MODELING THE EFFECT OF VENTILATION ON FIRE-INDUCED ENVIRONMENT IN A LARGE-SCALE RESIDENTIAL STRUCTURE

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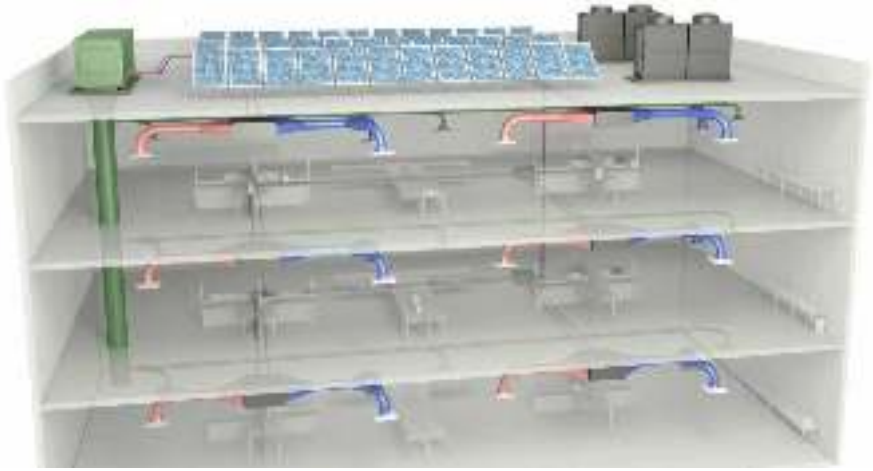
Background and motivation

- Smoke inhalation was found to be leading cause of fire-related deaths between 2017 and 2019 in the U.S.[1]
- HVAC network may impact transport of combustion products [2-4]
  - Modeling this behavior accurately important for performance-based design solutions
- FDS couples CFD solver with coupled-hybrid HVAC model[3]
  - Few validation studies investigated the capability of FDS to predict pressure development [4]
  - Further validation of the model is necessary, especially for large-scale structure



https://www.youtube.com/watch?v=BTDpIZ3I2UM

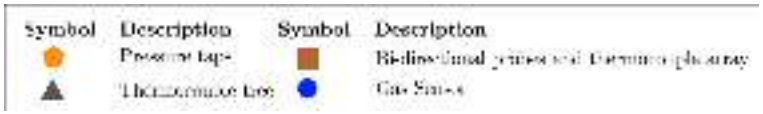
[1] USFA-FEMA. 2021. "Civilian Fire Fatalities in Residential Buildings (2017 - 2019)."
[2] Hostikka, Simo, Rahul Kallada Janardhan, Umar Riaz, and Topi Sikanen. FEMTC 2016.
[3] Ralph, Benjamin, Ricky Carvel, and Jason Floyd. 2019, https://doi.org/10.1080/19401493.2019.1608304.
[4] Ghanekar, Shruti, Craig Weinschenk, Gavin P. Horn, Keith Stakes, Richard M. Kesler, and Tonghun Lee. https://doi.org/10.1016/j.firesaf.2022.103534.

