Engineering Controls to Reduce Formaldehyde Exposures: What works, what doesn't, and why?

Frank R. Demer, MS, CIH, CSP
University of Arizona, Tucson, AZ 85721

All projects usually begin with identification of problem to be solved

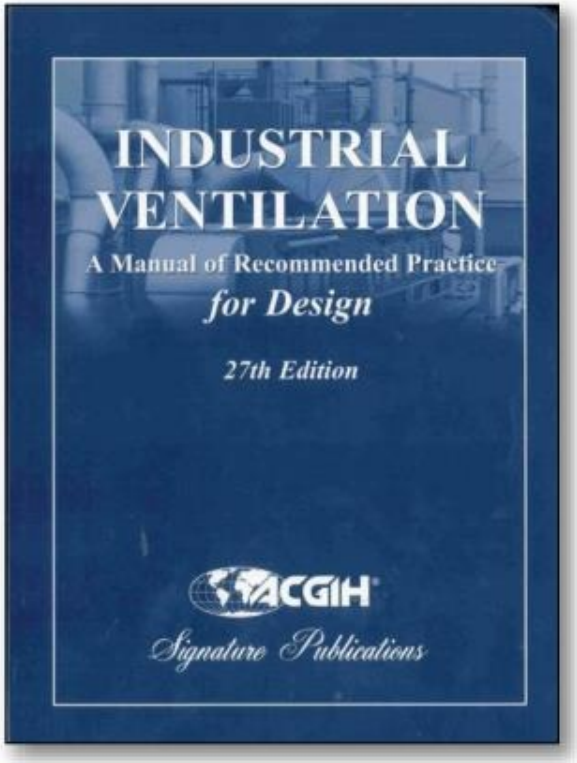
GROSS ANATOMY - THE PROBLEM

The Problem

- Preserved donors needed for extended dissection
  - against decomposition, microbial contamination, desiccation
- Traditional preservations method include formaldehyde
  - irritant, sensitizing gas and known human carcinogen
  - very low OEL
- Close access to donors required, without significant formaldehyde exposure, in teaching environment
  - exposure primarily by inhalation and also skin contact
  - relative quite required for communication

Hierarchy of Exposure Controls

- Elimination/Substitution
- Process Modification
- Engineering Controls
- Administrative Controls
- Personal Protection



ACGIH Industrial Ventilation – A Manual of Recommended Practices (1951 - 2010)

ENGINEERED VENTILATION CONTROLS – APPLYING PROVEN ESTABLISHED PRINCIPLES

Bibliography of Articles on Formaldehyde

- American Association of Anatomists website
- http://www.anatomy.org/sites/default/files/pdfs/Formaldehyde_Bibliography_6-11.pdf

Engineered Ventilation Controls

- Dilution “General” ventilation
  - Dilution of contaminated air with uncontaminated air
- Local exhaust
  - Captures contaminants at generation point(s) and remove from workplace through duct system

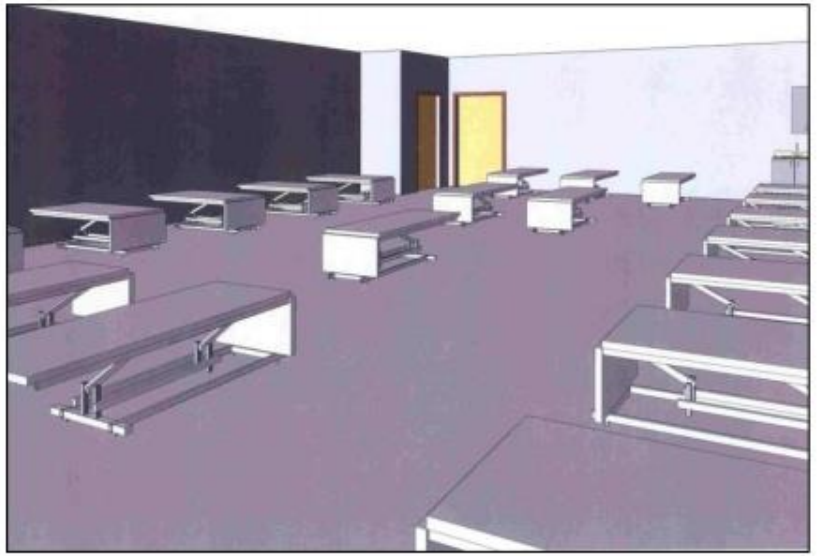
Dilution Ventilation Criteria

(per ACGIH Vent. Manual)

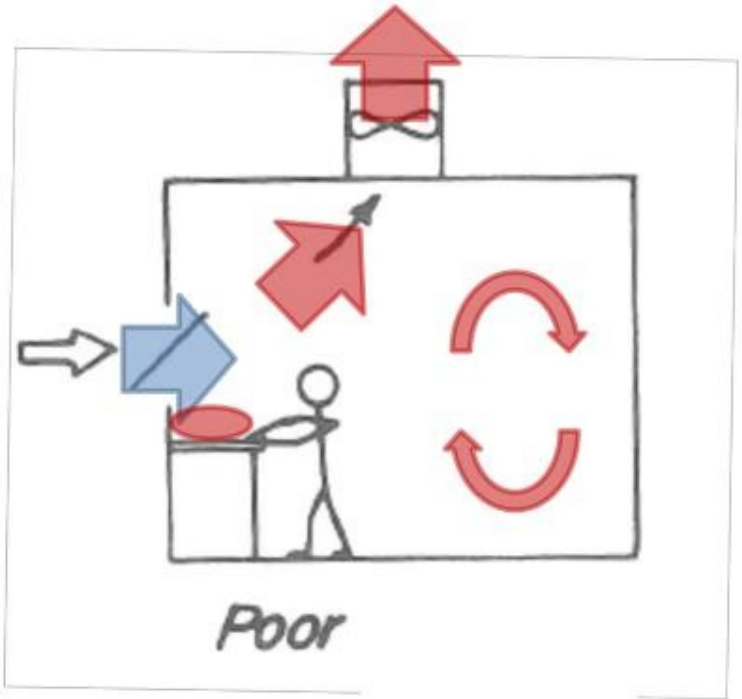
- Toxicity of contaminant must be low ✗
  - Typically used to control organic liquids with OELs >100 ppm
- People must be far enough away from source OR ✗

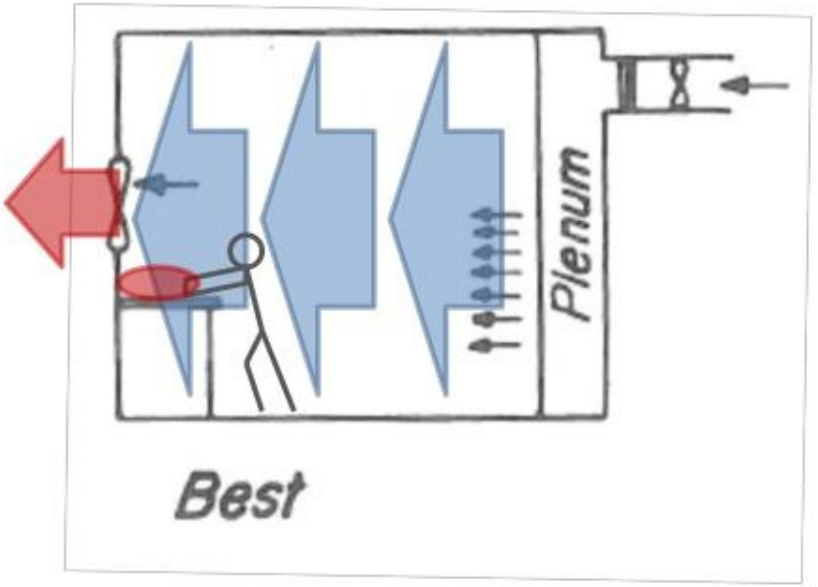
  Generation of contaminant must be in low concentrations so that workers will not have exposures >OEL ✗
- Contaminant generation must not be too great or dilution airflow rate will be impractical ✗
- Generation of contaminants must be reasonably uniform

Dilution Ventilation Alone is Inadequate



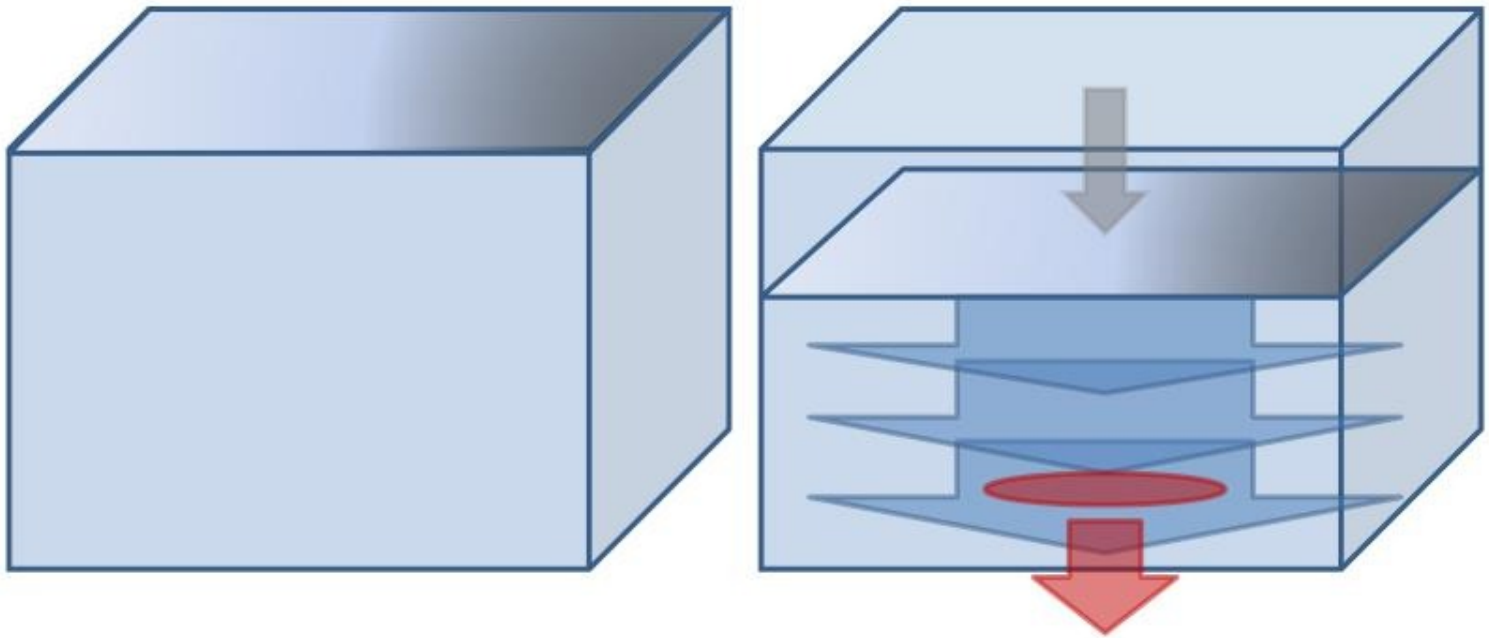
Dilution Ventilation as Supplemental Control





Dilution Ventilation Maximized By:

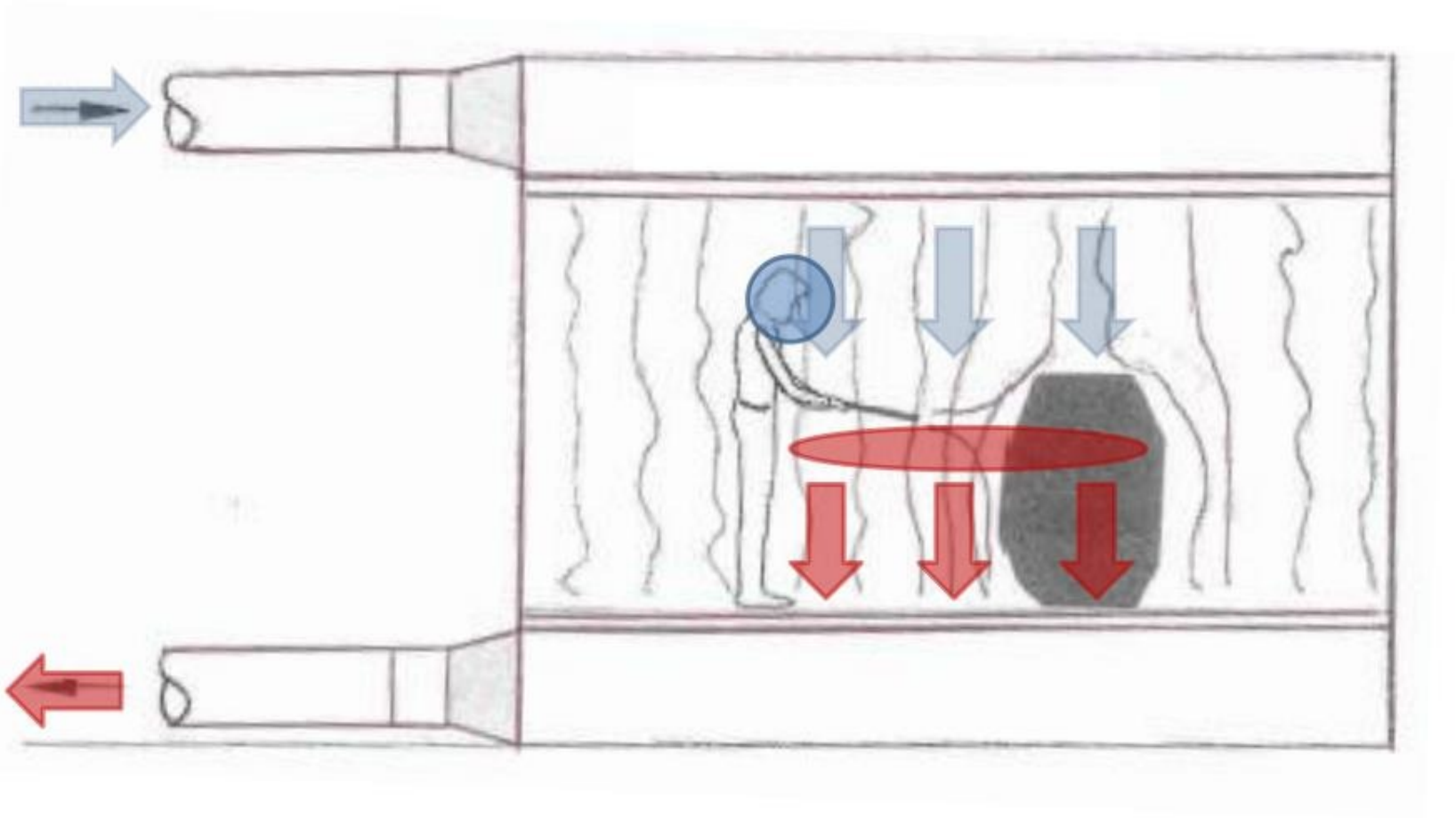
- Lowering ceiling to reduce room volume
- Introducing and exhausting air in a top to bottom “plug” fashion
- To increase effective room air exchanges



Lowering Ceiling

9 ft (2.7 m)

Top to Bottom “Plug” Airflow



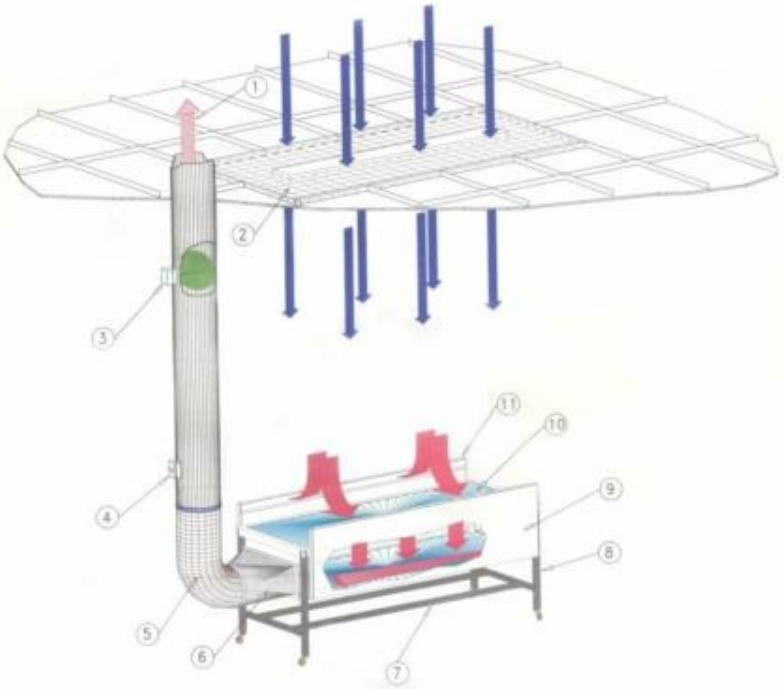
Is Formaldehyde Heavier Than Air?

