The Impact of Industrial Ventilation Systems on Energy Conservation

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Presentation Overview

- Principles of ventilation design for contamination control
  - General exhaust ventilation
  - Local exhaust ventilation
- Impact of ventilation on energy use
  - HVAC systems used in industry
  - Energy costs associated with HVAC use
- Optimizing energy use while protecting workers and the environment

The Basics

- Ventilation is used as an end-of-pipe control to
  - Reduce worker exposures
  - Together with air pollution control devices, reduce environmental releases
- Every cubic foot of air that is exhausted from the plant will be replaced
- The replacement air must be conditioned
  - This talk will focus on heating replacement air

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Types of Ventilation for Contaminant Control

- General exhaust ventilation (GEV)
  - Also called dilution ventilation
  - Simplest, but usually not the best choice
- Local exhaust ventilation (LEV)
  - More difficult to design, install and maintain than GEV
  - Usually preferred to GEV
- Replacement air systems
  - Also called make-up air
  - Largest source of energy use in ventilation systems

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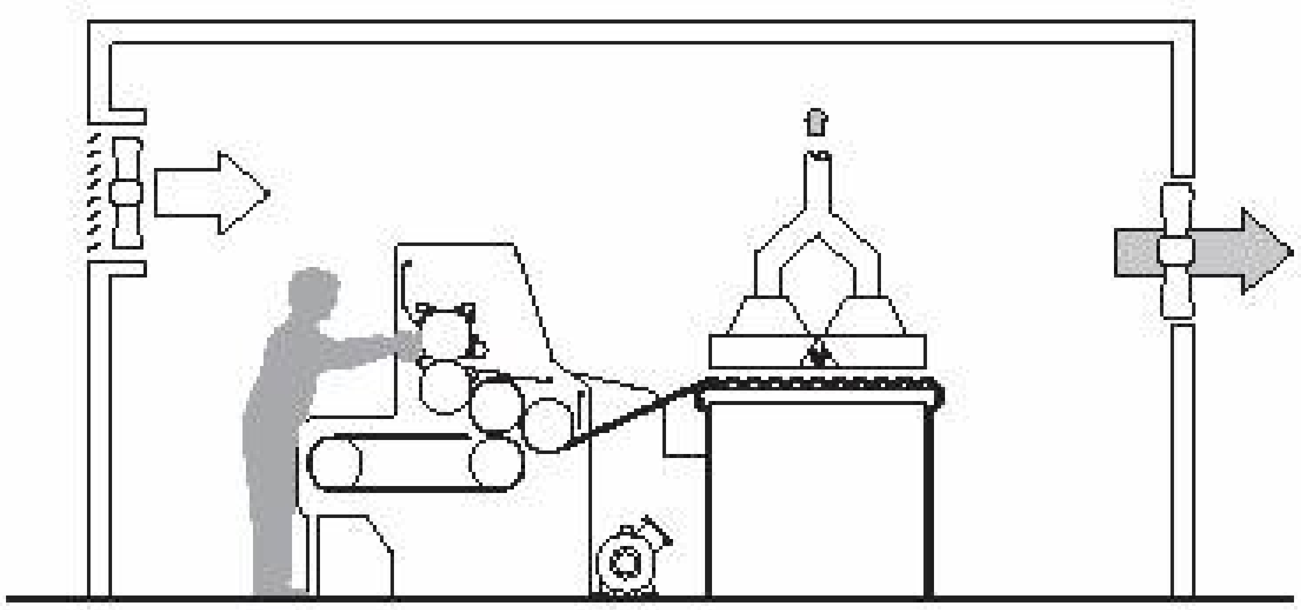
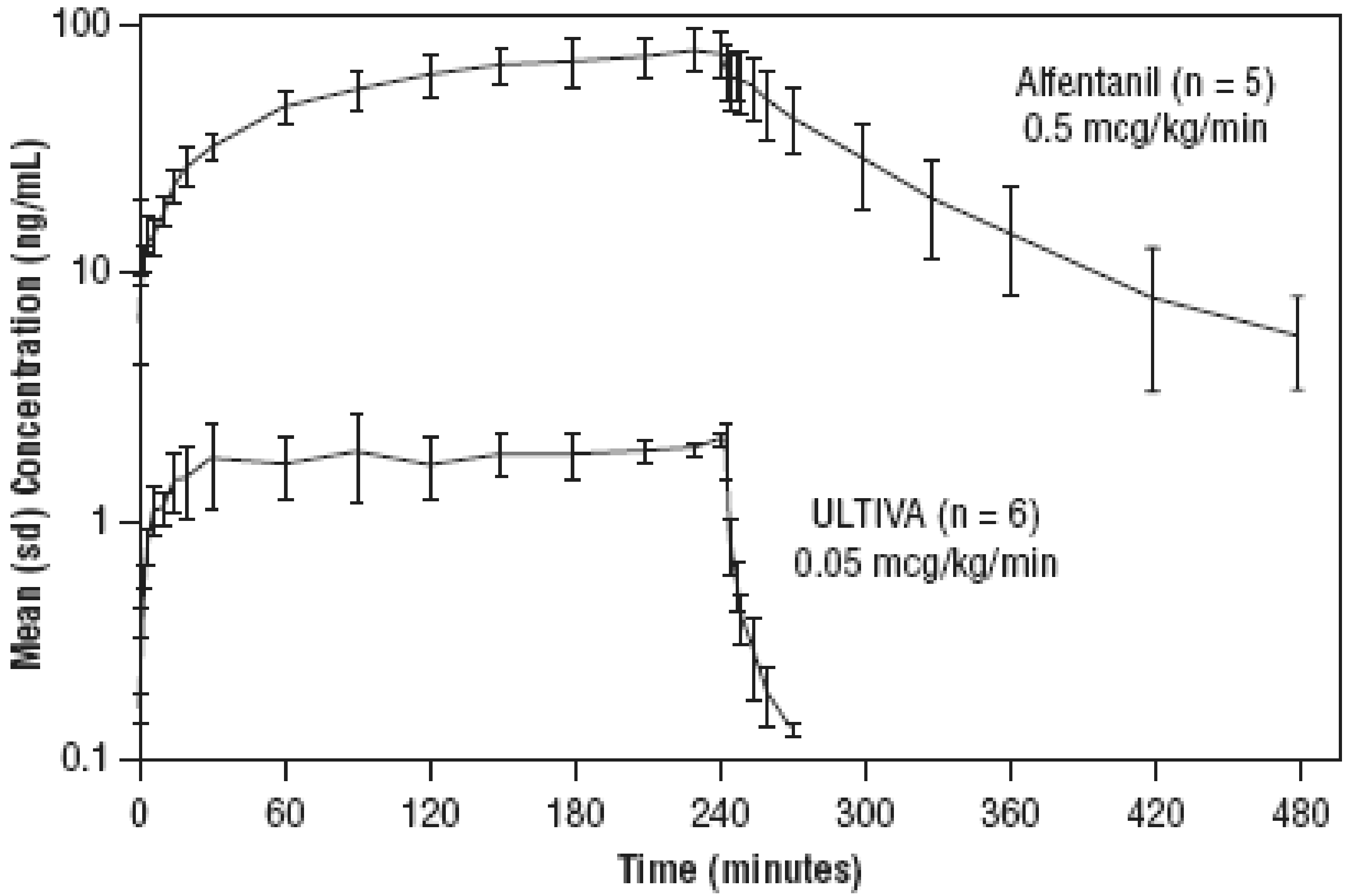
General Exhaust Ventilation



