ENVE 576
Indoor Air Pollution
Spring 2014

Week 14: November 25, 2014
Applications and standards
Course wrap-up

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Built Environment Research @ IIT

Advancing energy, environmental, and sustainability research within the built environment

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This time and last time

13	Nov 18	IAQ measurement techniques (cont.) Infectious disease transmission	39–41	
14	Nov 25	Applications • Standards and manufacturer ratings Modeling software	36–38	Blog #4 due
15	Dec 2	*Lecture cancelled: Review panel travel*		
Final	Dec 9 5-7 PM	No final exam – final presentations		Final project due Blog #5 due

Last time:

- Infectious disease transmission

This time:

- Applications and standards
  - Software and practical guidance

**No class next week

Final project papers and presentations

Team	Topic
1: Ivan Jose and YiYun Fan	Emissions from enclosures
2: Kyleen Hoover	Indoor carbon monoxide
3: Muhammad Akbar and Harshil Modi	Pollen and control
4: Jihad Zeid	E-cigarettes
5: Torkan Fazli and Sina Nabavi	Particle filtration
6: Tongchuan Wei and Sibo Liu	Radon
7: Boyang Lu and Shujun Zhang	Plants and IAQ
8: Haoran Zhao and Zhice Hu	Cookstoves and IAQ
9: Andi Mele, Dan Zhao, and Sheng Xiang	Swimming pools and IAQ

Papers due Tuesday, December 9 by 5 PM in class or uploaded to BB

- 7000 words max., follow the template on BB

Presentations given Tuesday, December 9 in class 5-7 PM

- 12 minutes maximum – I will cut you off if you go long!

APPLICATIONS AND STANDARDS

Applications: Software

- I think we should all be aware of some of the software tools available for modeling air pollution in indoor environments
- You can always build well-mixed mass balance models in Excel or other programs (e.g., Matlab, Mathematica, python, R, etc.)
  - Time-varying (dynamic) or steady state
  - Multi-compartments if necessary
  - Monte carlo for testing sensitivity to inputs
- Other tools include:
  - CONTAM
  - CFD

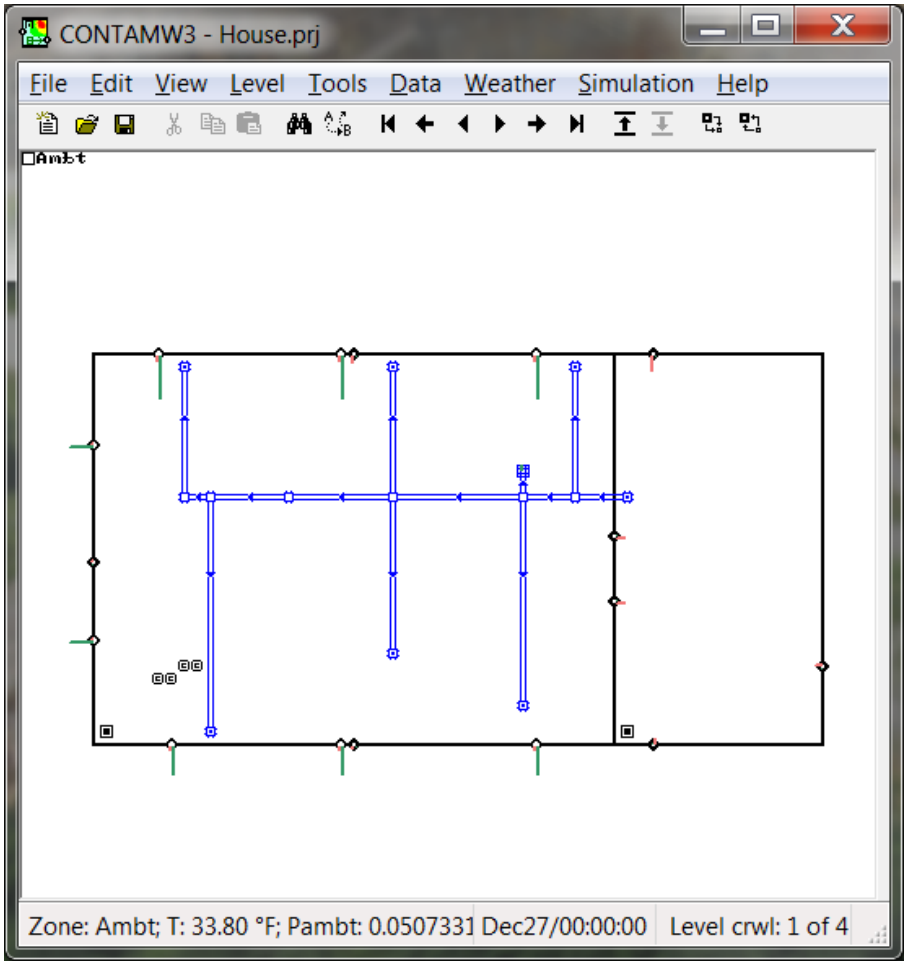
CONTAM

- Multi-zone airflow and contaminant transport analysis software
- Can be used to account for:
  - Airflows (infiltration, exfiltration, room-to-room airflows, wind-driven flow, stack effects)
  - Contaminant concentrations and mechanisms (dispersion indoors, transformation, adsorption, desorption, filtration, deposition, and others)
  - Personal exposures