- Specific density of formaldehyde gas = 1.067 (air = 1)
- Specific density of 10 ppm formaldehyde in air =

$$\frac{(10\ \text{ppm} \times 1.067) + (999{,}990\ \text{ppm} \times 1)}{1{,}000{,}000\ \text{ppm}} = 1.00000067$$

Low ppm formaldehyde-contaminated air does not sink – it diffuses in all directions and moves with air currents

Top to Bottom “Plug” Airflow

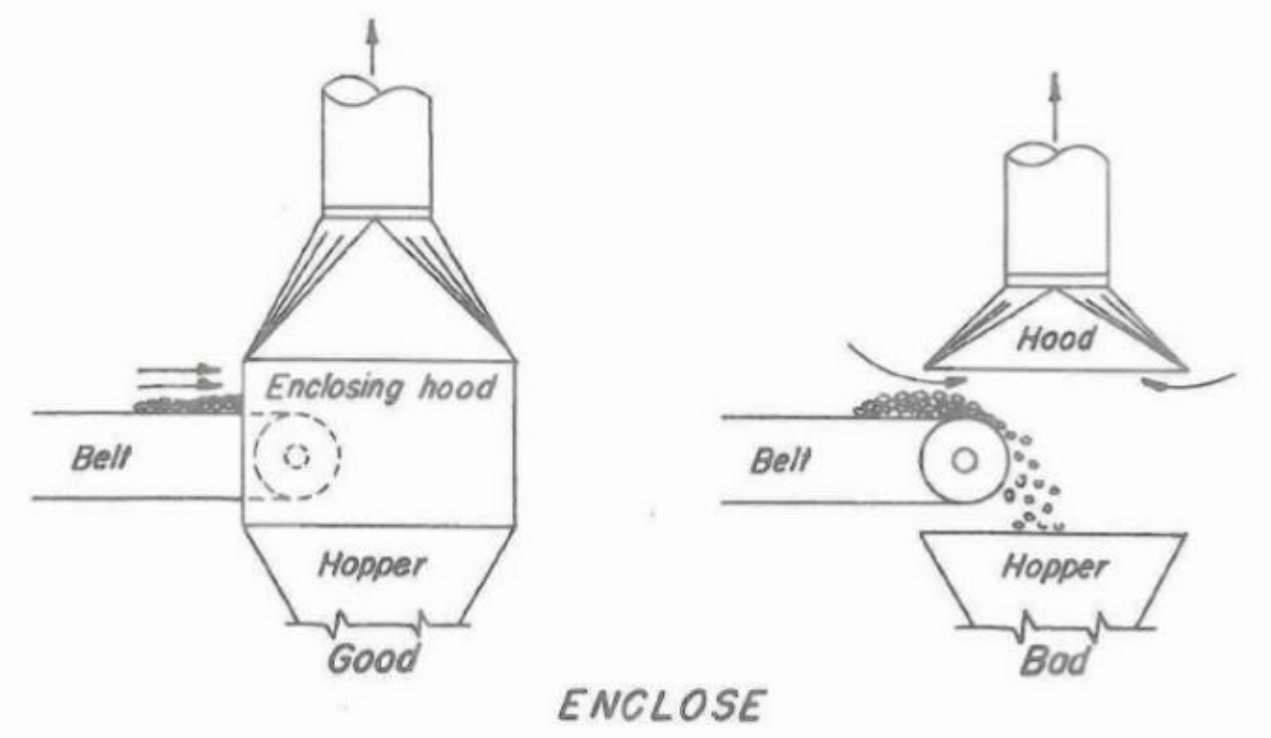


Local Exhaust

Local Exhaust Hood Design Principles

(per ACGIH Vent. Manual)

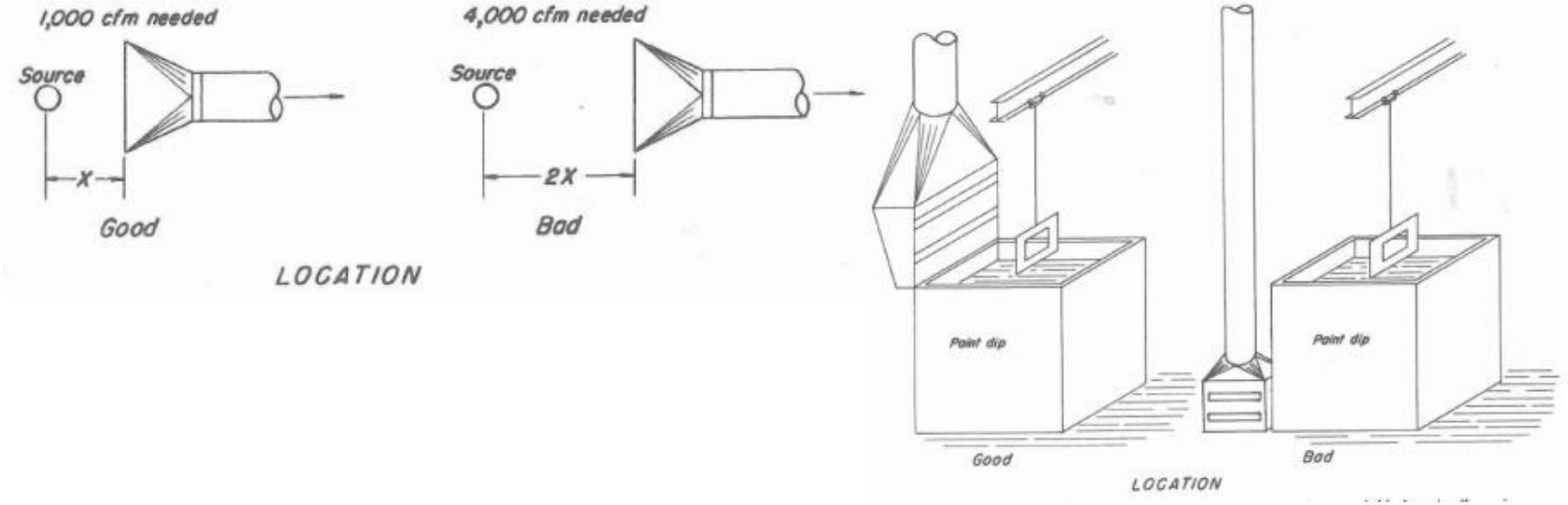
- Minimize all opposing air motion about the process
- Enclose operation as much as possible



Local Exhaust Hood Design Principles

(per ACGIH Vent. Manual)

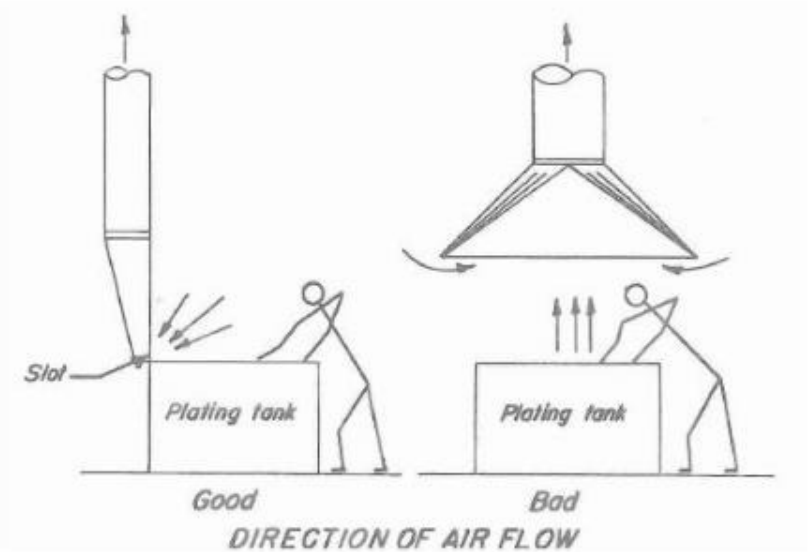
- Minimize all opposing air motion about the process
- Enclose operation as much as possible
- Place hood as close to source as possible



Local Exhaust Hood Design Principles

(per ACGIH Vent. Manual)

- Minimize all opposing air motion about the process
- Enclose operation as much as possible
- Place hood as close to source as possible
- Locate hood so contaminant is removed away from breathing zone of user



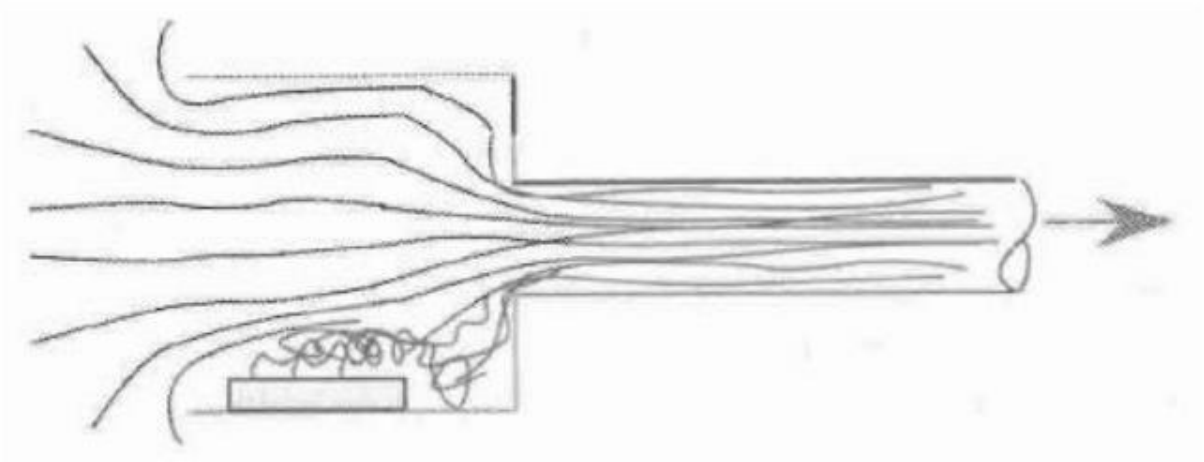
Local Exhaust Hood Design Principles

(per ACGIH Vent. Manual)

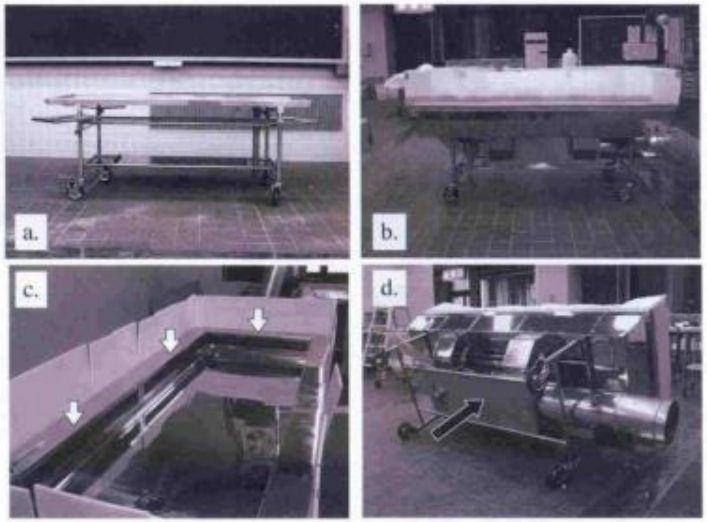
- Minimize all opposing air motion about the process
- Enclose operation as much as possible
- Place hood as close to source as possible
- Locate hood so contaminant is removed away from breathing zone of user
- Create air flow past source sufficient to capture contaminant in hood