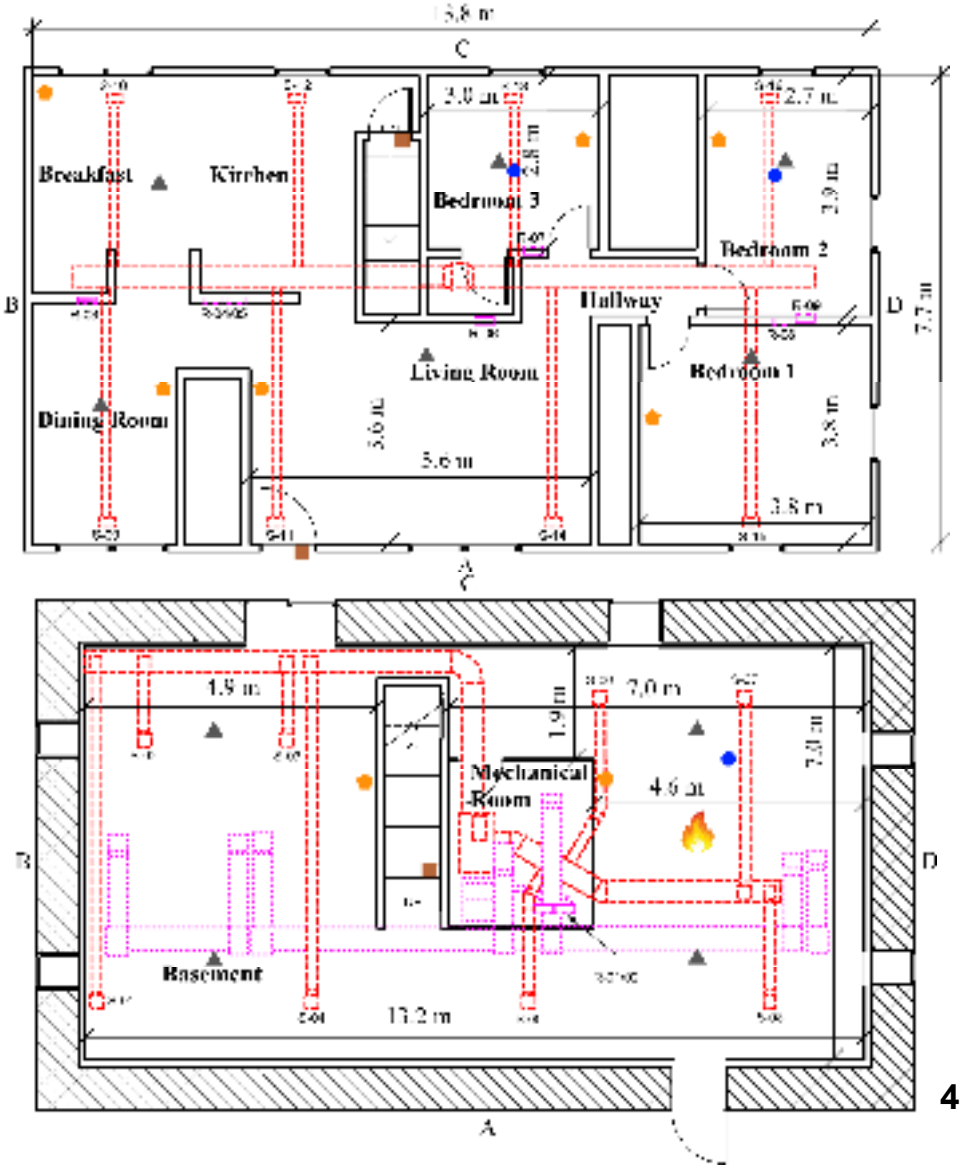
Objective

- Provide further validation of FDS
  - Use FDS to simulate previously conducted gas burner experiments in a purpose-built residential structure
- Discuss challenges and practical guidance for modeling of fire-scenario in an HVAC-equipped structure

Experimental setup

- Purpose-built, two-story, residential structure in Delaware County Services Training Center, Pennsylvania
- 29 Experiments conducted with fires in bedroom 1, living-room, or basement
- HVAC status (on vs off) and door position (open vs closed) changed one at a time in the experiments
- Four basement fire experiments selected for this study

