Evaluation of the 12.5 cfm/Miner Requirement for Refuge Alternatives Supplied with Fresh Air

Cory DeGennaro

Mechanical Engineer

Pittsburgh Mining Research Division

RA Partnership

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Regulations state that O_2 must be maintained between 18.5%–23% and CO_2 must be maintained below 1%

- RAs can use O_2 cylinders and CO_2 scrubbing material

- RAs using O_2 cylinders must supply O_2 at **1.32 cfh per person**
- RAs using O_2 cylinders must remove CO_2 at **1.08 cfh per person**
- RAs using a BAS must supply fresh air at **12.5 cfm per person**
- RAs using a BAS do not need scrubbing material due to high volume of fresh air

Test equipment was repurposed to evaluate the amount of fresh air flow required to maintain O_2 and CO_2 levels

- CASE Lab: sealed shipping container
  - Volume for 21 occupants based on regulations
  - No CO_2 scrubbing material was used
- O_2 and CO_2 monitors
- Safety-related sensors
- Human Breathing Simulator
- Gas mass flow controllers

Propane combustion and supplemental CO_2 were used to match human O_2 consumption and CO_2 generation

- The propane combustion equation ($C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$) was used to calculate mass flow rates for each gas on a per-person basis using mandated rates for O_2 consumption and CO_2 generation

Type of gas	Approximate mass flow rate per person (grams/minute)
O_2 to be consumed	0.80
C_3H_8 needed to consume O_2	0.22
Combustion air (including 20% excess)	4.45
CO_2 from combustion	0.66
CO_2 from human breathing	0.90
Supplemental CO_2 needed (Human breathing - Combustion)	0.24

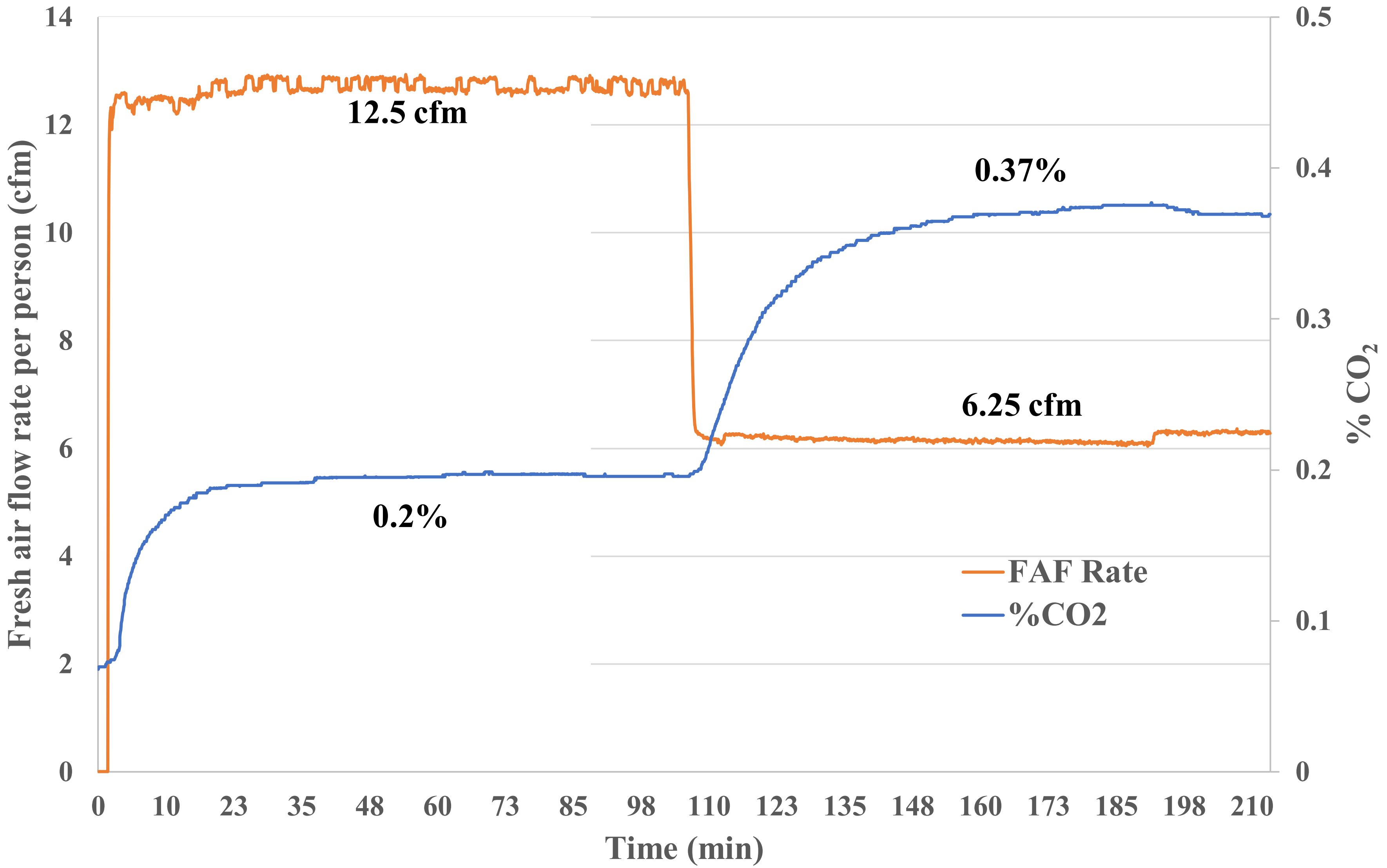
A centrifugal fan simulated a BAS by providing fresh air into the enclosure to mitigate CO_2 rise