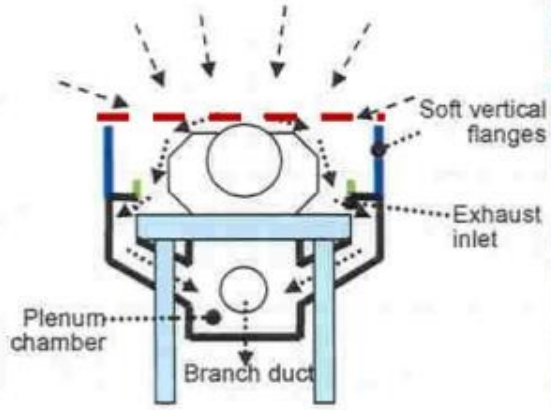
Local Exhaust

- Enclosing hoods



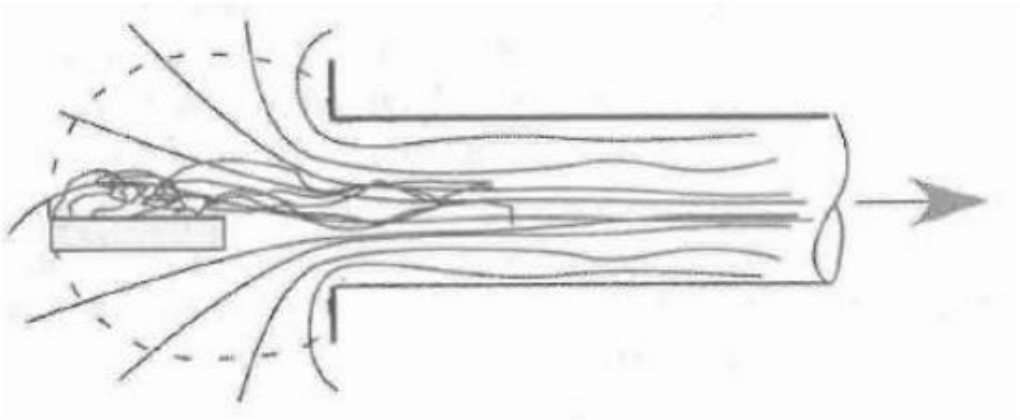
Enclosing Hood Anatomy Table





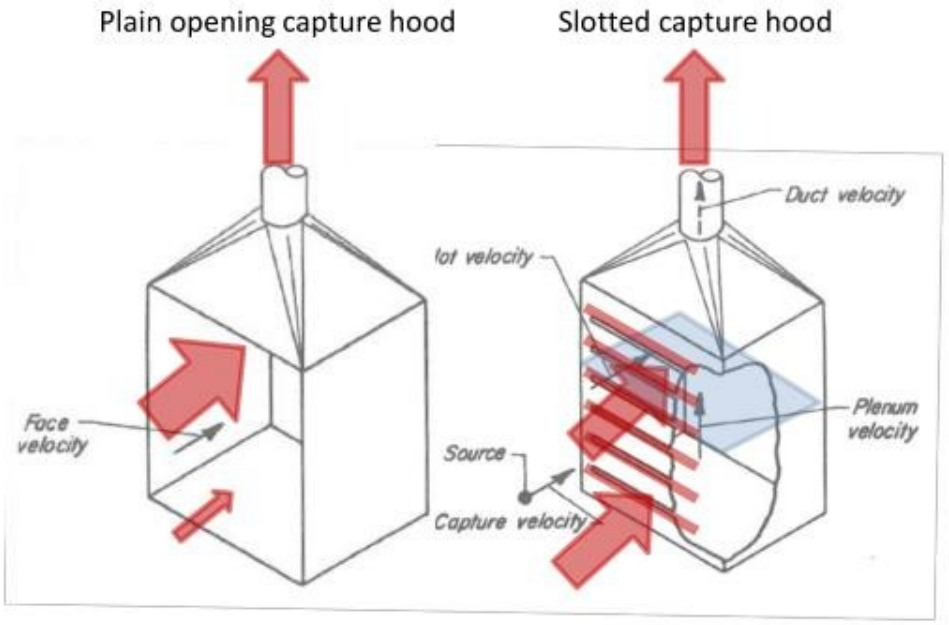
Local Exhaust

- Enclosing hoods
- Capturing hoods



Local Exhaust

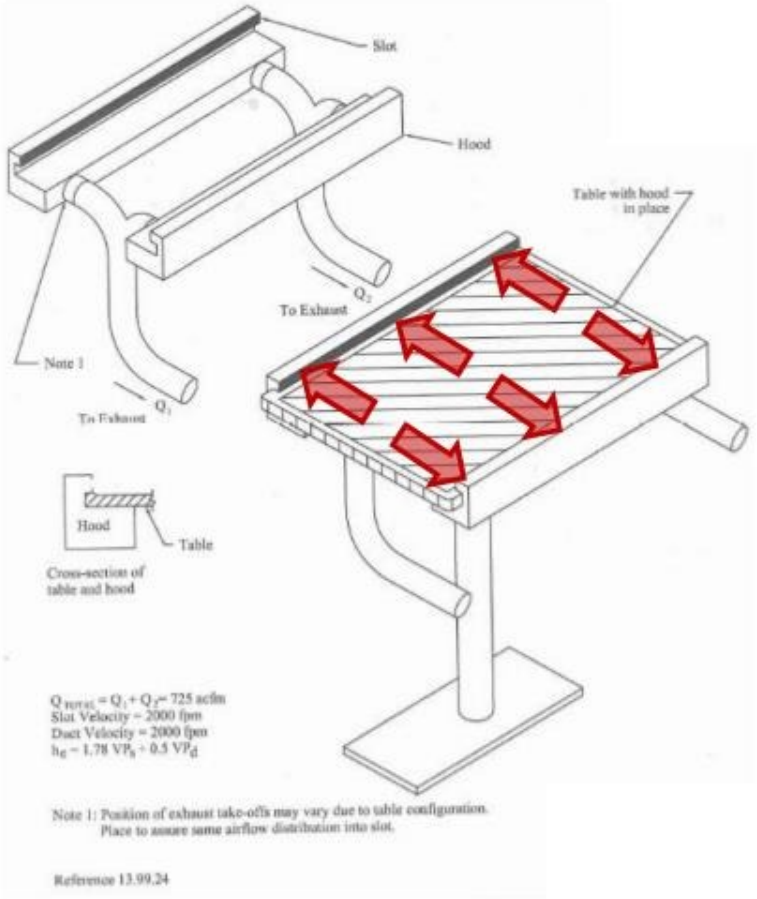
- Enclosing hoods
- Capturing hoods
  - Plain opening
  - Slot hood



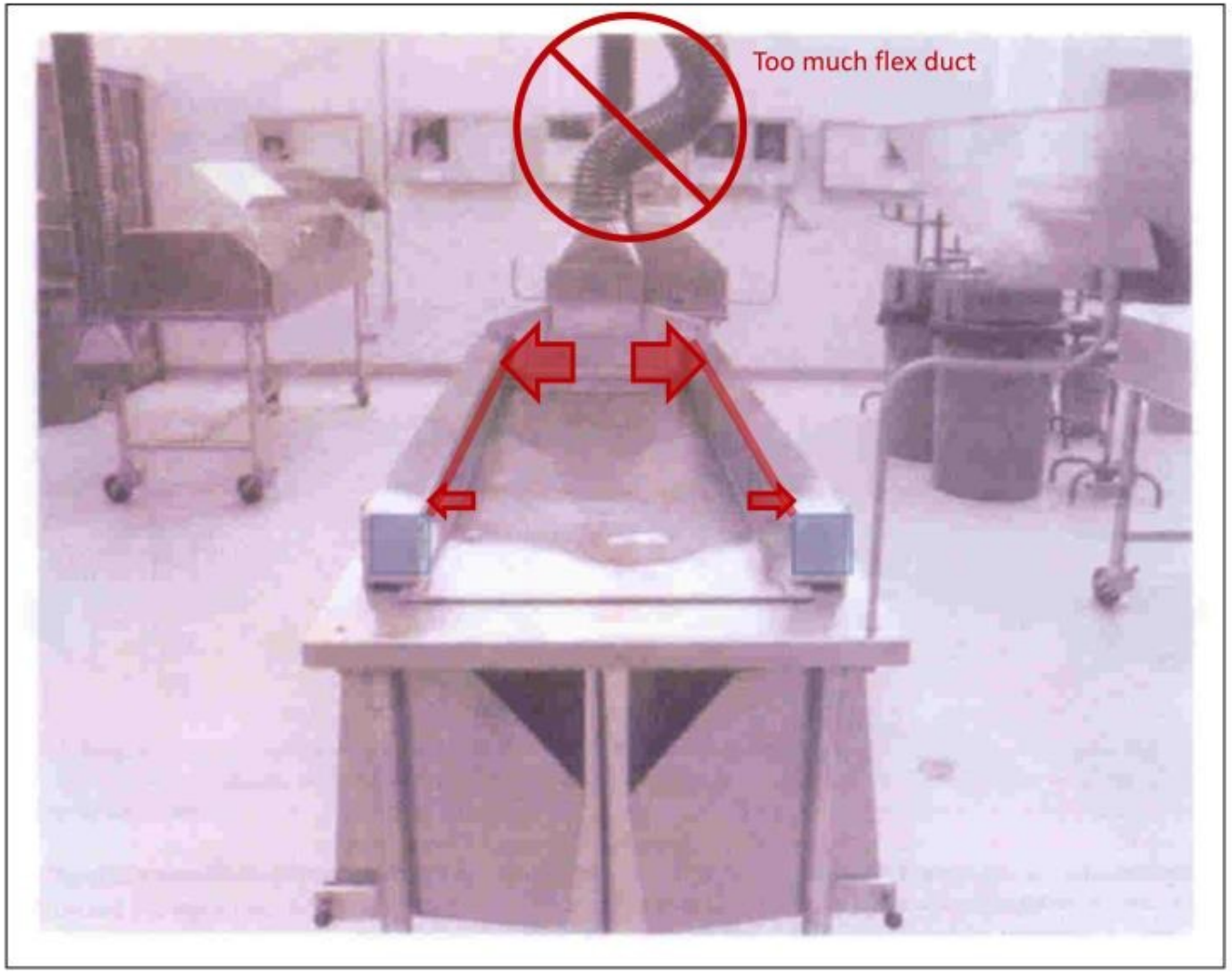
- To force uniformity of air flow across, and along length, of slots
- Plenum cross-sectional area must be > 2 times slot area

Side Slot Mortuary Table

(per ACGIH Vent. Manual)

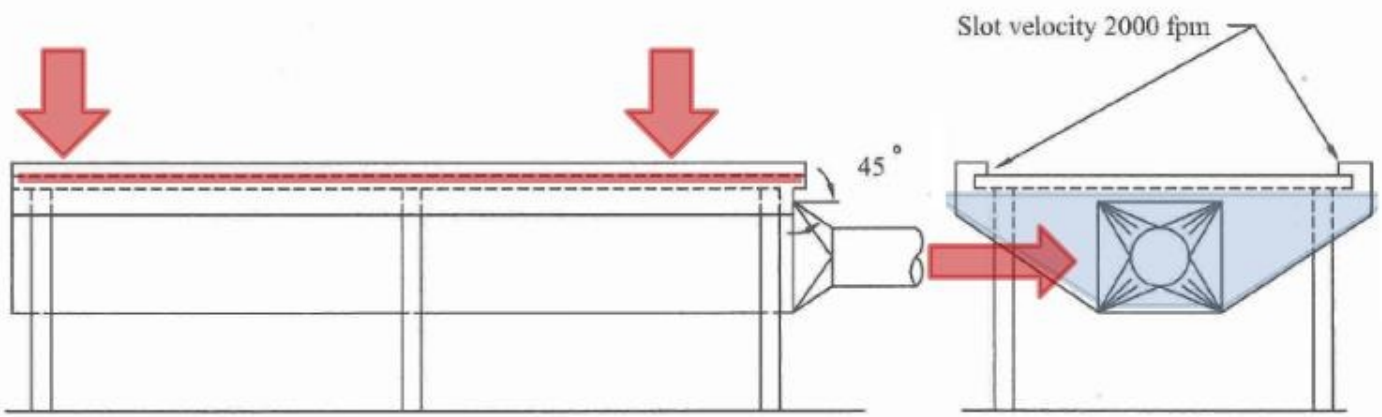


Undersized Side Slot Plenum ✗



Side Slot Table

(per ACGIH Vent. Manual)



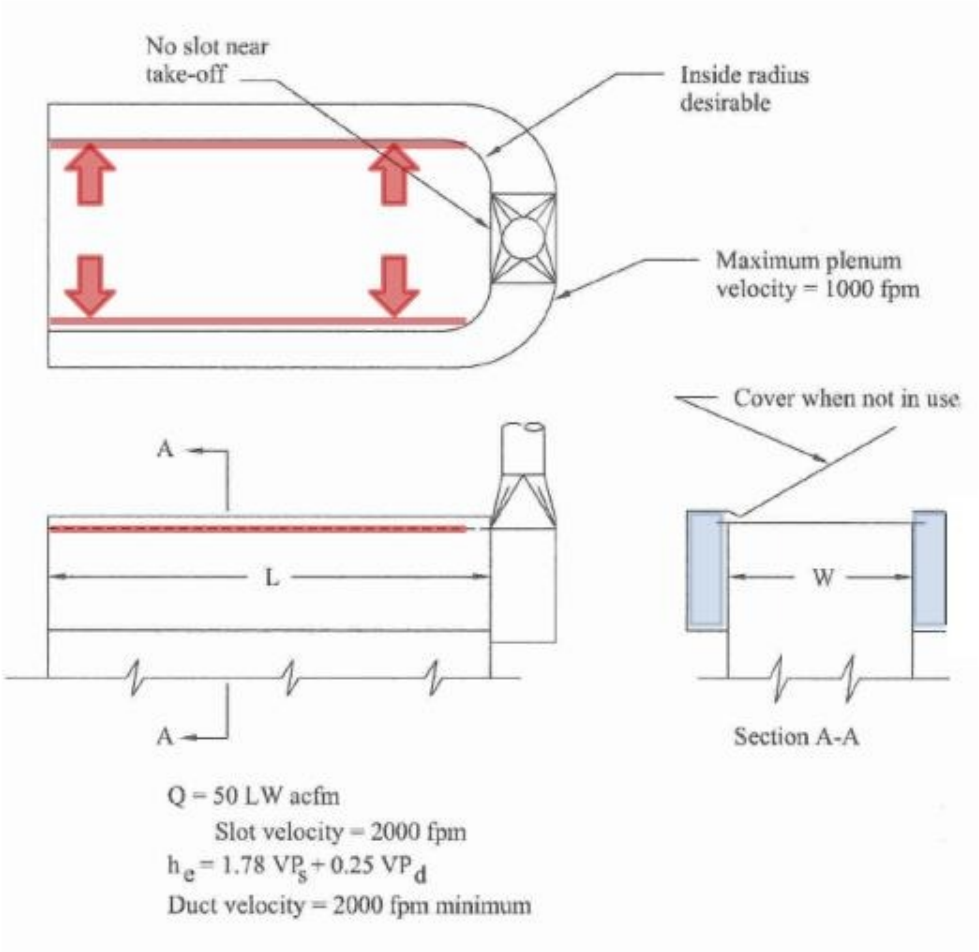
Q = 50-100 acfm/ft^2 of table top.
Minimum duct velocity = 2000 fpm
$h_e = 1.78\ VP_s + 0.25\ VP_d$
Note: See "Open Surface Tanks", VS-70-01 and VS-70-02 for other suitable slot types. Airflow rate may be calculated on dilution basis if data are available.
Maximum plenum velocity = 1/2 slot velocity.
Large plenum essential for good distribution.

Perimeter Slot Anatomy Table

Table too wide

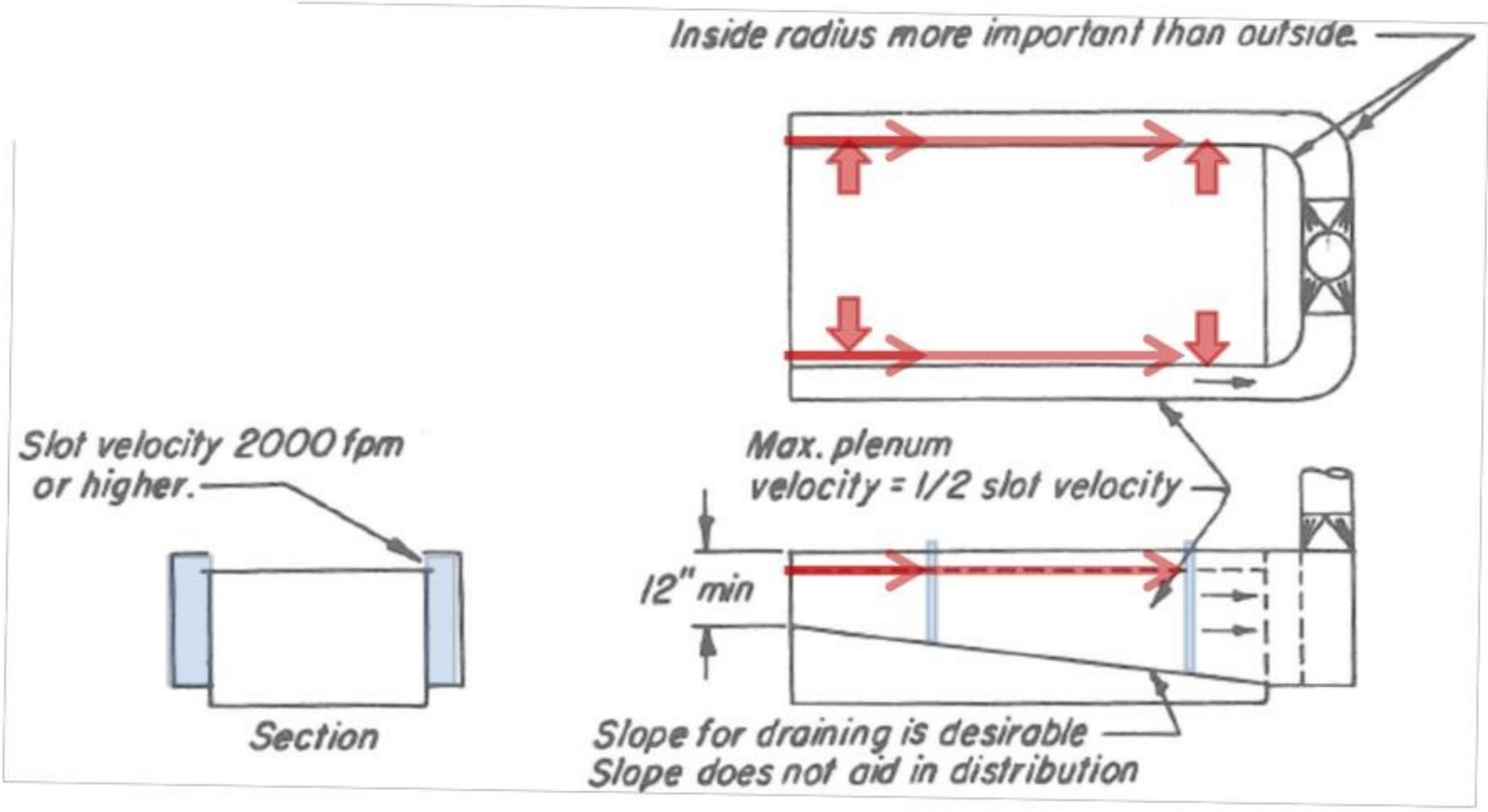
Solvent Degreasing Tank Side Slot Ventilation