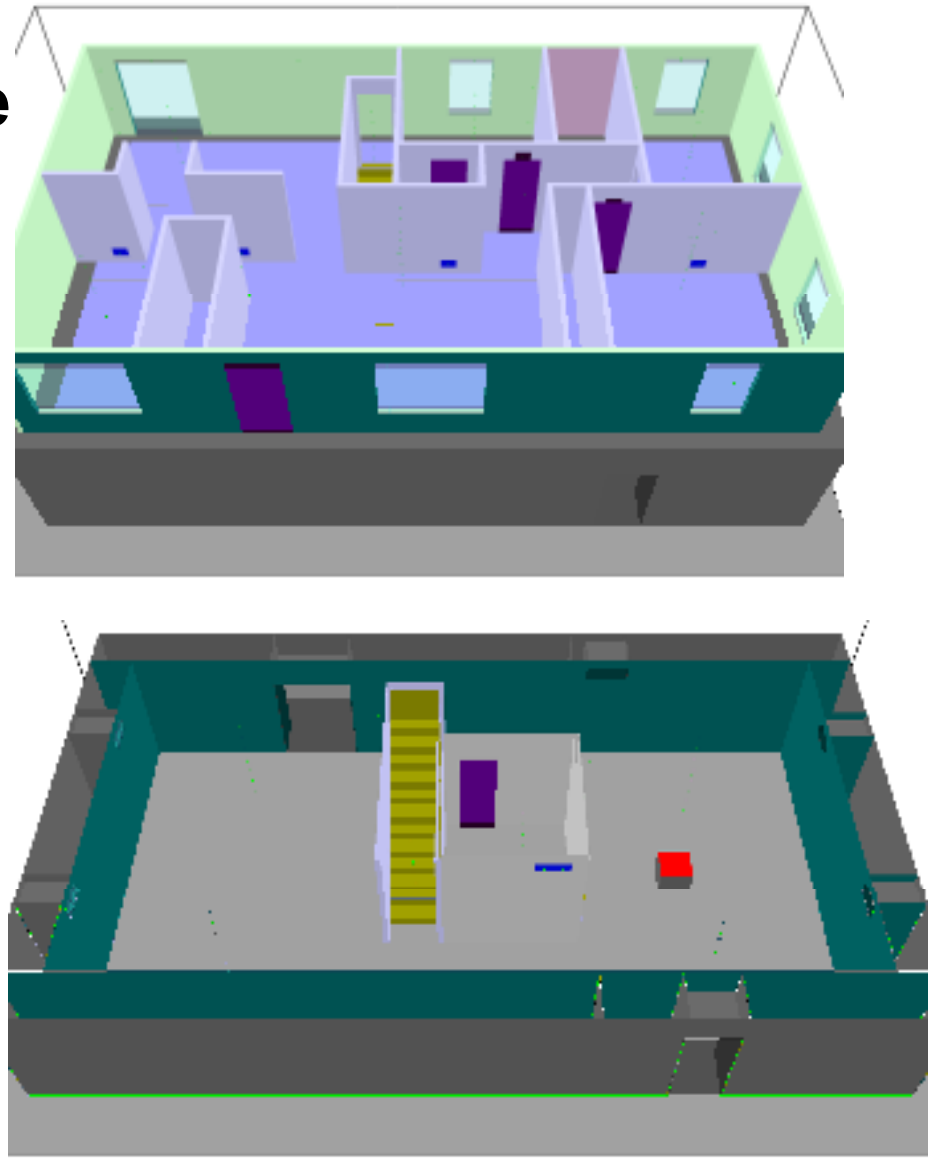




Simulation setup – Structure

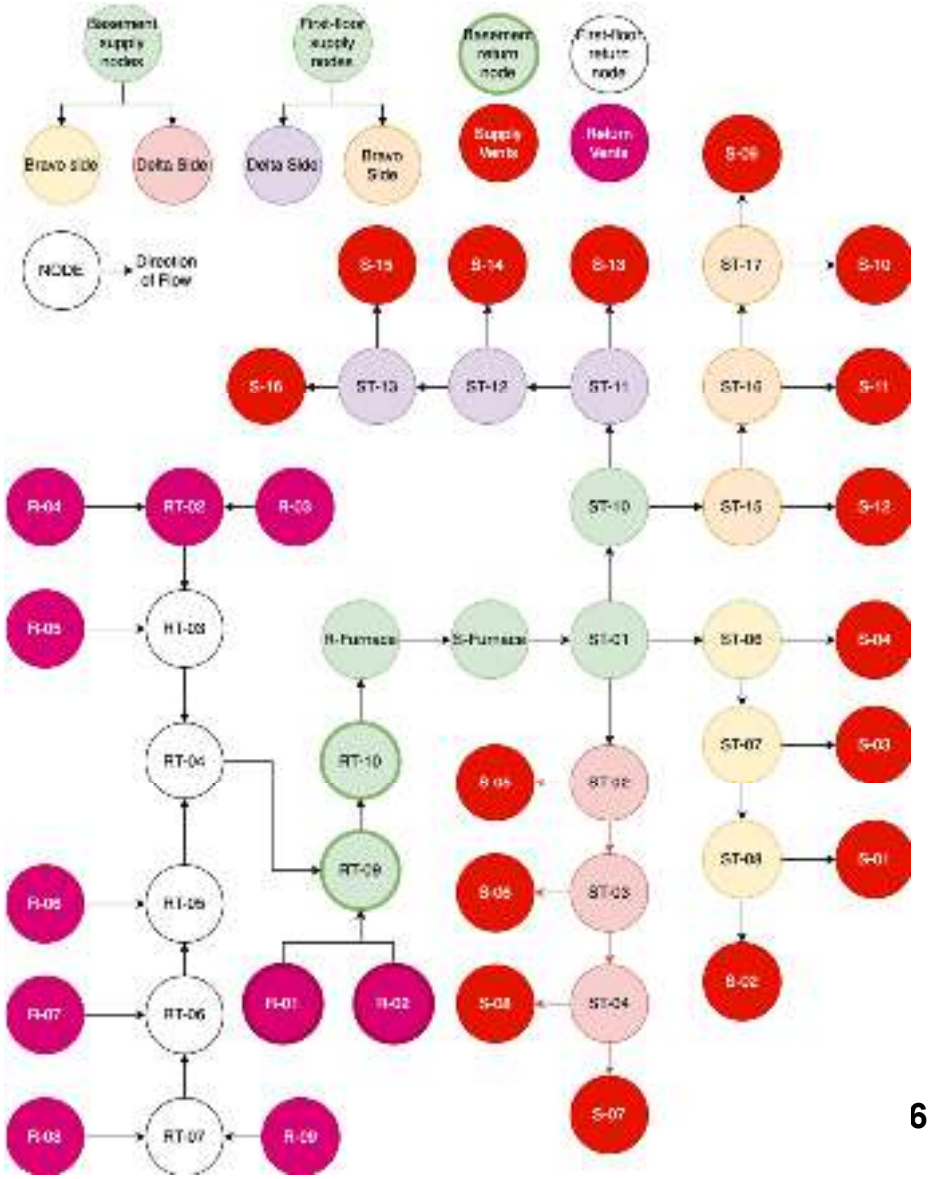
Experiment label	HRR (kW)	HVAC status	Stairwell Door position	Test #
Ba1	300	Off	Open	23
Ba2	300	On	Open	24
Ba3	300	Off	Closed	25
Ba4	300	On	Closed	26

- Structure built to closely follow the built environment with the assistance of Pyrosim
- 10 cm cell size was selected for all simulations