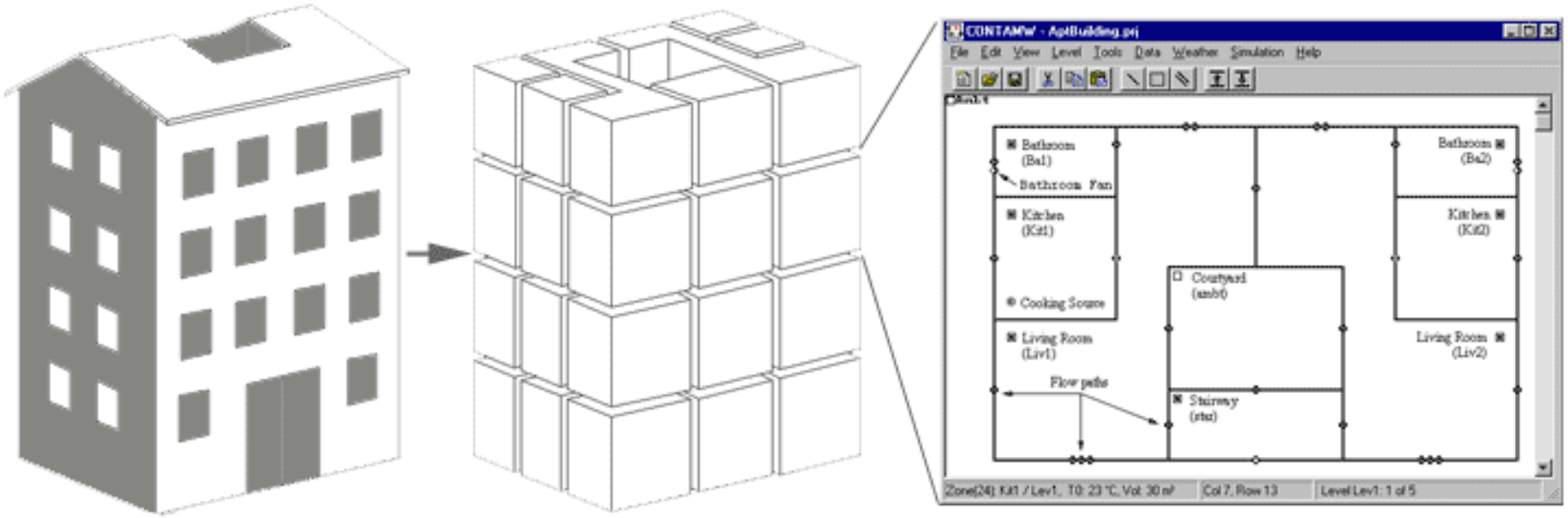
http://www.bfrl.nist.gov/IAQanalysis/CONTAM/

CONTAM

- You can build a building and set flow rates and boundary conditions everywhere
- It solves mass balances for you
- Does not give spatially-resolved concentrations unless you build a compartment for it



