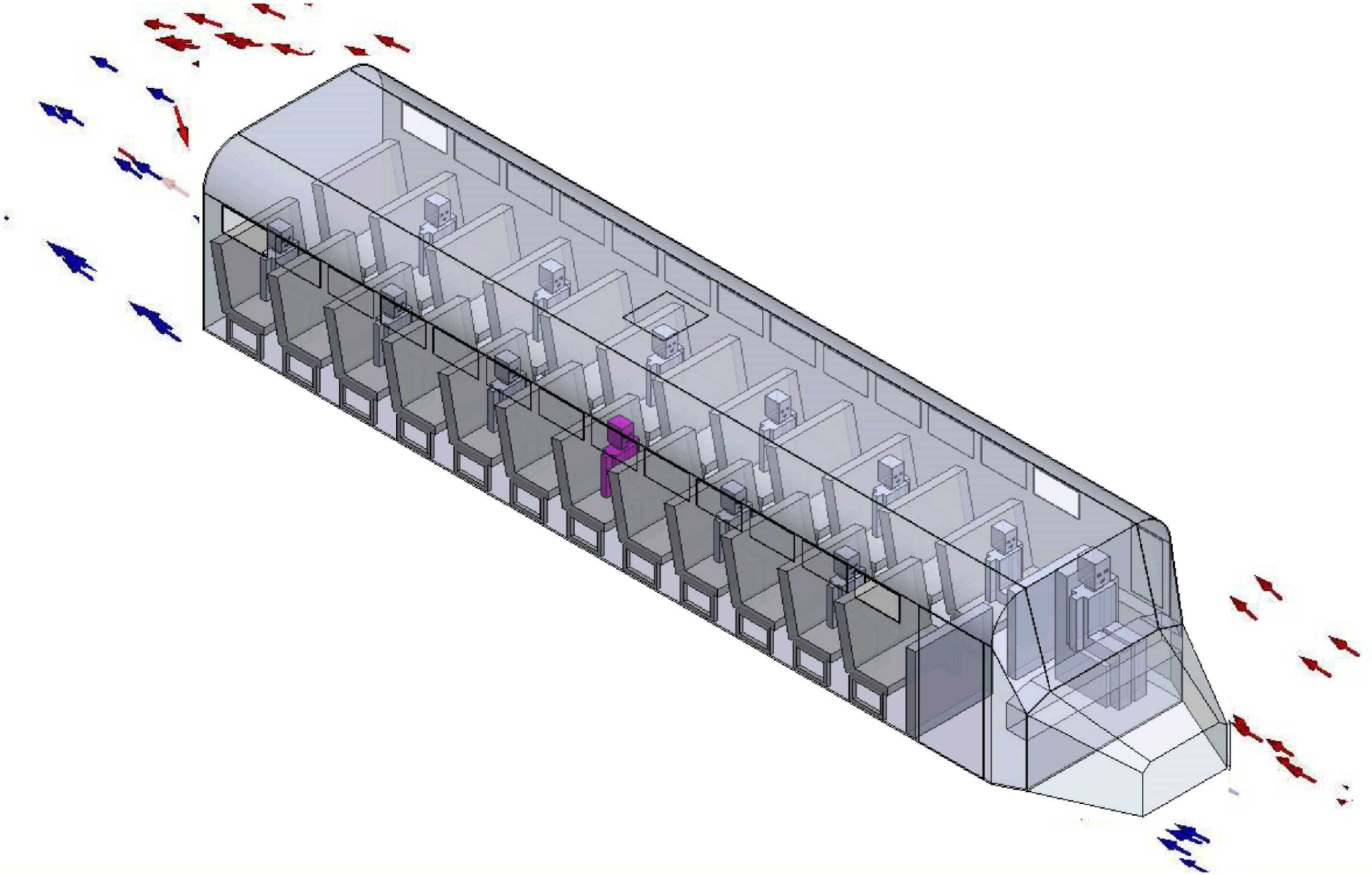




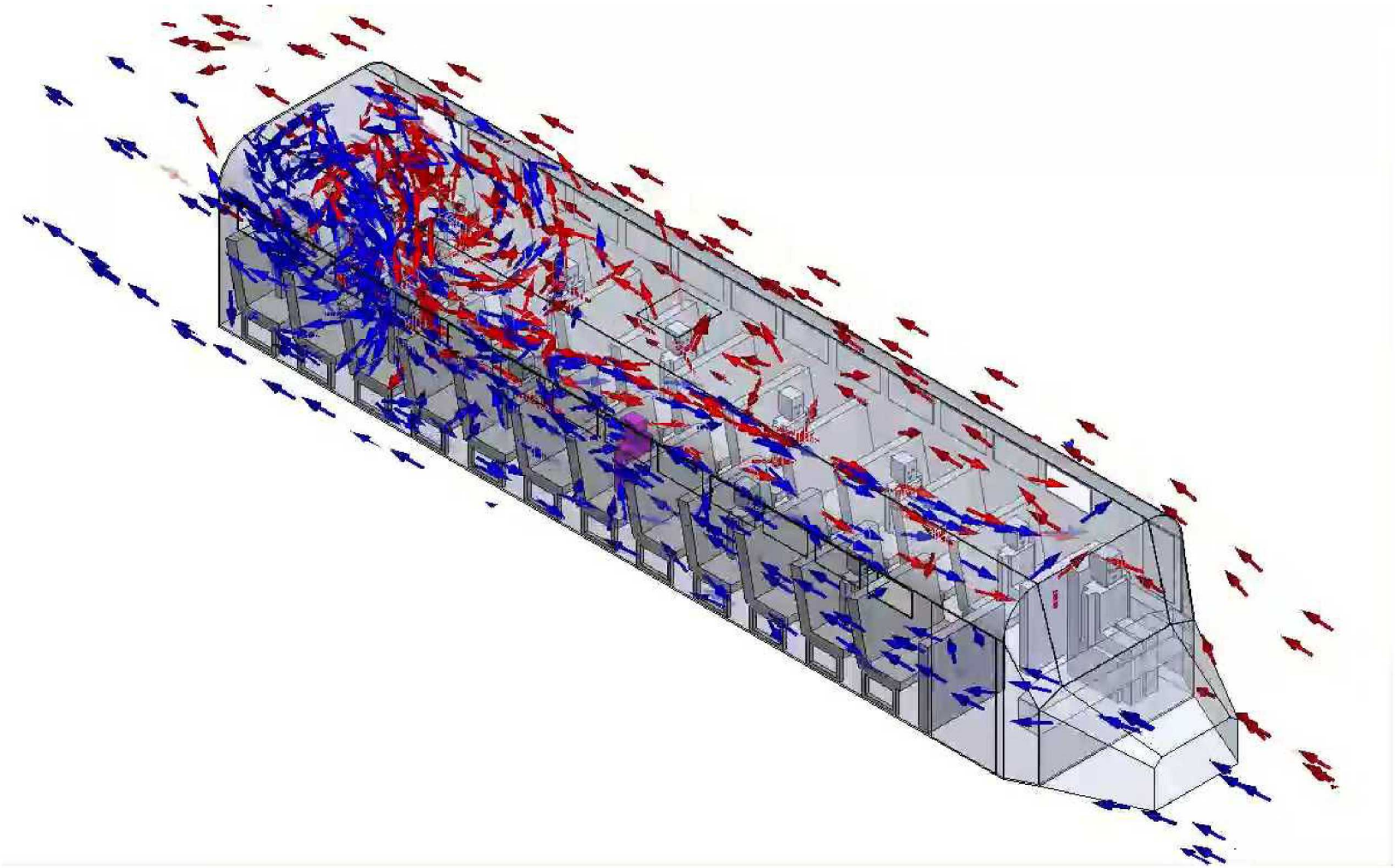




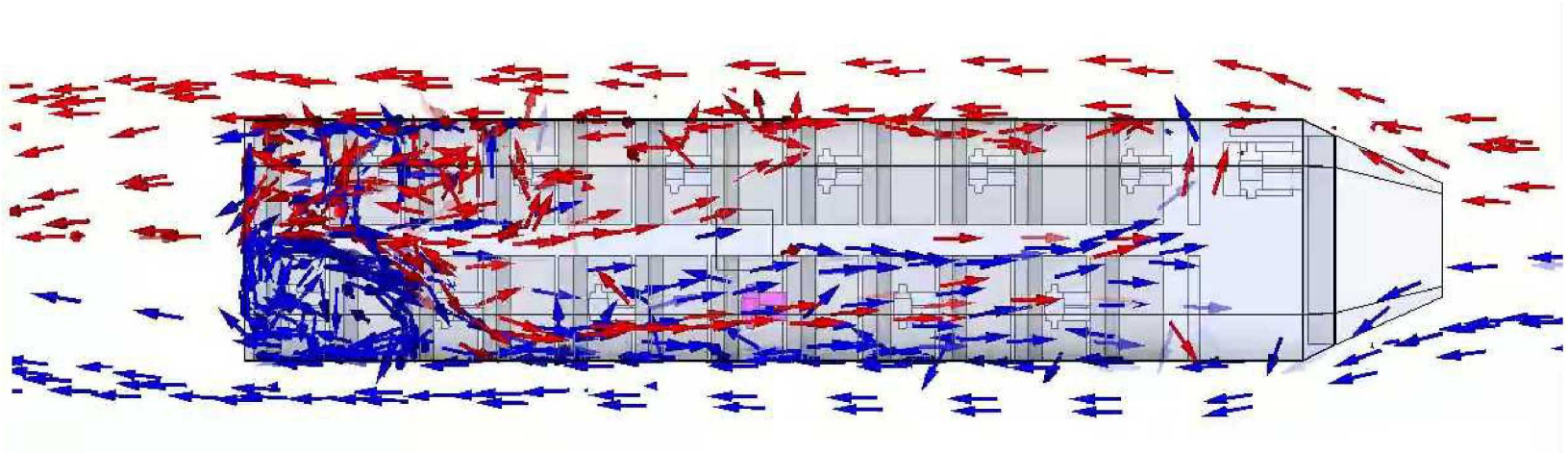
Moving Bus – Front and Back Windows Open

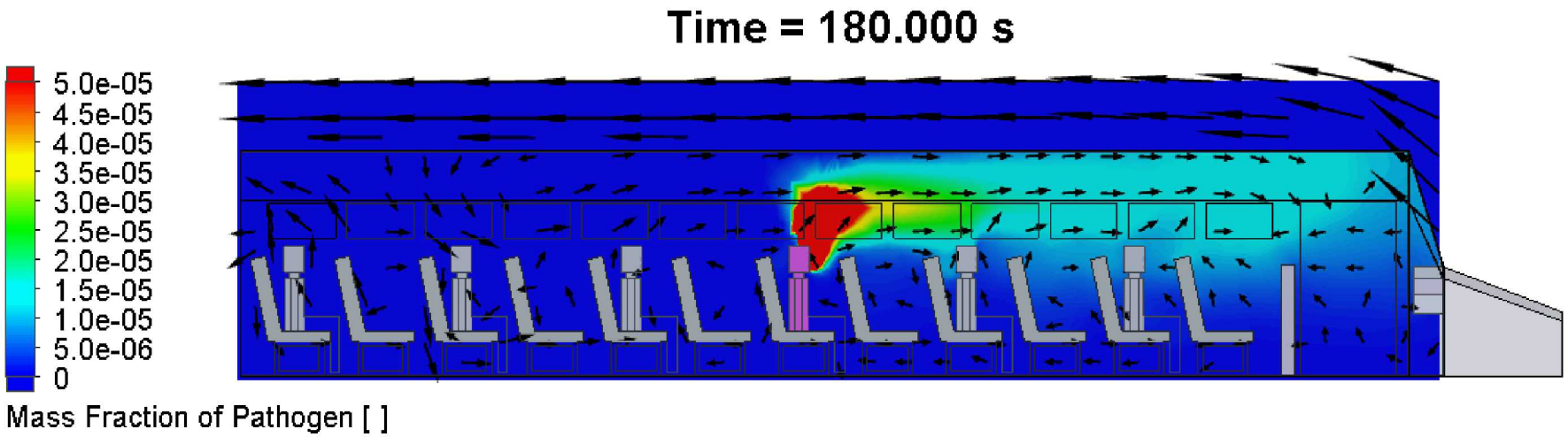


Moving Bus – Front and Back Windows Open



Moving Bus – Front and Back Windows Open





Findings and Next Steps

Findings

- CFD model was able to provide reasonable matches with measured temperature and velocity measurements in 72-passenger bus while heater was on
- CFD model was used to simulate alternative bus scenarios (stationary/moving, different window/hatch/door openings)
  - Opening just the emergency hatch (in the roof of the bus) as suggested by APS is NOT recommended
  - Need at least two sets of openings to maximize through-flow conditions and minimize concentrations and exposure

Next Steps

- Perform simulations of exposure risks for additional ventilation scenarios
  - Infected source location
    - Front, middle, back
- Repeat analysis for smaller bus with A/C?
- If modeling warrants, perform aerosol or tracer testing in stationary and moving buses