- Consists of a centrifugal fan, variable frequency drive, and air flow measurement station
- Air flow is measurable from 100–1,100 cfm
- The FAF rate was adjusted based on interior conditions

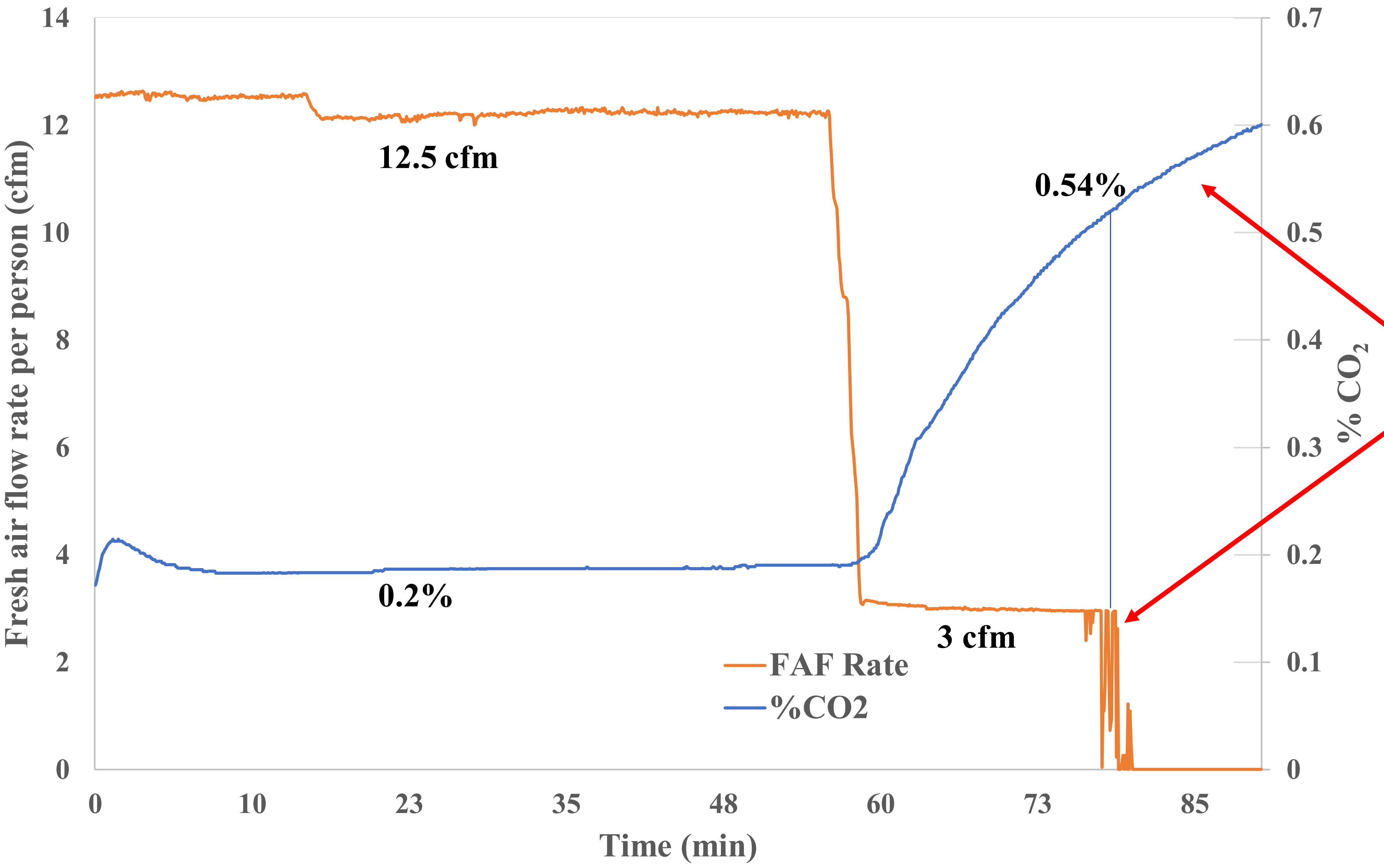
Iterative fresh air flow rate reductions allowed us to identify a relationship between fresh air and CO_2 levels

