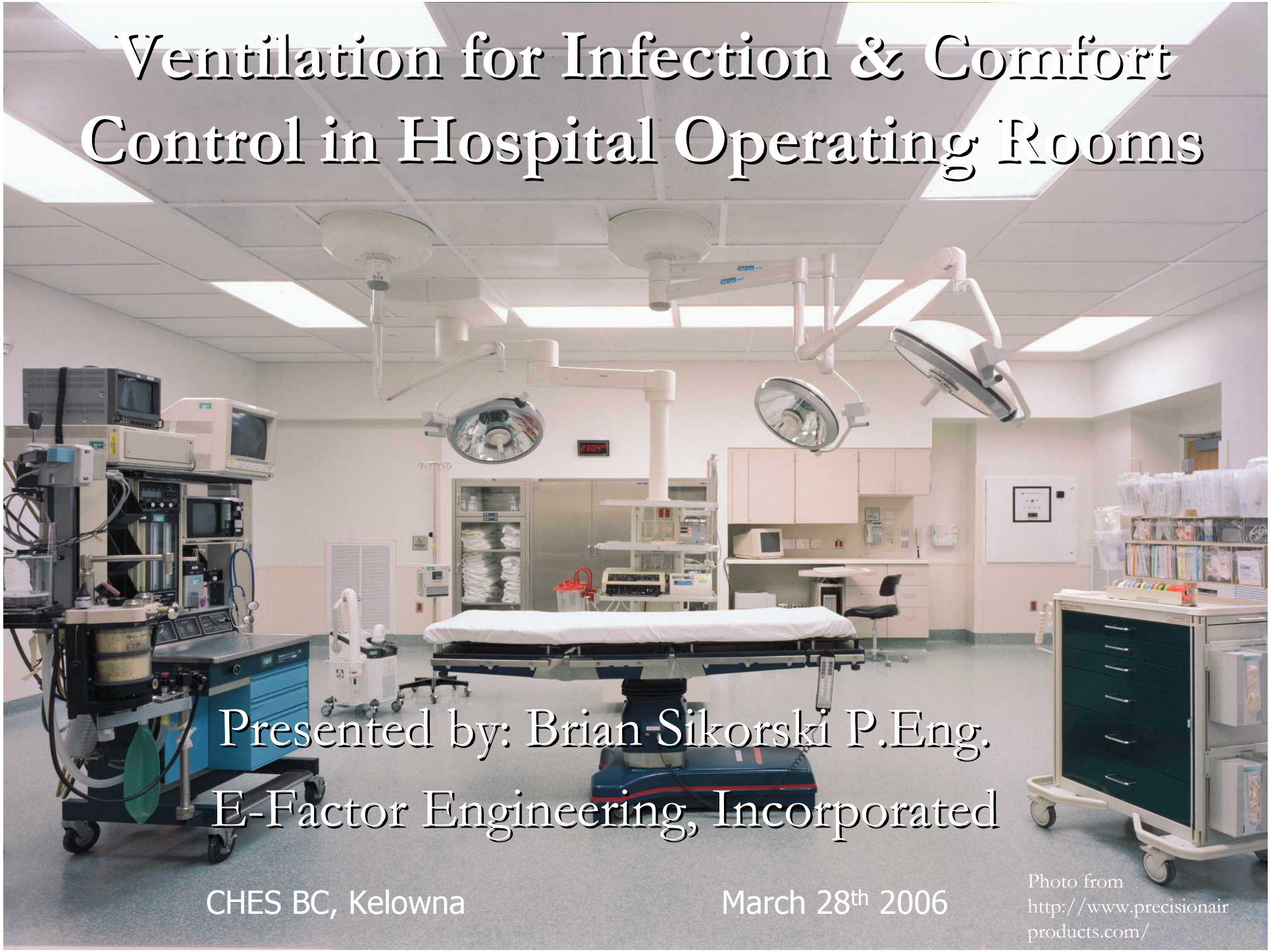
Ventilation for Infection & Comfort Control in Hospital Operating Rooms



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CHES BC, Kelowna

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Photo from http://www.precisionairproducts.com/

Presentation Overview

- The Role of Ventilation in Operating Rooms
- Design Guidelines and Standards Review and Comparison
- Air Filtration – To HEPA or not to HEPA?
- Air Change Requirements for the OR
- Air Diffusion System Design
- Temperature and Humidity Control
- Air Handling Systems
- Energy Conservation Ideas

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Buzzwords and Acronyms

- AIA – American Institute of Architects
- ASHE – American Society of Healthcare Engineering
- ASHRAE – American Society of Heating, Refrigeration, and Air Conditioning Engineers
- CDC – Center for Disease Control
- CHES – Canadian Health Engineering Society
- HICPAC - Healthcare Infection Control Practices Advisory Committee

- AII - Airborne Infection Isolation (negative)
- OR – Operating Room (positive)
- PE – Protective Environment (positive)

The Infection Problem

OR air distribution. While surgical methods have improved since modern antiseptic surgery began in the 1860s, each year some 700,000 patients in the US suffer from surgical site infections (SSIs).

Data shows that the direct cost of additional healthcare for these SSI cases is at least US$3.5 billion annually. These are only the costs seen by the hospital. The full cost including time away from work, degraded life style, suffering and death is surely much higher and demands the attention of every profession involved.

Robert Bazell of NBC News reported on December 27, 2000: "It's a danger of staggering proportions. Every year, one in twenty Americans—8 million people—develop an infection, with 88,000 of them dying. The biggest threat: "supergerms" resistant to antibiotics…."

ASHRAE – Working to Ensure Healthcare Facilities Remain Healthy, a report by Ronald Vallort, Past President ASHRAE, Inc. 2005 from Business Briefing: Hospital Engineering & Facil. Mgmt.