CONTAM



REAL BUILDING

Idealized Building

CONTAM Building Model

CONTAM

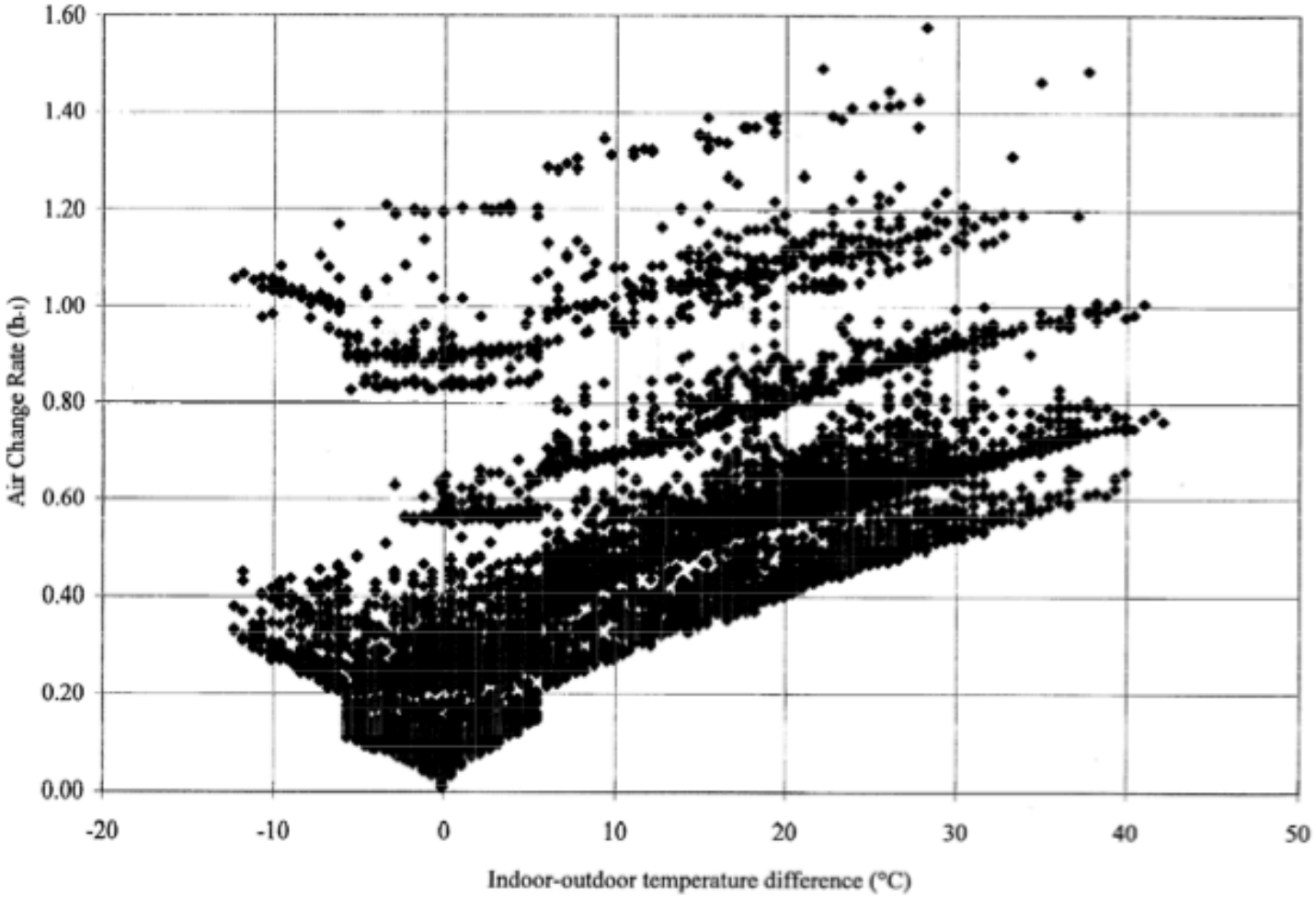


Figure 19 Hourly Air Change Rates for Albany: Whole House Exhaust Fan in KLA Zone Operated During Occupancy (Case #5B)