General ventilation for cleaning a printing press

Typical Concentration Plot



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Maximum Concentration

$$C_{max} = (GK/Q) \times 10^6$$

Where

C_{max} = contamination concentration (ppm)

G = contamination generation rate (ft^3/min)

Q = GEV air flow (ft^3/min)

K = mixing factor (dimensionless)

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Estimation of Generation Rate

- Easiest case – solvent evaporation
- Need some estimate of solvent use over time – assume it all evaporates

$$G\ (\text{cfm}) = \frac{G(\text{lb/min}) \times 453\ \text{g/lb} \times 24.5\ \text{L/mole}}{MW\ (\text{g/mole}) \times 28.3\ \text{L/ft}^3}$$

$$= \frac{390\ G\ (\text{lb/min})}{MW}$$

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Estimation of Generation Rate, Cont.

$$G\ (\text{lb/min}) = \frac{G\ (\text{pts/h}) \times 1.04\ \text{lb/pt} \times \text{s.g.}}{60\ \text{min/h}}$$

$$= 0.017 \times \text{s.g.} \times G\ (\text{pt/h})$$

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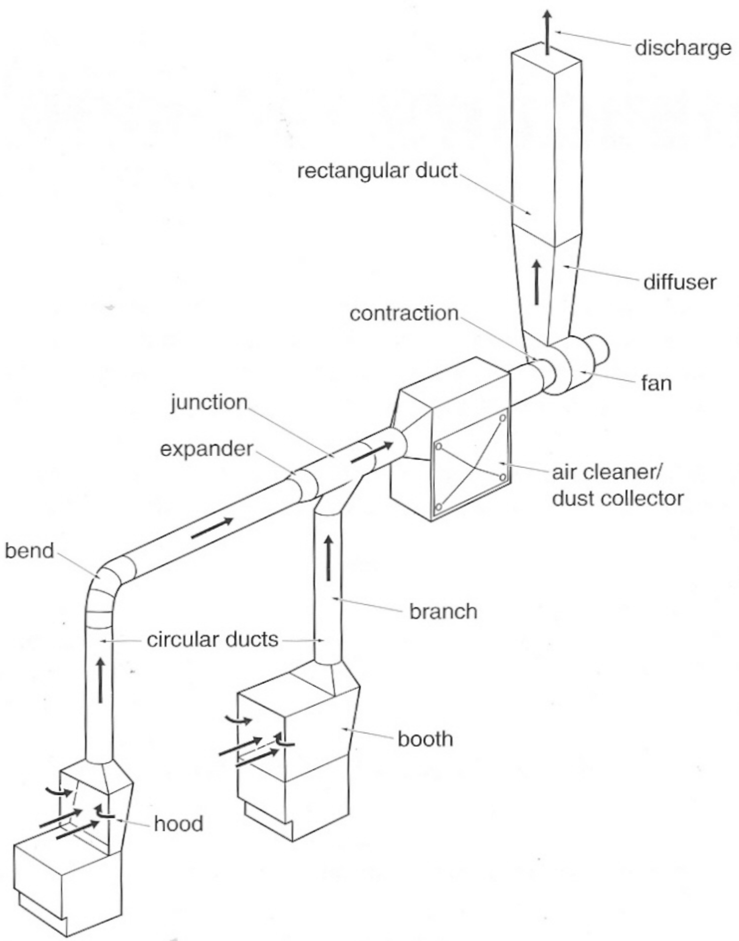
Local Exhaust Ventilation



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HEV Spot Ventilation at Cowlitz County

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Comparison of GEV v. LEV

- GEV only *reduces* contaminant concentration, while a properly designed LEV system can *eliminate* worker exposure
- GEV generally requires much more air flow than a properly designed LEV system
- People choose GEV because it is simpler and has lower *capital* costs, but usually GEV has much higher *operating* costs

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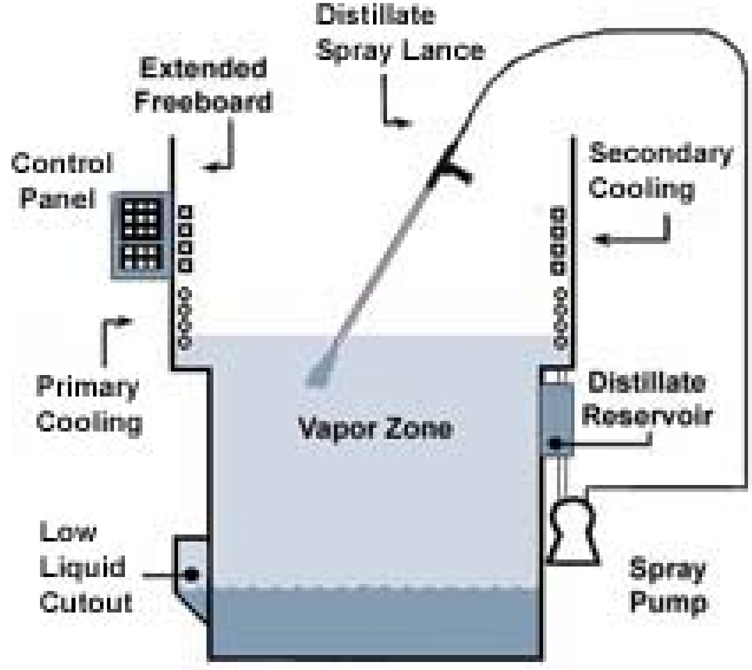
Example – Vapor Degreaser

Assume:

- TCE used – TLV = 10 ppm
- G = 1 ft^3/min TCE vapor
- K = 5



Vapor Spray Degreaser

GEV Calculation

The air flow required to hold the maximum TCE calculation equal to its TLV is:

$$Q = (GK/TLV) \times 10^6$$
$$= (1 \times 5/10) \times 10^6$$
$$= 500{,}000 \text{ ft}^3/\text{min} \text{ !!!!!!!}$$

AND – worker is still being exposed at the TLV!

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GEV Variables

- GEV is dependent on both the contaminant generation rate and toxicity
- E.g., if the TLV is 100 ppm, Q = 50,000 cfm

  TLV is 1000 ppm, Q = 5,000 cfm

- Therefore, GEV makes more sense for low-toxicity exposures

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But if You Use LEV…..

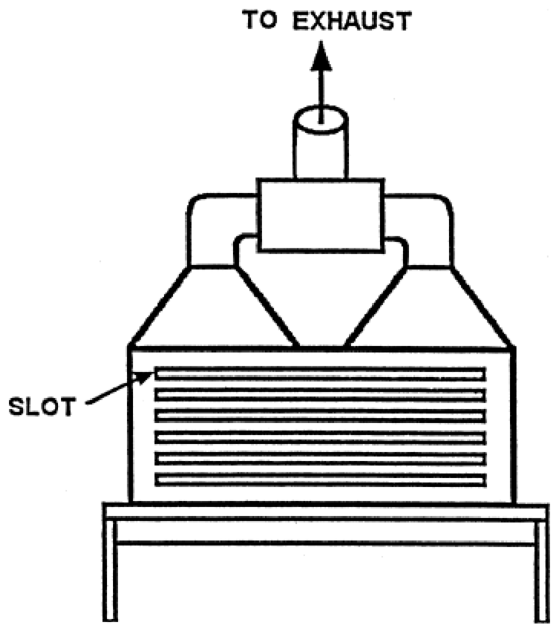
Assume the tank is 3 ft long (L) by 2 ft deep (x).

