Location Dependent Variability of Effective Ventilation Rates Within Hospital Isolation Rooms

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Introduction

- Nosocomial infection rates have been on the rise
- Negative pressure rooms and isolation rooms are used in hospitals to protect patients, staff and visitors from the spread of infectious disease
Design recommendations

- Pressure differential > -0.01 in H$_2$O
- ACH > 12 (new and renovation)
- Airflow direction
  - Into the room
  - Clean to dirty airflow in room toward patient
Quantitative evaluation

- Containment checks using tracer gas and looking for leaks in adjacent air spaces
- In room mixing is complex and poorly understood
- Ventilation effectiveness in room is little studied
Previous research

• Study of effectiveness of UV for disinfection
  – Mean lifetime of particles in room does not reduce in proportion to increasing ventilation rate
  • Alani et al 2001
Previous research

- CFD studies
  - Increased ACH useful only to a point
  - Position of inlet and outlets are important
  - 9 ACH optimum
  - 3 outlets
  - 8 ACH supplied (1 ACH infiltrate)
    - Huang and Tsao, 2005
Research questions

• How much does air mixing (ACH) vary within in negative pressure rooms?

• Can simple room geometry characteristics account for air the air mixing variability that exists?
Hypothesis

- ACH at different locations in negative pressure rooms will not vary more than 30% from the mechanical ventilation rate.
Hypothesis

• Effective ACH at different locations in negative pressure rooms will be greater the closer the location is to a line drawn from the inlet to the outlet.
Materials

- 9 negative pressure rooms
  - Data collection is on-going
- Aerosol generator
  - Virtis SG-80
- Particle counter
  - MetOne Model 237
- Balometer
- Hot wire anemometer
Methods

• Room geometry measured
• Mechanical ventilation measured
• At each of 9 locations in room
  – Fan used to induce good mixing
  – Aerosol released
  – Fan turned off
  – Concentration decay of 1.0 \( \mu m \) aerosol measured
Example sample plan

Sampling Layout
Methods

• Aerosol concentration decay and room geometry used to determine $ACH_{Local}$ and $Q_{Local}$
• In a well mixed room

$$C_t = C_0 \cdot e^{-\frac{Q}{V} \cdot t}$$

• For a location in an incompletely mixed rooms this represents the decay given the effective ventilation rate at that point
Example decay – Ped Exam 5
location #2
Methods

• The decay equation can be linearized

\[ C_t = C_0 \cdot e^{\frac{-Q}{V} \cdot t} \]

\[ \frac{C_t}{C_0} = e^{\frac{-Q}{V} \cdot t} \]

\[ -\ln\left(\frac{C_t}{C_0}\right) = \frac{Q}{V} \cdot t \]
Methods

\[- \ln \left( \frac{C_t}{C_0} \right) = \frac{Q}{V} \cdot t\]

- This in the form of a linear equation
  - LHS: dependent variable
  - \( t \): independent variable
  - \( Q/V \): slope of the line
Local air change rate – Ped Exam
5 location #2

\[-\ln(C_t/C_0) = 0.3775 \times t + 0.016\]

\[r^2 = 0.9974\]
Example results: 586-16
Example results: MICU 1-2
<table>
<thead>
<tr>
<th>Room</th>
<th>Mech ACH</th>
<th>Avg of locations</th>
<th>s</th>
<th>min</th>
<th>max</th>
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<td>7.5</td>
<td>2.5</td>
<td>2.6</td>
<td>10</td>
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<tr>
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<td>4.9</td>
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<td>1.7</td>
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<td>11</td>
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<td>15</td>
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</table>
Local mixing

- Because different rooms have different mechanical ventilation rates
- Local ACH as a fraction of mechanical ACH used for analysis
- k
Variability within rooms

![Variability within rooms diagram]

- Rooms: 58615, 7801314, ECPED8, MICU, PEDICU3, 58616, ECPED11, ECPED910, PEDEXAM5
- Variability metric: K
- Values: 2.5, 2.0, 1.5, 1.0, 0.5, 0.0, -0.5
- Sample sizes: 9, 10, 8, 9, 9, 8, 9, 8
Effect of distance from “straight flow line”
Correlation of Distance from line and k

- No statistical correlations
- However in many cases it is a point or two that impact the analysis
Variability at a given location

- Lower $k$ values in general had the most variability in local mixing
- Expressed as variability in linearized decay curve
  - $r^2$
Variability at a given location

MICU location 4

\[-\ln(C_t/C_0) = 0.0429 \times t + 0.0374\]

\[R^2 = 0.5192\]
Variability at a given location

![Graph showing variability at a given location](image)
Conclusions

• All rooms had at least one location that the local air change rate was 30% or more below the mechanical ventilation rate
Conclusions

- Simple room geometry metrics are not sufficient to predict the effective mixing rates at locations within a negative pressure room.
- Visual inspection of maps of mixing variability often identifies the reason for an outlier to a simple predictive approach.
- How to capture this in an algorithm is being explored.