INTEGRATING INDOOR AIR QUALITY AND ENERGY EFFICIENCY IN BUILDINGS

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México

Outline

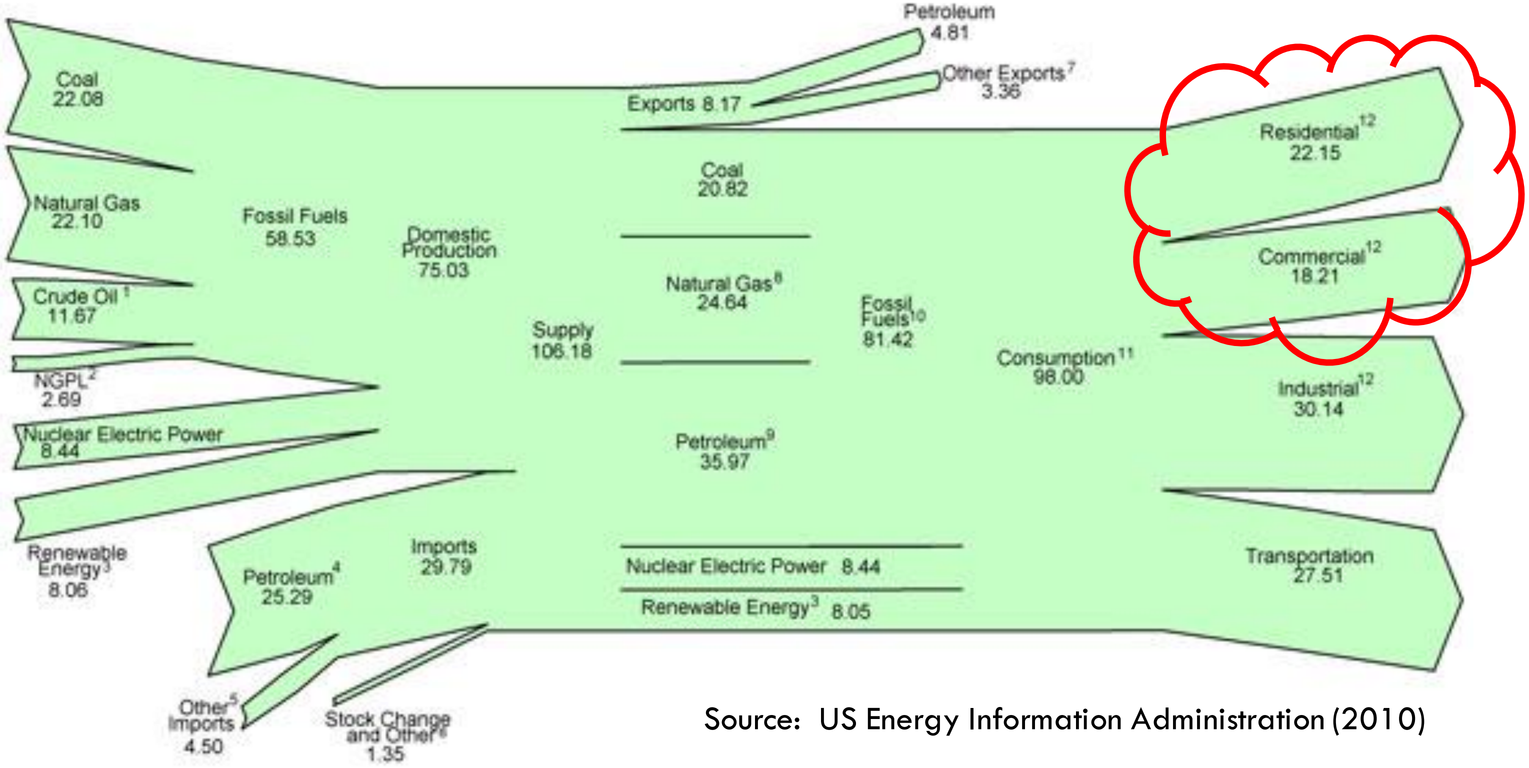
- Connection between IAQ and energy use
- Importance of indoor air quality (IAQ)
- Current status of IAQ control
- Efficient IAQ technologies
- Integrating IAQ and energy efficiency
- Conclusions

Energy conservation and ambient environment are high priorities…

- Component efficiency
- Reduced system energy use intensity
- Stratospheric ozone depletion
- Global climate change
- Use of alternative fuels
- Protection of water supplies

Buildings are the largest energy end-use sector

- ~ 40% of US primary energy use
  - 22% residential /18% commercial



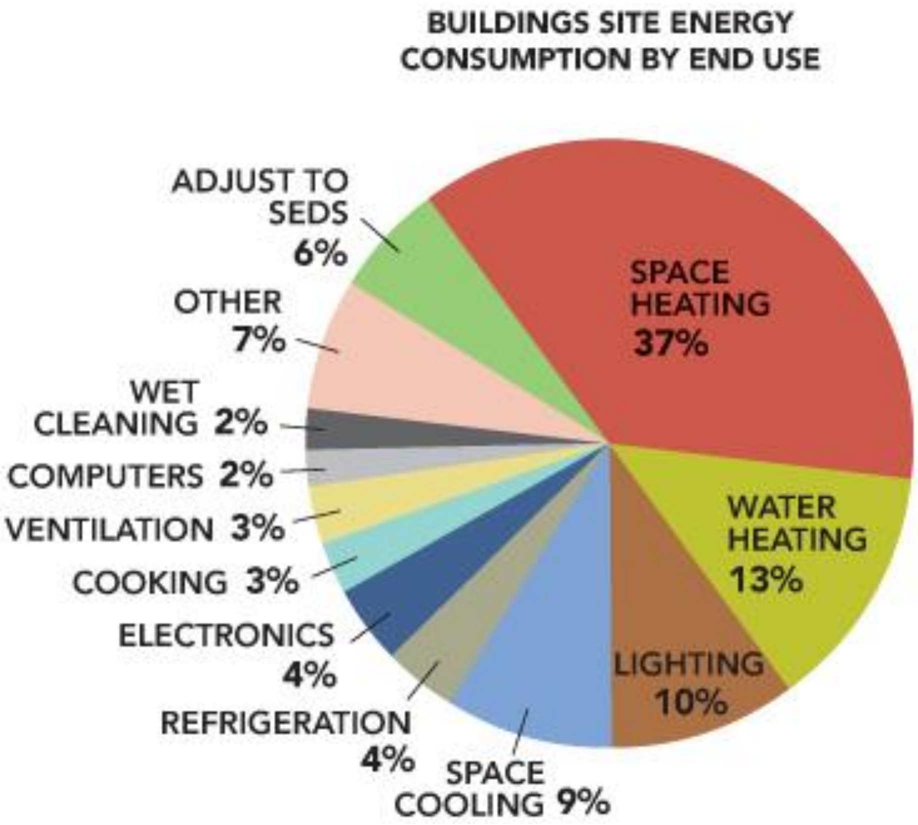
Source: US Energy Information Administration (2010)

Priority of energy, ambient environment apparent in law, policy, programs…

- US Energy Laws
  - National Energy Conservation Policy Act (1978, amended)
  - Energy Policy Act of 1992
  - Energy Policy Act of 2005
  - Energy Independence and Security Act of 2007
  - Emergency Economic Stabilization Act of 2008
  - American Recovery and Reinvestment Act of 2009
- Other Public and Private Initiatives
  - Montreal Protocol (1987, amended
  - Kyoto Protocol (1997, amended)
  - Directive on Electricity Production from Renewable Energy Sources (EU, 2001)
  - Directive on the energy performance of buildings (EU, 2002)
  - ASHRAE Vision 2020
  - many others…

More than half of building energy use is for environmental control

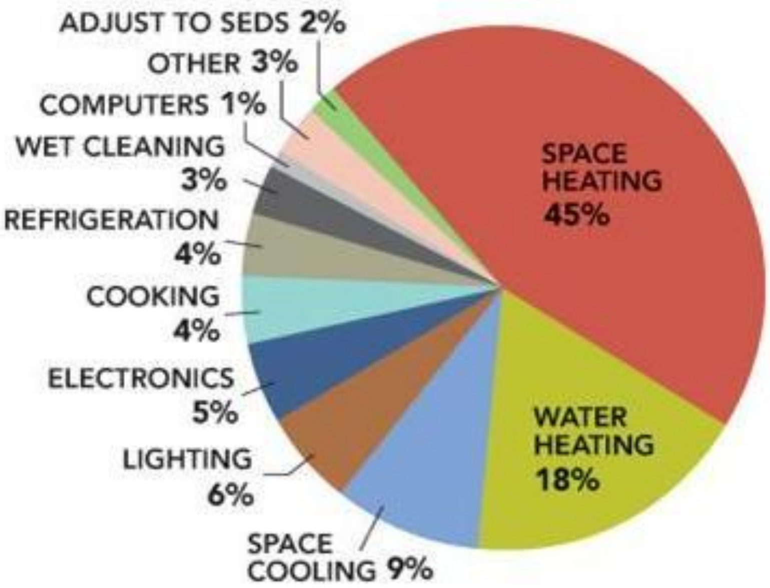
- US buildings, all types
  - Space heating 37%
  - Lighting 10%
  - Space cooling 9%
  - Ventilation 3%
  - **TOTAL 59%**
  - **HVAC 46%**