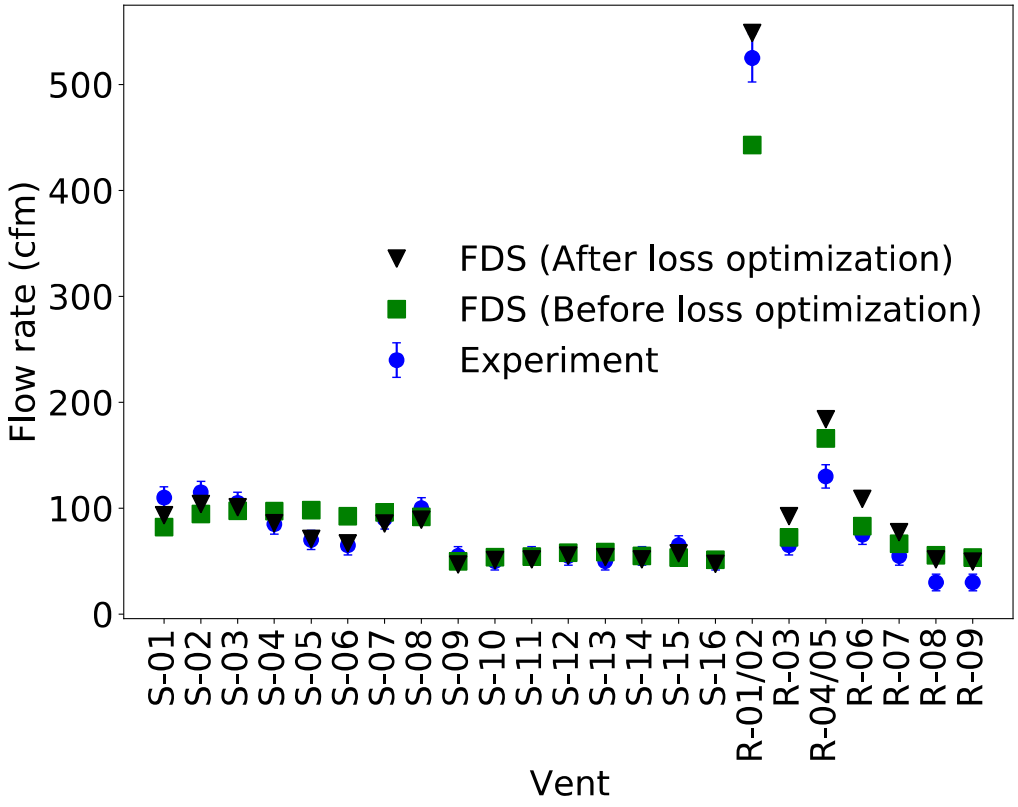


Simulation setup – HVAC

- HVAC duct network built by defining vents, nodes, and ducts connecting the nodes
- Loss coefficient initialized using ASHRAE Fundamentals' Handbook
- Measured vent flow rates (cold-flow) were used as target to optimize loss coefficients in the simulation
- Equivalent leakage area of 0.137 m^2 (found in accordance with ASTM E 779) was distributed on first floor and basement using either zone leakages or local leakages
- Leakage area was distributed according to fraction of leakage perimeter of each zone or local leak path (windows/door) respectively.