ASHRAE HVAC Design Manual for Hospitals and Clinics Appendix D

Surgical Site Infection (SSI)

- The Surgical Site - the area of the wound subject to infection
- Sources of Infection – mainly from skin cells shed from exposed regions of skin, both from operating room staff and the patient.[1] (Up to 30,000 dead cells/hour can fall from a surgeon's face)[2]
- These skin cells or squames particles are around 10 µm in diameter.
- A unit of bacteria contaminated squames is a cfu
- Not likely to infect but possible.
- "Many SSI cases are caused by airborne exogenous organisms"[3]

See endnotes on last slide for references

Protection of Surgical Site

Protect the Surgical Site from Infection by providing:

- Proper Clothing worn by OR occupants
- Antibiotic Treatment of the Wound
- Sterilized Instruments
- **Effective Ventilation to Dilute and Remove Contaminants**

The Ventilation Solution

"Evidence from many studies leaves no doubt that hospital air quality and ventilation play decisive roles in affecting air concentrations of pathogens...and, in this way, have major effects on (reducing) infection rates"

Report to The Center for Health Design for the "Designing the 21st Century Hospital Project". This project is funded by the Robert Wood Johnson Foundation. September 2004.

Standards and Guidelines

"At this point in time, there is no internationally agreed standard for air quality in hospitals and healthcare facilities"[1]

1. Excerpt from "An Update on Proposed ASHRAE Standard", Frank .A. Mills BSc, CEng presented at Seminar "Hospital Infection Control", London, 13 June 2005

Design Standards & Guidelines for OR Ventilation

- ASHRAE Standards and Guidelines
  - Standard 52.1 1992 and 52.2 1999: laboratory methods for testing air filter performance
  - 2003 Handbook HVAC Applications Ch. 7 - Health Care Facilities
  - HVAC Design Manual for Hospitals and Clinics (2003)
  - Standard 170p Ventilation of Healthcare Facilities ASHRAE/ASHE (expect – Spring 2006)
- CSA Standards
  - Z317.2-01 Special Requirements for Heating, Ventilation , and Air Conditioning in Health Care Facilities
- American Institute of Architects:
  - Guidelines for Design and Construction of Hospital and Health Care Facilities: 2001 Edition (wait for 2006 edition)
- BC Building Code –
  - Part 9 References to CSA Z317 and ASHRAE HVAC Handbook

ASHRAE Standard 52.2 Filters and MERV

- Standard 52.2 – 1999: Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size
- Std develops the MERV (Minimum Efficiency Reporting Value)
  - filter's performance is determined by comparing airborne particle counts upstream and downstream of the air filter
  - MERV's are accompanied by a resistance to air flow measurement (pressure drop)
  - MERV's number 1 to 20 with highest being most efficient

ASHRAE Standard 52.2 Test Results

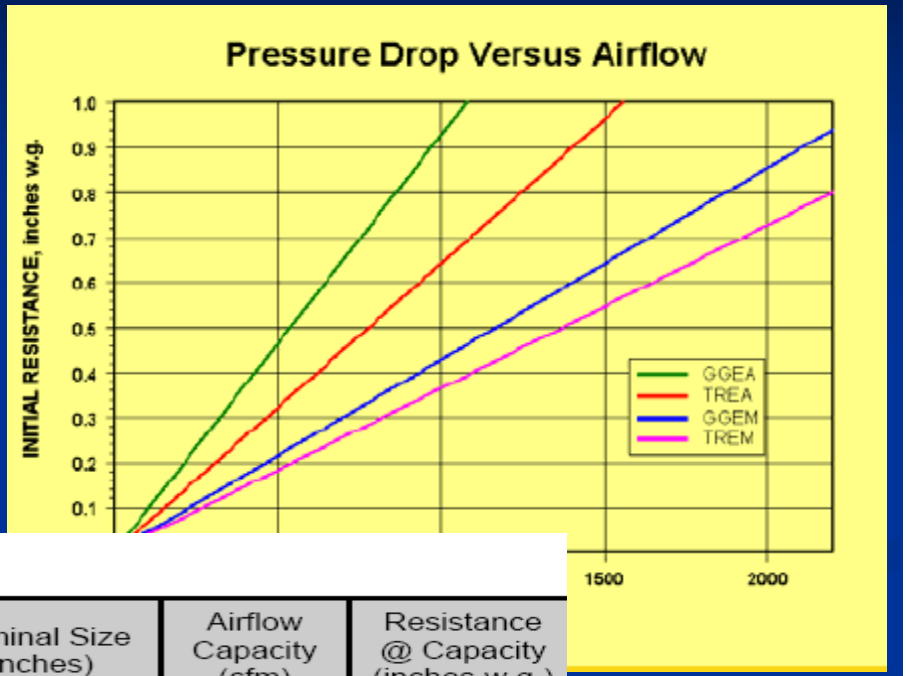
Typical Air Filter Type	Disposable Panel Filters, Fiberglass & Synthetic Filters, Permanent Self Cleaning Filters, Electrostatic Filters, Washable Metal Foam Filters	Pleated Filters, Extended Surface Filters, Media Panel Filters	Non-Supported Bag Filters, Rigid Box Filters, Rigid Cell / Cartridge Filters	Non-Supported Bag Filters, Rigid Box Filters, Rigid Cell / Cartridge Filters	HEPA Filters, ULPA Filters, SULPA Filters
MERV Std. 52.2	**1-4**	**5-8**	**9-12**	**13-16**	**17-20**
DOP for HEPA/ULPA					99.97% to 100%
Average Dust-Spot Efficiency	<20 %	<20 to 35%	40 to 75%	80 to 95%+	
Average Arrestance ASHRAE Std. 52.1	60 to 80%	80 to 95%	>95 to 98%	98 to 99%	N/A
Particle Size Ranges	>10.0 µm	3.0-10.0 µm	1.0-3.0 µm	0.30-1.0 µm	<0.30 µm
Typical Air Filter Applications	Residential, Light Commercial, Equipment Protection	Industrial Workplace, Commercial, Paint Booths	Industrial Workplace, High End Commercial Buildings	Smoke Removal, General Surgery, Hospitals and Health Care	Clean Rooms, High Risk Surgery, Hazardous Materials

https://wpb1.webproductionsinc.com/danforthfilter/secure/store/HEPA-Filters-MERV.asp