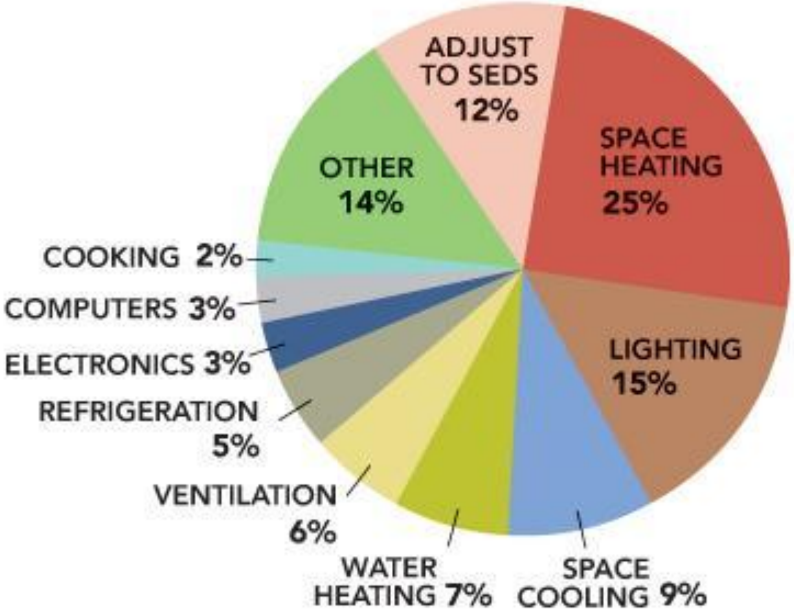
Source: US DOE Buildings Energy Data Book (2010)

Residential & commercial differ, but environmental control dominates both

US Residential Site Energy End Use



US Commercial Site Energy End Use



Source: US DOE Buildings Energy Data Book (2010)

“That all people should have free access to air and water of acceptable quality is a fundamental human right.”

~World Health Organization, *Air Quality Guidelines for Europe, 2nd ed.*

“An energy declaration without a declaration related to the indoor environment makes no sense.”

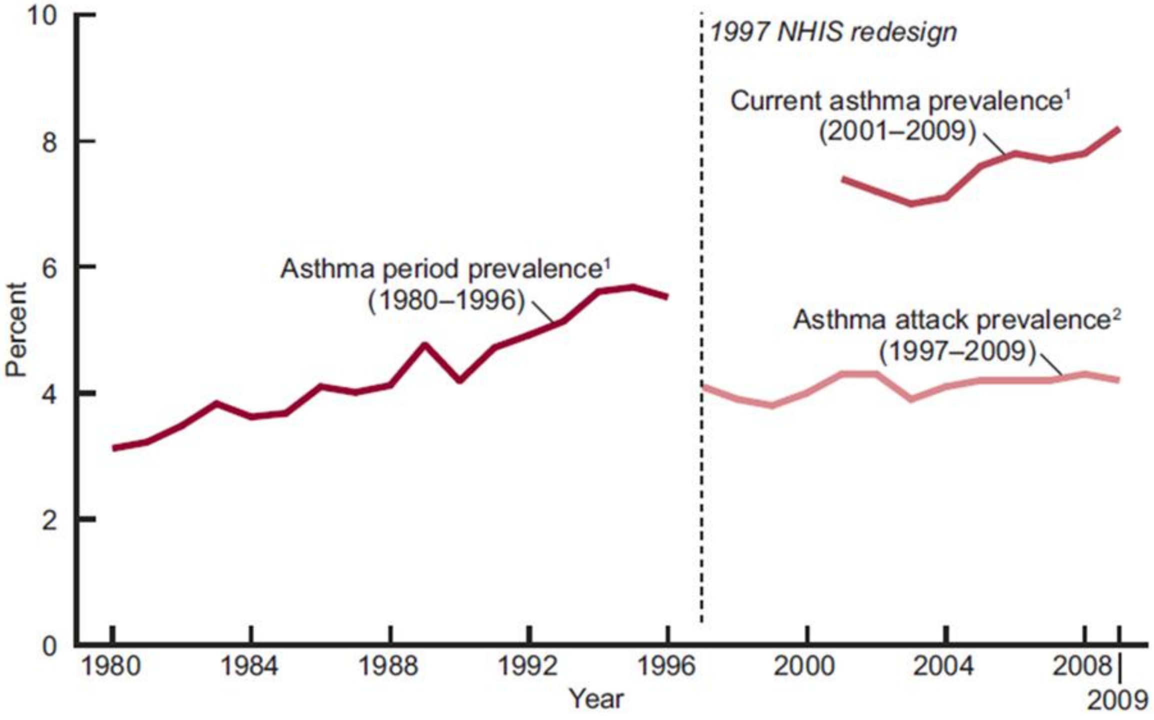
~Bjarne Olesen, Olli Seppänen, Atze Boerstra. *Criteria for the Indoor Environment for Energy Performance Of Buildings – A New European Standard.*

Importance of IEQ - asthma

- According to US CDC based on data collected in 2007, 2008, 2009
  - 8.2 % of population/26 million people affected
  - 10.5 million missed school days
  - 14.2 million missed work days
  - 475,000 hospital stays
  - 3,447 deaths

- Asthma triggers (CDC)
  - ETS
  - Dust mites
  - Outdoor air pollution
  - Cockroach allergens
  - Pets
  - Mold
  - Wood smoke
  - Respiratory infections

Asthma incidence is increasing rapidly in the US and elsewhere



[1] Statistically significant trend.

[2] Trend not statistically significant.

NOTE: See "Technical Notes" for definition of each prevalence type.

SOURCE: CDC/NCHS, National Health Interview Survey (NHIS).

Healthcare and productivity costs

(Fisk, W. How IEQ Affects Health, Productivity. ASHRAE J., May 2000)

Source of Productivity Gain	Potential Annual Health Benefits	Savings, $Billion (1996)	Savings, $Billion (2012)
Reduced Respiratory Illness	16 - 37 Million Avoided Cases of Common Cold or Influenza	6 - 14	9 - 21
Reduced Allergies and Asthma	8% - 25% Decrease in Symptoms within 53 Million Allergy Sufferers and 16 Million Asthmatics	1- 4	1- 6
Reduced Sick Building Syndrome Symptoms	20% - 50% Reduction in SBS Health Symptoms Experienced Frequently at Work by ~15 Million Workers	10 - 30	15 - 44
Productivity Gain from Lighting/ Thermal Improvements		20 - 160	30 - 237

Put another way…

- The value of the health and productivity of the occupants of a building can be more than an order of magnitude greater than the cost of the energy it consumes
- Annual energy cost: \$1 - \$3/ft^2 (~€9 – €25/m^2)
- Annual functional costs: \$80 - \$600/ft^2 (~€680 – €5100/m^2)

Poor IAQ is not a problem of wealthy countries

- Unvented indoor biomass cooking remains common in developing nations
- ~2,000,000 deaths per year due to chronic exposure, mostly women and children
  (Smith, K. R. 2003. The global burden of disease from unhealthy buildings: preliminary results from comparative risk assessment. Proc. Healthy Buildings 2003)

…and to this add concern about the role of indoor exposure in real or feared epidemics – SARS, tuberculosis, influenza

What we know about IAQ on a practical level

- Factors that are correlated with perceived air quality and air quality problems
  - Dampness
  - Ventilation rate
  - Building materials and other sources
  - Indoor air chemistry
- Not enough known to prescribe specific control levels for most contaminants and for mixtures of many interacting contaminants

State of knowledge is reflected in methods

- Source control
  - Remove known hazards
  - Local exhaust for sources that cannot be removed
- Task ventilation and general ventilation – dilute everything
- Non-specific particulate filtration – inorganic, viable and non-viable organic
- Moisture control – prevent mold growth

Comfort vs. Sensory Load & Ventilation

- Fanger hypothesized that the individual is the best sensor for air quality
- Defined "sensory load" in terms of the bioeffluent production of one sedentary adult
- Defined sensory load from material emissions and activities such as smoking in olf units