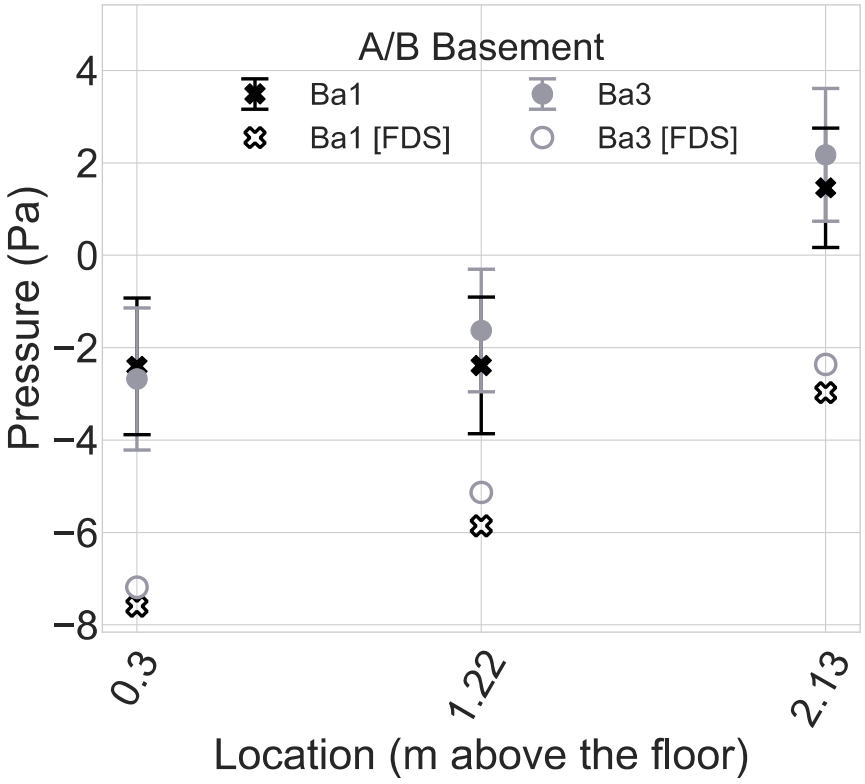
Simulation setup - HVAC network flow

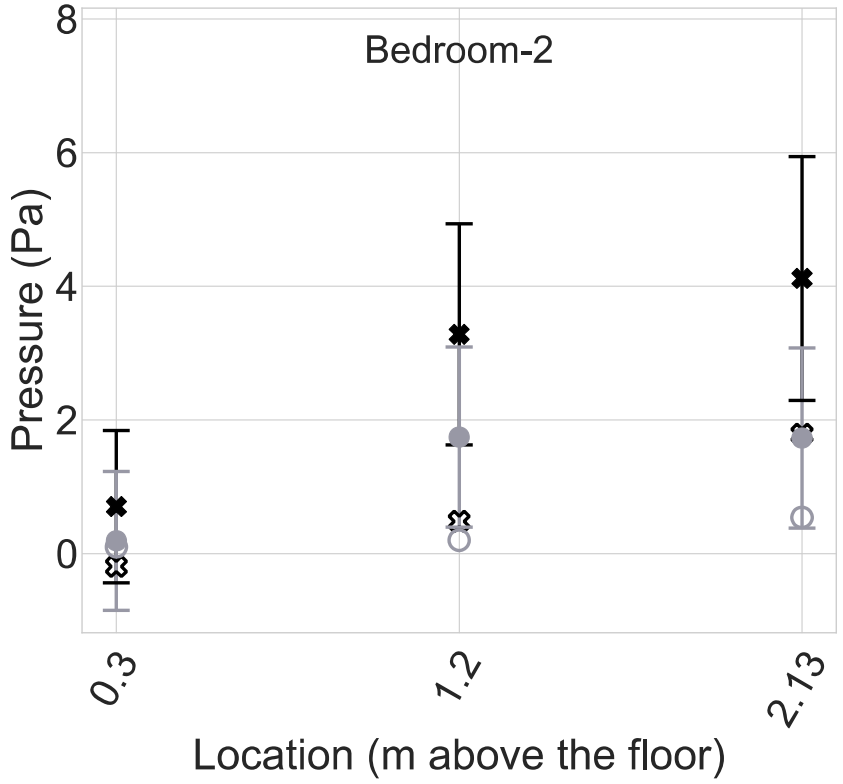


Results

Results – Pressure development

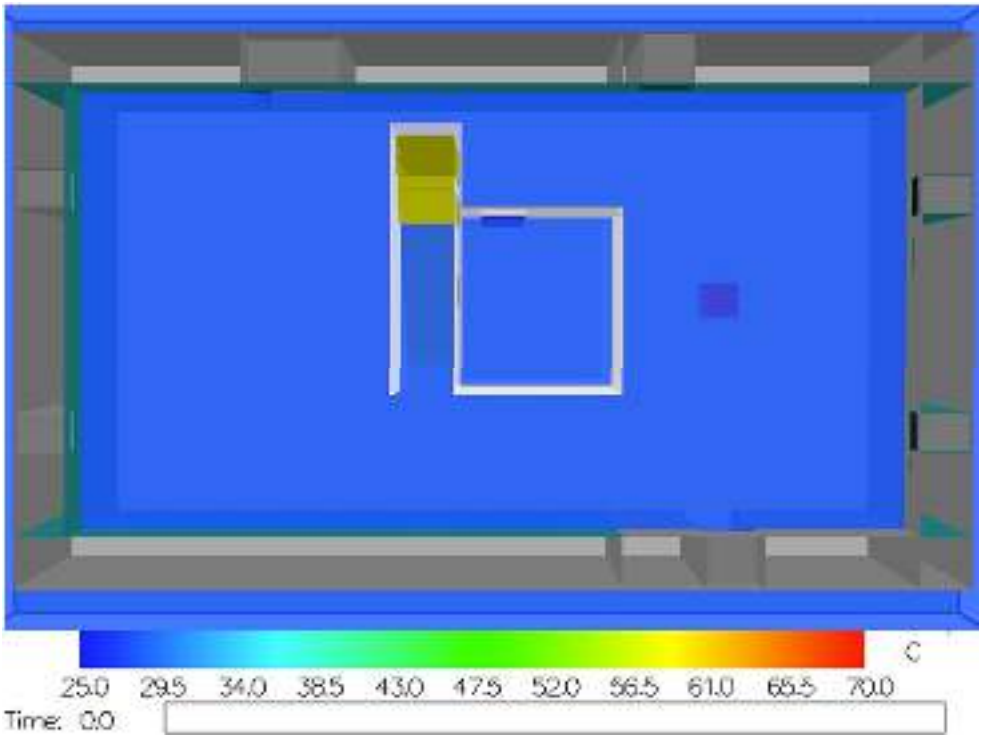
- Steady-state pressures - Using Local Leakage approach