- Begin simulating human breathing (propane combustion and supplemental CO_2 flow)
- Begin with a fresh air flow rate of 12.5 cfm per person
- Allow interior CO_2 to stabilize
- Adjust fresh air flow rate
  - Reduce by 50% if CO_2 is less than 1%
  - Increase by 50% if CO_2 is greater than 1%
- Continue until 1% is reached
- *O_2 and CO_2 concentrations were averaged over the interior volume**
- *Testing began with 21 simulated occupants (262.5 cfm total)**
- *Minimum measurable fresh air flow limitations required increased number of simulated occupants**
- *Occupancies tested ranged from 21–58**

CO_2 concentration reached 0.2% for 12.5 cfm/person (626.5 cfm total) and 0.37% for 6.25 cfm/person (131 cfm total) for 21 simulated occupants

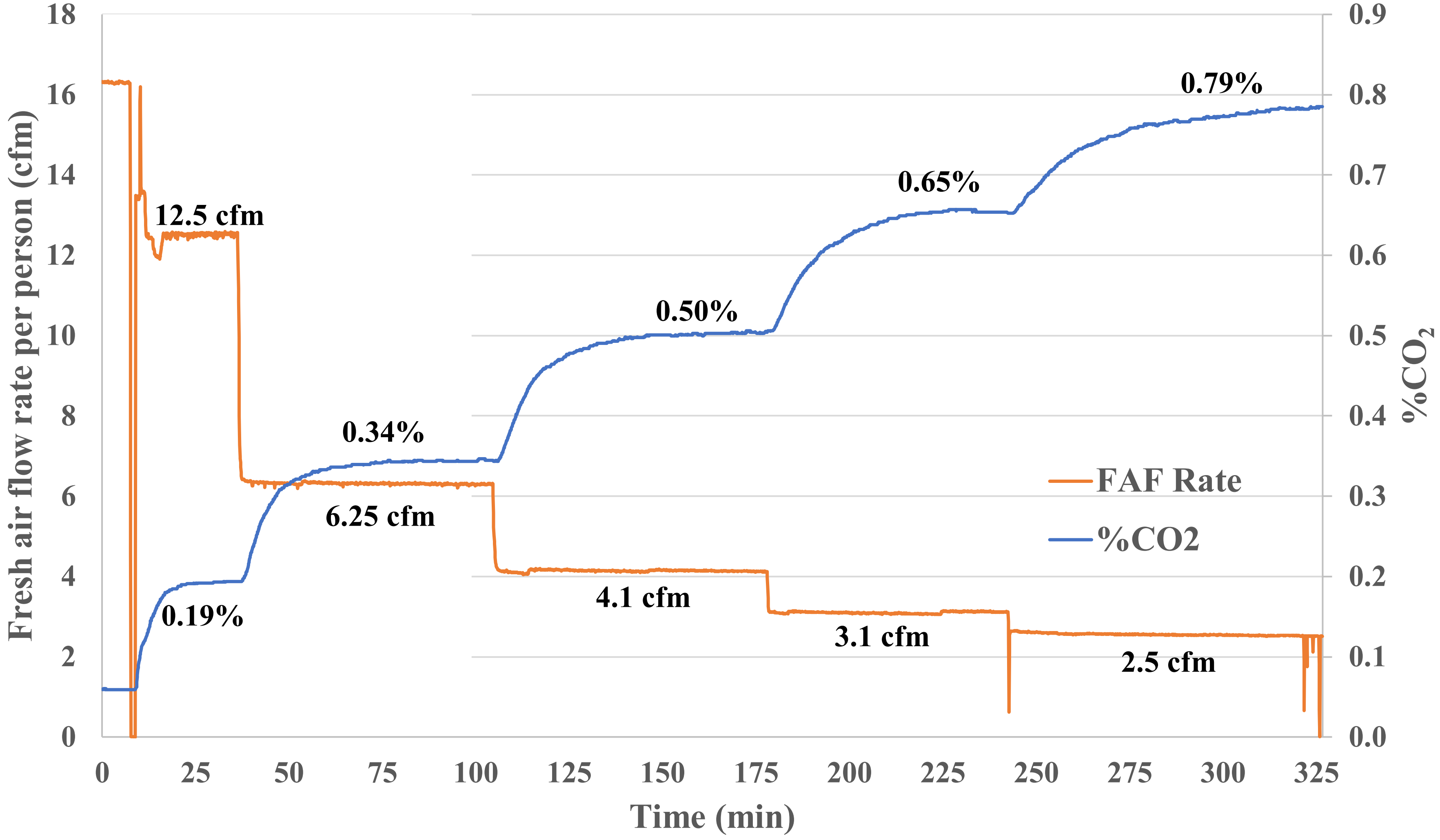


CO_2 concentration reached ~0.54% for 3 cfm/person (102 cfm total) for 34 simulated occupants