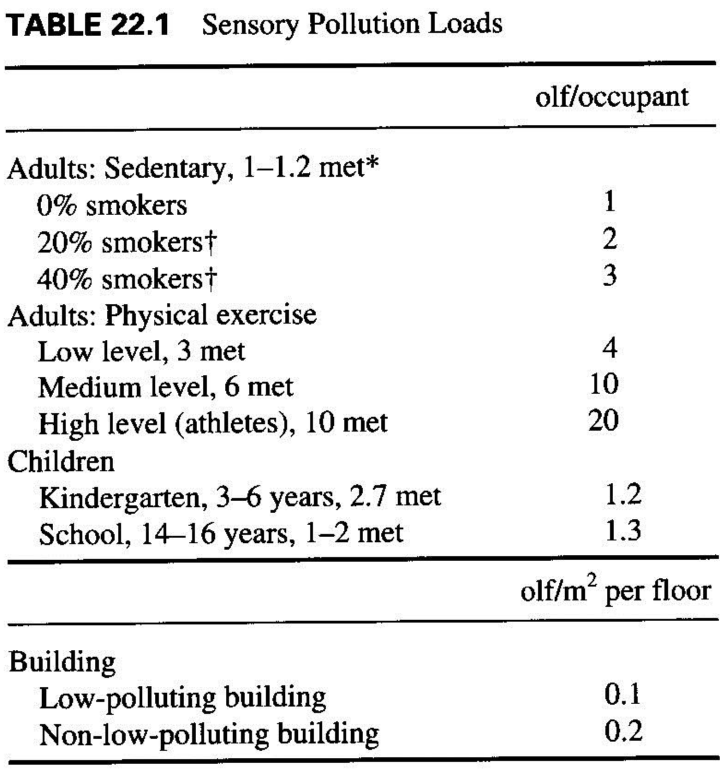
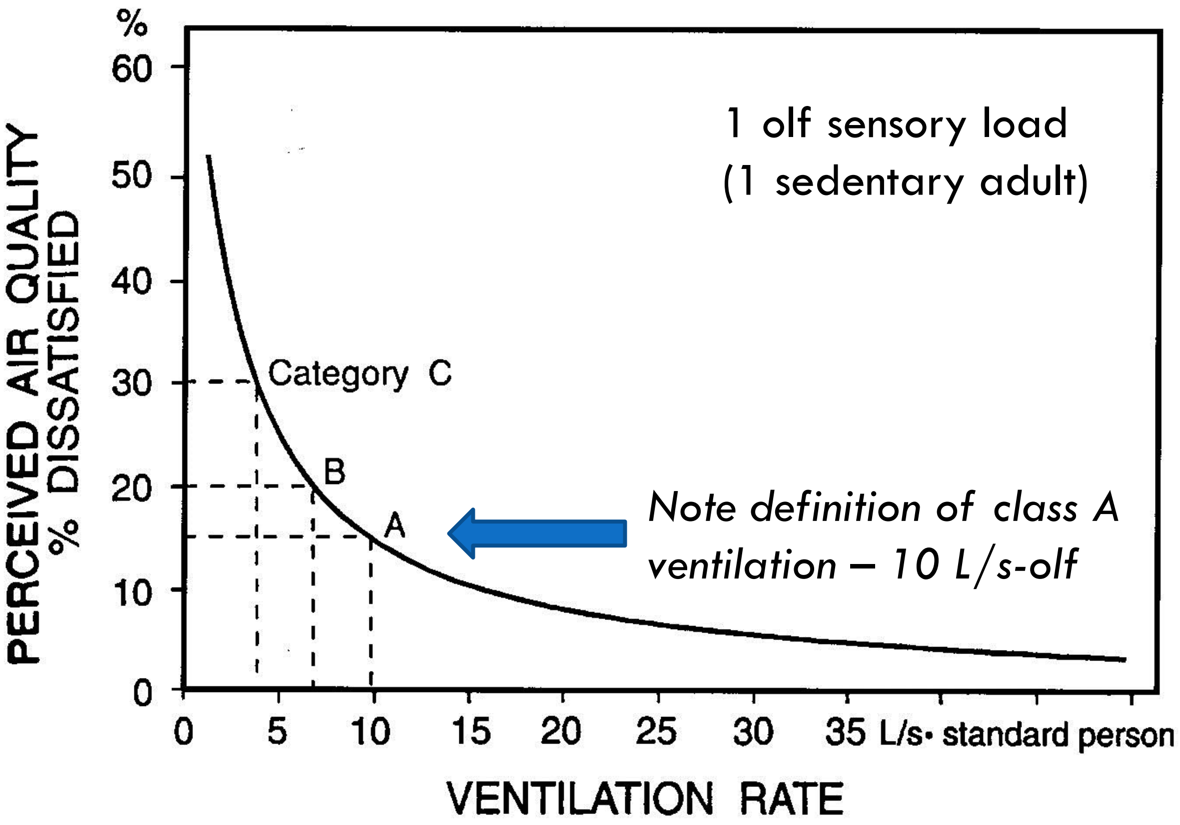


TABLE 22.1 Sensory Pollution Loads

	olf/occupant
Adults: Sedentary, 1–1.2 met*	
0% smokers	1
20% smokers†	2
40% smokers†	3
Adults: Physical exercise	
Low level, 3 met	4
Medium level, 6 met	10
High level (athletes), 10 met	20
Children	
Kindergarten, 3–6 years, 2.7 met	1.2
School, 14–16 years, 1–2 met	1.3
	olf/m^2 per floor
Building	
Low-polluting building	0.1
Non-low-polluting building	0.2

Fanger, P. O. (2008) "Perceived Air Quality and Ventilation Requirements" in Indoor Air Quality Handbook, J. Spengler, J. McCarthy and J. Samet eds.

Comfort vs. Sensory Load &Ventilation

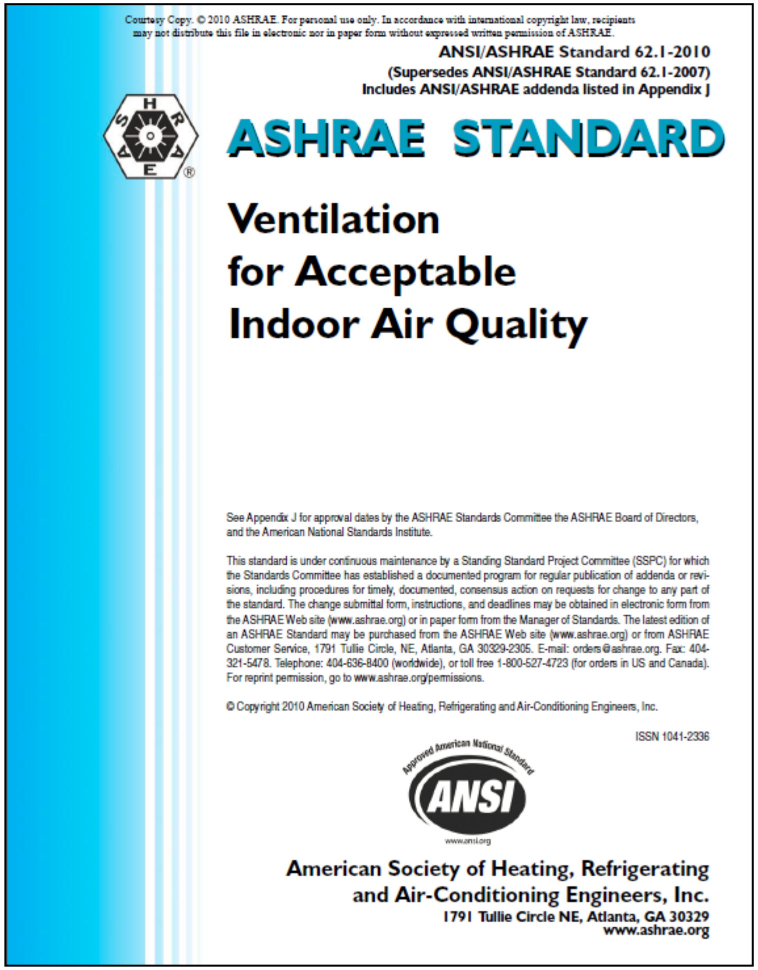


Note definition of class A ventilation – 10 L/s-olf

Fanger, P. O. (2008) "Perceived Air Quality and Ventilation Requirements" in Indoor Air Quality Handbook, J. Spengler, J. McCarthy and J. Samet eds.

ASHRAE Standard 62.1- Air Quality

- Additive ventilation requirements for occupants and building
- Minimum requirements for quality of ventilation air
- Adjustments for air distribution effectiveness
- MERV 6 particulate filtration (ASHRAE Std. 52.2)
- Basic requirements for system design and construction



ANSI/ASHRAE Standard 62.1-2010
(Supersedes ANSI/ASHRAE Standard 62.1-2007)
Includes ANSI/ASHRAE addenda listed in Appendix J

ASHRAE STANDARD

Ventilation for Acceptable Indoor Air Quality

See Appendix J for approval dates by the ASHRAE Standards Committee the ASHRAE Board of Directors, and the American National Standards Institute.

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE Web site (www.ashrae.org) or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE Web site (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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ASHRAE Standard 62.1- Air Quality