Air Filtration – HEPA Filters

- HEPA – **H**igh **E**fficiency **P**articulate **A**ir filters
  - Originally developed in the 1940's by AEC to filter out radioactive particles
  - The filter shall exhibit a minimum efficiency of 99.97% when tested at an aerosol of 0.3 μm (micrometers) diameter (DOP)
  - Pressure drop shall be about 1.0 in wc @ 1000 cfm for 24" x 24" x 11 ½" (DOE-STD-3020-97)

HEPA Filter Performance



PERFORMANCE DATA

Model	Efficiency	Nominal Size (inches)	Airflow Capacity (cfm)	Resistance @ Capacity (inches w.g.)
GGEA-200-**	99.99% @ 0.3 Micron	12 x 12 x 11.50	225	1.0"
GGEA-450-**		12 x 24 x 11.50	475	
GGEA-725-**		18 x 24 x 11.50	750	
GGEA-1000-**		24 x 24 x 11.50	1040	
GGEA-1250-**		30 x 24 x 11.50	1300	
TREA-200-**		12 x 12 x 11.50	340	
TREA-450-**		12 x 24 x 11.50	725	
TREA-725-**		18 x 24 x 11.50	1140	
TREA-1000-**		24 x 24 x 11.50	1560	
TREA-1250- **		30 x 24 x 11.50	1970	

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Proposed ASHRAE Standard 170p

- Standard 170P, Ventilation of Health Care Facilities
- To be released June 2006
- Based on Existing ASHRAE recommendations, HVAC Design Manual, AIA Guidelines, and extensive pier and member review.
- Intent to limit potential for infection transfer via ventilation paths
- Specifies ventilation design for Operating Rooms

ASHRAE/ASHE Standard 170p

- OR's will be placed in 3 classifications[1]:
  - Class **A**: least stringent – local anesthesia, includes most clinics and medical office buildings used for minor surgery
  - Class **B**: single or multi-specialty facilities where sedation anesthesia or dissociative drugs are administered
  - Class **C**: most stringent - single or multi-specialty facilities administering general anesthesia

1. Based on the "Guidelines for Optimal Ambulatory Surgical Care and Office Based Surgery" (American College of Surgeons 2000)

ASHRAE Standard 170p

- Minimum outside air change rate to be 4 ACH and total to 20 ACH
- Air Filtration
  - for general OR to be filtered 1st to MERV 8 and 2nd to MERV 14, large organ transplant and orthopedic surgery to MERV 17 (HEPA) in 2nd bank
- Pressure
  - Maintain at positive pressure wrt. adjoining spaces >= 2.5 Pa (0.01 in w.g.)
- Proposed temperature and humidity conditions
  - Room 68 F to 75 F (20 C to 23.8 C)
  - RH range from 30% to 60%
- Minimum requirement for type and location of diffusers
  - Probably Laminar Flow Ceiling Grilles – Group E downflow, low entrainment of room air
  - Return Air Grilles are proposed to be low side wall not less than 150 mm (6 in.) above the floor

ASHRAE Std 170p Air Diffusers

- "Shall" be:
  - Centered in the room over the surgical table
  - Must extend 12"-18" (300 to 450 mm) beyond table footprint (with allowance for other stuff in ceiling e.g. lighting anchors, gas columns for outlets
- "Shall" have:
  - Face velocity shall be between 25 and 35 fpm (0.125 m/sec – 0.18 m/sec)

CSA Z317.2-01 Special Requirements for HVAC Systems in Health Care

- Three **Area** Classifications I II and III. Class I includes Patient Care **areas** with "Risk" to the patient – Including Operating Rooms (very general)
- Three Classes of **Facilities** A, B, and C. Class A has surgical operating rooms

CSA Z317.2-01 Special Requirements for HVAC Systems in Health Care

For Operating Rooms

- Minimum outside air change rate to be 6 ACH and total to 20 ACH
- Air Filtration
  - Specialized Operating Rooms shall be 99.97 % Efficient (HEPA)
- Pressure 6.11.2 specifies that:
  - Differential between areas shall be greater than 0.762 mm of water pressure (7.5 Pa, 0.03 in wc) (3 times ASHRAE 170p)
- Proposed temperature and humidity conditions
  - Room 17 C to 27 C
  - RH range from 45% to 55%
- Minimum requirement for type and location of diffusers
  - 6.12.3.2 specifies that:

    Air supply for operating rooms, delivery rooms…shall be through nonaspirating ceiling outlets near the center of the work area…

CSA and HEPA Filters for OR's

- CSA Z317.2-01 Article 6.8.4 states:

  Where present, HEPA filters in the supply air systems shall be

  a) Located at the point where the air enters the room
  b) Provided with test ports before and after the filter, and tested…
  c) Designed to permit removal, disposal, and replacement without introducing contamination … of the area served
  d) Provided with means to indicate pressure drop to a BMS or a local alarm to indicate pressure drop

Guideline Comparisons for ACH and Filtration

Source	Room Types	Minimum Air Changes/Hour ACH	Minimum Outside Air ACH	Minimum Filtration Efficiency
ASHRAE 1999 Handbook HVAC Applications	Operating Room Delivery Room	25 (Recirculating Air System) or 15 (All Outdoor Air System)	5 or 15	99.97% for Orthopedic, Bone Marrow and Organ Transplant. 90% for General Procedure and Delivery Rooms.
American Institute of Architects 2001 Edition Guidelines for Design & Construction of Hospital & Health Care Facilities	Operating/Surgical Cystoscopic Rooms Delivery Room Trauma Room Procedure Room	15	3	90%
	Bronchoscopy, Triage, ER or Radiology Waiting Rooms	12	3	
	Endoscopy	6	2	
Canadian Standards Assoc. CSA Standard Z317.2–01 September, 2001	Operating Rooms Endoscopy, Bronchoscopy, Cystoscopy, PACU, Surgical Day Care, Caesarean Delivery	20	6	99.97%