(per ACGIH Vent. Manual)

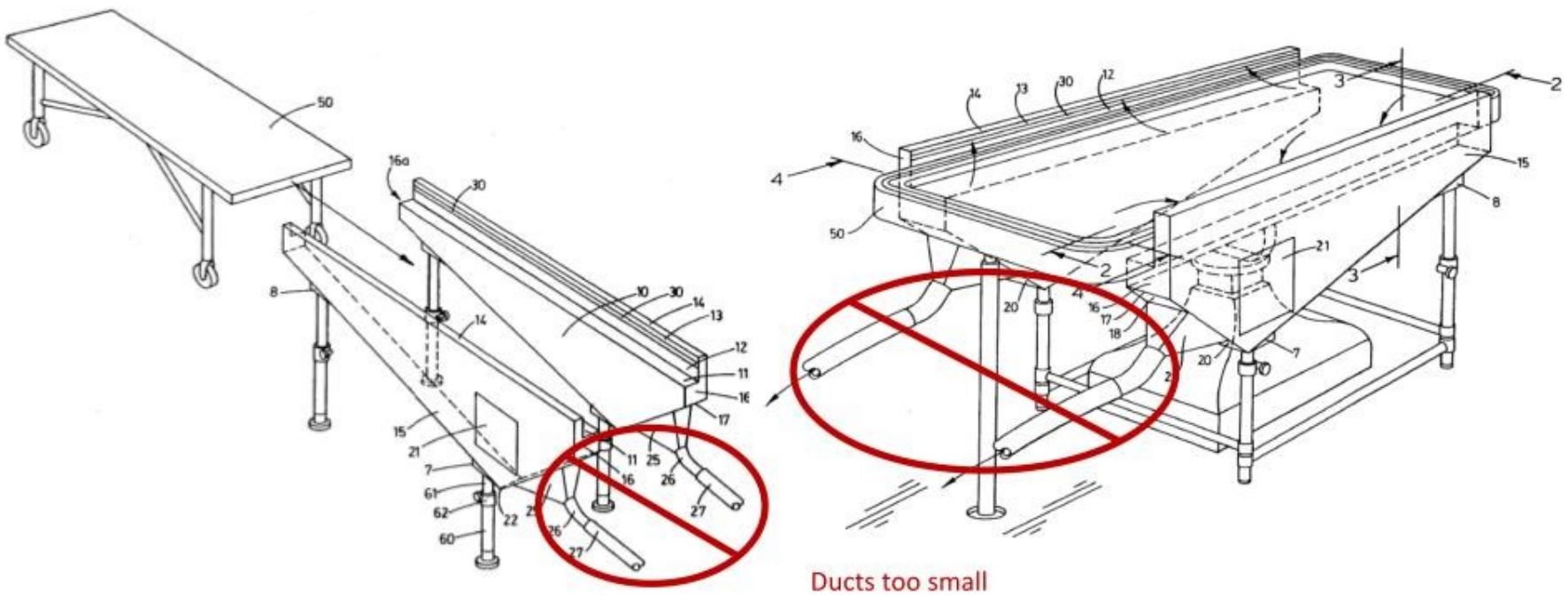


Solvent Degreasing Tank Ventilation w/ Side Slots and Sloping Plenum

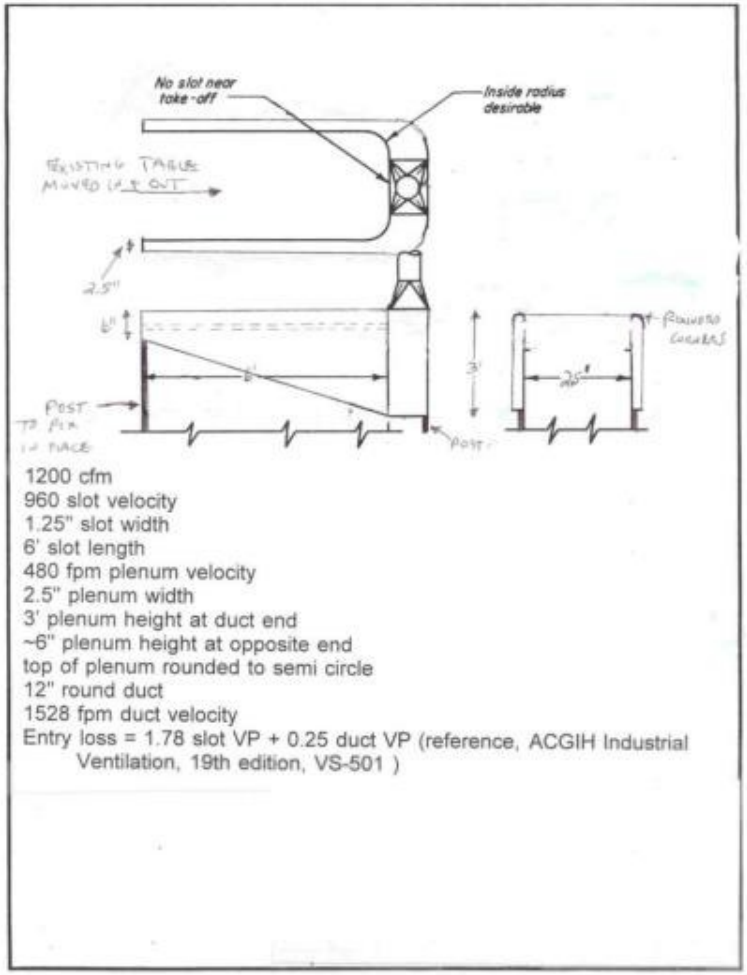
(per ACGIH Vent. Manual)



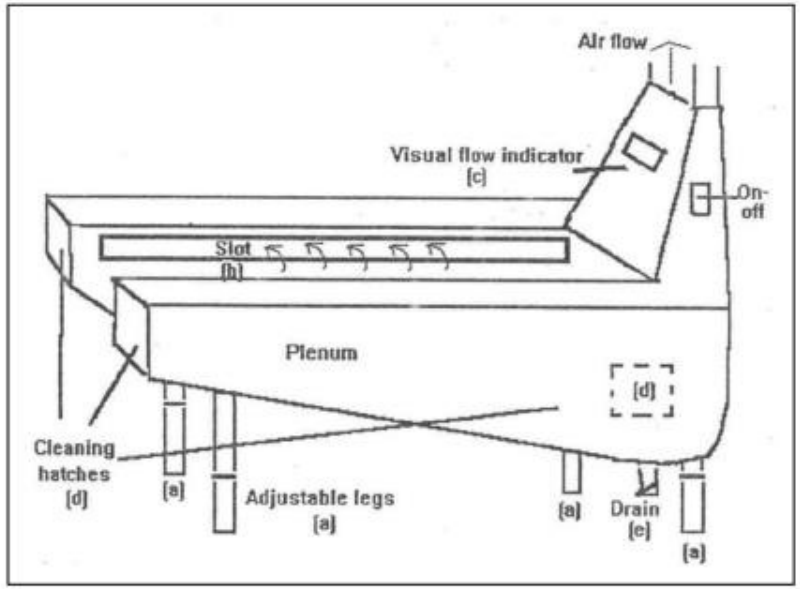
Side Slot Anatomy Station and Table w/ Sloping Plenum



Side Slot Anatomy Table Station w/ Sloping Plenum



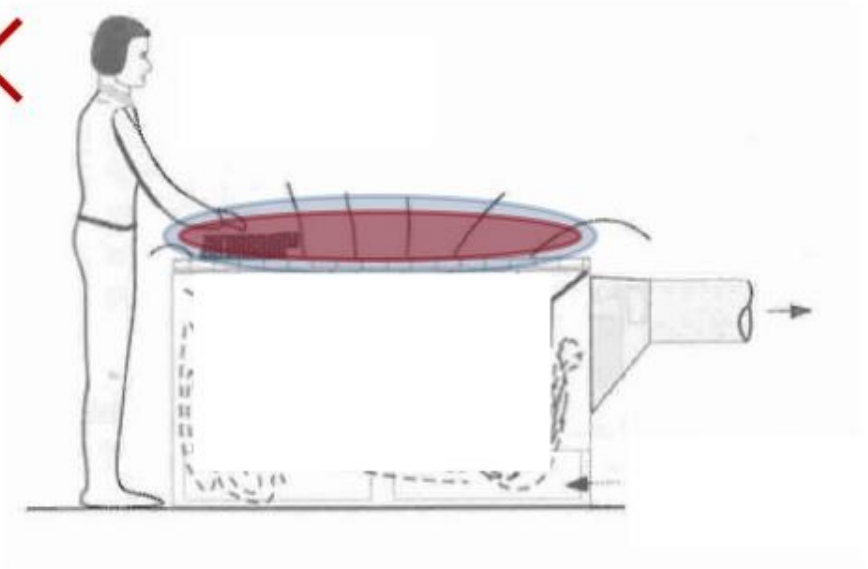
1200 cfm
960 slot velocity
1.25" slot width
6' slot length
480 fpm plenum velocity
2.5" plenum width
3' plenum height at duct end
~6" plenum height at opposite end
top of plenum rounded to semi circle
12" round duct
1528 fpm duct velocity
Entry loss = 1.78 slot VP + 0.25 duct VP (reference, ACGIH Industrial Ventilation, 19th edition, VS-501)



Side Slot Embalming Table w/ Sloping Plenum

Local Exhaust

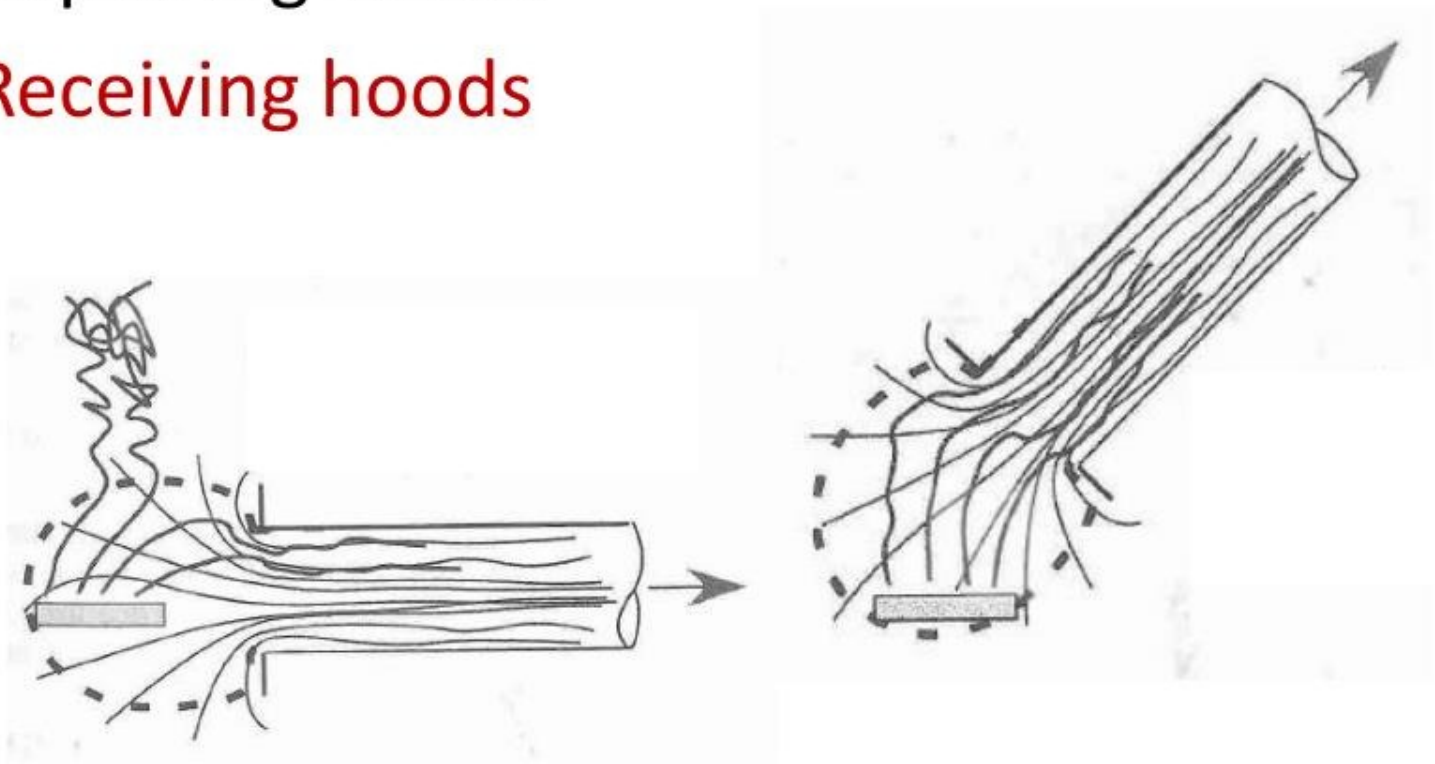
- Enclosing hoods
- Capturing hoods
  - Slot hood
  - Downdraft hood ✕



Downdraft Anatomy Tables ✗

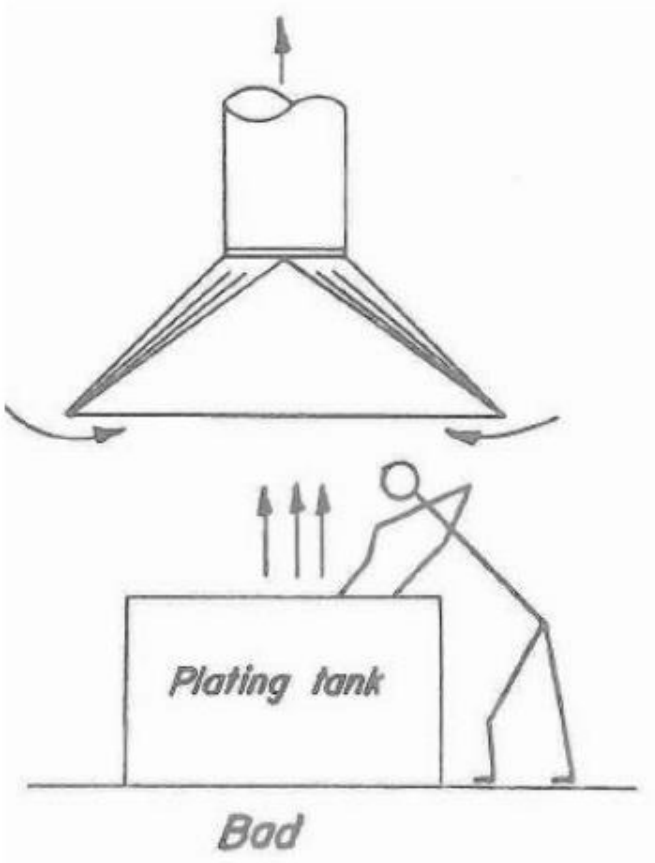
Local Exhaust

- Enclosing hoods
- Capturing hoods
- Receiving hoods



Local Exhaust

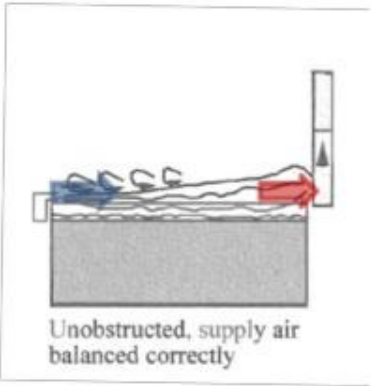
- Enclosing hoods
- Capturing hoods
- Receiving hoods
  - Canopy hood ✗