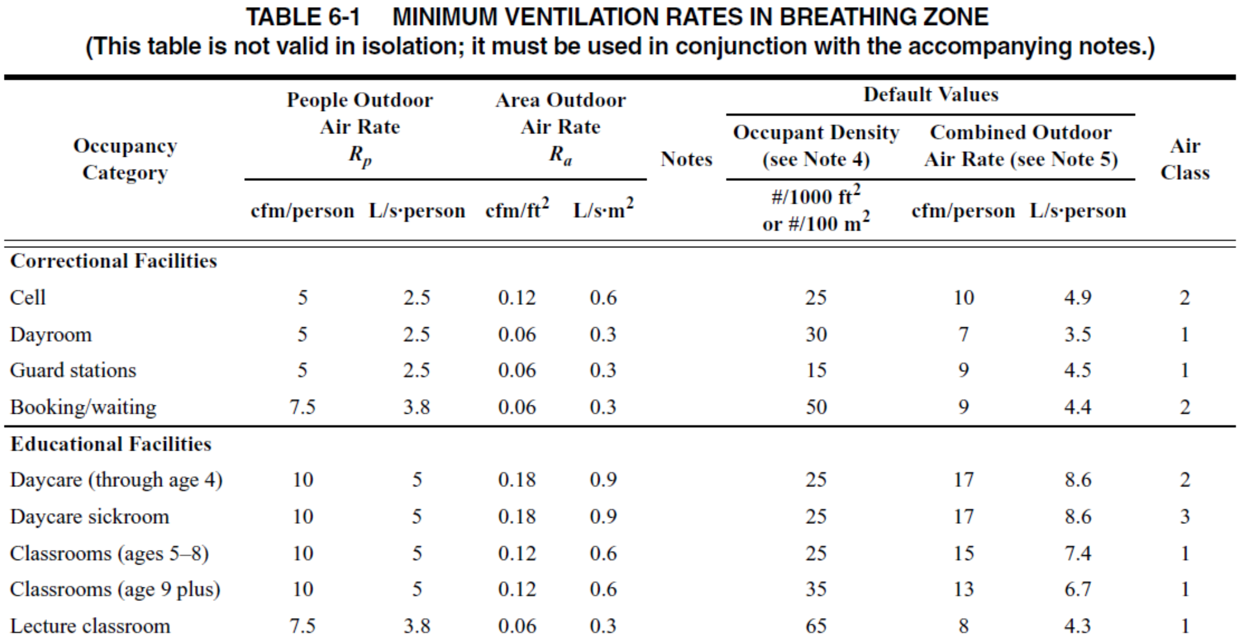


TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE

(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1

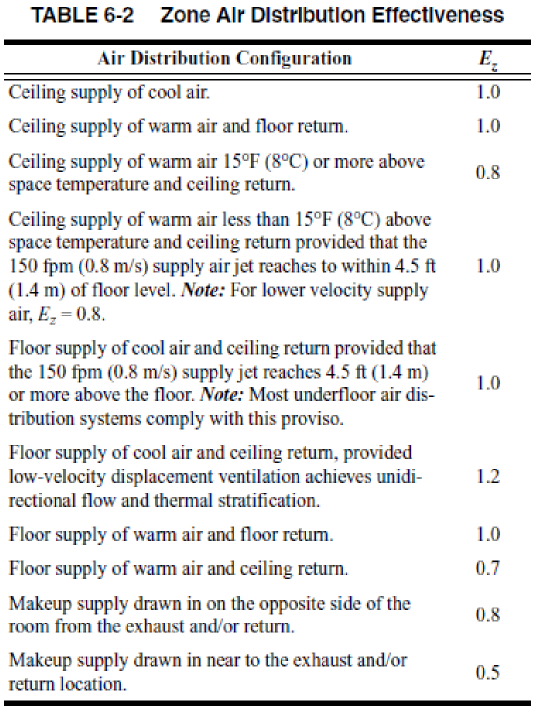
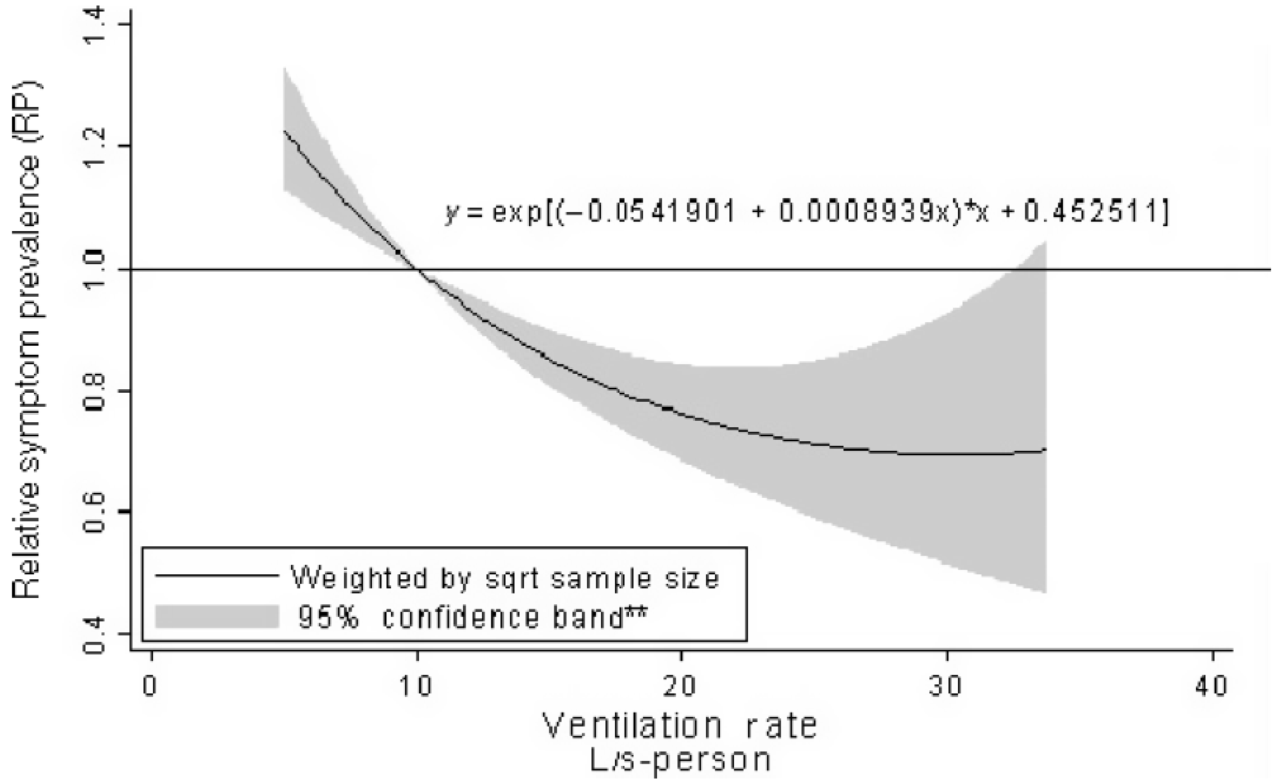


TABLE 6-2 Zone Air Distribution Effectiveness

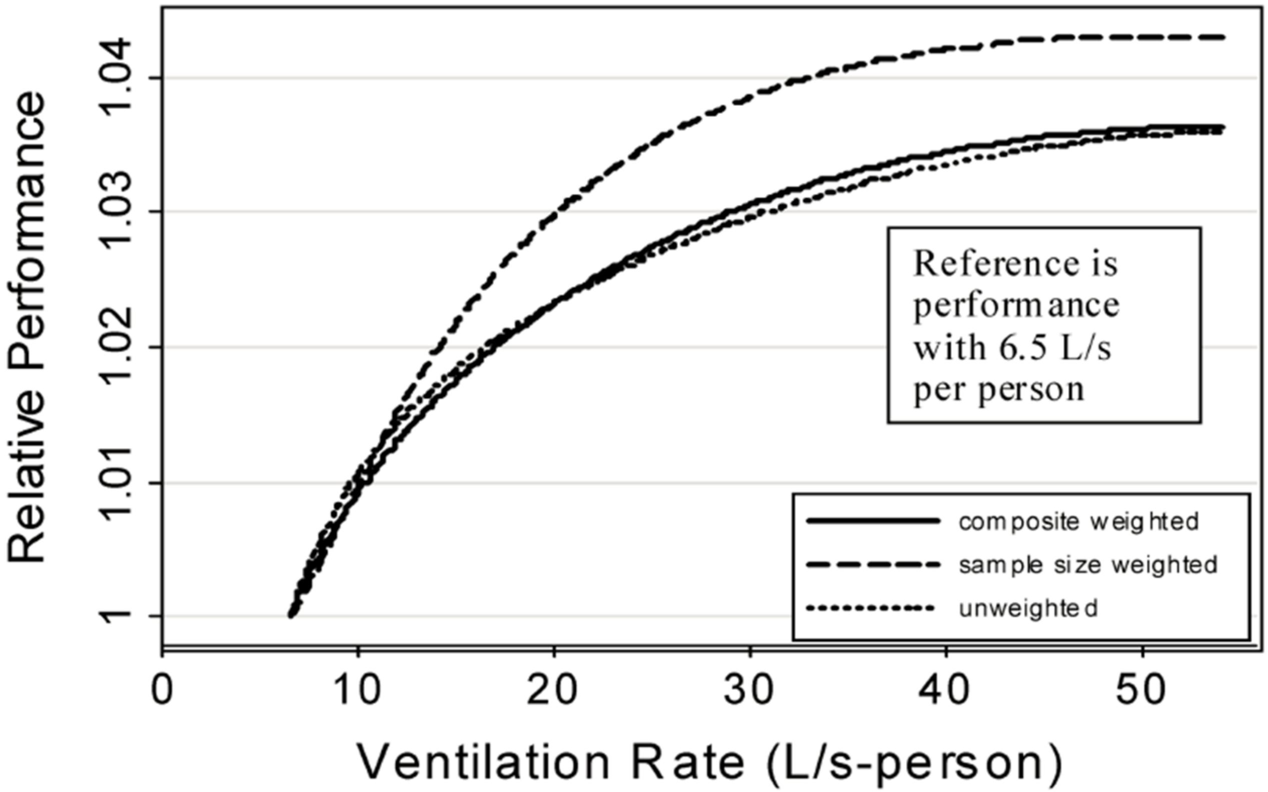
Air Distribution Configuration	E_z
Ceiling supply of cool air.	1.0
Ceiling supply of warm air and floor return.	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return.	0.8
Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level. ***Note:*** For lower velocity supply air, E_z = 0.8.	1.0
Floor supply of cool air and ceiling return provided that the 150 fpm (0.8 m/s) supply jet reaches 4.5 ft (1.4 m) or more above the floor. ***Note:*** Most underfloor air distribution systems comply with this proviso.	1.0
Floor supply of cool air and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification.	1.2
Floor supply of warm air and floor return.	1.0
Floor supply of warm air and ceiling return.	0.7
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return.	0.8
Makeup supply drawn in near to the exhaust and/or return location.	0.5