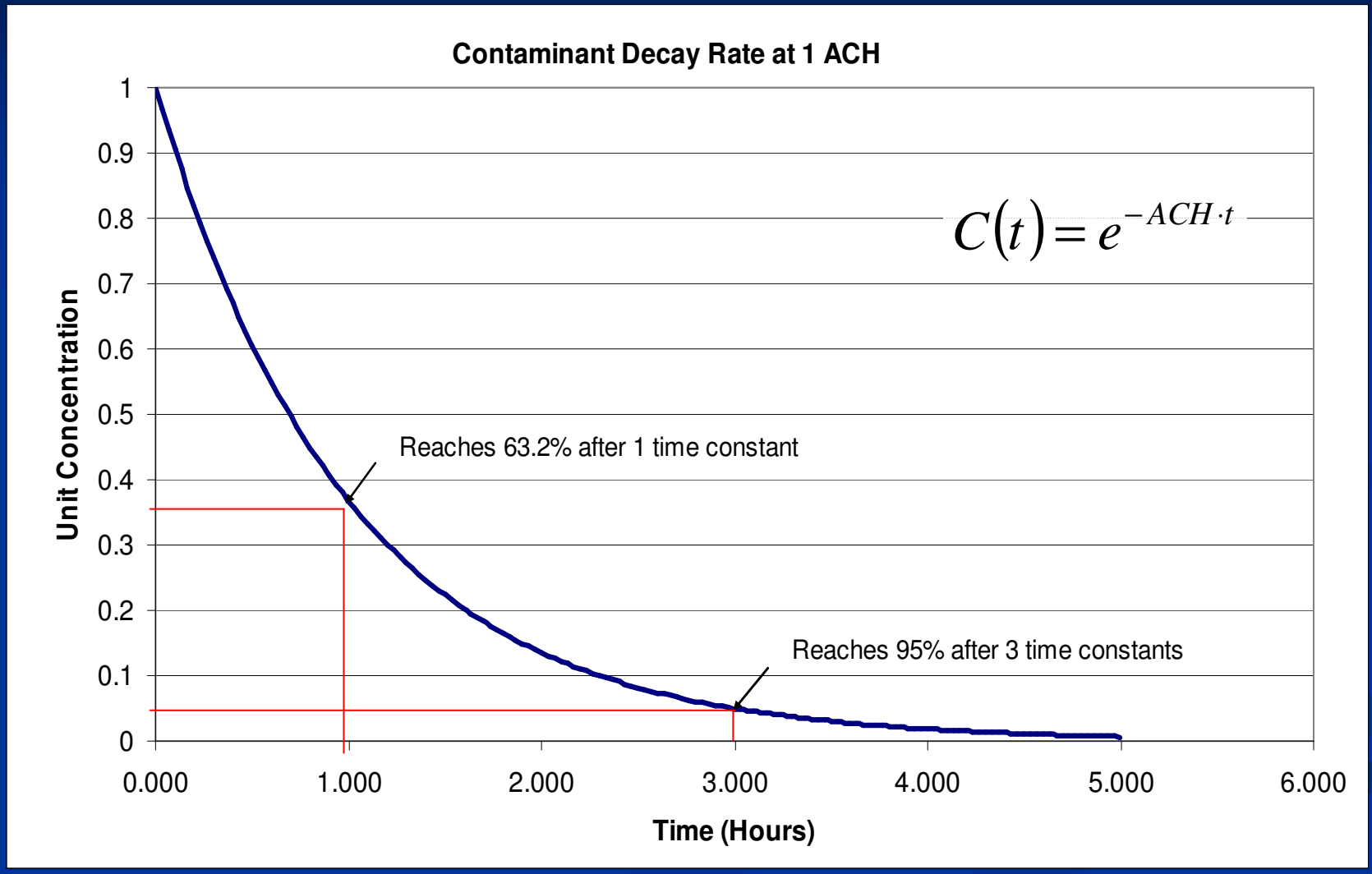
This table summarizes some of the current recommendations for operating room ventilation rates. Consult the actual documents for specifc requirements and exceptions.