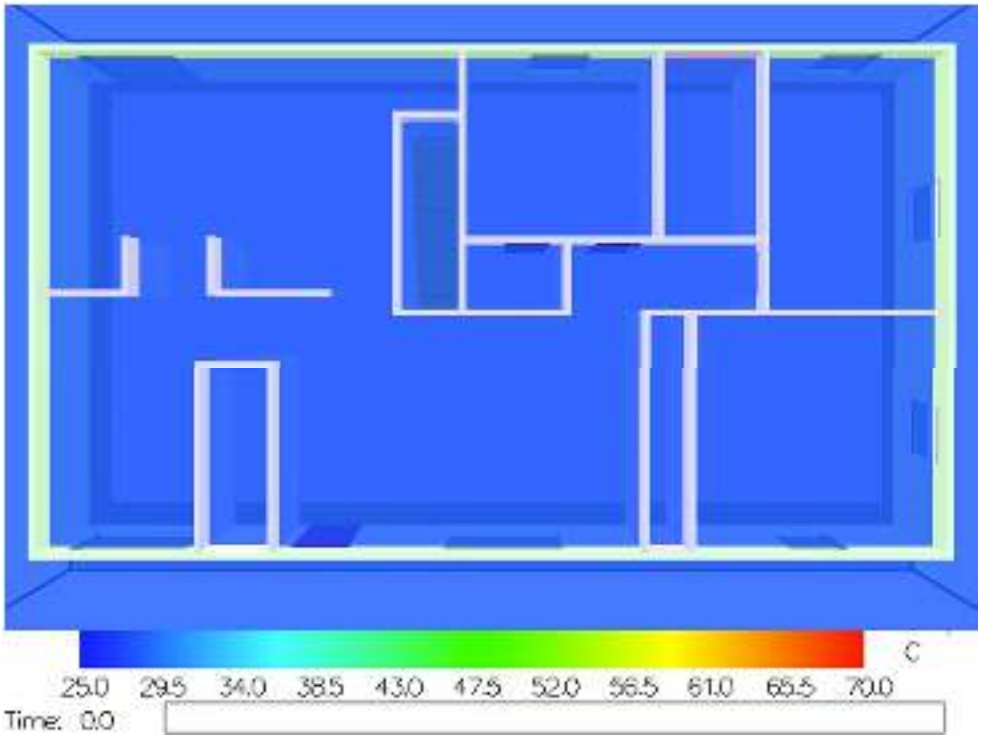




Results – Overview

- Test Ba2 (HVAC on, stairwell door open) simulation

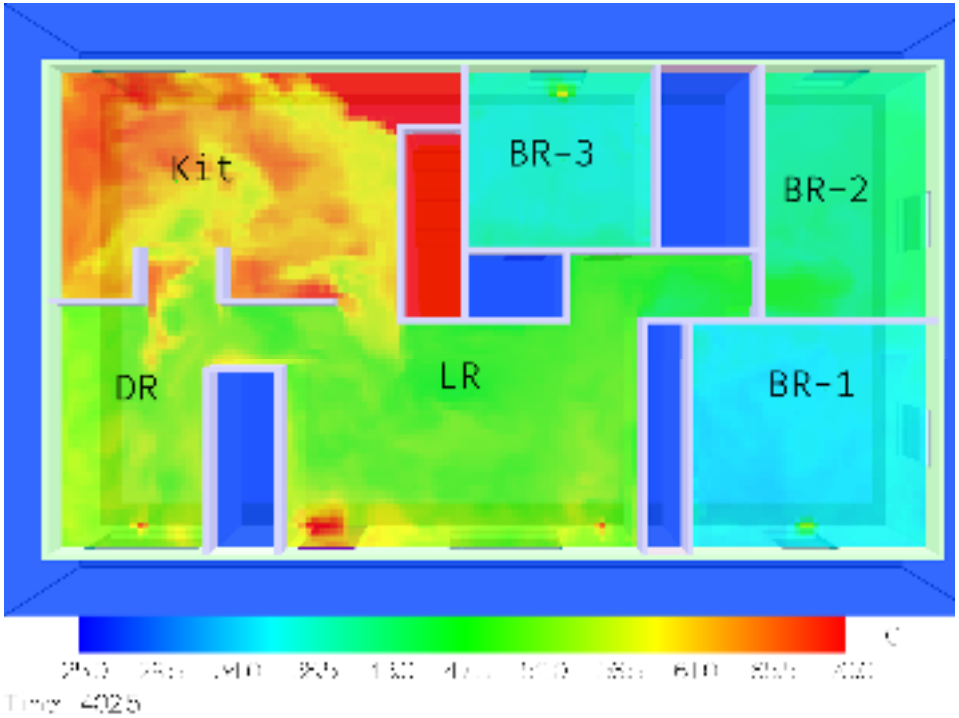




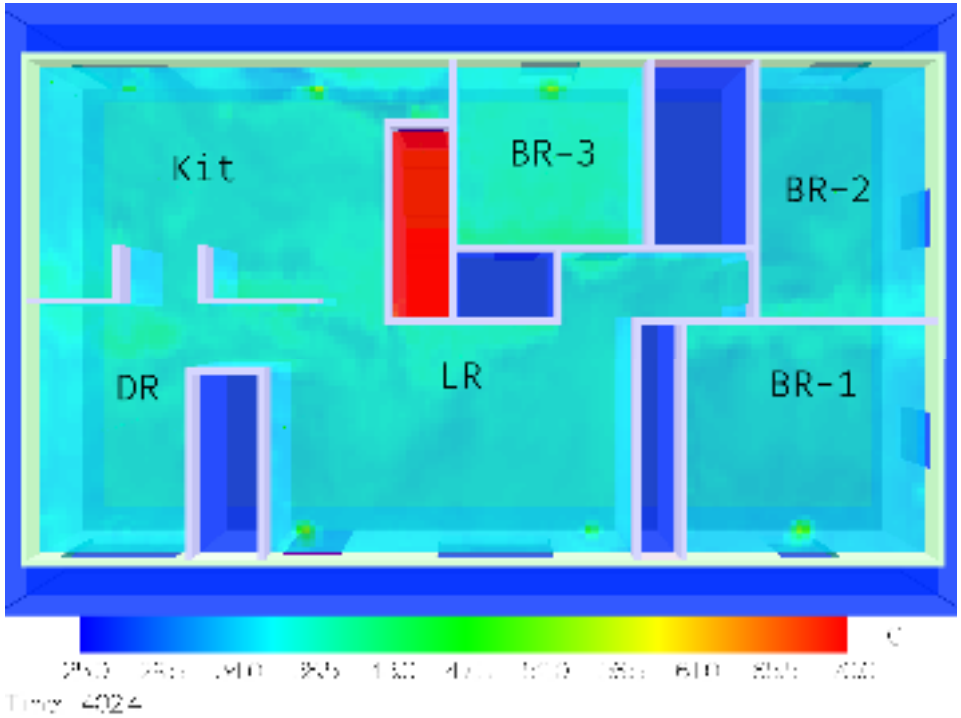
Temperature slices at about 1.8 m above the floor