Canopy Hood Over Embalming Table ✗

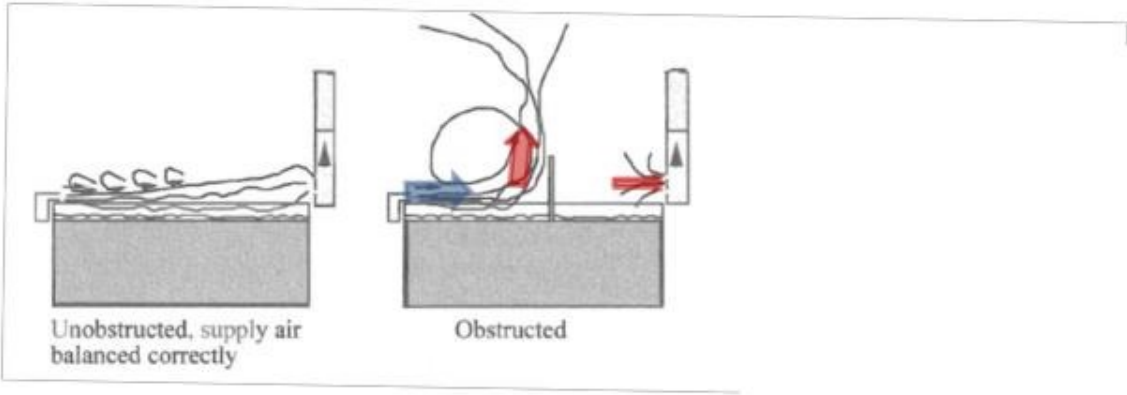
Local Exhaust

- Enclosing hoods
- Capturing hoods
- Receiving hoods
  - Canopy hood
  - Push-pull hood



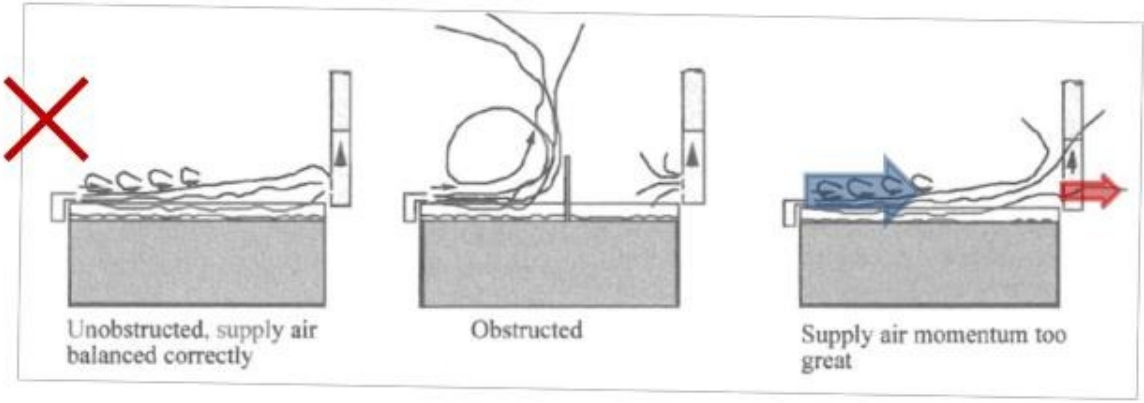
Local Exhaust

- Enclosing hoods
- Capturing hoods
- Receiving hoods
  - Canopy hood
  - Push-pull hood



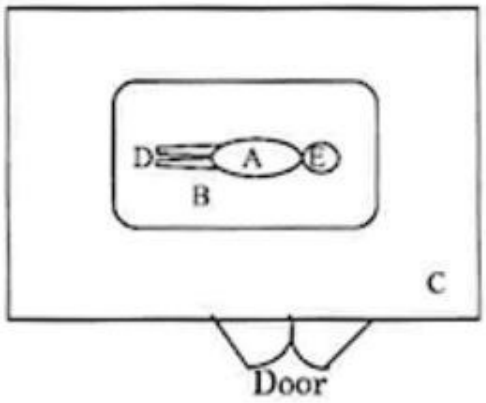
Local Exhaust

- Enclosing hoods
- Capturing hoods
- Receiving hoods
  - Canopy hood
  - Push-pull hood

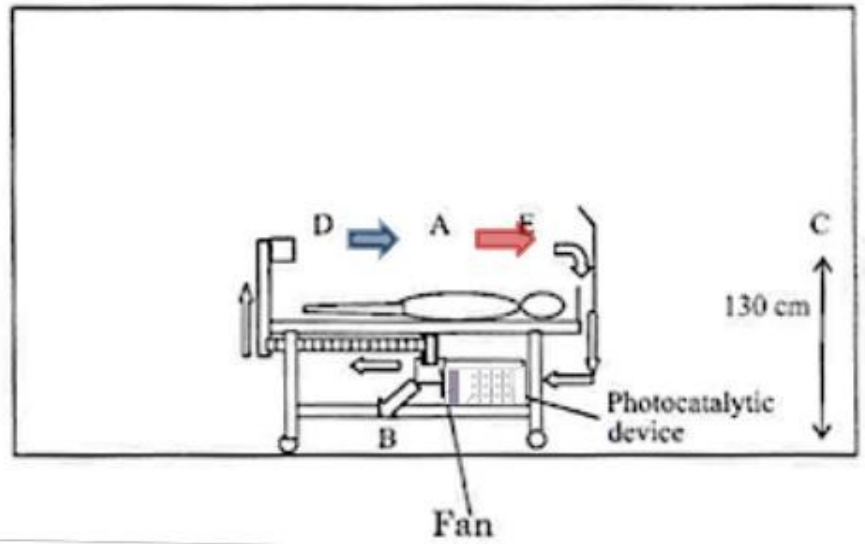


Push-Pull Hood Anatomy Table

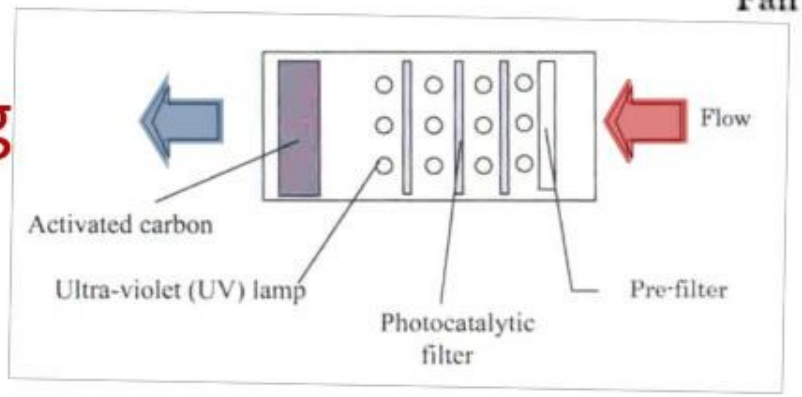
Plane figure



Dimensional figure



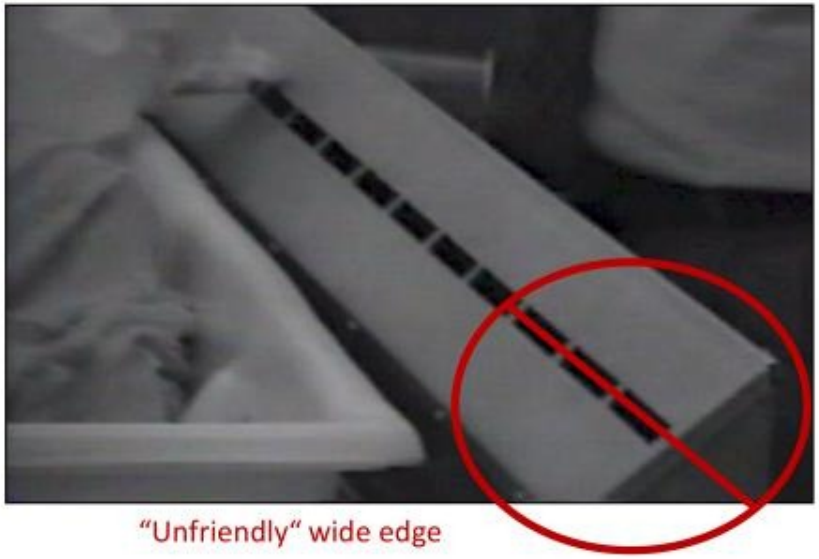
Recirculating



Engineered Ventilation Controls

- Dilution ventilation
- Local exhaust
  - Enclosing hoods \
  - Capturing hoods } Recirculating or 100% exhaust
  - Receiving hoods /

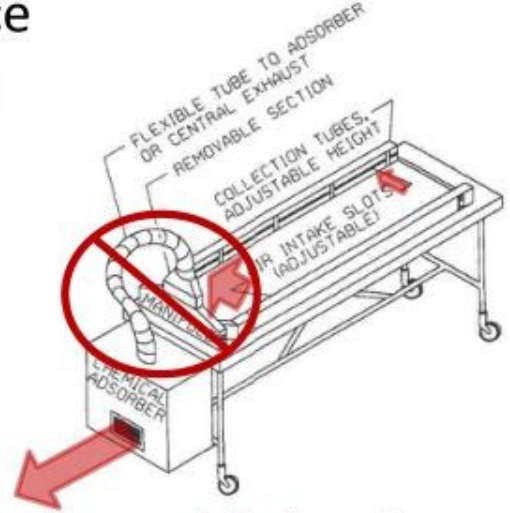
Recirculating Side Slot Table



"Unfriendly" wide edge

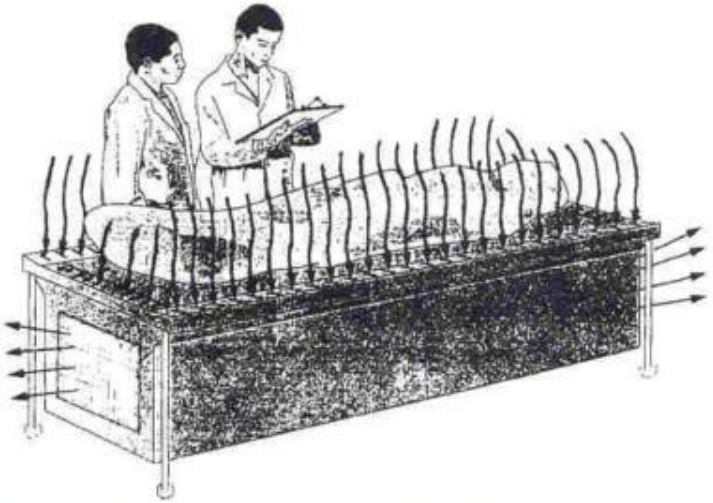
- Formaldehyde filtering media - expensive, requires frequent changing
- Reliable and sensitive monitoring system required to detect filter breakthrough
- Noisy w/ significant room air turbulence

Not Ideal



Duct too small – too much flex duct – plenum too small

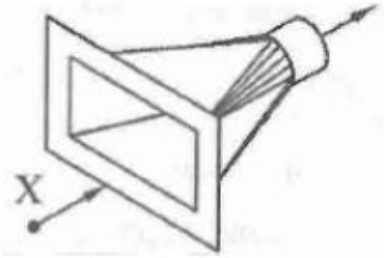
Recirculating Downdraft Table

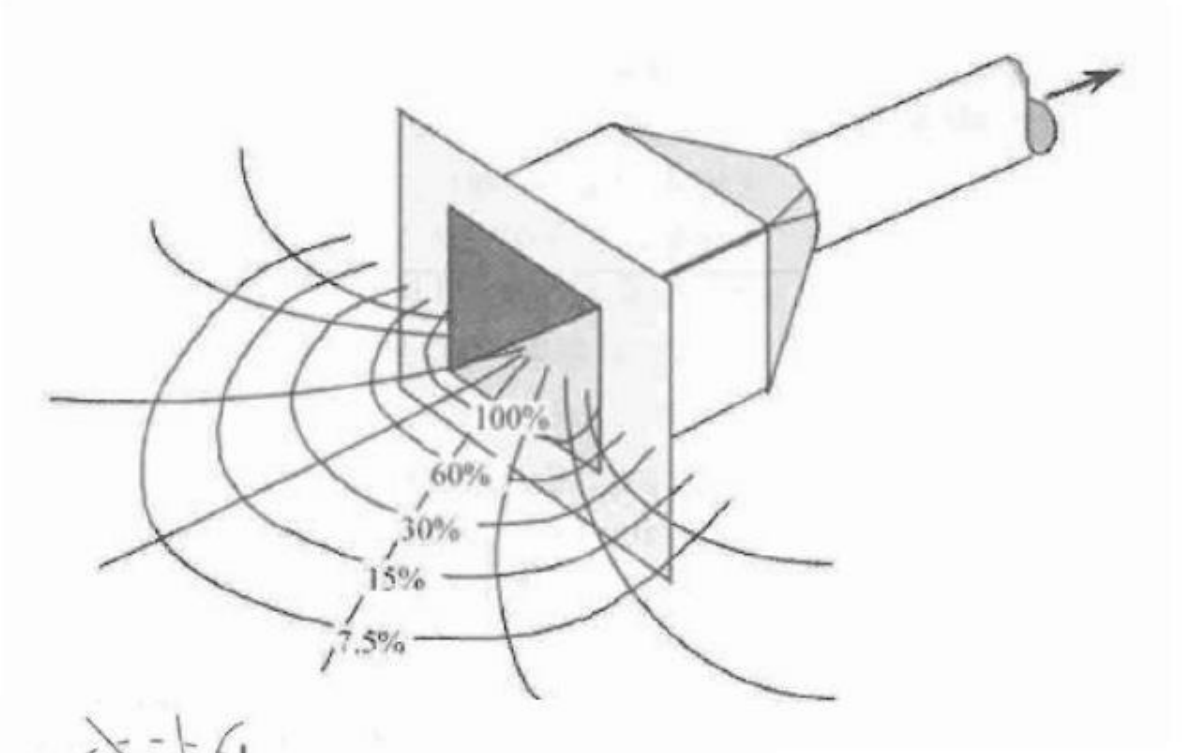


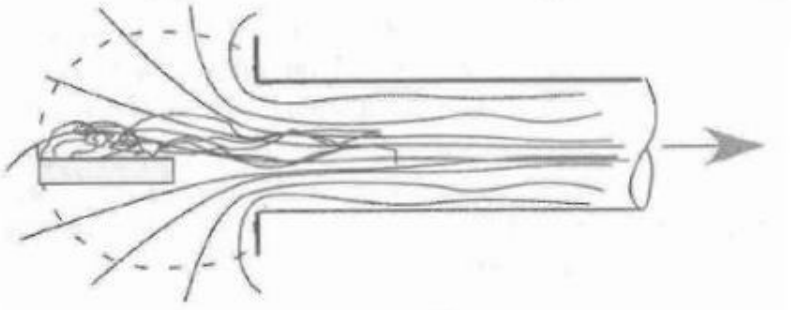
100% Exhaust

- Preferred to exhaust to outside
- 5-10% less make-up air than exhaust to keep room negative in pressure
  - Note - recirculating side slot table will require some general exhaust (5 – 10% of supply) to keep lab negative in pressure to surrounding areas
- Air flow sufficient to adequately capture formaldehyde