Air Change Rate Discussion

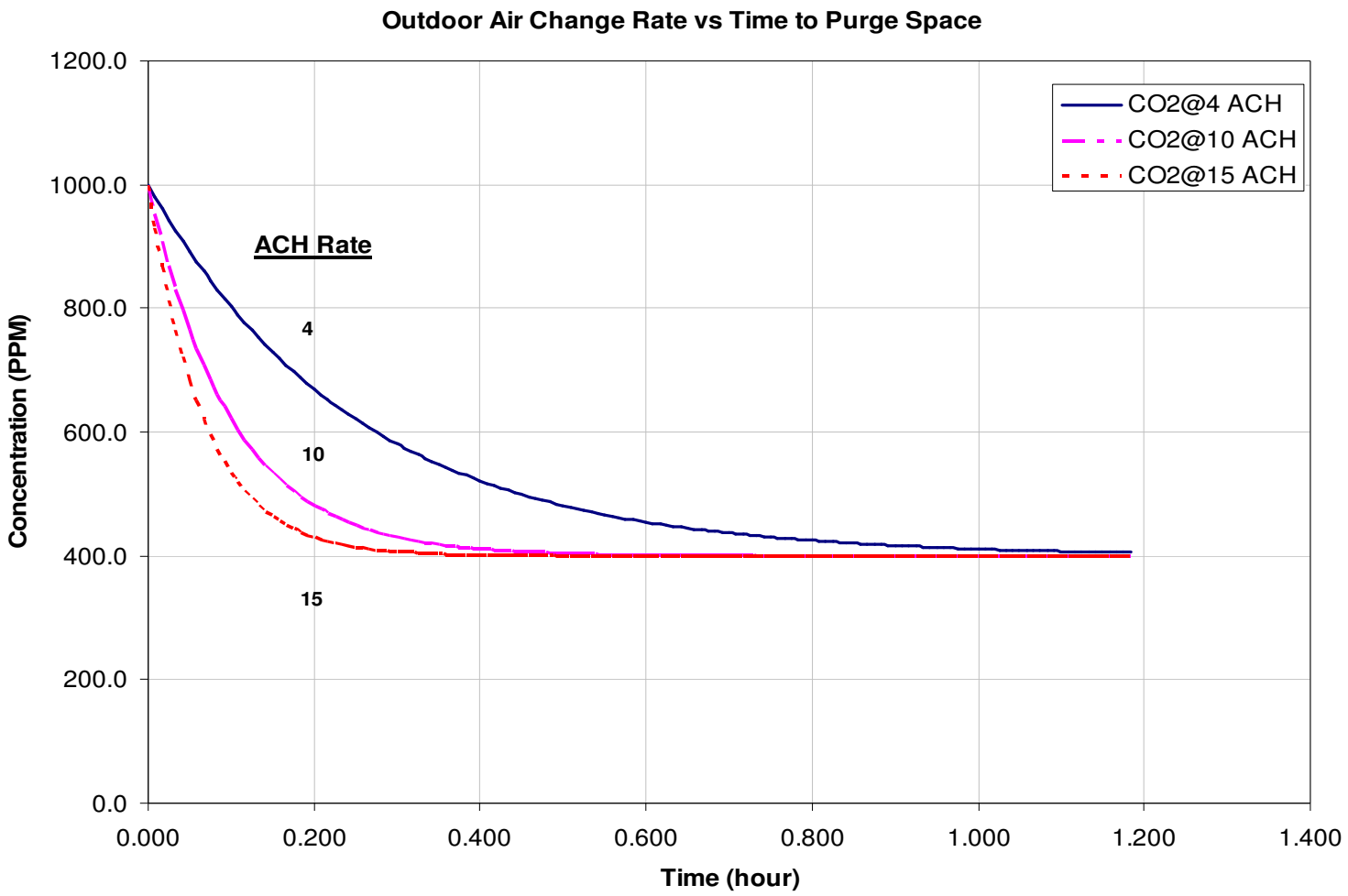
Simple Definition

- ACH = CFM x 60/Room Volume (ft^3)
- This is the Total Air Change Rate in a room
- The outdoor air portion creates the air change, removes odours, chemicals, and gases
- Recirculated air is OK to remove particles
- Comment:
  - In North America it is standard practice to recirculate air while in the UK it is not allowed. Who is right?

Some Air Change Theory



Air Change Rate Effects on Contaminants



Air Change Rate Review

- Standards/Guidelines cite minimum ACH rates
- Studies show extreme rates do not help (Memarzadeh)
- It takes 5 ACH_{OA} time constants to clear 99% of a contaminant released quickly into a room
- Air Change effectiveness depends on the room design, diffuser locations, ceiling heights and room size.

Comparison of Effectiveness of ACH and Diffuser Type Performance

TABLE 4
Percentage of Particles Vented from Room After One Hour

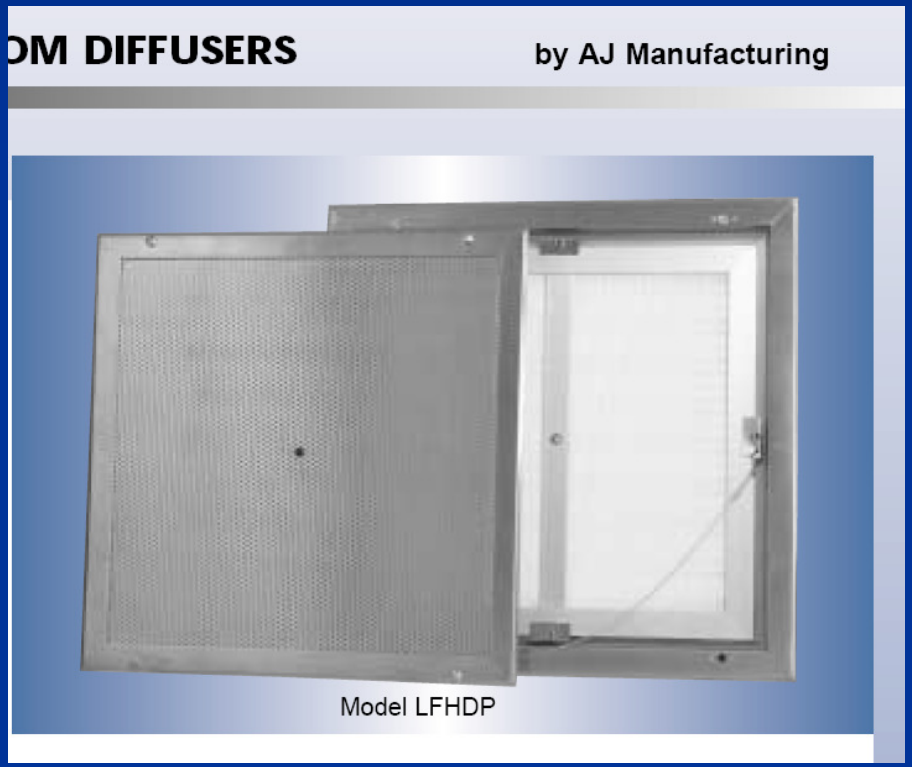
Case	System	ACH	Percentage of Particles Vented from Room After One Hour		
			Main	Nurse	Surgical
1	Conventional	18.75	41.9	49.7	46.0
2	Laminar	150	99.4	98.4	94.8
3	Laminar	15	77.3	49.7	73.3
4	Laminar (mixed)	20	80.4	54.2	86.7
5	Laminar (low only)	20	85.9	60.8	86.0
6	Laminar (high only)	20	83.8	72.1	80.1
7	Unidirectional flow with curtains	37.25	63.5	65.0	64.9
8	Upward displacement	37.25	74.3	77.4	44.3
9	Non-aspirating diffusers	25	72.4	74.1	60.7
10	Low supply/high exhaust	18.75	69.2	81.8	73.8
11	Goldman concept	19	52.2	48.2	44.7