Results – Overview

Test Ba2 (HVAC on, stairwell door open) simulation

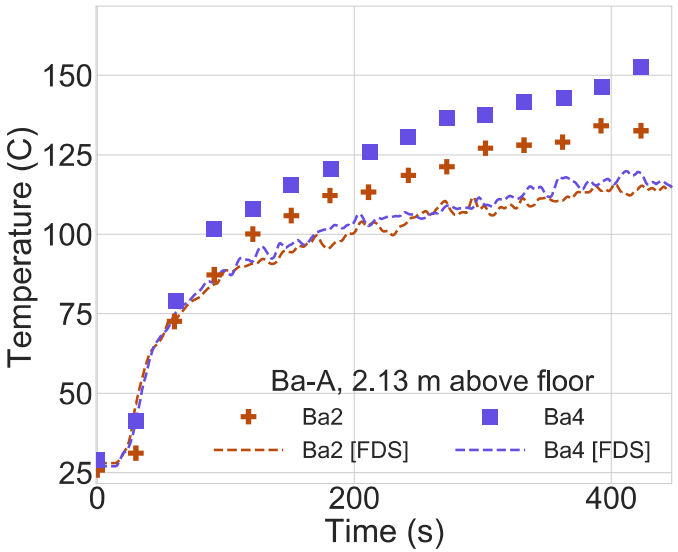


Test Ba4 (HVAC on, stairwell door closed) simulation

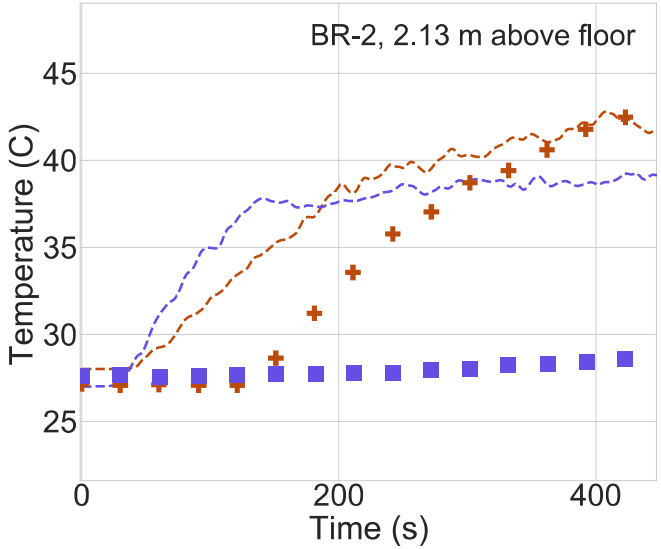


Results – Temperature prediction

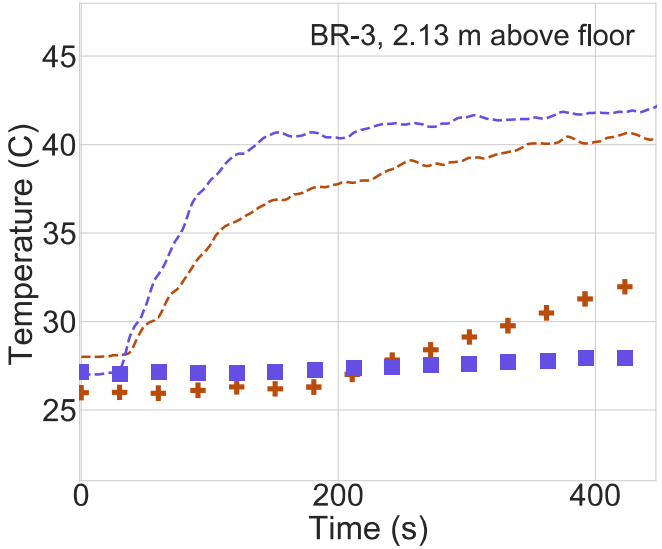
Fire – Room (Basement)