Use a slot hood along the back side, assuming a capture velocity (V_c) of 150 ft/min:

$$Q = 2.8LxV_c$$

$$= 2.8 \times 3 \times 2 \times 150$$

$$= 2{,}500\ ft^3/min$$



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But You have to Optimize the LEV System!

Same example, but use a canopy hood located 3 ft (H) over the degreasing tank:

The perimeter around the tank (P) = 10 ft

$Q = 1.4PHV_c$

$= 1.4 \times 10 \times 3 \times 150$

$= 6{,}300\ ft^3/min$

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Replacement Air Systems

Gas Fired Replacement-air Units

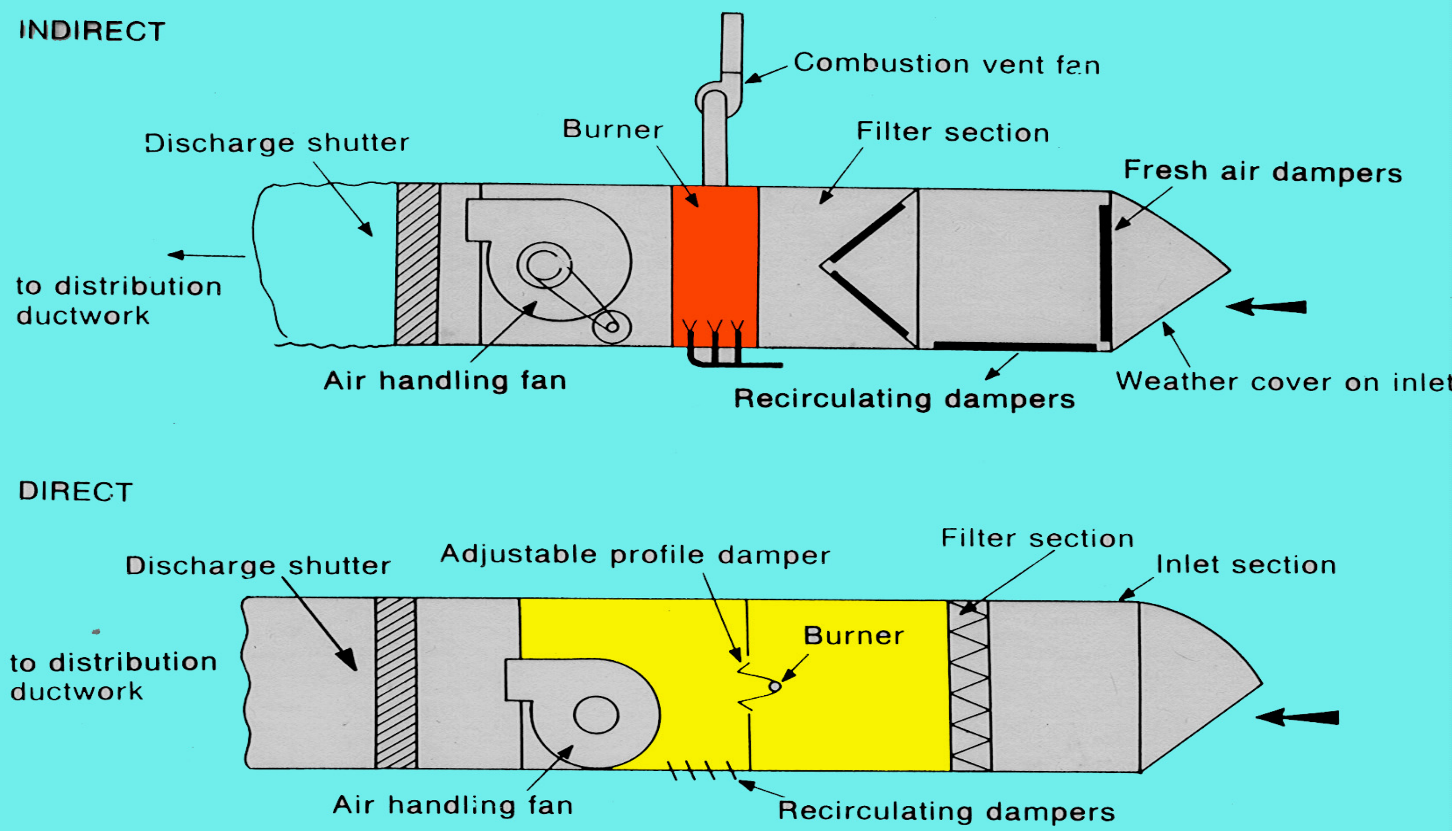

Figure 12.2 Gas-fired replacement-air units: The indirect-fired unit is equipped with a burner chamber and heat exchanger, so the replacement air stream and gas combustion process are separate. These units are equipped with recirculating dampers. The products of combustion of the direct-fired gas units are delivered to the workplace. If air is recirculated from the workplace, it must be introduced downstream of the burner; otherwise, fugitive air contaminants will be thermally degraded in the burner and delivered to the space. The direct-fired replacement air units are equipped with elaborate controls which permit their safe operation.