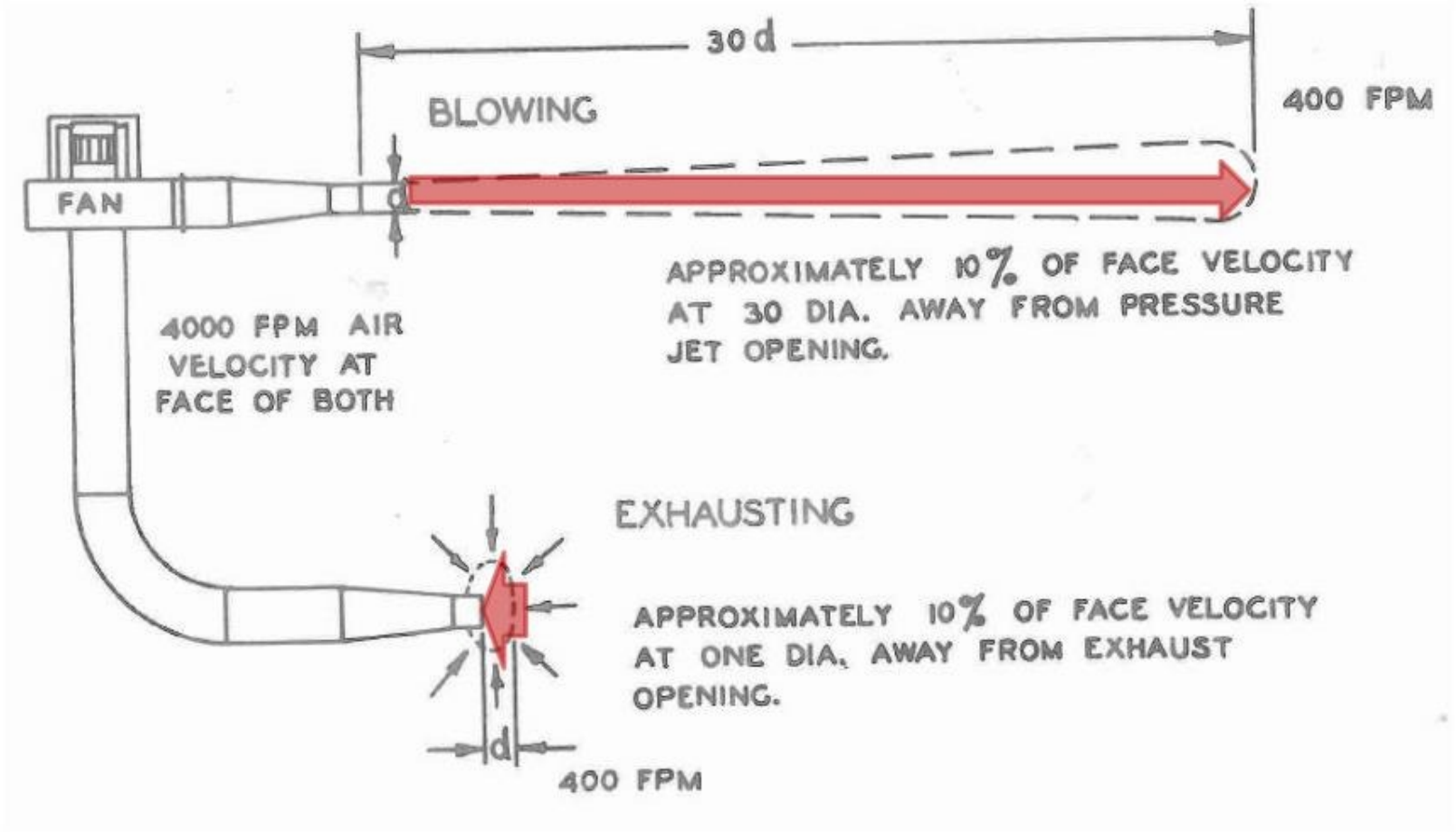
Effective Zone of Hood Capture







Blowing vs. Exhausting



Effective Capture Zone - Capture Velocity or Proper Volume

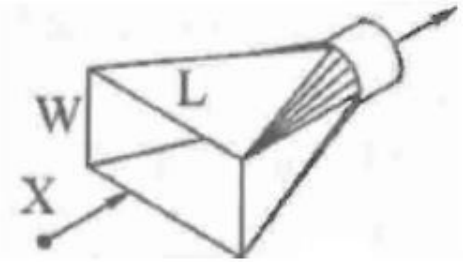
(per ACGIH Vent. Manual)

Conditions of Contaminant Dispersion

Released with practically no velocity into quite air (e.g., evaporation)

Capture Velocity **OR** **Proper Volume**

75-100 ft/min
(0.035-0.047 m/s)



Small Hoods

50-100 cfm/ft^2
(0.26-0.51 m^{3}s/m^2)

Large hoods

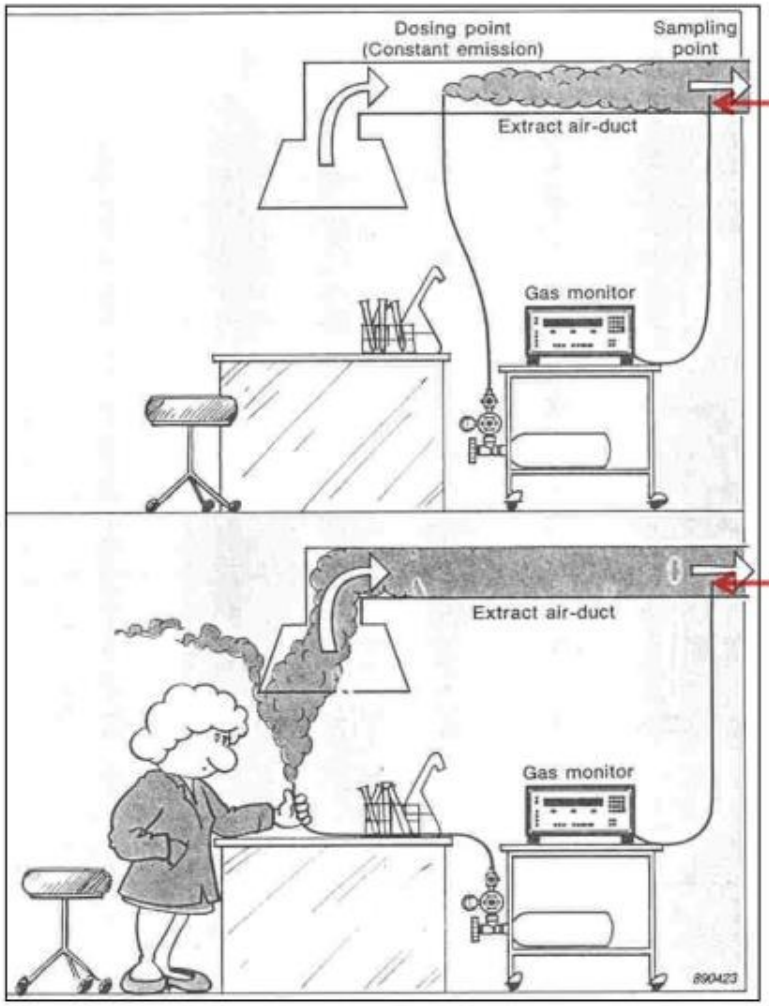
- Large air mass moving into hood
- Contaminant under influence of hood for longer time
- More dilution due to above

Proper Exhaust Volume - Anatomy Table

- ~16 ft^2 (~1.5 m^2) table area at 50 – 100 cfm/ft^2 (0.26-0.51 m^3s/m^2)
- 800 – 1600 cfm (0.38 – 0.76 m^3/s) per table

Tracer Gas Testing

Hood Capture Efficiency = as-used tracer gas capture conc. / 100% tracer gas capture conc.



100% tracer gas capture concentration (measured in duct)

as-used tracer gas capture concentration (measured in duct)

Proper Exhaust Volume – Anatomy Table

(tracer gas testing by NIOSH and University of Arizona)

- 700 – 1600 cfm (0.33 – 0.76 m^3/s) per table
- Lowest end of range only applicable with ideal conditions

Figure 4. Vapor distribution apparatus (table top)

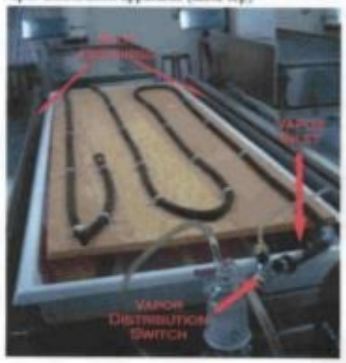
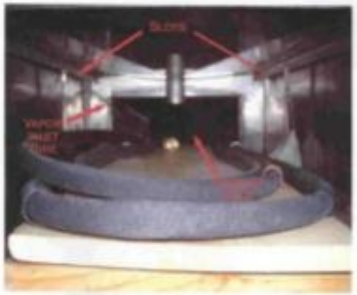
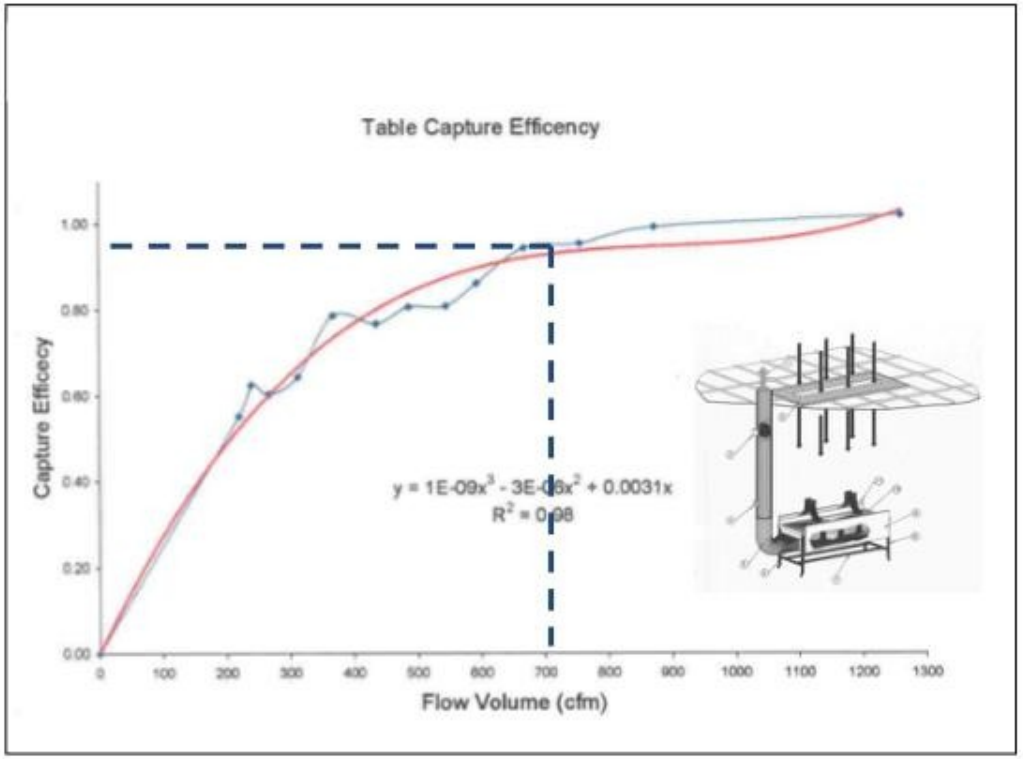


Figure 5. Vapor distribution apparatus (inside plenum)





Factors Affecting Choice Within Hood Flow Range

700 – 1600 cfm (0.33 – 0.76 m^3/s) per table

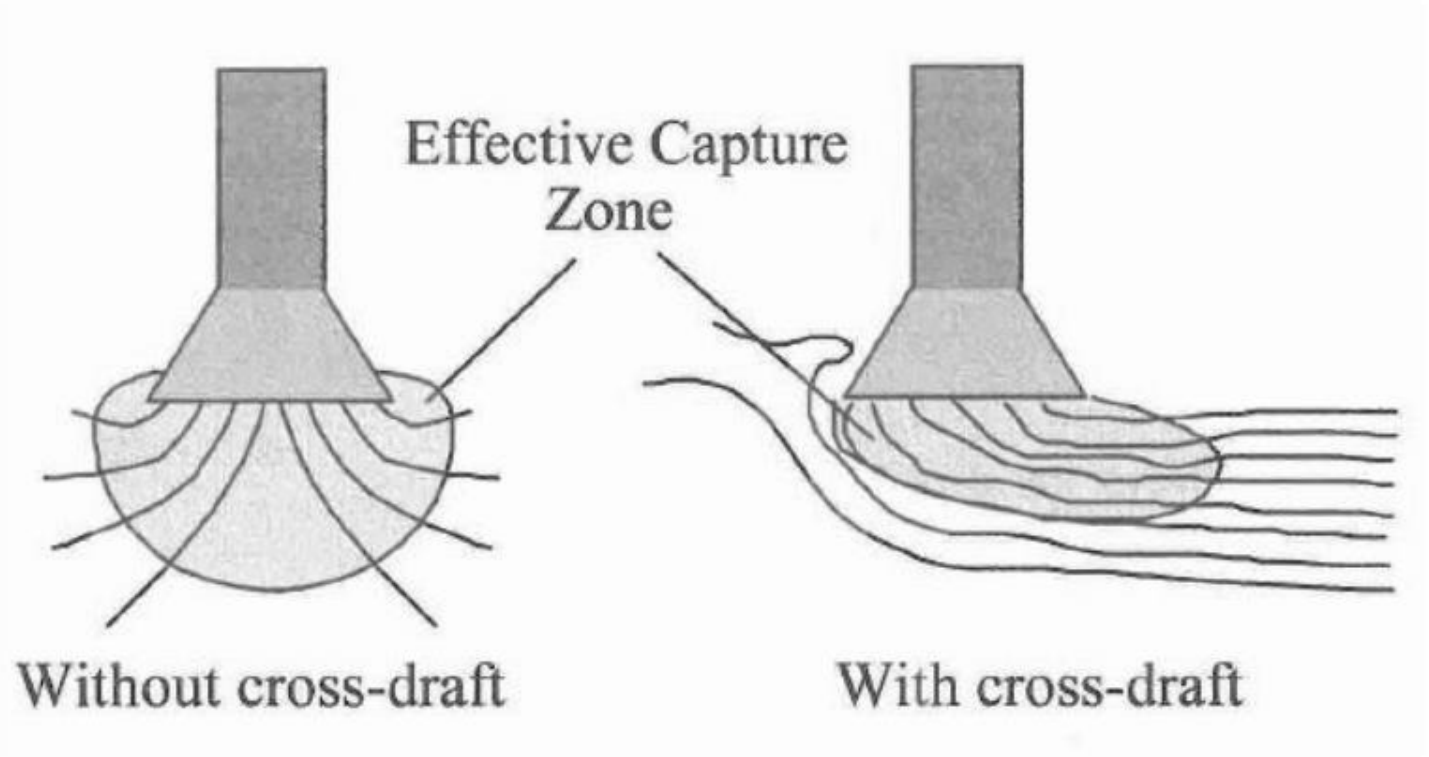
Lower End of Range (700 cfm)

- Large hood – large air mass in motion
- Contaminants of low toxicity
- Intermittent, low production
- Minimal room air currents
- Use of table top, flanges and baffles
- Unobstructed airflow into hood

Upper End of Range (1600 cfm)

