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The Resistance of HEPA Filters in a Ventilation Duct on Leakpath Factor Calculations

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Disclaimer

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The Resistance of HEPA Filters in a Ventilation Duct on Leak Path Factor Calculations

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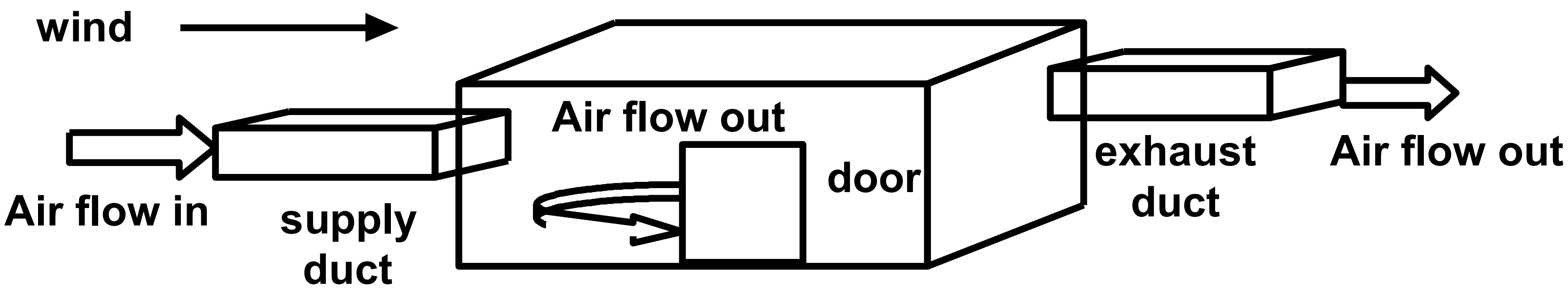
Introduction

Purpose: Study the impact of the flow resistance of HEPA filters on leak path factor calculations

Model: One room with 3 leak pathways

- Room, 100 ft W x 40 ft L x 12.5 ft H
- Door, flow area A = 10 in^2
- Exhaust duct, D = 4 ft, L = 300 ft, flow area A = 12.6 ft^2
- Supply duct, D = 3 ft, L = 225 ft, flow area A = 7.07 ft^2
- Wind speed, u = 1m/s = 3.28ft/s = 2.2 mph
- $P_{room} = P_{envir}$ = 14.7 psi
- 1 kg of Pu, 100% respirable, d = 2 μm, ln(σ) = 0.7



Introduction

Basic Formulas

1. Input to CONTAIN code:

- **Wind induced pressure, ΔP_w**

  $\Delta P_w = \frac{1}{2} C \rho u^2$, u = wind velocity

Wind pressure coefficient C

Upwind	Side	Downwind
+ 0.7	- 0.35	- 0.4

- **Wind induced air flow velocity in duct or door gap, v_w**

  $\Delta P_{duct} = \frac{1}{2} (f L/D + K) \rho v_w^2 = \frac{1}{2} C \rho u^2$

  $v_w = [C/(fL/D + K)]^{1/2} u$

  $Q_w = v A$ Q_w = wind induced flow rate, A = flow area

2. CONTAIN code will calculate:

- **Pressure difference, ΔP, between room and envir. due to induced air flows**
- **Air flow velocity, v, due to ΔP**

  $\frac{1}{2} (f L/D + K) \rho v^2 = \Delta P$

LPF Calculation #1

Condition: Exhaust and supply ducts dampers close, only door leakage, i.e., only one pathway.

- **Resistance**

  $K = K_{entrance} + K_{exit} = 0.5 + 1 = 1.5$

  $R = f\,L/D + K = 0.0 + 1.5 = 1.5$

- **Wind induced airflow thru. door gap,** $Q_w = -\,6.56$ **cfm (from room to envir)**

$Q_w = -\,10\ in^{2}*\ (0.35/1.5)^{1/2}*1m/s = -\,6.56$ **cfm (beware unit conversion)**

LPF = 3.2 %

LPF Calculation #2

Condition: Exhaust and supply ducts dampers open, door leakage, i.e., 3 pathways.