Persily and Martin **2000** A Modeling Study of Ventilation in Manufactured Houses National Institute of Standards and Technology. NIST Report

CONTAM

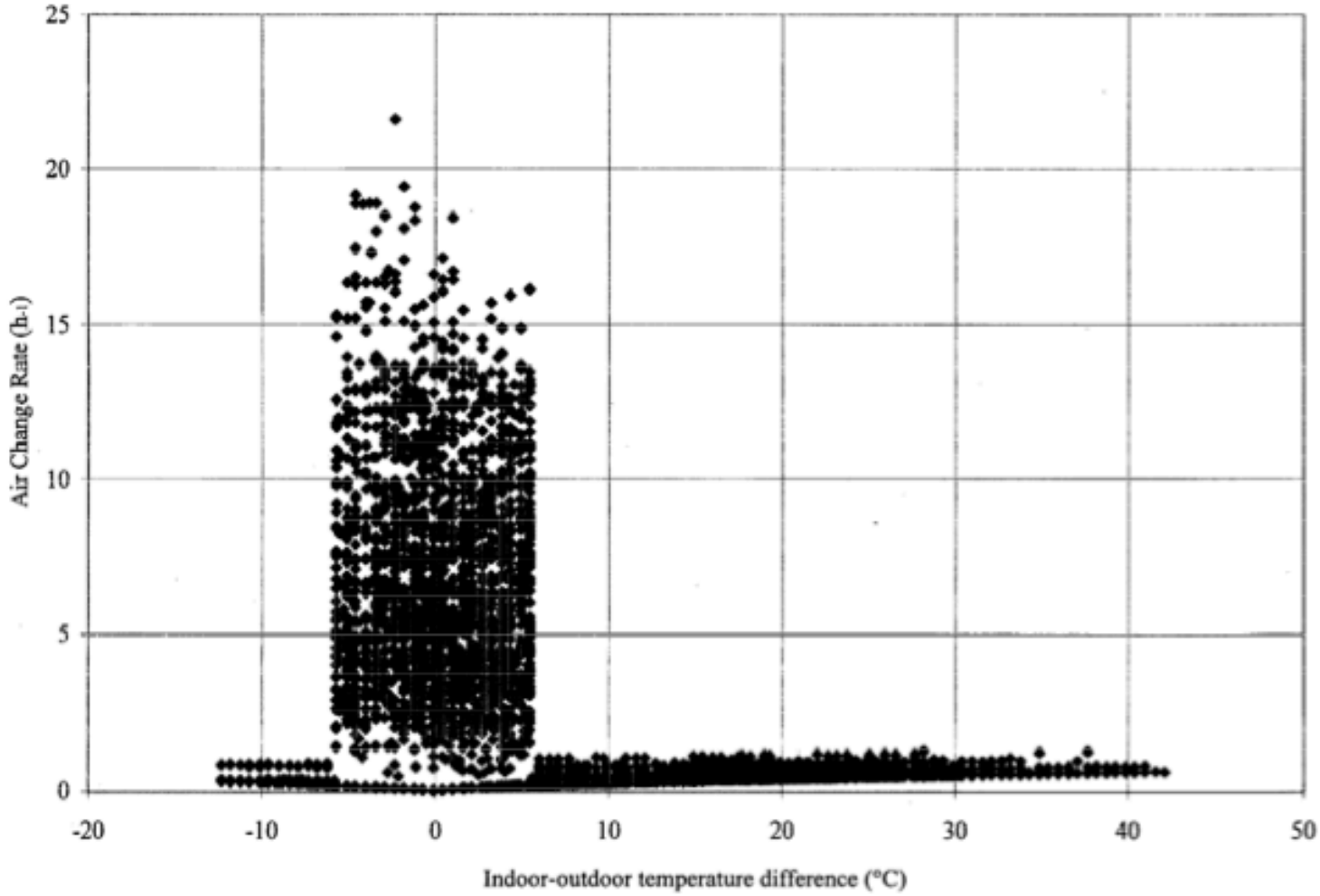
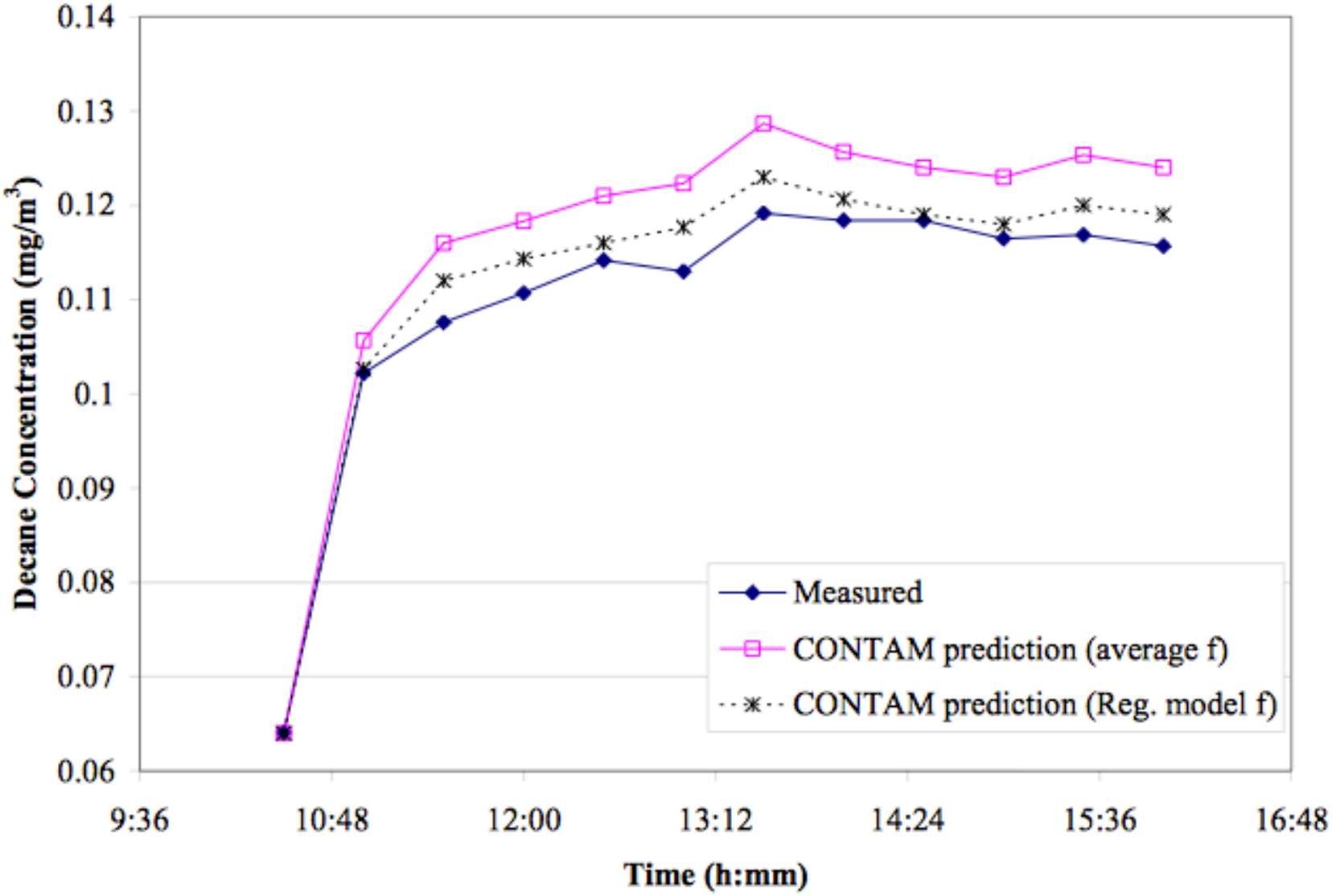