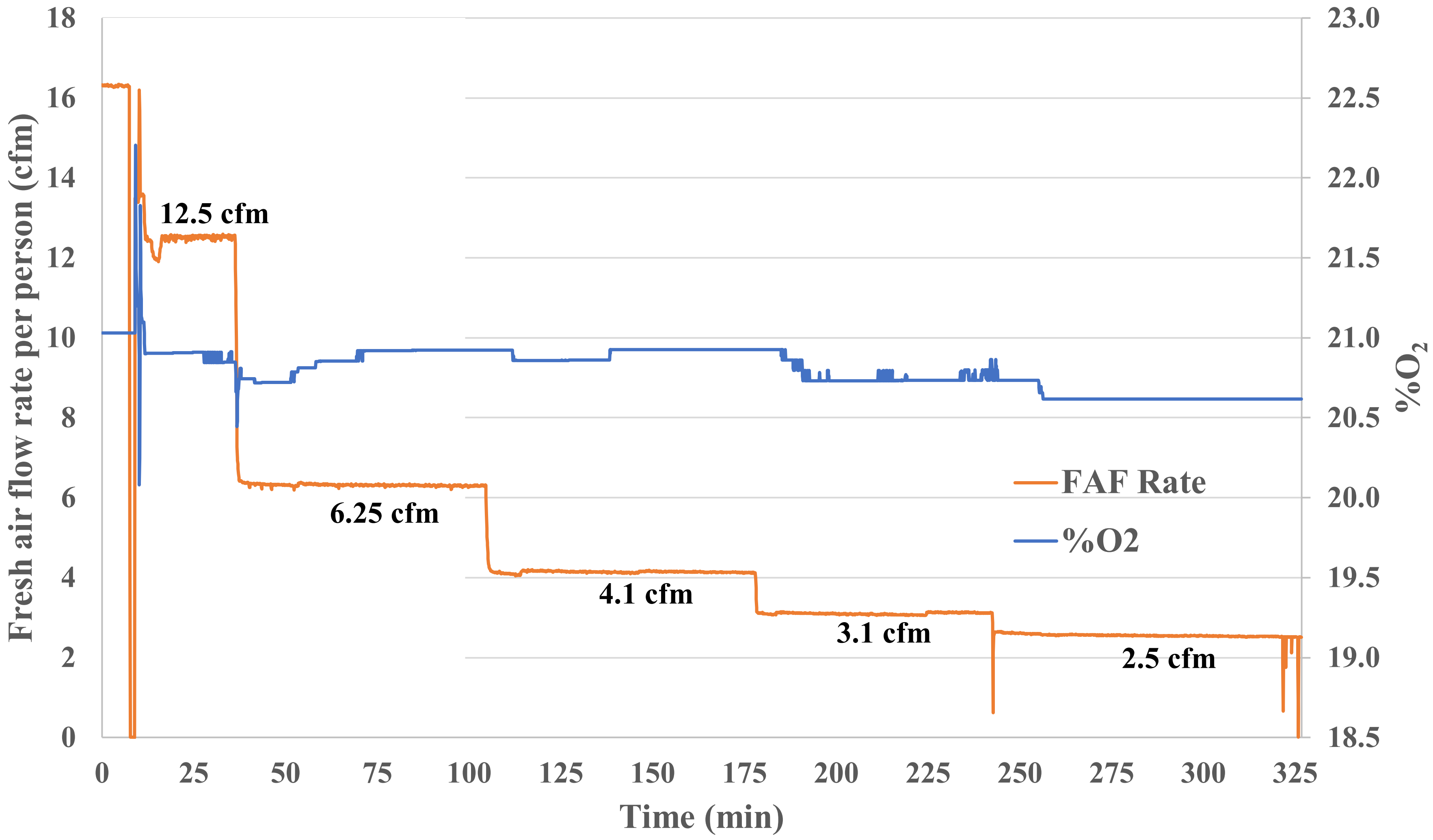


Fresh air flow was shut off due to time

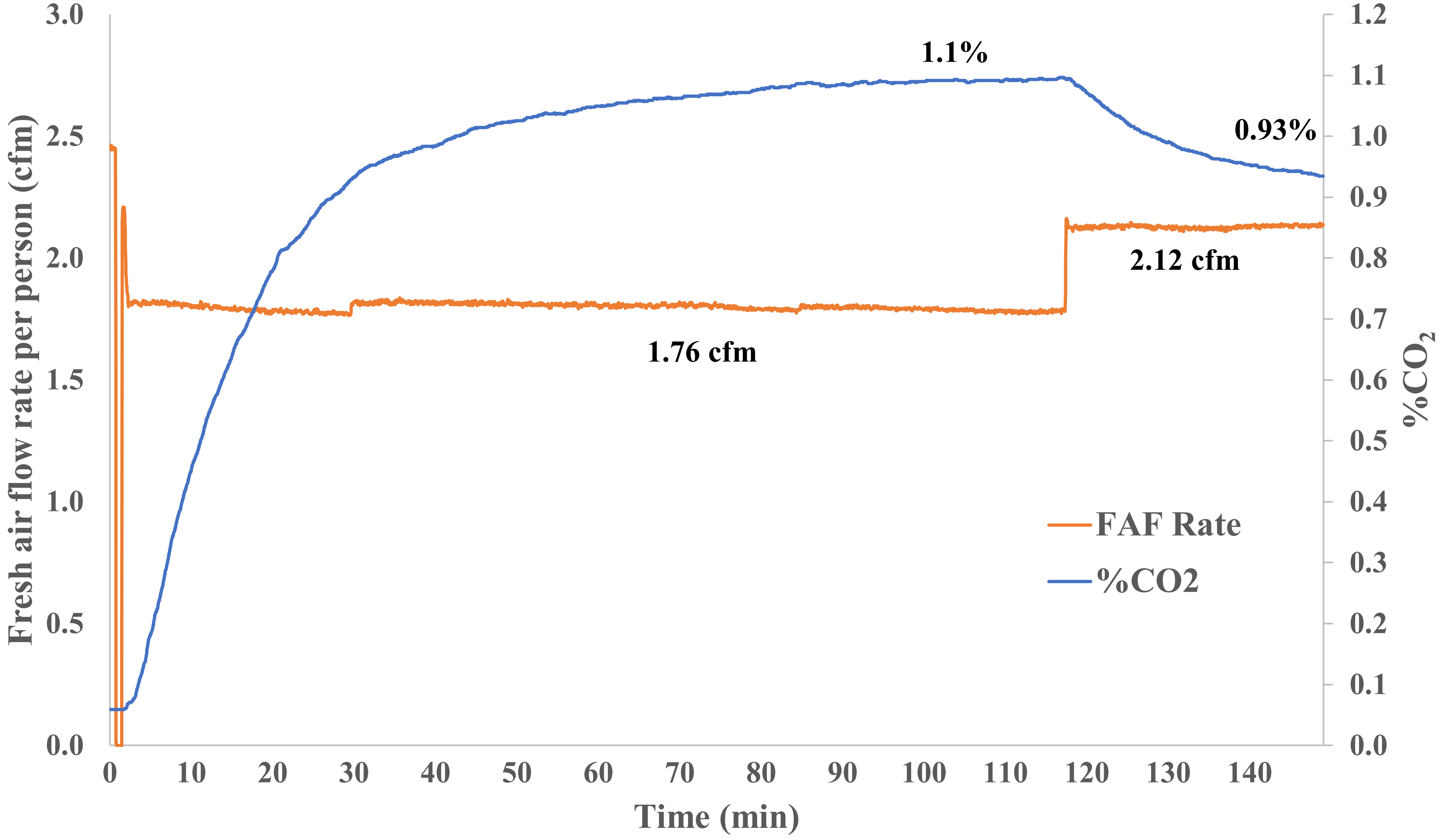
CO_2 concentration reached 0.79% for 2.55 cfm/person (102 cfm total) for 40 simulated occupants