By-pass Steam System

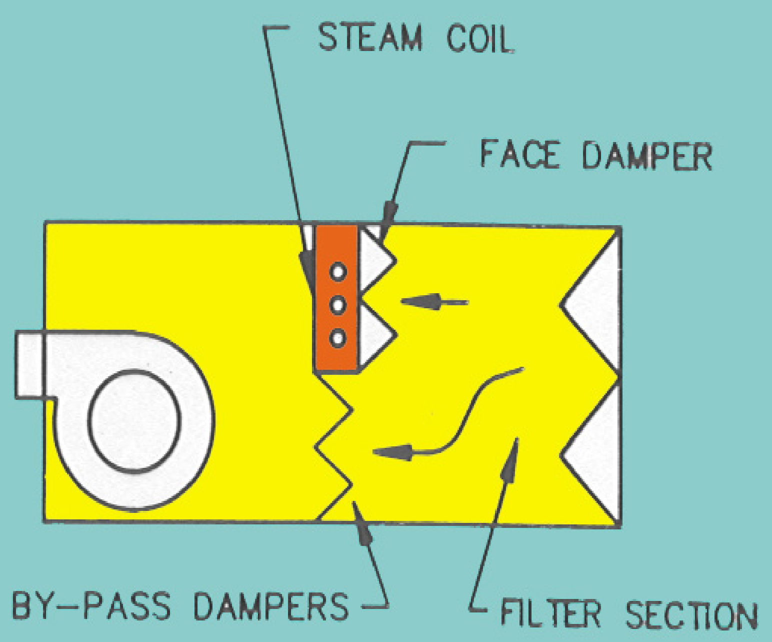

FIGURE 7-9 BY-PASS STEAM SYSTEM

Annual Heating Cost

$$C = \frac{0.154 Q d_g t c_f}{\eta H_f}$$

Where

C = heating cost, $/year

d_g = annual degree days at your location

t = hours/week replacement air system operates

c_f = cost of fuel

η = efficiency of heating unit

H_f = heat content of the fuel

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TABLE 7–7. Heating Degree Day Normals and Average Winter Temperatures

City	Albany	Boston	Chicago	Cleveland	Detroit	Minneapolis	NY	Phila-delphia	Pitts-burgh	St. Louis	Wash., DC
Avg Temp (F) Dec–Feb	24	22.4	25	28	25.9	16	33.2	33.3	29	32.2	33.4
Discharge Air Temp (F)	Heating Degree Days										
80	11782	10409	10613	11343	10959	13176	9284	9652	10797	8943	8422
79	11425	10049	10277	10982	10605	12826	8937	9300	10436	8624	8089
78	11062	9690	9940	10621	10256	12478	8596	8954	10076	8310	7764
77	10709	9242	9610	10265	9914	12135	8265	8619	9726	8003	7446
76	10356	8994	9283	9915	9581	11797	7938	8285	9379	7702	7139
75	10009	8652	8972	9570	9247	11475	7620	7959	9036	7413	6835
74	9669	8317	8656	9229	8920	11142	7308	7641	8702	7121	6538
73	9333	7790	8349	8898	8599	10816	7004	7328	8372	6839	6250
72	9007	7668	8046	8567	8291	10496	6706	7028	8050	6560	5974
71	8682	7354	7750	8248	7981	10180	6421	6728	7740	6289	5703
70	8364	7046	7468	7928	7678	9870	6146	6438	7429	6023	5438
69	8256	6749	7183	7617	7383	9567	5871	6158	7127	5767	5179
68	7750	6458	6905	7313	7100	9269	5606	5886	6833	5523	4929
67	7452	6175	6635	7016	6816	8975	5349	5618	6546	5277	4690
66	7162	5903	6373	6722	6543	8687	5101	5360	6272	5053	4455
65	6881	5633	6122	6445	6278	8410	4858	5109	5997	4822	4229
64	6607	5370	5875	6165	6020	8131	4621	4864	5734	4595	4014
63	6340	5118	5638	5897	5772	7858	4394	4628	5483	4379	3798
62	3081	4873	5399	5636	5533	7590	4176	4397	5234	4168	3588
61	5829	4643	5164	5381	5290	7339	3957	4172	5006	3963	3383
60	5586	4399	4936	5140	5054	7086	3747	3952	4769	3761	3182