Figure 21 Hourly Air Change Rates for Albany: Window Operation

Persily and Martin **2000** A Modeling Study of Ventilation in Manufactured Houses National Institute of Standards and Technology. NIST Report

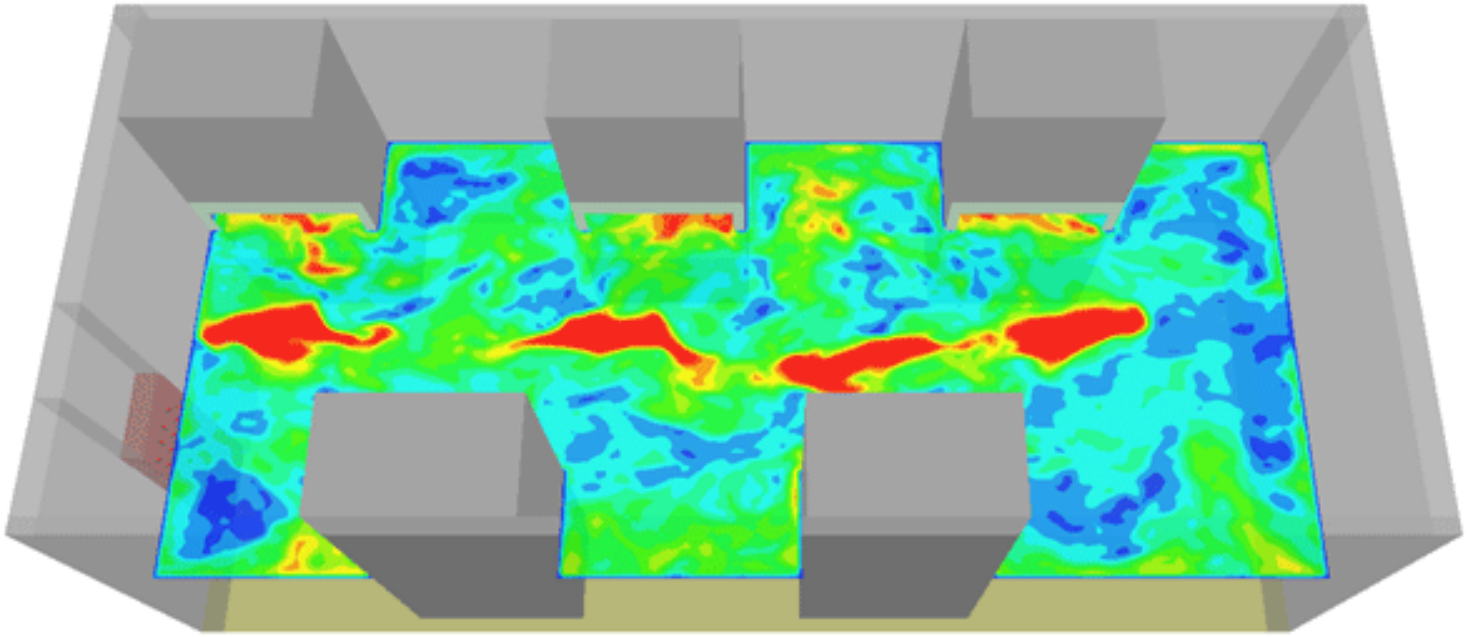
CONTAM



Howard-Reed et al. **2005** Indoor Air 2005 Conference

CFD

- If you want more highly resolved spatial detail, turn it computational fluid dynamics (CFD)