ASHRAE Transactions: Research

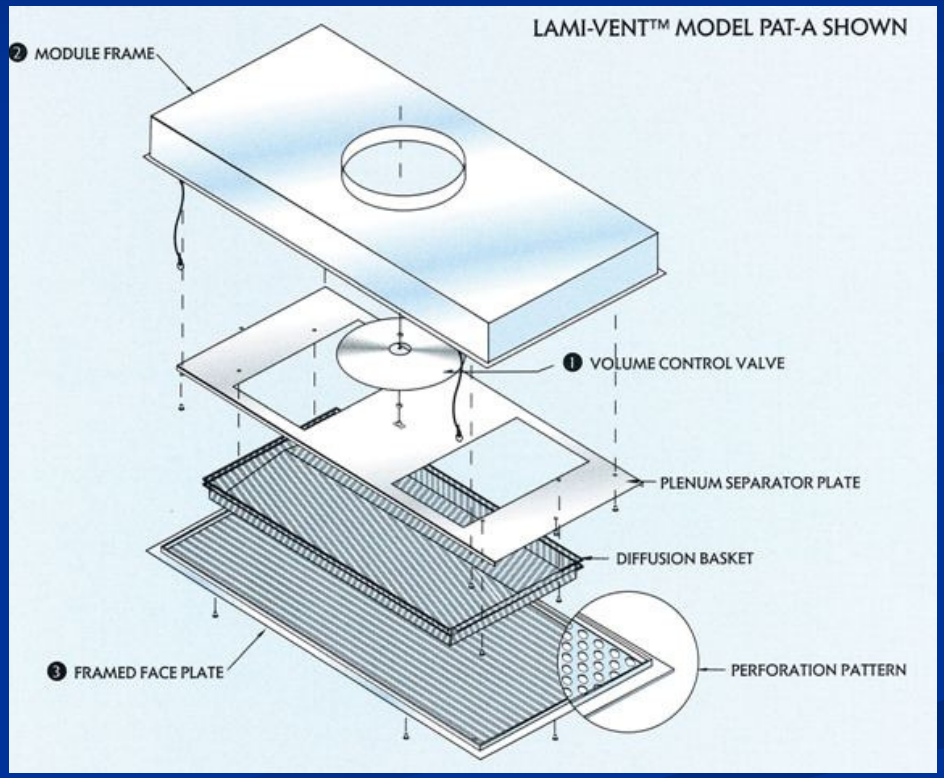
From "Comparison of Operating Room Ventilation Systems in the Protection of the Surgical Site", Farhad Memarzadeh, P.E., Ph.D. Andrew P. Manning, Ph.D. ASHRAE Transactions Research 2002

Air Diffuser Options

- Laminar Perforated Diffusers



Laminar Diffuser With Terminal HEPA Filter



Precision Air Products: Laminar diffuser

Good (and Bad) Ventilation Design

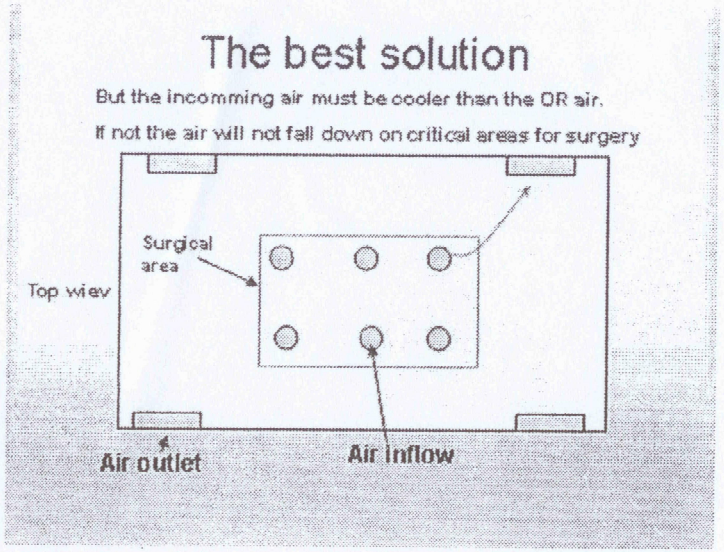


Figure 1, Air inlet from several diffusers at the ceiling and evacuation in each corner at floor level. Provided right temperature of incoming air this is an excellent choice

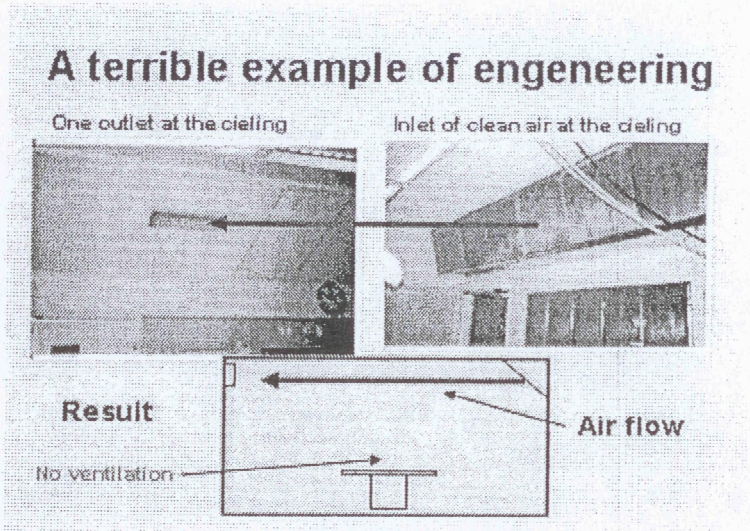


Figure 2. Air inlet at ceiling and evacuation at ceiling. Despite rather cold incoming air the air flow did not reach the level of the OR table

"Operating Room Ventilation – Why and How – Some Drawbacks Suggestions – and Economy" Sven Friberg, Babro Friberg UMEA Sweden

Air Diffuser Array Design

- Complete Laminar Grid (Kelowna Hospital)

Produce a low velocity air flow, non-aspirating, vertical air pattern.