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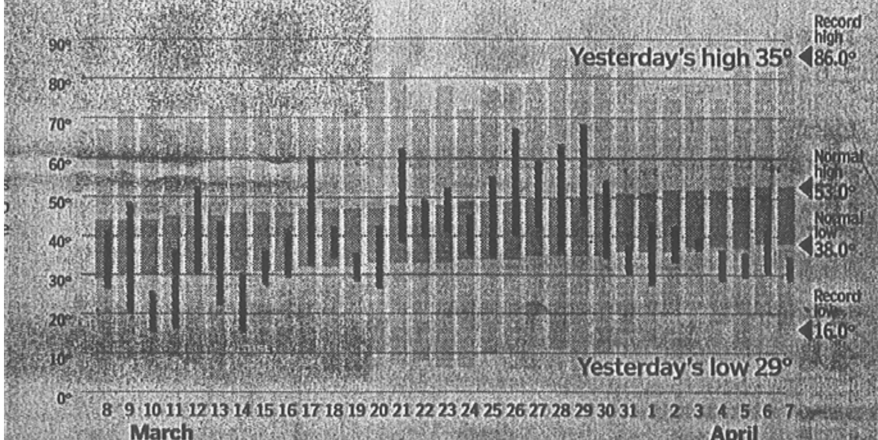
Read the Globe

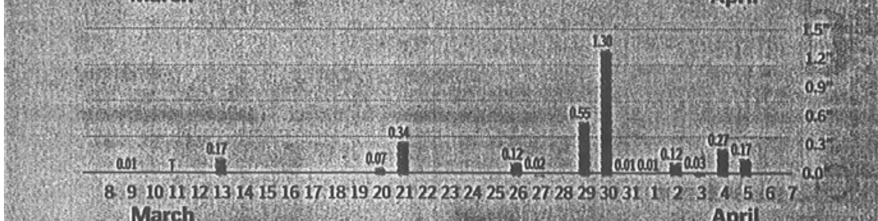
Boston's recent climate (valid at 7 p.m. EDT yesterday)

Yesterday	
High/low	35/29
Mean	32
Departure from normal	-14
Departure for month	-64
Departure for year	-391
7 p.m. rel. humidity	61%

Degree days	Heat	Cool
Yesterday	33	0
Monthly total	206	0
Normal to date	143	0
Season total	5464	0
Season normal	4989	0
Last year to date	4174	0

April readings	Actual	Norm.
Avg. daily high	39.6	52.3
Avg. daily low	31.1	37.0
YTD avg. temp.	29.9	34.1





24 Hr. Precipitation (valid at 7 p.m. EDT yesterday)

Yesterday	0.00"	Month to date	0.60"	Year to date	10.62"
Precip days in April	5	Norm. month to date	0.89"	Norm. year to date	11.96"

Climate data are compiled from National Weather Service records and are subject to change or correction.

Fuel Sources

Fuel	BTU/unit	Typical Efficiency (%)	Available BTU/unit
Coal	12,000 BTU/lb	50	6,000
Oil	142,000 BTU/gal	75	106,500
Gas – Direct Fired	1,000 BTU/ft^3	90	900
Gas – Indirect Fired	1,000 BTU/ft^3	80	800

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Assume Oil in Boston

- Cost = $3.50/gal
- Degree days = 5633 @ 65 F
- Full-time operation (168 h/wk)

$$C = \frac{0.154 Q d_g t c_f}{\eta H_f}$$

C = 0.154(5633 dd)(168 h/wk)($3.50/gal)(Q)/106,500 BTU/gal

= $4.80 per cfm per year to heat replacement air in Boston

For 40 hours/week, ~ $1/cfm/year

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Let's Revisit our TCE Example

- Assume 40 h/week operation, $1/cfm/year

GEV - $500,000 per year

LEV – canopy hood - $6,300 per year

LEV – slot hood - $2,500 per year

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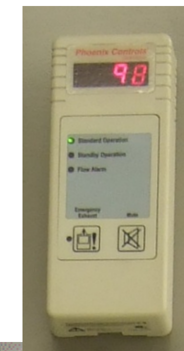
Payback Period

- Assume that the LEV system with a slot hood cost $20,000 more than the GEV system

PP = $20,000/($500,000 - $2,500/year)