- CFD programs solve the Navier-Stokes equations for viscous, heat conducting fluids
  - Accounts for conservation of momentum, energy, and mass

CFD: Navier-Stokes Equations

Navier–Stokes Equations

3 – dimensional – unsteady

Glenn Research Center

Coordinates: (x,y,z)

Velocity Components: (u,v,w)

Time : t Pressure: p Heat Flux: q

Density: ρ Stress: τ Reynolds Number: Re

Total Energy: Et Prandtl Number: Pr

Continuity:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

X – Momentum:

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}=-\frac{\partial p}{\partial x}+\frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:

$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho v^2)}{\partial y}+\frac{\partial(\rho vw)}{\partial z}=-\frac{\partial p}{\partial y}+\frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho w^2)}{\partial z}=-\frac{\partial p}{\partial z}+\frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}\right]$$

Energy:

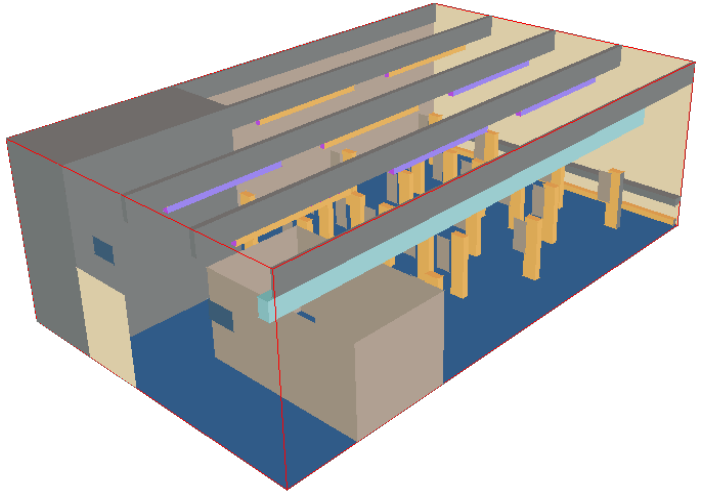
$$\frac{\partial(E_T)}{\partial t}+\frac{\partial(uE_T)}{\partial x}+\frac{\partial(vE_T)}{\partial y}+\frac{\partial(wE_T)}{\partial z}=-\frac{\partial(up)}{\partial x}-\frac{\partial(vp)}{\partial y}-\frac{\partial(wp)}{\partial z}-\frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right]$$
$$+\frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\tau_{xx}+v\tau_{xy}+w\tau_{xz})+\frac{\partial}{\partial y}(u\tau_{xy}+v\tau_{yy}+w\tau_{yz})+\frac{\partial}{\partial z}(u\tau_{xz}+v\tau_{yz}+w\tau_{zz})\right]$$

CFD simulations

- Involves discretizing an indoor space into a “mesh”
  - Thousands of small cells representing individual nodes
  - Develop a system of equations to solve Navier-Stokes
  - We use software for this (e.g., Fluent, AirPak, openFOAM, IES, others)

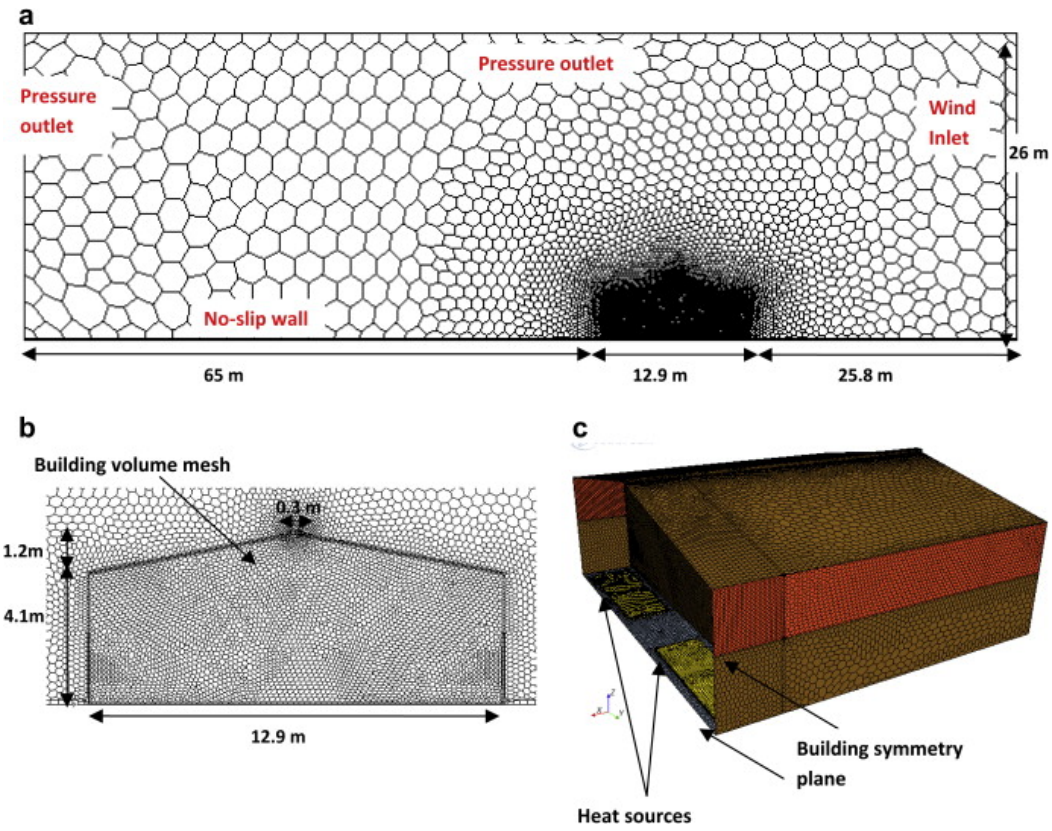
Take real geometry….