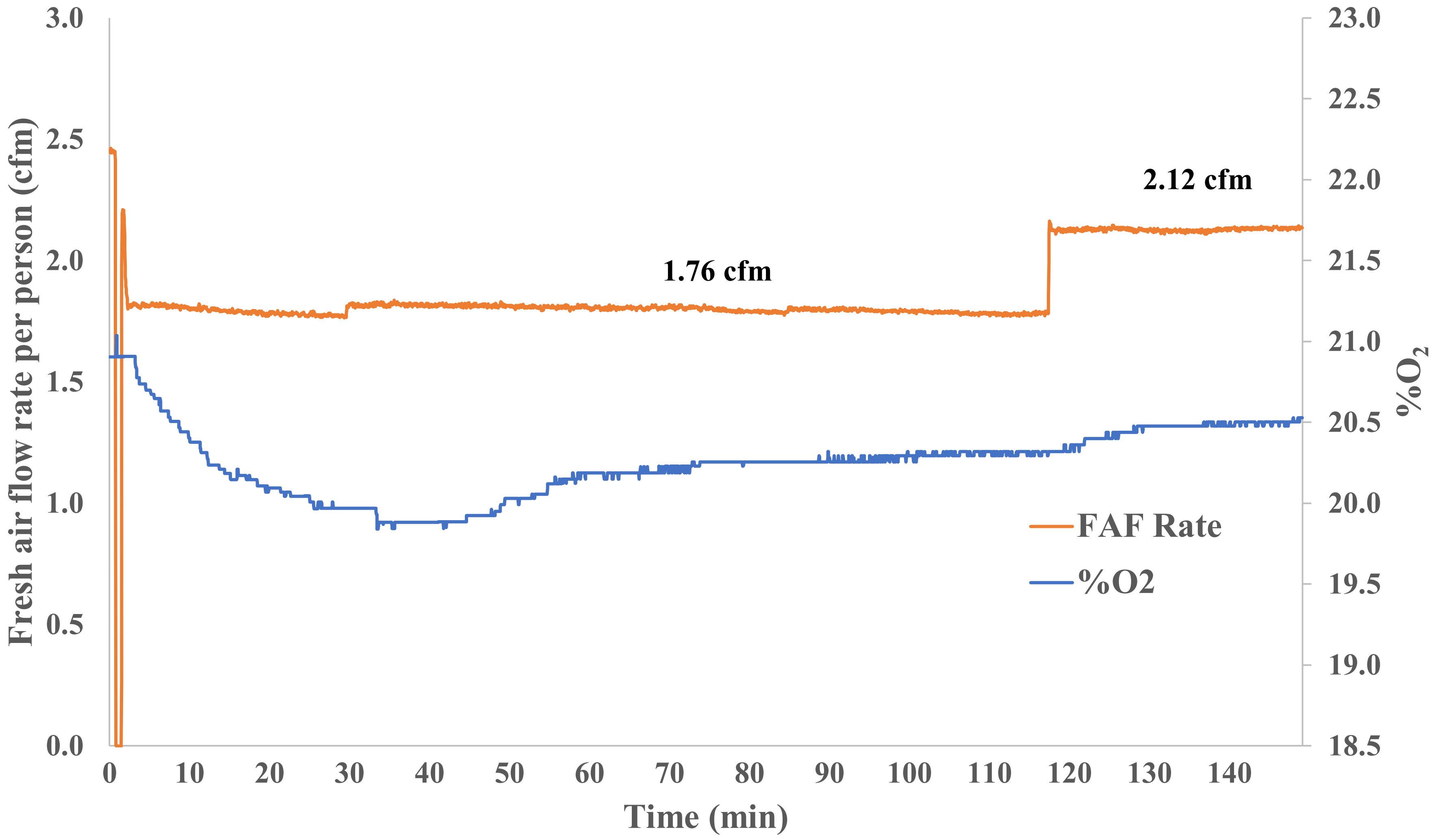
O_2 levels remained within the mandated range for 2.55 cfm/person



CO_2 concentration reached 1.1% for 1.76 cfm/person (102 cfm total) and 0.93% for 2.12 cfm/person (123 cfm total) for 58 simulated occupants