Sick Building Syndrome Symptoms vs. Ventilation Rate



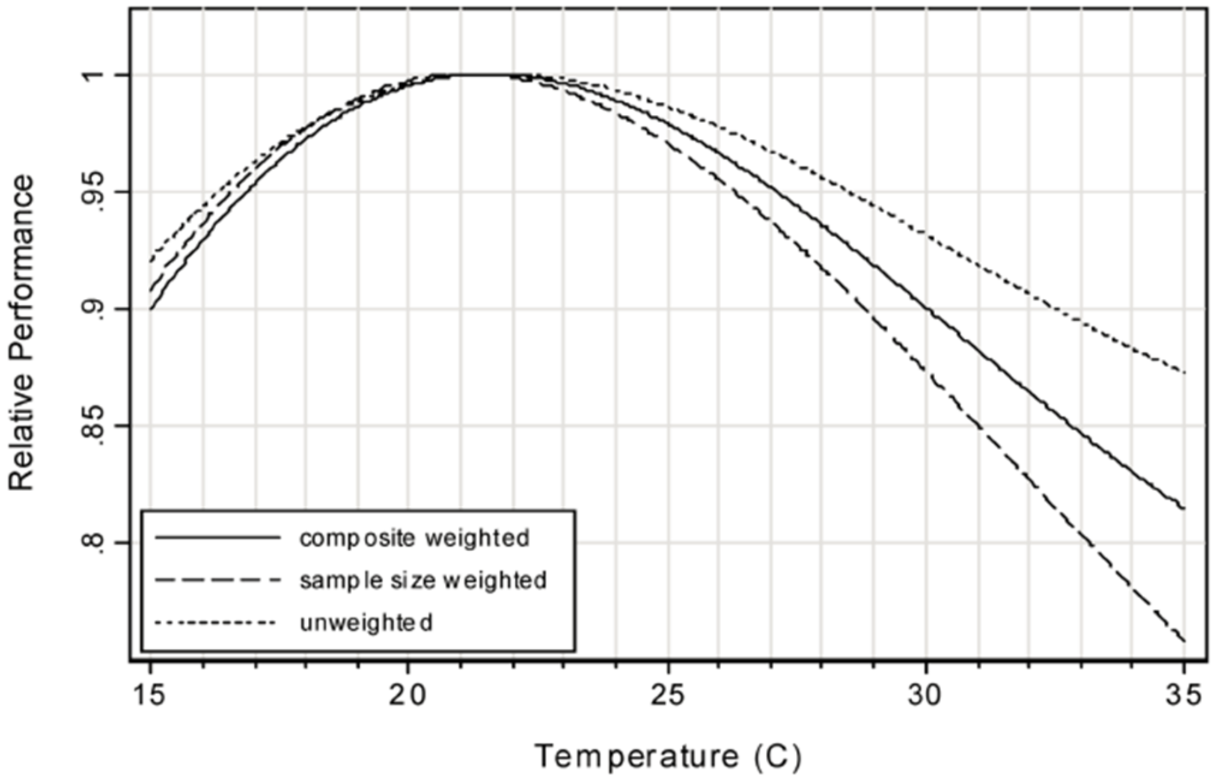
Source: W. Fisk, A Mirer, M. Mendell. 2009. Quantitative relationship of sick building syndrome symptoms with ventilation rates. Indoor Air

Productivity vs. Ventilation Rate



Source: Seppänen, O. and W. Fisk. 2006. Some Quantitative Relations between Indoor Environmental Quality and Work Performance or Health. HVAC&R Research.

IAQ perception is affected by interactions with other IEQ parameters



…and observe ~12% increase in SBS symptoms per 1°C above 22.5°C

Probability of Infection vs. Ventilation Rate

- Wells-Riley is a widely example of a model for infection risk

$$P = 1 - \exp\left[\frac{\left(-\frac{ipqt}{V}\right)}{\eta_v + \eta_f + \eta_d}\right]$$

- Relates probability of infection to infectious source strength and ventilation rate
- Can be generalized using equivalent ventilation rate

- P = proportion of new disease cases among susceptibles
- i = number of infectors
- p = breathing rate
- q = rate of production of infectious particles by infector
- t = time infectors and susceptibles share a space or ventilation system
- V = indoor air volume
- η = air change rate, real or effective (v = ventilation, f = filter, d = deposition)

Current ventilation requirements

- Codes and standards predominantly reference subjective comfort – e.g., ASHRAE Standard 62.1:

  Acceptable Indoor Air Quality: *air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.*

- New information on influence of IEQ variables has made little penetration into practice – e.g., LEED credit for ASHRAE 62.1 + 30%

Current minimum standards may aim too low

- IEQ is the cumulative impact of air quality, thermal environment, lighting quality, acoustic environment
- Overall acceptability multiplicative? If so, and all four target 80%, overall ~40%
- Fall even shorter of optimal health/productivity levels

…HVAC designer assumes code provides good IAQ and then focuses on minimizing energy use/cost, perhaps too much, given the human cost.

Achieving High IAQ Efficiently

- Energy recovery from ventilation air
- Allowance for intermittent occupancy
- Dynamic ventilation control
- DOAS
- Air treatment as a substitute/supplement for ventilation

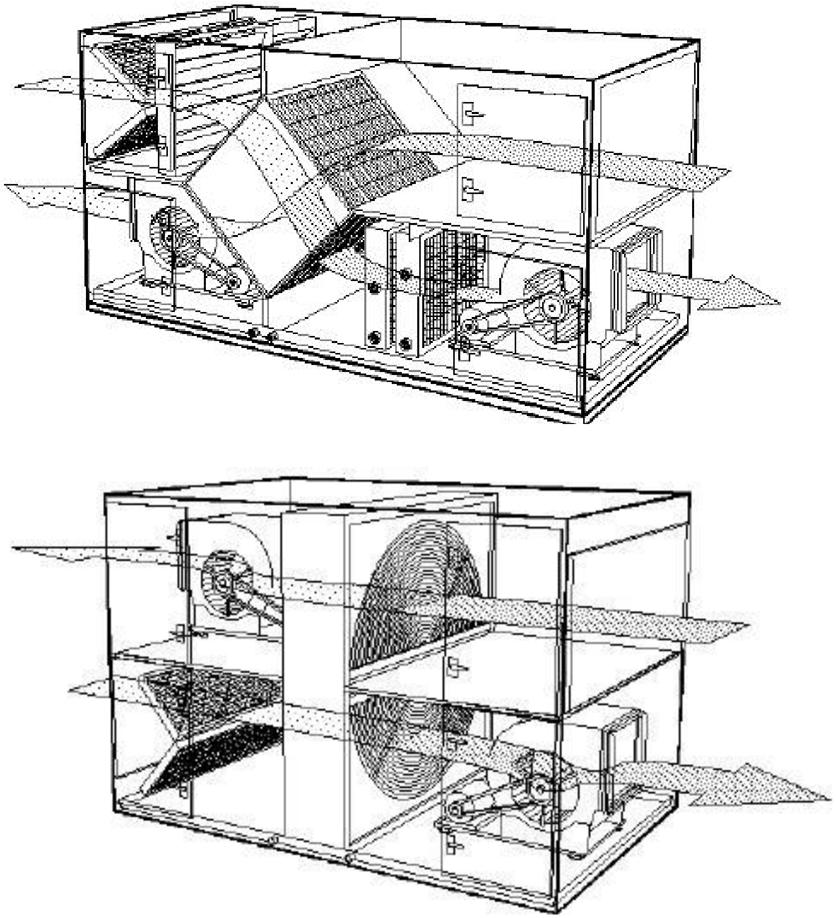
…all permitted by ASHRAE Standard 62.1, encouraged by 90.1

USGBC-LEED

- Increased ventilation (ASHRAE 62.1 or CEN Standard EN 15251: 2007+30%)
- Dynamic ventilation
- Natural ventilation
- Low emission materials

Ventilation air energy recovery

- Needed in extreme cold or hot/humid climate
- Sensible or sensible/latent – function of climate
- Required ASHRAE 90.1for some systems (>5000 cfm (2.4 m^3/s and > 70% OA)

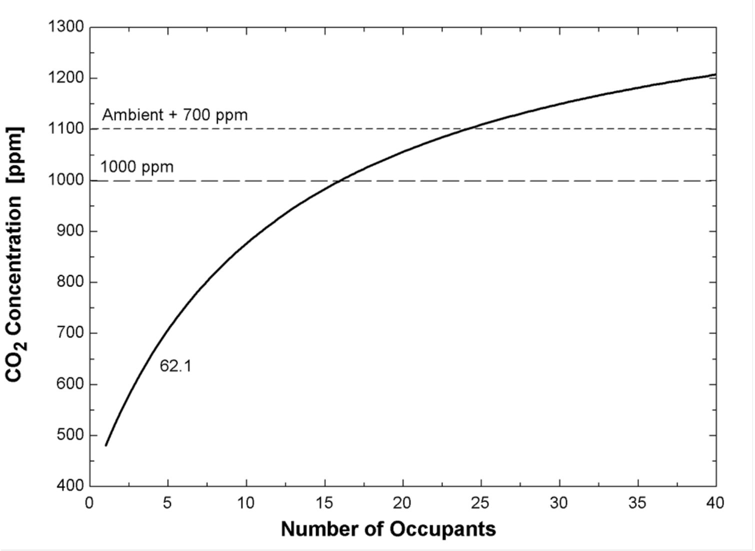


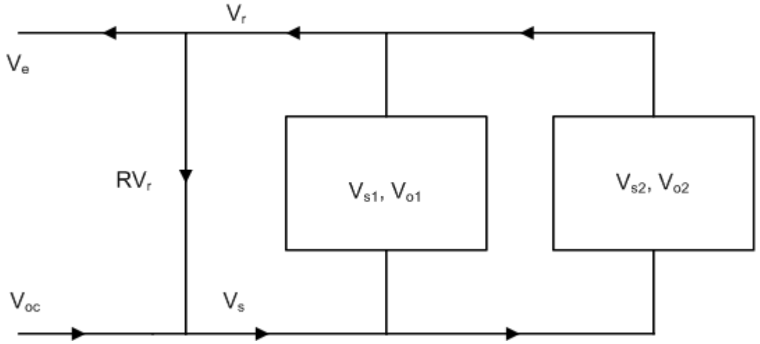
Dynamic Ventilation Control (Demand Controlled Ventilation)