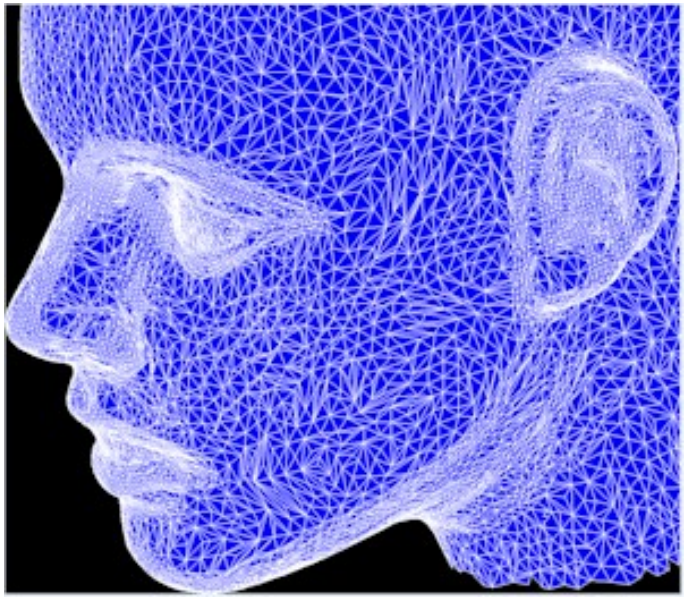
… and convert to model geometry



Images courtesy Atila Novoselac, UT-Austin

Defining a mesh

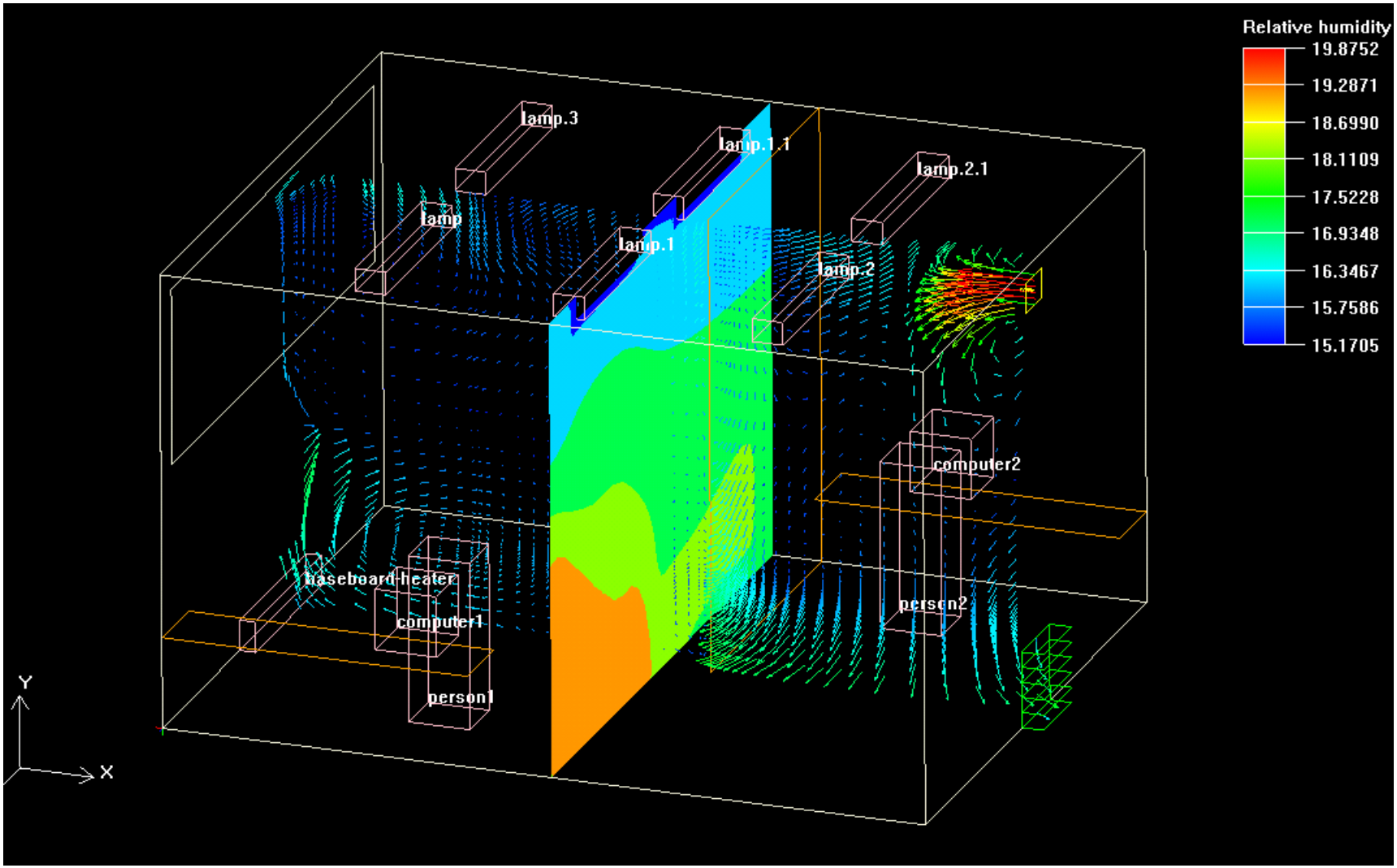




Peter V. Nielsen

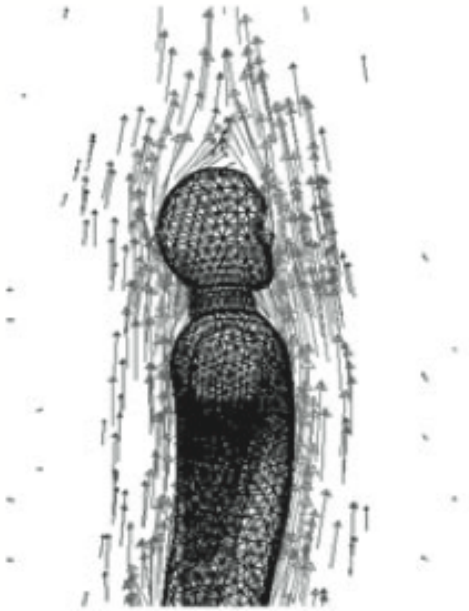
Images courtesy Atila Novoselac, UT-Austin