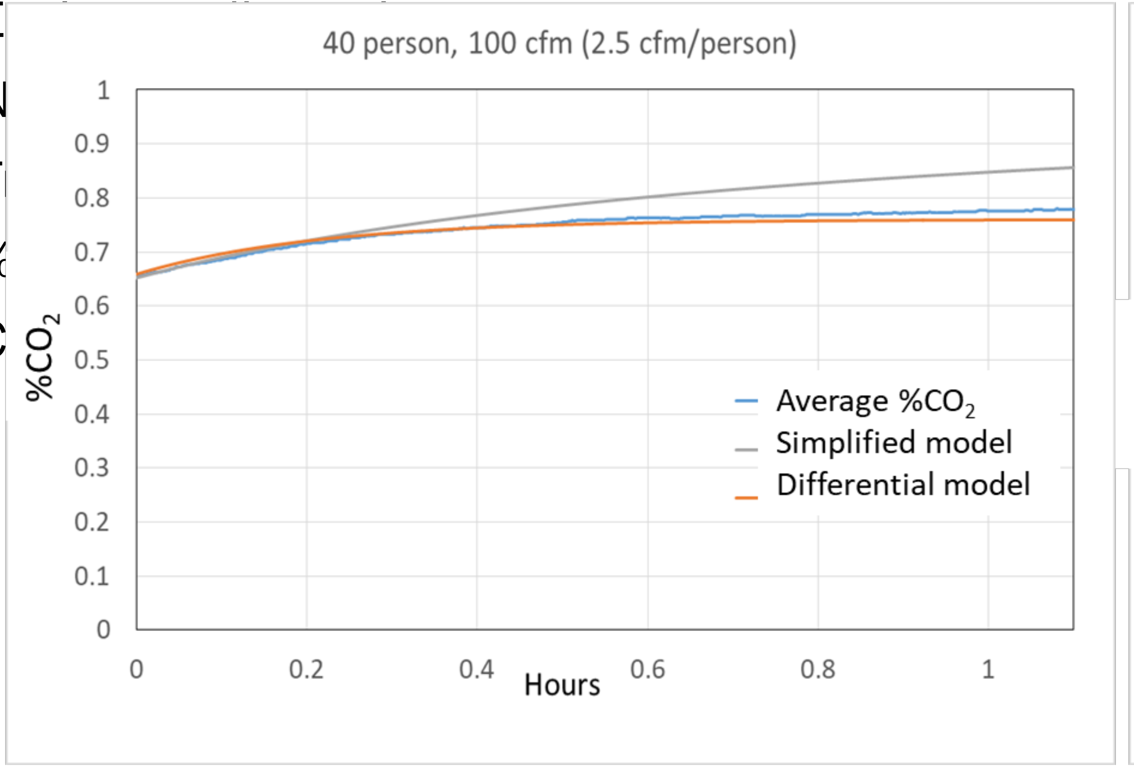


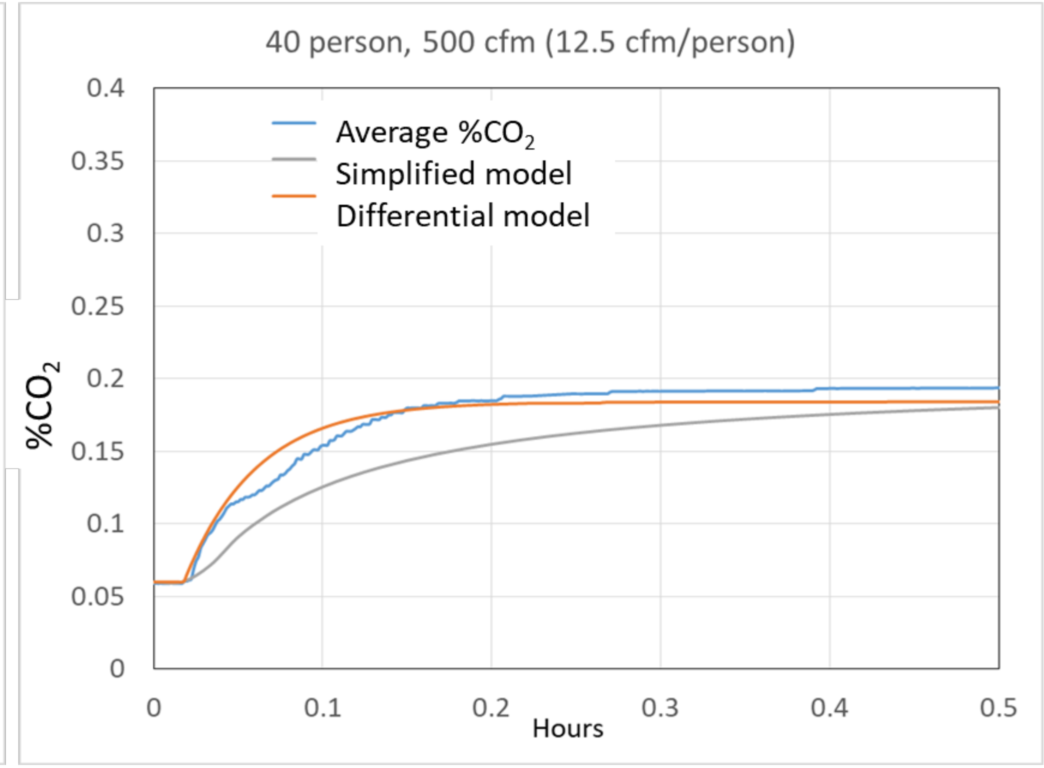
O_2 levels remained within the mandated range for lowest tested fresh air flow rate of 1.76 cfm/person