- If properly sized, ventilation flow rate can be reduced in proportion to occupancy
- Can significantly reduce energy if properly implemented
- Control options
  - Scheduled
  - On/off with occupancy sensors
  - Indirect occupancy count using CO_2 concentration (most common)
  - Direct occupancy count (developmental)
- Required by ASHRAE 90.1 for some high-occupancy density spaces

Issues with CO_2 based DCV

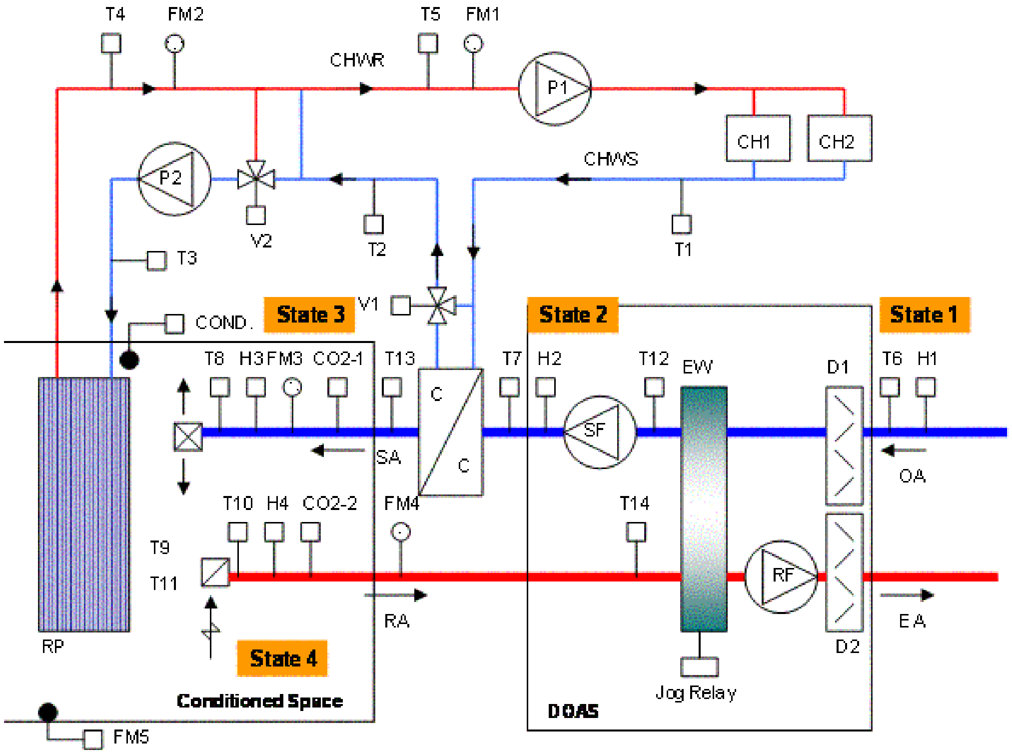
- Mediocre accuracy of HVAC-grade sensors
- People – building division of ventilation in ASHRAE 62.1 eliminates fixed set point approach
- Multiple spaces are a further complication





Dedicated Outdoor Air Systems

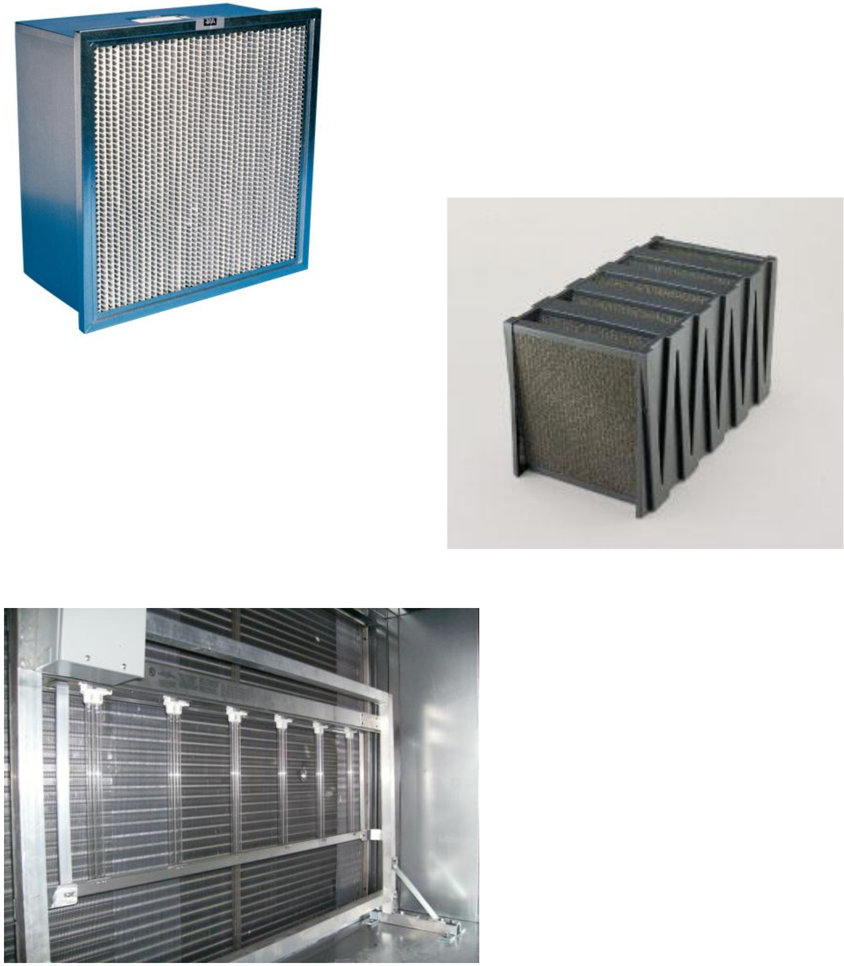
- 100% OA
- Minimizes design OA requirement
- Reduces fan power requirement
- DOAS meets full latent load
- Parallel sensible system can operate efficiently at higher temperature



Source: doas.psu.edu

Air Cleaners to Reduce Ventilation Requirement

- Filters for all particulates – media, electrostatic
- Sorbents for VOCs and other gas phase contaminants
- UVGI for surface and airborne bio-contaminants
- Photocatalytic oxidation and others…

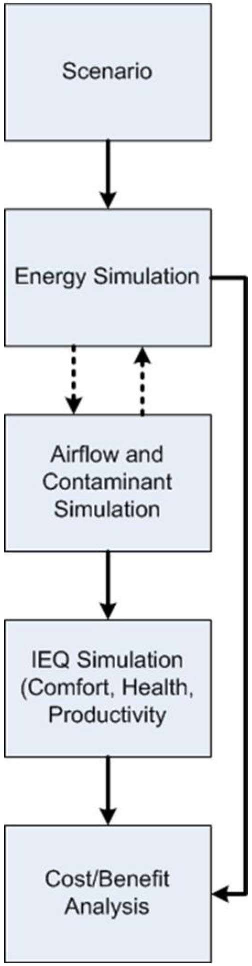


Integrating IAQ and Energy Efficiency

- Design emphasis is imbalanced
  - IAQ is reduced to code ventilation rate
  - Real effort goes into energy efficiency – evaluation and optimization of system alternatives using modeling
- Few simiulation tools have integrate coupled simulation of energy and IAQ
- In the research arena, IAQ and energy are mainly the domains of different communities that work independently

Elements of an integrated analysis

- Energy simulation
  - Thermal
  - Equipment performance
- Air (and contaminant) flow modeling
  - Multizone (e.g. CONTAM)
  - CFD
- IAQ performance modeling
- Economic analysis



Studies directed at integrated design: Fisk, et al., effect of economizer

- Fisk, W., D. Faulkner, O. Seppänen, J. Huang. 2005. Economic Benefits of an Economizer System: Energy Savings and Reduced Sick Leave. ASHRAE Transactions 111(2).
- Would not classify as a “low energy IAQ technology” because IAQ benefit, if realized, is accidental
- Combines energy modeling with Wells-Riley based sick leave analysis for two-story office in Washington DC.