- **Door:**

  Resistance, R = 1.5

  Q = - 6.56 cfm (from room to envir)

- **Exhaust duct:**

  Resistance, f = 0.024, R = 0.024*300 ft/4 ft + 1.5 = 3.3

  Q = - 859 cfm (from room to envir)

  (Note: f is determined by iteration based on the Reynold number, duct size, and material [CRANE, 1979])

- **Supply duct:**

  Resistance, f = 0.024, R = 0.024*225 ft/3 ft + 1.5 = 3.3

  Q = + 641 cfm (from envir to room)

LPF = 81 %

LPF Calculation #3

Condition: Exhaust and supply ducts dampers open with HEPA filters, door leakage, i.e., 3 pathways.

HEPA filters are physically located inside the ducts, no credit taken for filtration, but consider the flow resistance of HEPA filters.

HEPA filter design: Nuclear Air Cleaning Handbook (DOE-HDBK-1169-2003):
(1 in. w.g. pressure drop will produce 1,000 cfm per 2-ft x 2-ft HEPA filter element)

$\Delta P_f = (\Delta P_{f0} / q_{f0})^* q_f$ — ΔP_f = pressure drop across of filter,

$q_f = A_{f0} * v_f$ — q_f = flow rate per filter element

A_{f0} = flow area per filter element = 4 ft^2

ΔP_{f0} = 1 in. w.g

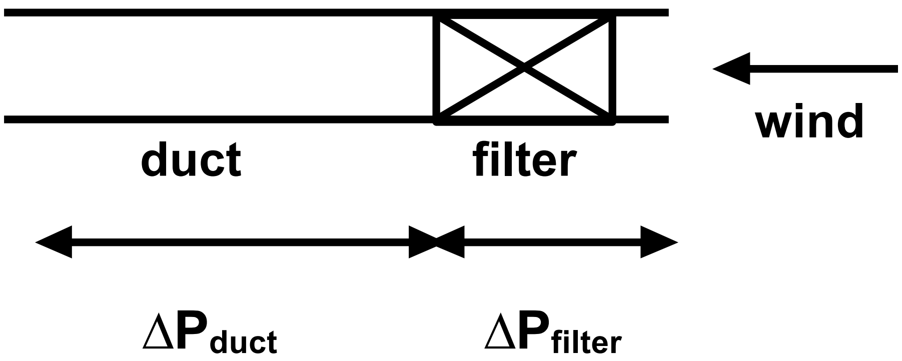
q_{f0} = 1000cfm per 2-ft x 2-ft HEPA filter element = $A_{f0} * v_{f0}$ = 4 ft^{2*} v_{f0}, v_{f0} = 4.17 ft/s

$Q = A*v = A_f * v_f$, $A_f = n*A_{f0}$, n is the no. of 2ft x 2ft filter element, A_f is the flow area

$$\Delta P_f = (\Delta P_{f0} / v_{f0})^* v_f = (\Delta P_{f0} / v_{f0})^* (A/A_f)^* v$$

LPF Calculation #3 (cont.)

$\Delta P_{duct} + \Delta P_{filter} = \Delta P_{wind}$



$\frac{1}{2}(f\ L/D + 1.5)\ \rho\ v^2 + (\Delta P_{f0}\ /v_{f0})^*\ (A/A_f)^*\ v = \frac{1}{2}\ C\ \rho\ u^2$, open duct with filters

(This is a quadratic equation, $v = [-b + (b^2 - 4ac)^{1/2}]/2a$

Compare Calculation #2

$\frac{1}{2}(f\ L/D + 1.5)\ \rho\ v^2 = \frac{1}{2}\ C\ \rho\ u^2$, open duct without filters

LPF Calculation #3 (cont.)