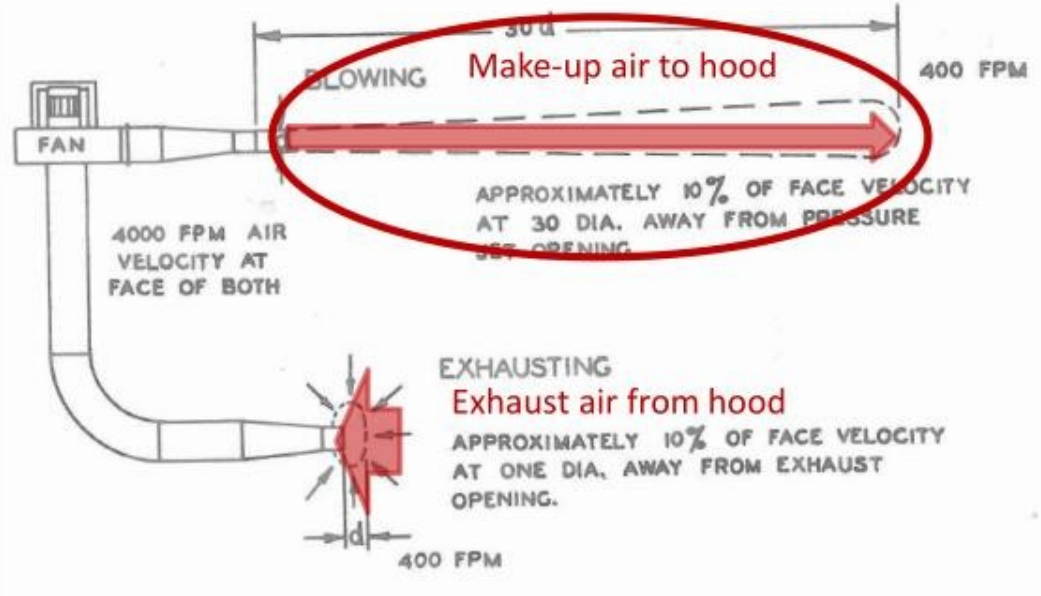
- Small hood - local control only
- Contaminants of high toxicity
- High production, heavy use
- Disturbing room air currents
- Free standing hood
- Objects and surfaces that impede air flow into hood

Effects of Cross Drafts



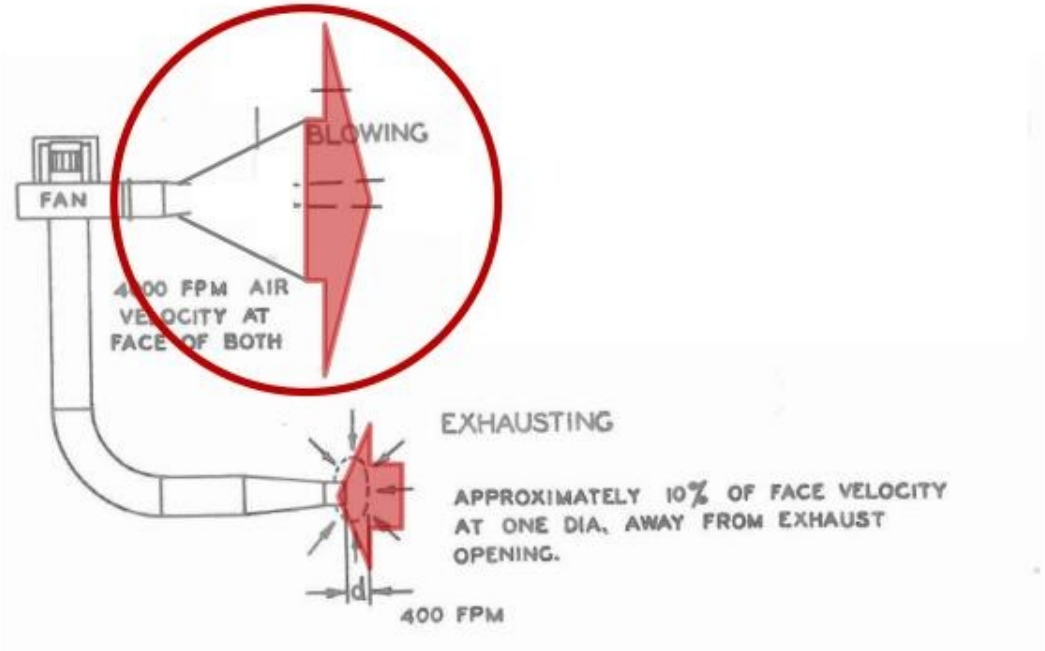
Make-Up (Replacement) Air

- Exhaust air from hood (air out) = Make up air to hood (air in)
- V = Q/A, Air velocity (V) = air flow (Q) / area (A)



Make-Up Air (Replacement Air)

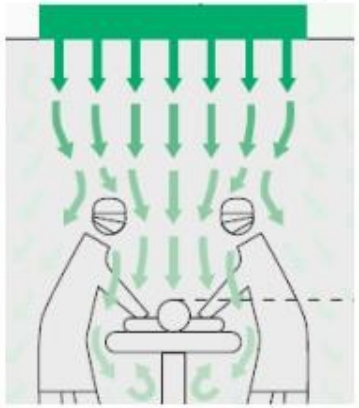
- Exhaust air from hood (air out) = Make up air to hood (air in)
- V = Q/A, Air velocity (V) = air flow (Q) / area (A)
- Release make-up air above table, over large area in direction of exhaust (goal is <25% capture velocity)
- ≥24 ft^2 (≥2.3 m^2) make-up air area (3, 2' x 4' ceilings tiles)

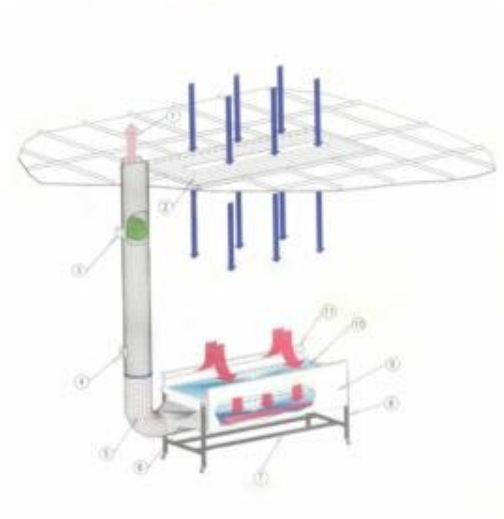


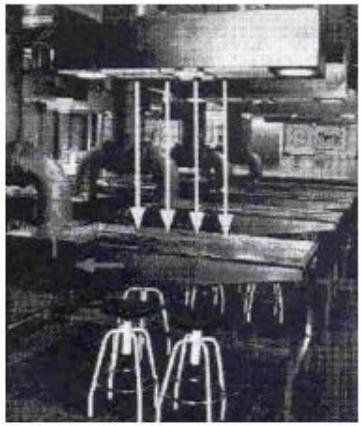
Make-Up Air (Replacement Air)

Preferred

(large, laminar flow diffuser above table)





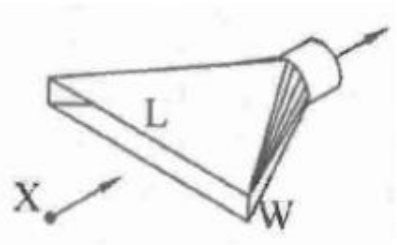


Avoid

(small, directional diffusers)

Table Tops, Flanges and Baffles

Plain opening



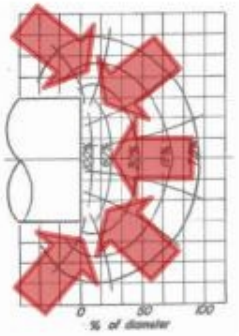


Table Tops, Flanges and Baffles

Plain opening

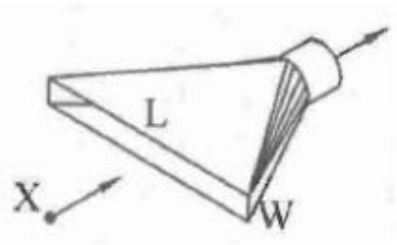


Table top

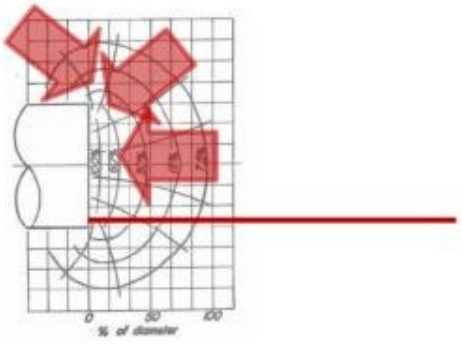
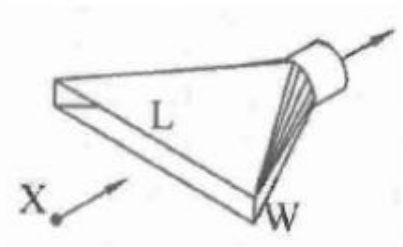


Table Tops, Flanges and Baffles

Plain opening



Flange

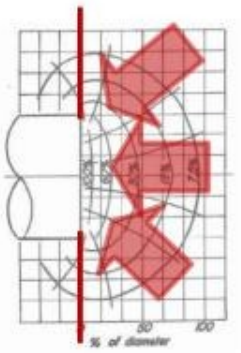
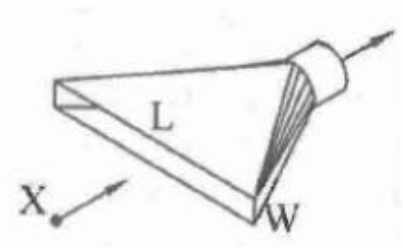


Table Tops, Flanges and Baffles

Plain opening



Baffle

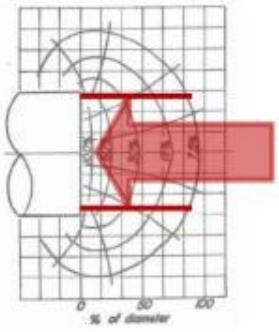
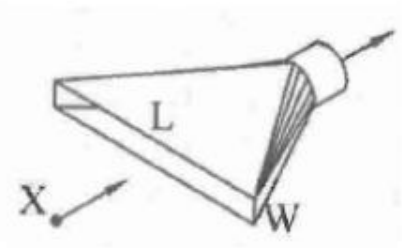
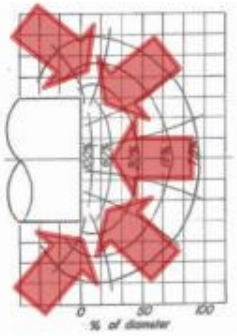


Table Tops, Flanges and Baffles

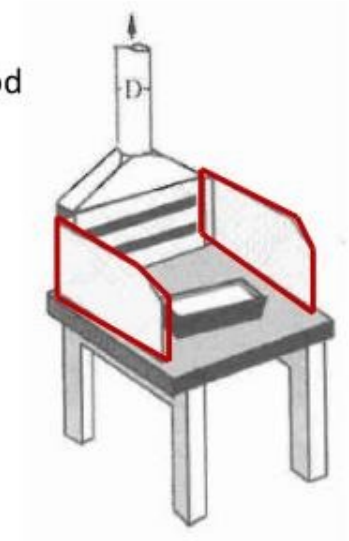
- Channel more airflow over source reducing required airflow (flanges by as much as 25%)

Plain opening

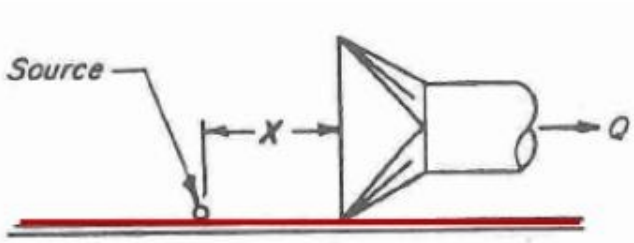




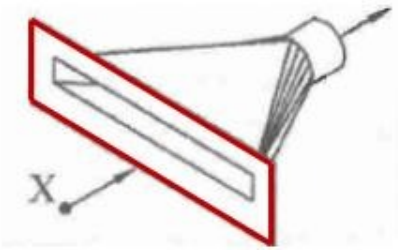
Baffled slot hood



Hood on table



Flanged slot



Flanged and Baffled Slot Tables

Flanged slot on table

Baffled slot on table

Airflow Obstructions

Preferred

(tight plastic sheeting that lies flat)

Avoid

(loose plastic sheeting)

Factors Affecting Choice Within Hood Flow Range

Lower End of Range (700 cfm)

- Large hood – large air mass in motion
- Contaminants of low toxicity
- Intermittent, low production
- Minimal room air currents
- Use of table top, flanges and baffles
- Unobstructed airflow into hood

Upper End of Range (1600 cfm)

- Small hood - local control only
- Contaminants of high toxicity
- High production, heavy use
- Disturbing room air currents
- Free standing hood
- Objects and surfaces that impede air flow into hood

900 – 1200 cfm (0.42 – 0.57 m^3/s) per table

Duct Design Issues

- Air turbulence = noise
  - Remember - the gross anatomy lab is a teaching environment
- Air turbulence, friction and high air speed = money
  - The harder it is to move air - the greater capital equipment/operating costs

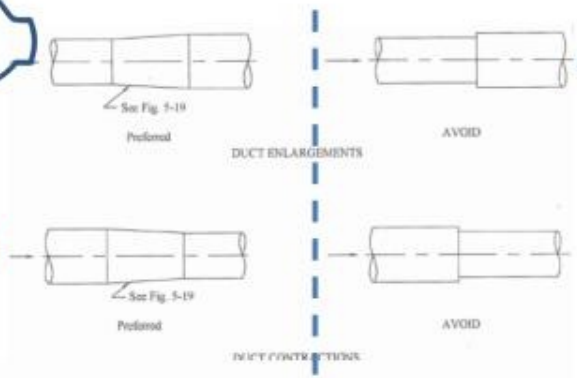
Duct Design Issues

- Smooth round duct preferred over rectangular or flex duct
  (< friction & turbulence, > structural integrity)
- Rectangular duct only when space requirements preclude round – as square as possible (< resistance)
- Use non-collapseable flex duct only where necessary and as little as possible (<2 ft)
- Avoid abrupt changes in duct direction and size when possible