Fisk, et al. results

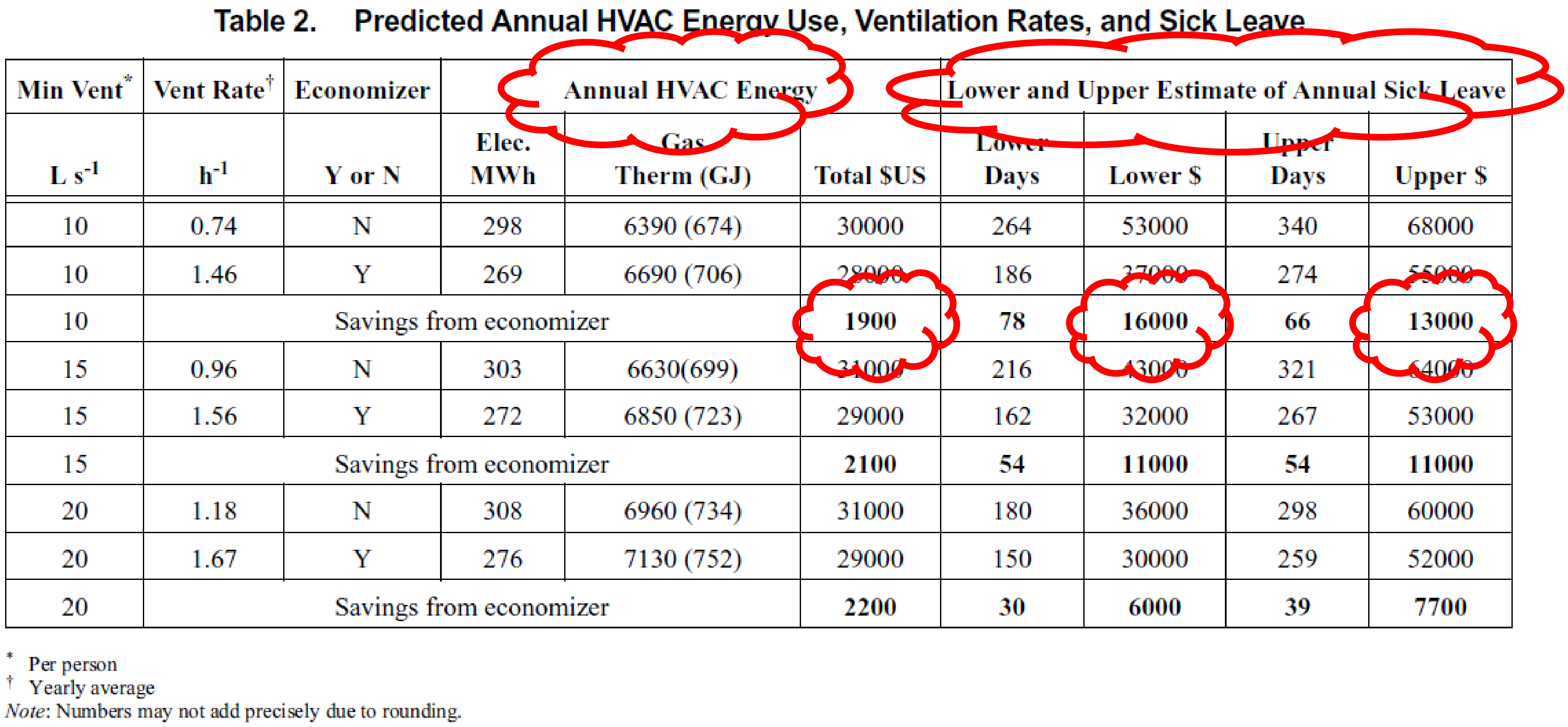


Table 2. Predicted Annual HVAC Energy Use, Ventilation Rates, and Sick Leave

Min Vent*	Vent Rate†	Economizer	Annual HVAC Energy			Lower and Upper Estimate of Annual Sick Leave			
L s^{-1}	h^{-1}	Y or N	Elec. MWh	Gas Therm (GJ)	Total $US	Lower Days	Lower $	Upper Days	Upper $
10	0.74	N	298	6390 (674)	30000	264	53000	340	68000
10	1.46	Y	269	6690 (706)	28000	186	37000	274	55000
10	Savings from economizer				**1900**	**78**	**16000**	**66**	**13000**
15	0.96	N	303	6630(699)	31000	216	43000	321	64000
15	1.56	Y	272	6850 (723)	29000	162	32000	267	53000
15	Savings from economizer				**2100**	**54**	**11000**	**54**	**11000**
20	1.18	N	308	6960 (734)	31000	180	36000	298	60000
20	1.67	Y	276	7130 (752)	29000	150	30000	259	52000
20	Savings from economizer				**2200**	**30**	**6000**	**39**	**7700**

* Per person
† Yearly average
Note: Numbers may not add precisely due to rounding.

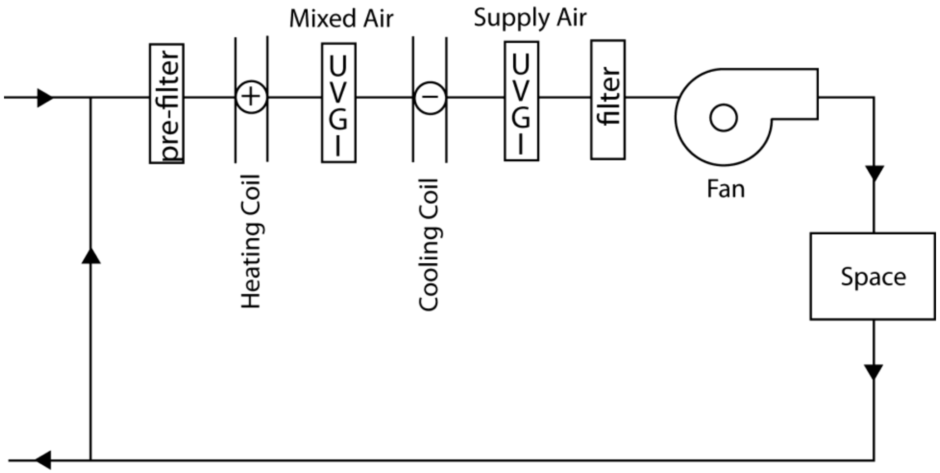
Health benefit is 3 – 8 times greater than energy savings

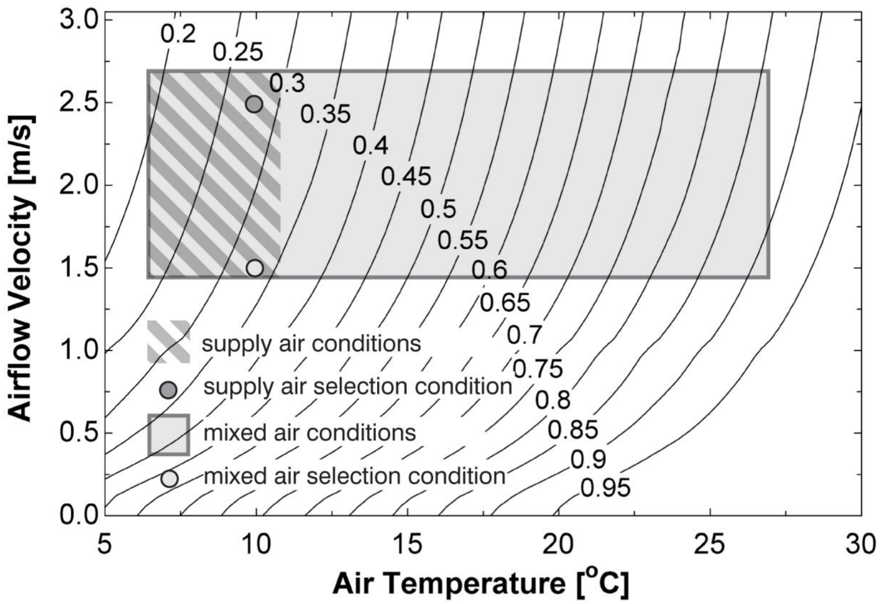
Studies directed at integrated design: Lee, et al., In-duct UVGI vs. filters

- Lee, B., W. Bahnfleth, and K. Auer. 2009. Life-cycle cost simulation of in-duct ultraviolet germicidal irradiation systems. Proceedings of Building Simulation 2009, the 11th International Building Performance Simulation Association Conference and Exhibition, July 2009, Glasgow, Scotland.
- Energy analysis, Wells-Riley based sick-leave analysis, life-cycle cost analysis of UVGI air disinfection compared with equivalent (MERV 12) filter
- Office building in New York City

Lee, et al. scenarios

- Base HVAC system (minimum OA, MERV 6) + UVGI downstream of cooling coil
- Base HVAC system + UVGI upstream of cooling coil
- Base HVAC system + filtration equivalent to UVGI (MERV 12)