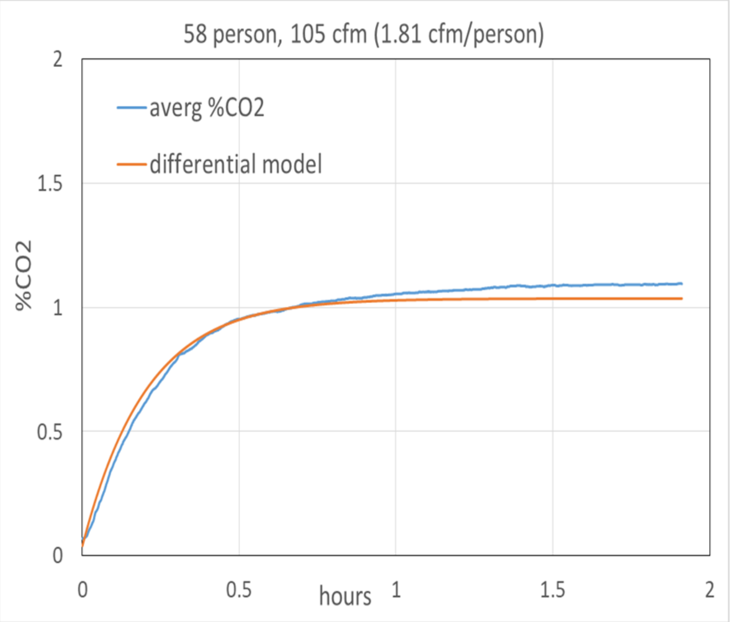
A theoretical model was developed to predict %CO_2 and validated using test data

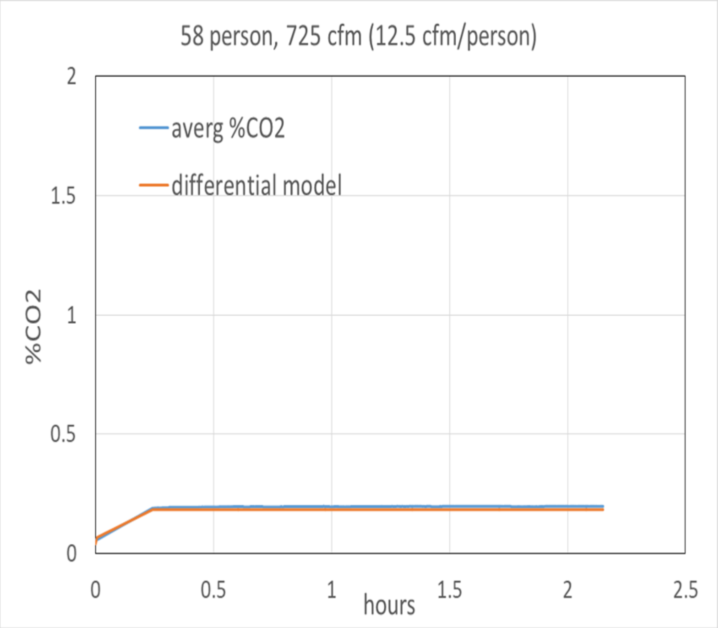
- Input parameters:
  - E
  - N
  - F
  - %
  - C





The model predicts that a fresh air flow rate of 1.87 cfm per person corresponds to 1% CO_2





N	Federal regulation of CFR FAF at 12.5 cfm/person (cfm)	Model Min FAF for CO_2 < 1% (cfm)	Model Min FAF for CO_2 < 1% (cfm/person)
1	12.5	NA	NA
54	675	101	1.87
55	687.5	103	1.87
56	700	105	1.88
57	712.5	107	1.88
58	725	108	1.86
59	737.5	110	1.86
60	750	112	1.87

Summary of test method and results

- Propane combustion and supplemental CO_2 were used to simulate human breathing based on RA regulations
- A centrifugal fan simulated a fresh air source, but measurement limitations required an increased number of simulated occupants
- The mandated 12.5 cfm per person for a fresh air source can maintain O_2 and CO_2 levels
- A fresh air flow rate between 1.76–2.12 cfm per person will mitigate CO_2 rise to 1% and still maintain O_2 within 18.5–23% (S.F. 6x –7x)
- Theoretical model predicts that a minimum fresh air flow rate of 1.87 cfm per person will mitigate CO_2 to 1% (S.F. 6.7x)

Questions?

Cory DeGennaro

CDeGennaro@cdc.gov

DeGennaro, C., Yan, L., Yantek, D., (2021). Fresh Air Flow Required to Maintain Safe Carbon Dioxide Levels and Provide a Breathable Air Environment in a Refuge Alternative. IMECE 2021, ASME. IMECE2021-68680. November 1-5, 2021.

Yan, L., Yantek, D. S., DeGennaro, C. R., Fernando, R. D., (2021). Mathematical Modeling for Carbon Dioxide Level Within Confined Spaces. IMECE 2021, ASME. IMECE2021-68452. November 1-5, 2021.