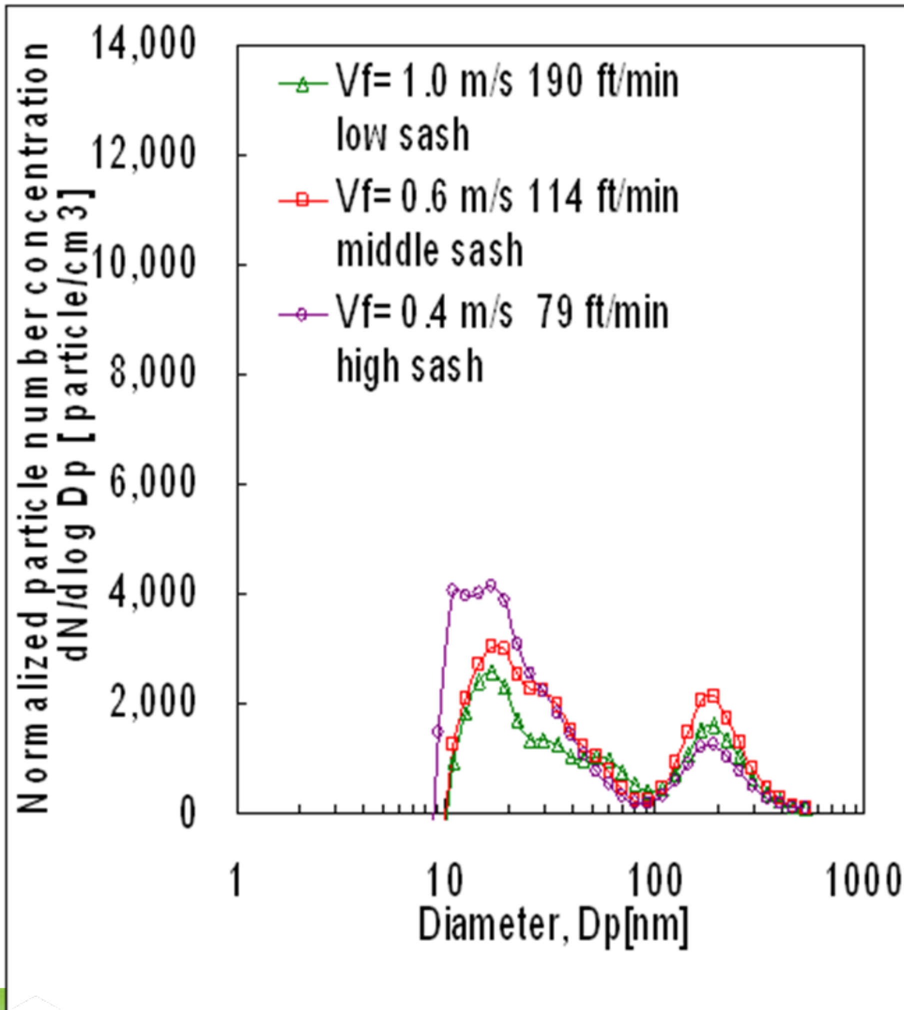
= 0.04 years = 2 weeks

Another Example – Fume Hoods for Nanoparticles

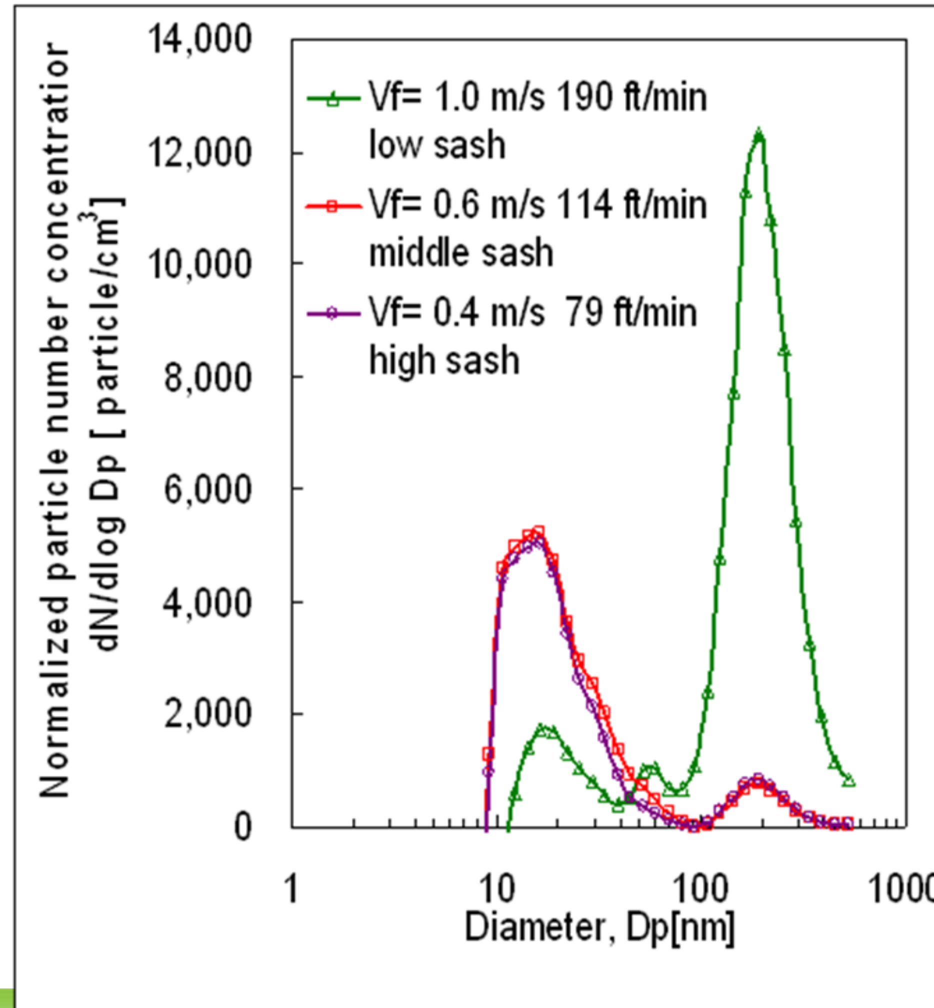


Breathing Zone- Conventional Hood

Transferring 100g Al_2O_3



Pouring 100g Al_2O_3



Note: Background concentration was subtracted.