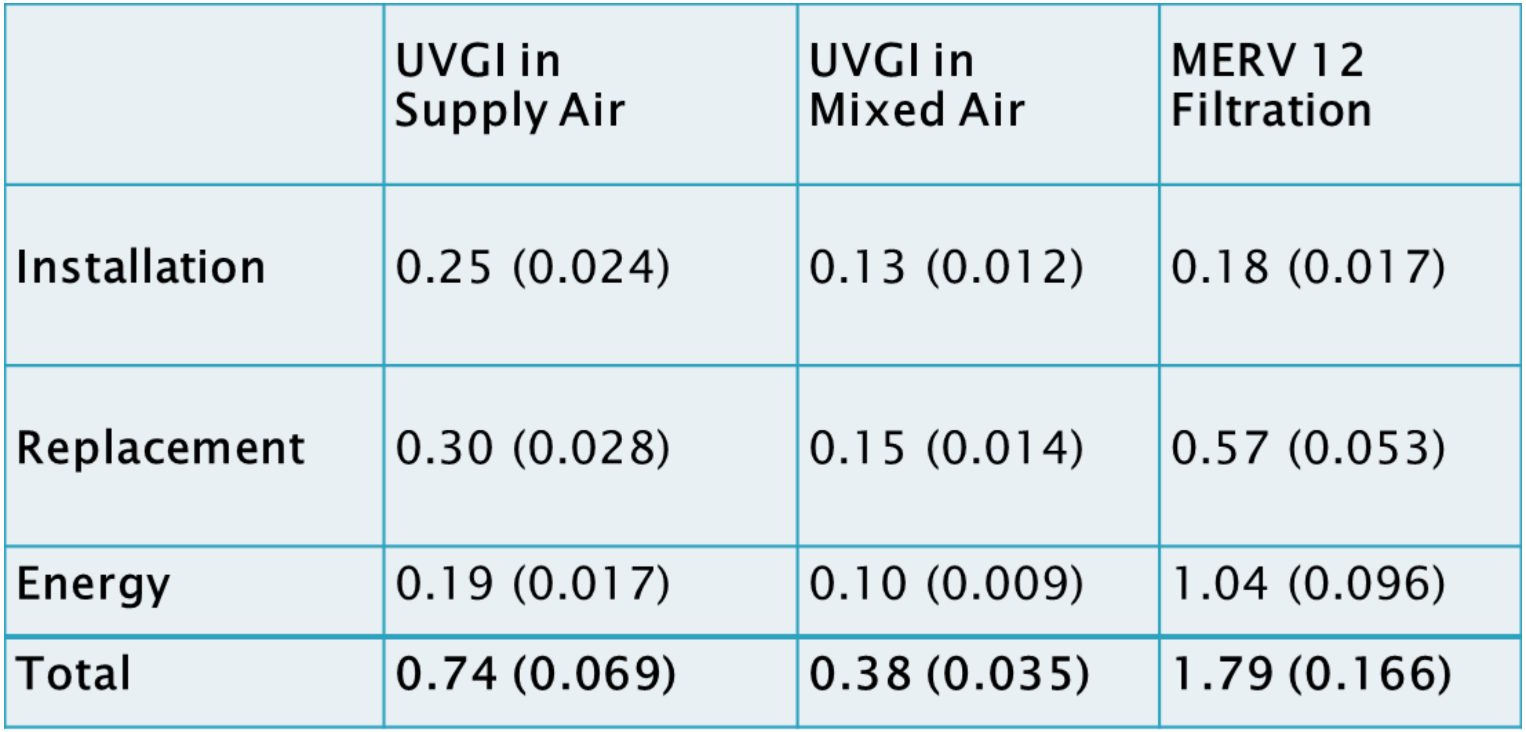




Lee, et al. energy and energy cost results

Annual Energy Consumption	UVGI @ SA	UVGI @ MA	MERV 12 filtration
Power to lamps (kWh)	6290	3189	–
Cooling (kWh)	1175	575	9975
Fan (kWh)	400	200	17175
Heating-electric (kWh)	-3063	-1487	-506
Net (kWh) kWh/m^2 (kWh/ft^2)	4802 2 (0.2)	2477 1 (0.1)	26,644 11 (1)
Cost ($) $/m^2 ($/ft^2)	480 0.20 (0.019)	248 0.10 (0.010)	2664 1.12 (0.104)

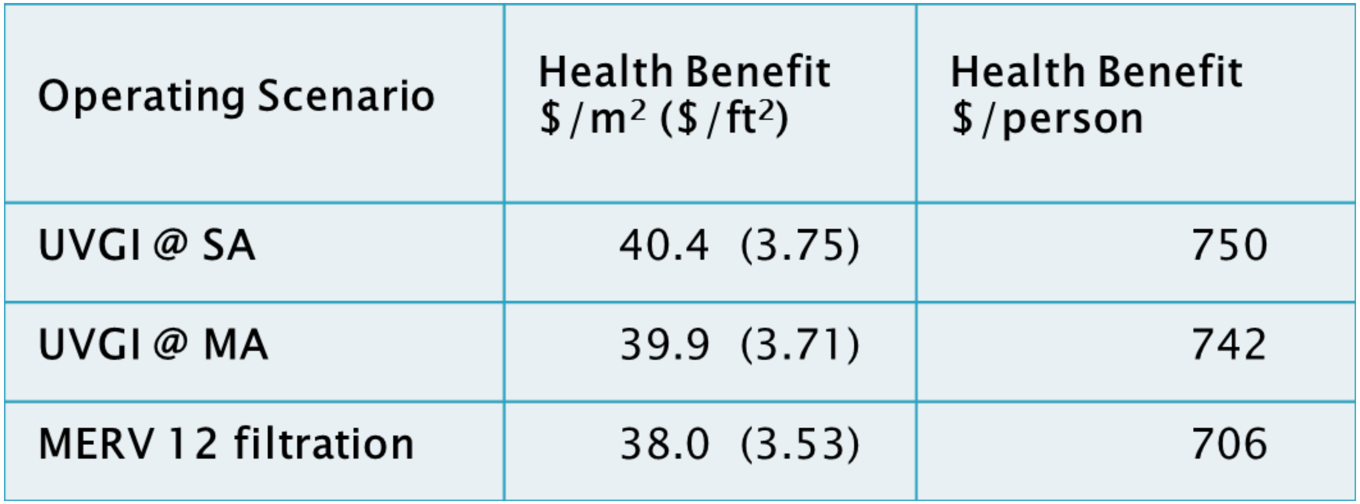
Lee, et al. life cycle cost results, without productivity impact - $\$/m^2$ ($\$/ft^2$)



	UVGI in Supply Air	UVGI in Mixed Air	MERV 12 Filtration
Installation	0.25 (0.024)	0.13 (0.012)	0.18 (0.017)
Replacement	0.30 (0.028)	0.15 (0.014)	0.57 (0.053)
Energy	0.19 (0.017)	0.10 (0.009)	1.04 (0.096)
Total	**0.74 (0.069)**	**0.38 (0.035)**	**1.79 (0.166)**

In this case, showed that UVGI was less expensive than filtration than filtration for same performance and one UVGI location was substantially better than the other

Lee, et al., annual productivity benefit



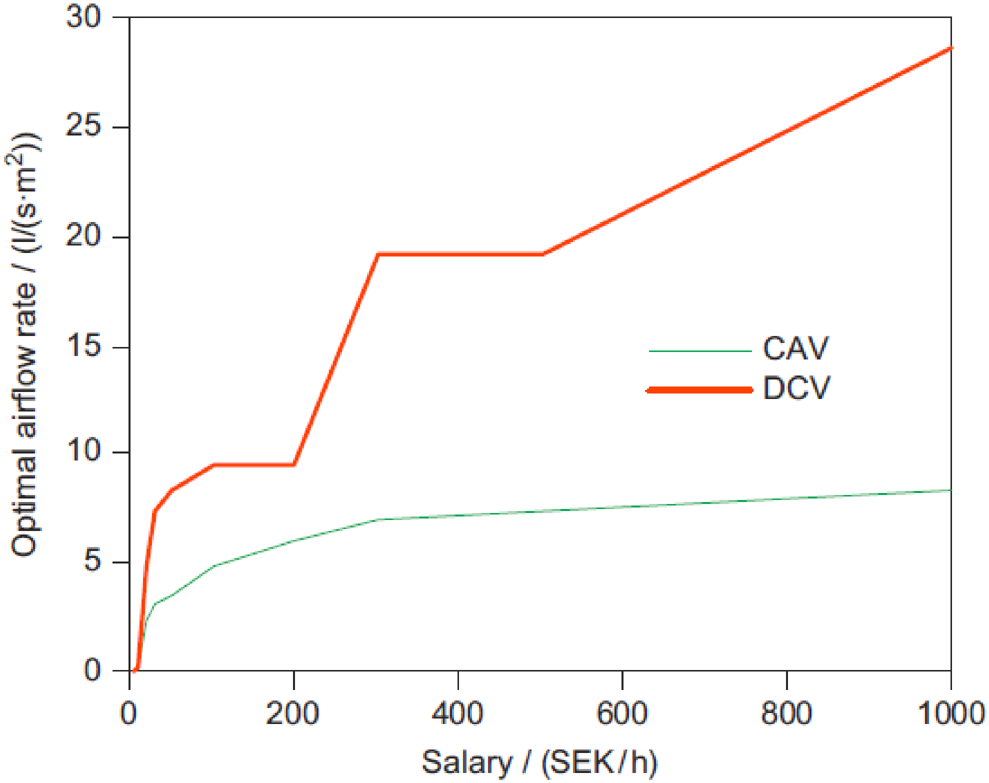
Operating Scenario	Health Benefit $\$/\mathrm{m}^2$ ($\$/\mathrm{ft}^2$)	Health Benefit \$/person
UVGI @ SA	40.4 (3.75)	750
UVGI @ MA	39.9 (3.71)	742
MERV 12 filtration	38.0 (3.53)	706

85% UVGI or additional MERV 12 filtration reduce relative risk by 50 – 55%, savings are ~20 – 100 times cost

Studies directed at integrated design: Johansson – Life cycle optimization

- Johansson, D. 2009. The life cycle costs of indoor climate systems in dwellings and offices taking into account system choice, airflow rate, health and productivity. Building and Environment (44):368-376.
- PhD dissertation – cost-optimal system and ventilation rate selection based on equipment, energy, health/productivity cost

Johansson – representative result: optimal ventilation vs. salary in an office



Conclusion: The more money you make, the better the air quality you get…especially if you have energy saving HVAC controls!

Summary

- Maintaining even mediocre IAQ uses lots of energy – and costs society a lot in quality of life and productivity
- We can do better with basic IEQ measures like ventilation, but that knowledge has not penetrated far into practice
- The energy and IAQ worlds do not overlap a lot – not enough yet – integration is interdisciplinary
- Process and tools are needed for design, and lots more research into parameters of IAQ and interactions of IEQ parameters