Open Bedroom

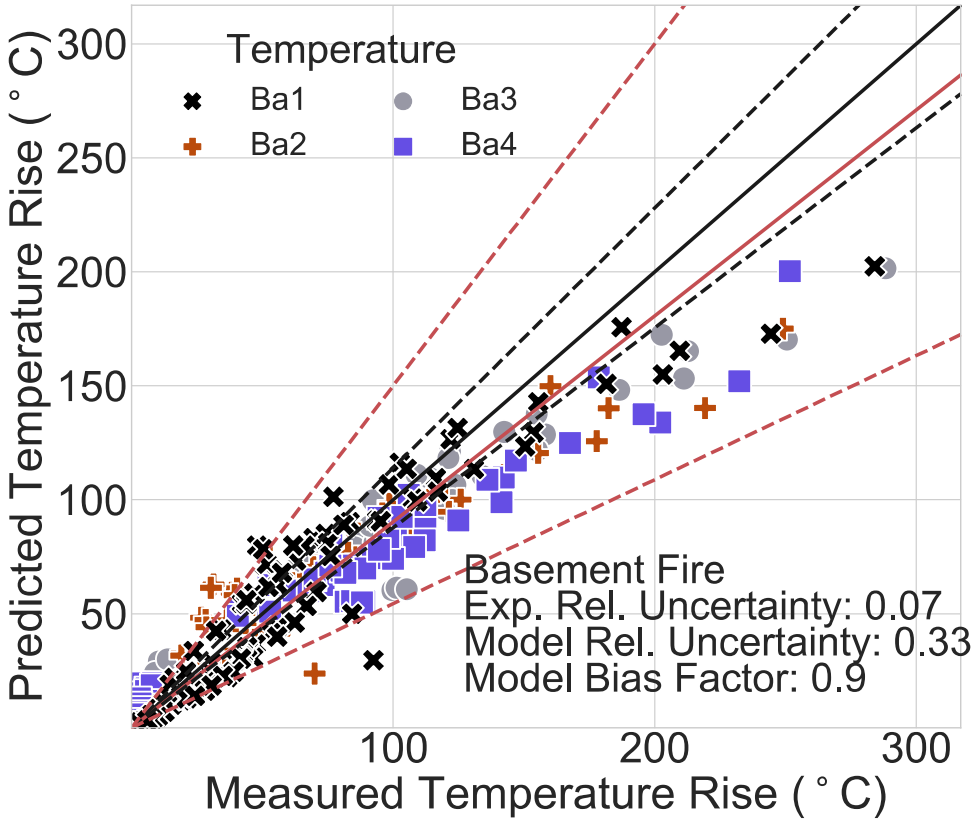


Closed Bedroom



- Including heat-loss from the duct (simulated as aircoil device in the duct supplying the closed bedroom) improved temperature prediction in the closed room (BR-3) where the transport occurred primarily via the HVAC supply vent.

Results – Validation result

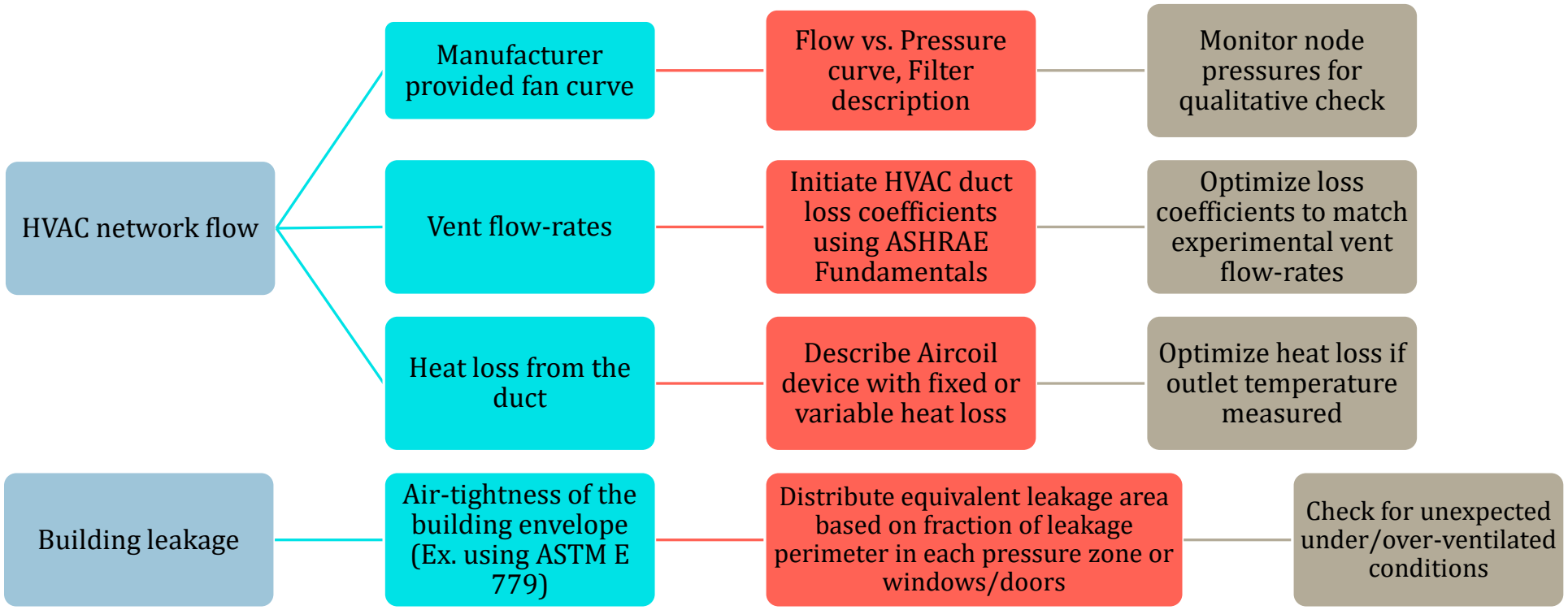


Gas species' prediction and validation results can be found in upcoming publication

(Chaudhari, Dushyant M., Craig Weinschenk, and Jason Floyd. 2022. "Numerical Simulations of Gas Burner Experiments in an HVAC-Equipped Residential Structure." [Manuscript in preparation].)

Discussion and Conclusions

FDS setup – Practical guidance



Conclusions

- Further validation of FDS performed for a controlled fire in a residential structure equipped with an HVAC system
  - —Qualitatively, FDS predicted buoyancy-induced transport of gases and unsteady transport through the HVAC network
  - —Uncertainty in leakage area, HRR, wall component properties might be responsible for the observed discrepancies
- A practical guidance for setting up FDS simulations in such scenario presented
  - —Optimized duct loss coefficient, air-tightness (equivalent leakage areas), HVAC fan curve were used for setting up simulations
  - —Including heat loss from the duct to the ambient simulated as aircoil device improved temperature rise prediction in closed rooms

Thank you

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