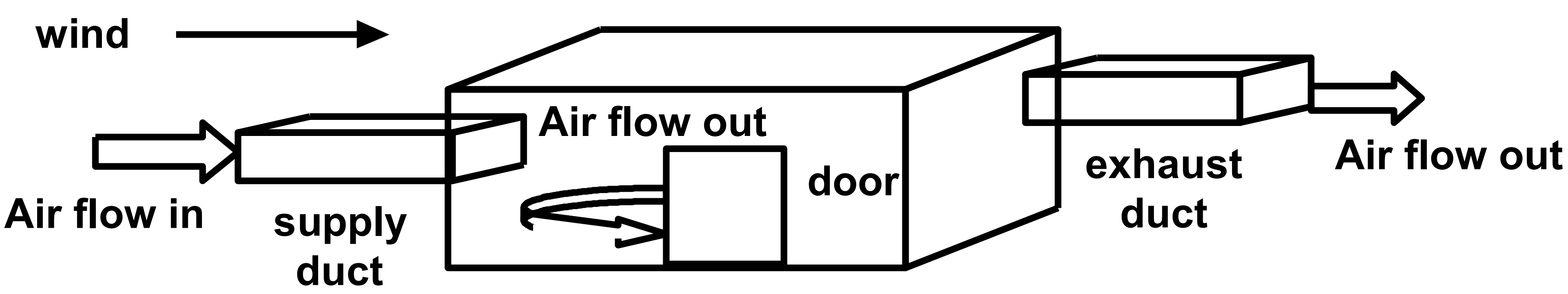
• Door,	Q = - 6.56 cfm
• Exhaust duct,	Q = - 2.98 cfm
• Supply duct,	Q = + 2.93 cfm

LPF = 4.6 %

Summary

Leak path Factors (1 m/s wind)

Door gap Exhaust and Supply ducts dampers close	Door gap Exhaust and Supply ducts dampers open without HEPA filters	Door gap Exhaust and Supply ducts dampers open with HEPA filter (Credit taken for HEPA filters flow resistance, but no credit for filtration)
3.2 %	81 %	4.6 %



Summary

Conclusions:

- **The wind produces large air flow in the open exhaust and supply ducts without HEPA filters, thus largely increase the LPF. This is unrealistic, because HEPA filters do physically exist inside the ducts.**
- **The flow resistance provided by the HEPA filters greatly reduces the air flow, thus greatly reduces the inflated LPF. (note: no credit is taken for the filtration)**
- **For a realistic evaluation of the LPF, it is extremely important to include the flow resistance provided by any components which are physically located inside the duct, e.g., filters, fans, etc).**

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For a nuclear facility, the building leak path factor (LPF) is an important parameter in the safety designation of the active ventilation system. An accidental release of radioactive airborne materials resulting in an unmitigated offsite dose that challenges the evaluation guideline may require a safety class designated active ventilation system for dose reduction. This requirement, however, is negotiable in case the building LPF can be shown to be much less than one.

In a day of calm wind, the building LPF of some nuclear facilities, depending on the accident scenario, may be shown to be around 10%. In some cases, this small LPF is sufficient to reduce the offsite dose below the evaluation guideline, and as a result only the building is required to be designated as a safety class passive confinement system or design feature.

The common leak paths of a building are door gaps, various building leaks, and air ventilation ducts; among them the leakage of airborne materials through the duct is usually the dominant contribution to the LPF.   The Airflow through the ventilation duct depends strongly on the wind speed. In a common conservative approach, the ventilation duct may be treated as open. The airflow through the duct due to the wind is thus:

$$\left(K + \frac{fL}{D}\right)\rho V^2 = c\rho U^2 \qquad \text{open duct} \qquad (1)$$

where V and U is the airflow through the duct and wind speed, respectively; and K, f, L, and D is the resistance, friction, length, and diameter of the duct, respectively.

In a day of strong wind, the airflow derived from Eq (1) may increases substantially. The large airflow in turn produces a large LPF. The unrealistic large airflow through the duct (and hence the large LPF) is mainly due to the open duct assumption of Eq (1).

This paper considers that the pressure drop across a filter is linearly proportional to the airflow velocity:

$$\left(K + \frac{fL}{D}\right)\rho V^2 + bV = c\rho U^2$$

duct with HEPA filter (2)

where b is a filter related coefficient.

Under similar strong wind condition, Eq (2) yields a much smaller airflow V (and hence a smaller LPF) compared with that based on Eq (1).