Air is exhausted evenly from low wall air grills.

Air Diffuser Array Design

- Laminar Grid with Perimeter Air Curtain (AJ Manufacturing)

Air Diffuser Array Design

Vancouver General Hospital: JP North OR9 Laminar Core with Perimeter Air Curtain

Air Distribution Performance

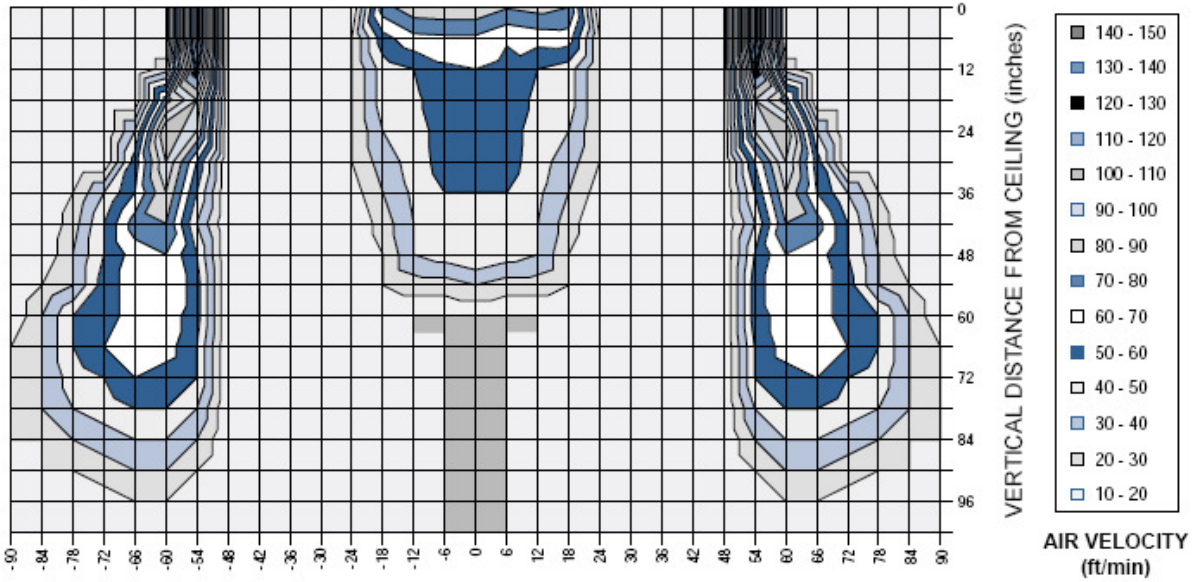
HOSPITAL/CLEAN ROOM DIFFUSERS by AJ Manufacturing

Performance Data

HOSPITAL OPERATING ROOM AIR DISTRIBUTION SYSTEMS

PERFORMANCE TEST – 12 x 8 MODULE

(Medium Airflow Range – 35 cfm/ft Perimeter / 30 cfm/sq. ft Center Panels)



NOTE:
The graph above shows actual air velocities and the associated isovels. This data was obtained in a full scale mock-up test performed on a standard 12 x 8 system.

Air Handling System Options

- VAV/CAV System with Terminal Reheat
- Dual Duct System with Mixing Boxes

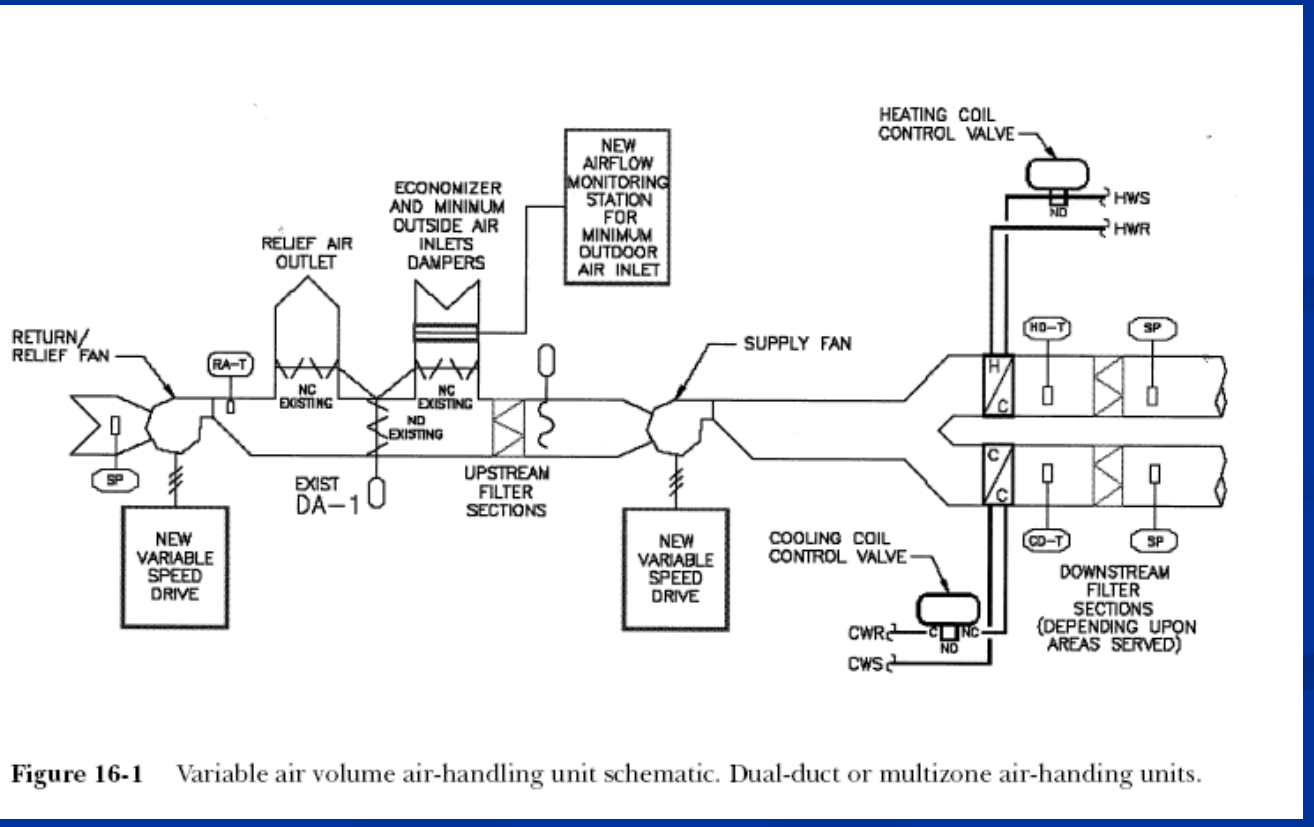
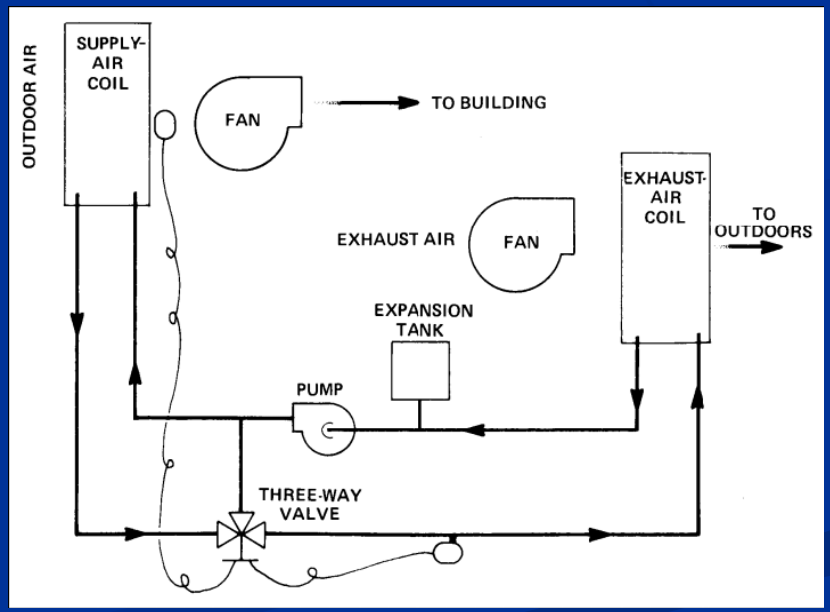