Airflow Pattern

Outside hood

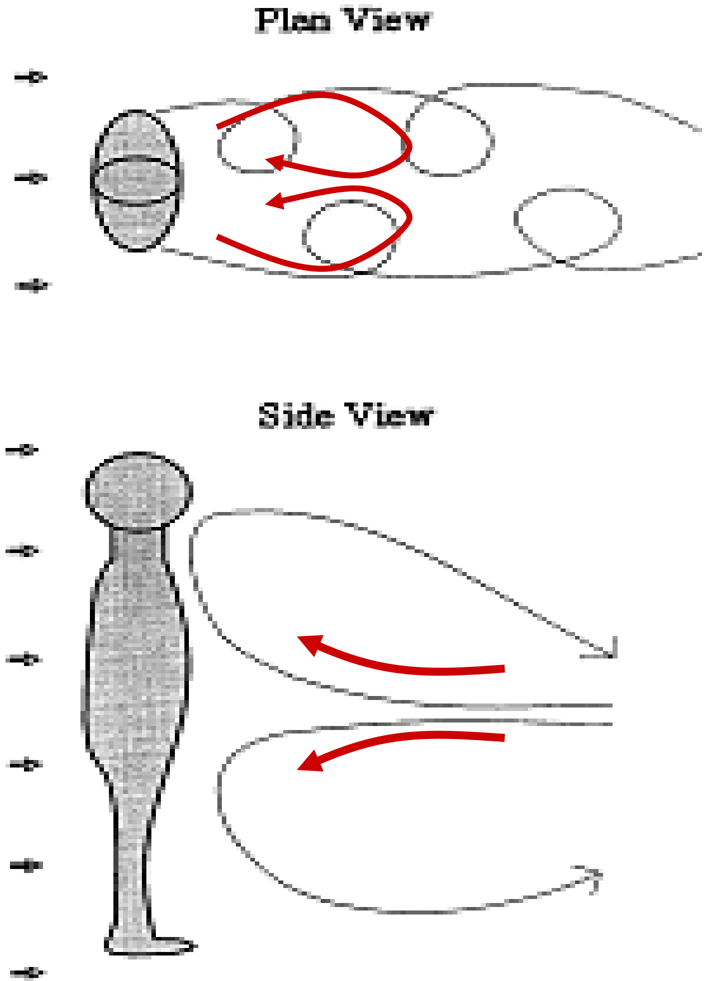


FIGURE 13. Airflow structure downstream of the mannequin

Inside hood

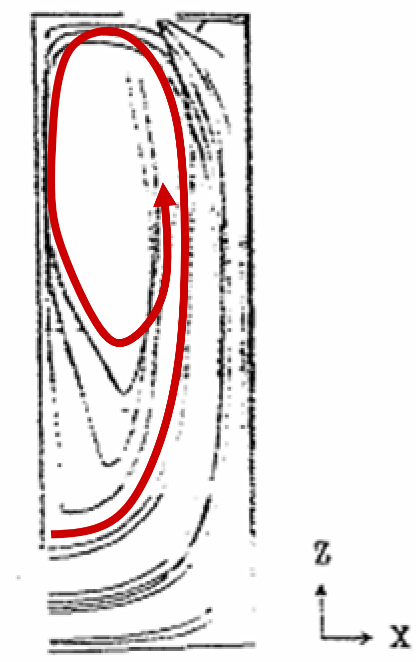


FIGURE 7. STREAMLINES IN USF FUME HOOD WITH 50% SASH OPENING

Reference: C Pathanjali and M Rahman, IEEE 1996

Reference: Kim, AM. IND. HYG. ASSOC. J. 52(7):287-296 (1991)

Alternatives to Conventional Hoods

- Biological safety cabinets
  - Work well, but still high air flow
- "Nano" hoods
  - Specifically designed for handling NPs
  - Very low air flow
  - Very high containment efficiency

Optimizing energy use while protecting workers and the environment

- Use TUR to eliminate the need for exhaust ventilation
- If you must use exhaust ventilation, use LEV instead of GEV whenever possible
- When using LEV, have a knowledgeable ventilation engineer design the best system
- Optimize your replacement air system
- Pay attention to maintenance!

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Thank You!

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