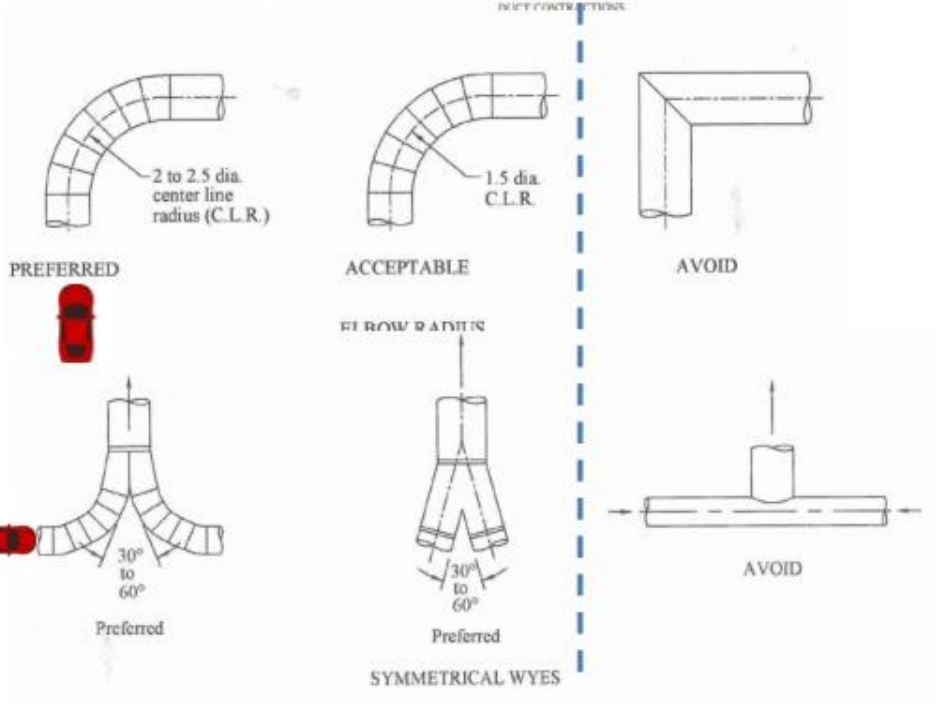
Duct Design

Preferred

Avoid

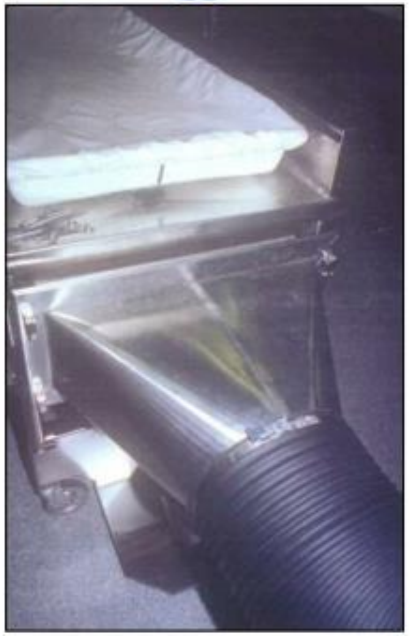


Excessive flex duct

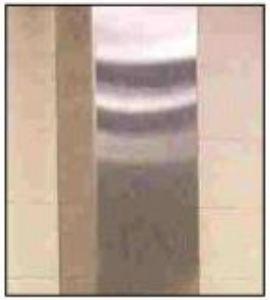


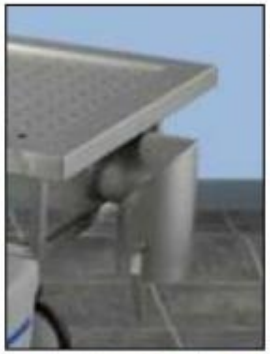
Duct Design

Preferred



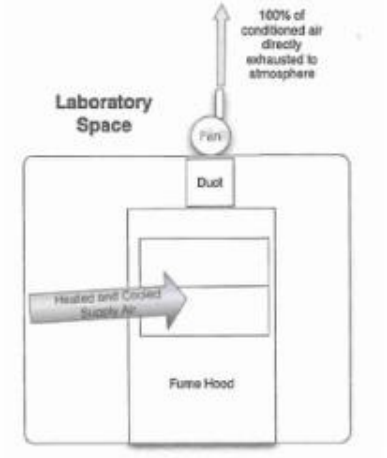
Avoid

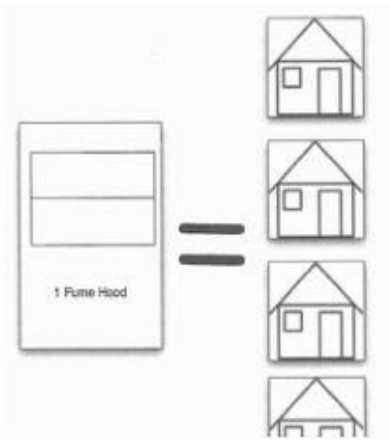




Economics

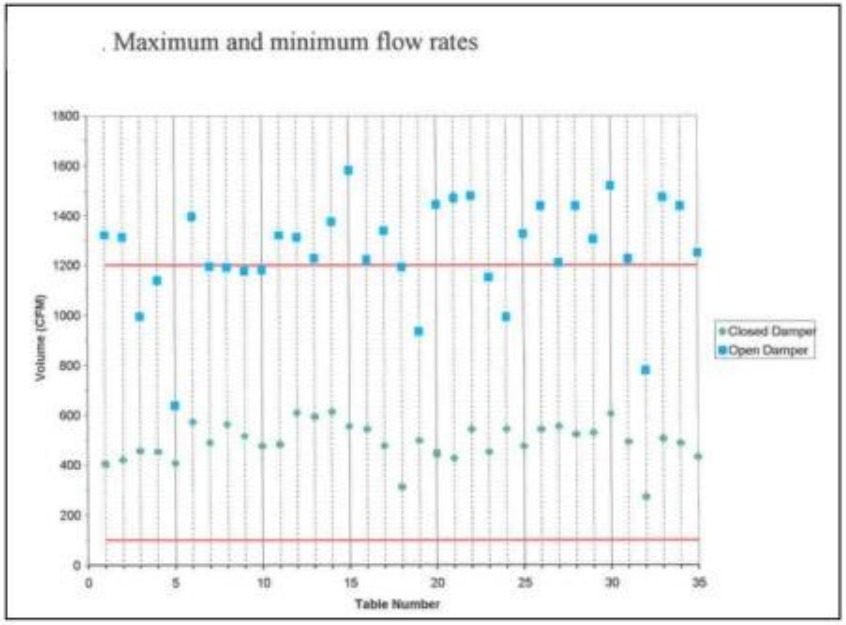
- 1000 – 2000 fpm (5.1 – 10.2 m/s) is economic optimum duct velocity for gases and vapors
  - 8 – 16 in round duct (0.20 – 0.41 m) for 700 – 1600 cfm (0.33 – 0.76 m^3/s)
  - 12 in round duct (0.30 m) for 900 – 1200 cfm (0.42 – 0.57 m^3/s)
- 1 fume hood (equivalent to side slot exhaust table) represents energy equivalents of 3.5 households in same climate (EPA estimate)
  - Consider "In use" and "Not in use" modes and performance indicators
- Incorporate existing equipment where possible

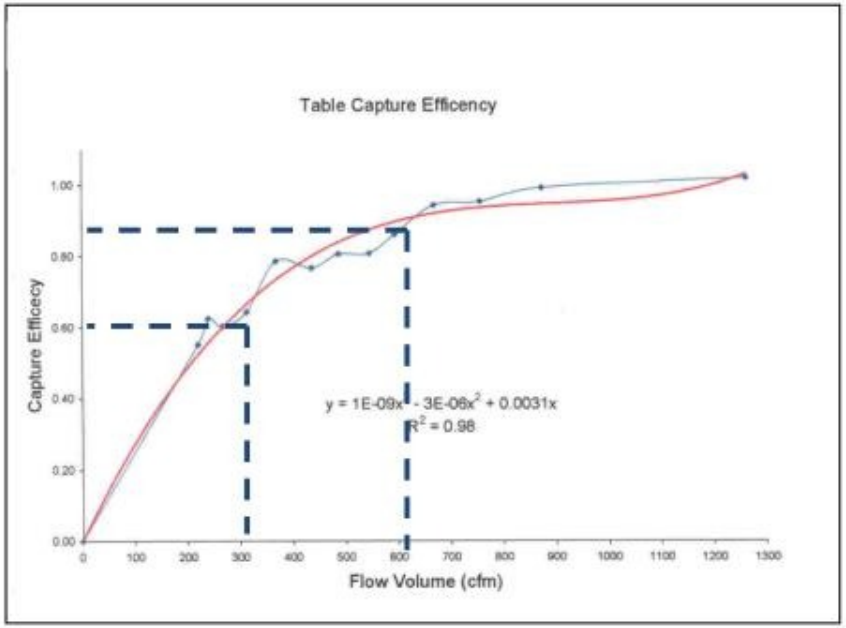




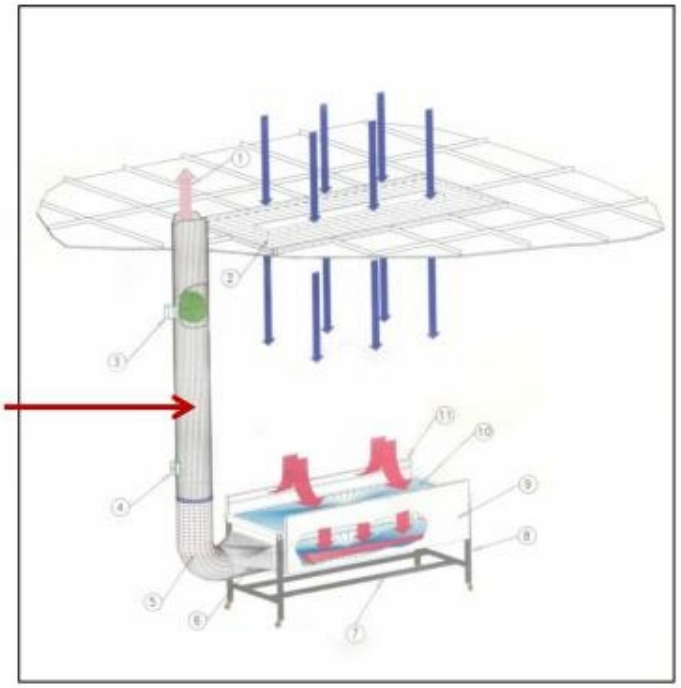
“Not in use” Mode

- 300 – 600 cfm (0.14 – 0.728 m^3/s), field verified by author
- Believed to be very conservative

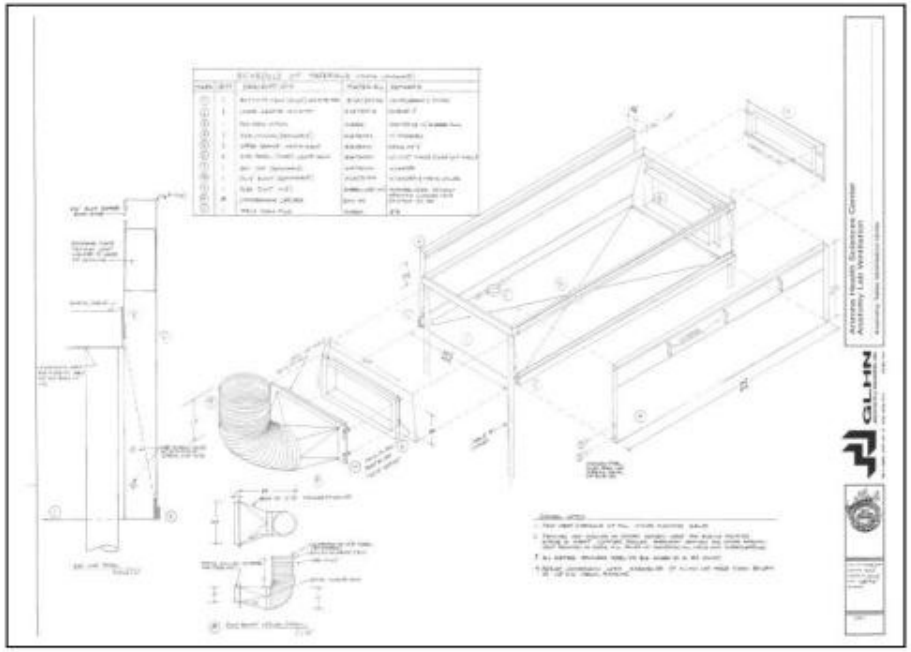


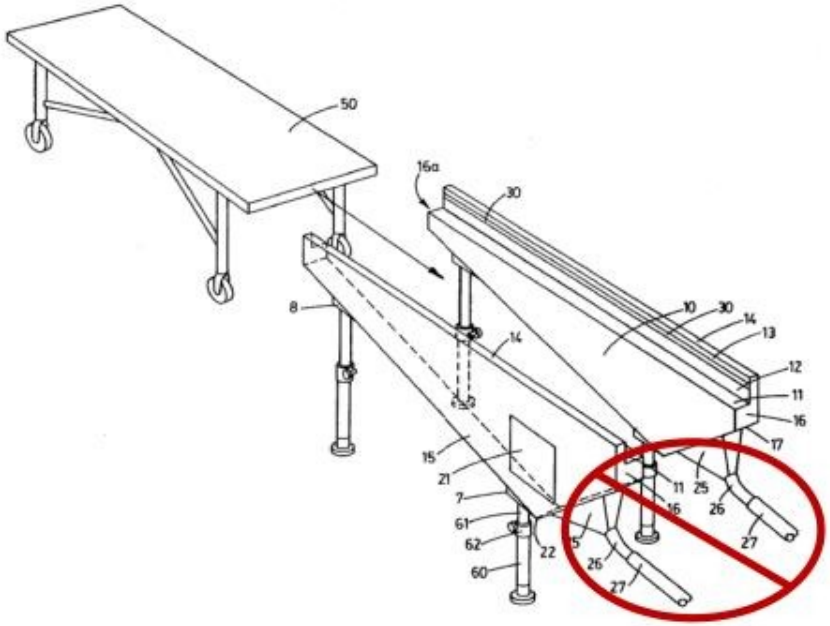


Performance Indicators



Using Existing Equipment

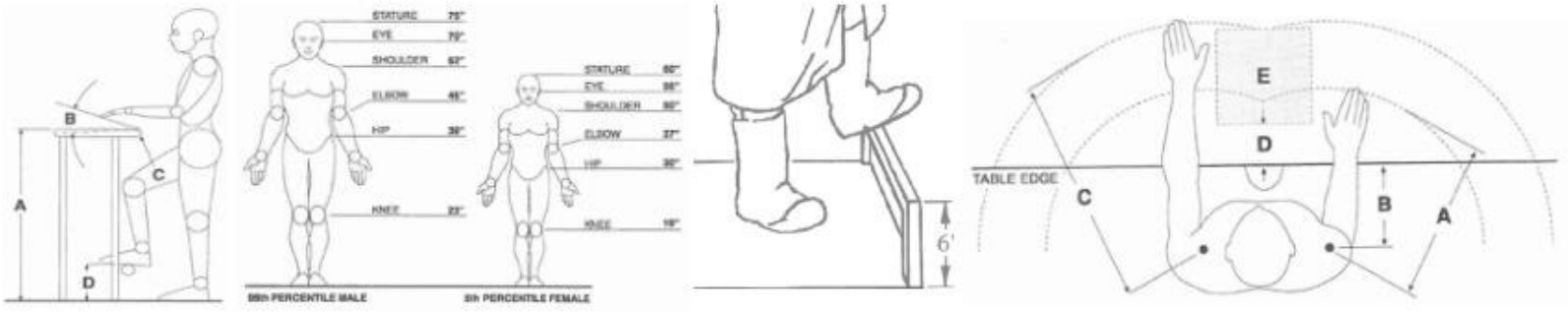




Ducts too small

Ergonomics

- Design for comfortable user posture - Ideally adjustable height
  - Specimen at standing elbow height, 37 – 44 in (0.94 – 1.12 m), if not adjustable, work at upper range and use step stools
  - Standing foot rail at 6 in (0.15 m), 1 in (0.254 cm) diameter rod
  - Minimize reach distance by keeping side slot plenums narrow
- Avoid “unfriendly” edges (e.g., contact stresses)
- Consider ease of cleaning
- Mock-up or prototype is highly recommended



Ergonomics

Preferred

Avoid

Engineering Controls to Reduce Formaldehyde Exposures in Anatomy

SUMMARY RECOMMENDATIONS

Summary Recommendations

- Reduce ceiling height, if possible - 9 ft (2.7 m)
- Flanged, side slot exhaust table/station design with appropriately-sized plenum
- 100% exhaust with 5 – 10 % less make-up air to keep room negative in pressure
- "On" mode: 900 – 1200 cfm (0.42 – 0.57 m^3/s) depending on lab conditions
- "Off" mode: 300 - 600 cfm (0.14 – 0.28 m^3/s), very possibly less, with specimen sealed in plastic bag when not in use
- Make-up air through large laminar flow diffuser directly above table - $\geq$24 ft^2 ($\geq$2.3 m^2)
- 1000 – 2000 fpm (5.1 – 10.2 m/s) duct velocity, round exhaust duct with < 2 ft (<0.6 m) flex duct and aerodynamic design features throughout, if possible
- Consider ergonomics and economics

Thank you for your attention
Questions?/Comments

Contact Information

E-mail: demer@email.arizona.edu

Phone: (520) 621-3585