Figure 16-1 Variable air volume air-handling unit schematic. Dual-duct or multizone air-handing units.

Heat Recovery Options

- Runaround Loop - Simple and Cost Effective, good for retrofit (50% eff.)
- Heat Pipe – good if exhaust very near supply (60% eff. or more)
- Fixed Plate Heat Exchangers (60% to 80%)
- Enthalpy Wheel – Up to 80% total recovery. Not allowed for OR's or AII's

Runaround Loop Heat Recovery



Temperature and Humidity Control

- Temperature Control
  - Use good sensors, calibrate regularly (annual)
  - Allow setpoint control only between values of 19 C to 22 C if possible, unless OR has special requirements
- Winter Humidity Control
  - Only use spray humidifiers from plant steam or Steam to Steam injection. Do not leave stagnant water.
  - Humidifiers should not be placed directly over the OR to avoid water leaks
  - Allow a long enough length of duct downstream to absorb all water – no carry over allowed
  - Get expensive RH sensors – reliable, accurate, low maintenance. Vaisala are best but > $400 ea.
- Tuning of Controllers
  - Air flow, temperature, and humidity need to be steady.

Special Temperature Conditions

- In Cardiac Surgery, some surgeons require temperatures to be rapidly lowered to 16 C and then rapidly heated to 26 C
- In solid organ transplant rooms, rooms need to be quickly lowered to 18 C or lower. With rooms under high loading, this may require sub-cooling of the air to 7.5 C

Energy Conservation

- Keep reheat to minimum
- Monitor OR temperatures and reset AHU SAT
- Install VFD on Supply/Return/Exhaust Fan and reset duct pressures (for VAV)
- Install Heat Recovery – for systems with 100% OA if economical
- Reduce Ventilation Rate when unoccupied to 40% or lower if pressure control maintained.
- Use low resistance air filters

VGH Operating Room Systems

- 24 OR's in VGH main surgical suite
- 4 are dedicated to emergency surgery
- All are 100% outdoor air around 20 ACH
- Newer OR's are served by VAV system w Terminal Reheat and Heat Recovery (runaround loop).
- Older OR's in Jim Pattison North are Dual Duct w/o heat recovery – air flow is reduced after hours
- Tour via BMS and Photos

Summary of Main Points

- Ventilation in Operating Rooms is for control of SSI.
- The main culprits for infection are squames shed by occupants.
- Many guidelines exist for Air Quality in Health Care but CSA Z317.2-01 and ASHRAE 170p focus on OR Ventilation
- HEPA filters are required for orthopedic, large organ transplant, surgery and should be at the diffuser.
- Rectangular Arrays of Laminar Diffusers without air curtain are preferred design for high risk surgery areas.
- Humidity control needs expensive sensors, regular calibration, and no potentially stagnant sources.
- Allow a range of temperature control but do not defeat the SSI needs.
- Energy Conservation is desirable, but room pressure and infection control must be maintained.

End Notes

- 1. Comparison of Operating Room Ventilation Systems in the Protection of the Surgical Site, Farhad Memarzadeh, P.E., Ph.D. (from ASHRAE HVAC Design Manual for Hospitals and Clinics)
- 2. Excerpt from "An Update on Proposed ASHRAE Standard", Frank A. Mills BSc, CEng presented at Seminar "Hospital infection control", London, 13 June 2005
- 3. From Research Considered on OR Air; *ASHRAE Insights, December 7th 2004*)