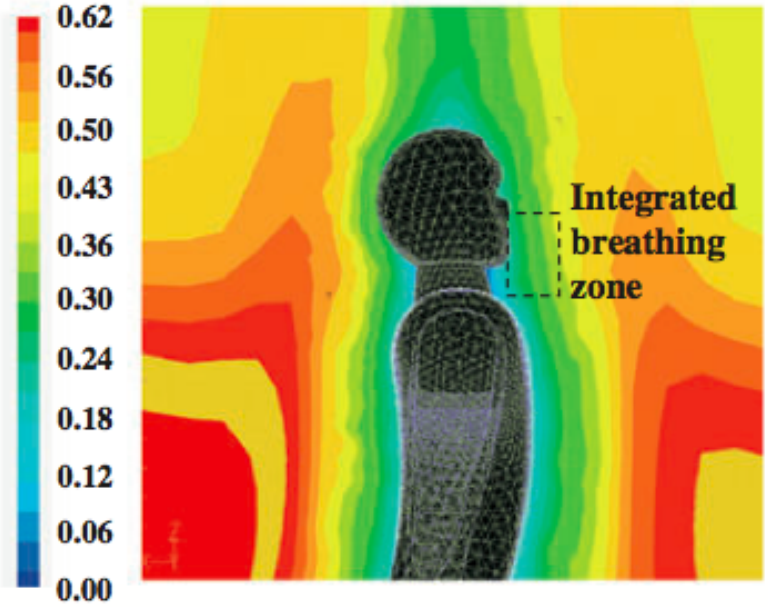
CFD outputs

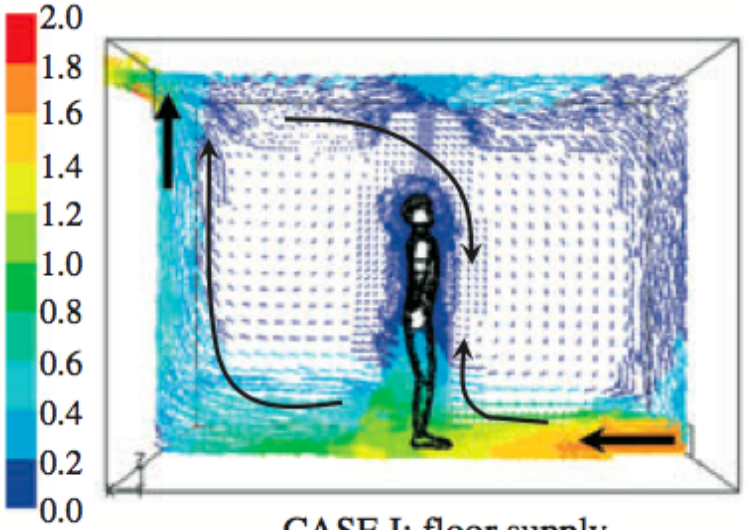


Images courtesy Atila Novoselac, UT-Austin

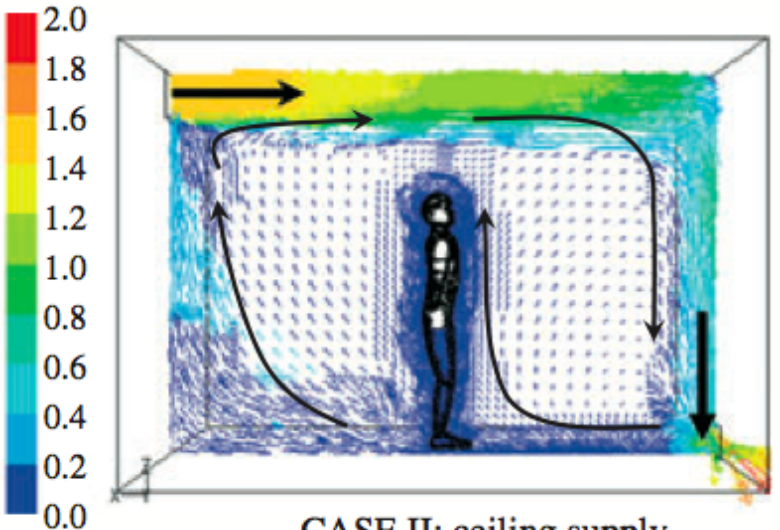
CFD outputs







CASE I: floor supply



CASE II: ceiling supply

Rim et al. 2009 *Indoor Air*

CFD outputs

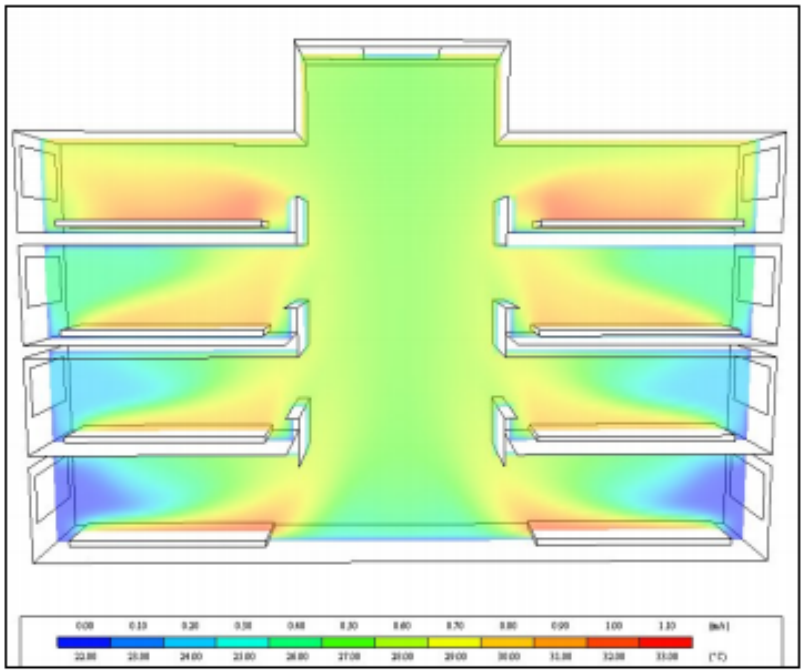


Figure 39: Temperature Contour Slice

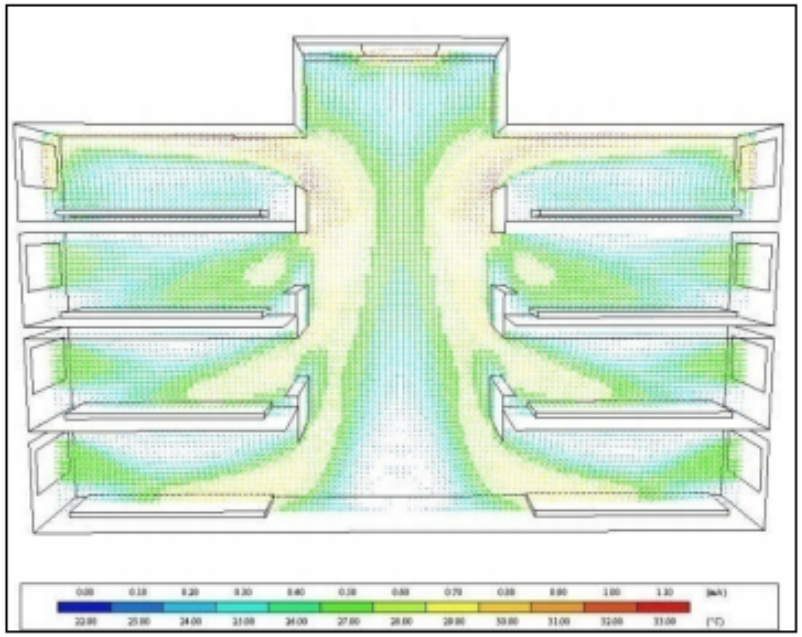


Figure 35: Velocity Vector Slice

Advantages and disadvantages of CFD

- Advantages
  - You can model complex phenomena in great detail
  - Easy to understand outputs

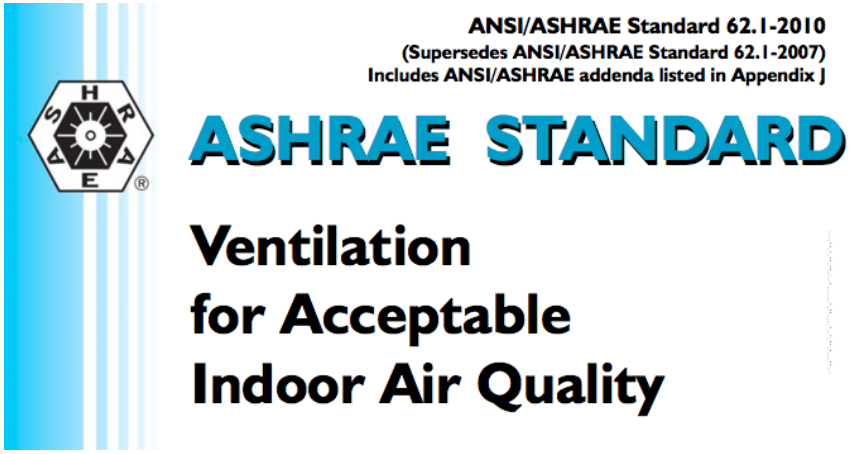
- Disadvantages
  - Time consuming and computationally intensive
  - Garbage in = garbage out
  - Solutions are limited merely to the specific environment and input conditions
    - It can be difficult to generalize results

IAQ STANDARDS AND GUIDELINES

IAQ standards

- There are only a few indoor air quality standards in the US
- Primarily:
  - ASHRAE Standard 62.1
  - ASHRAE Standard 62.2
  - Various state and local governmental standards
    - Most just refer back to ASHRAE
  - For individual materials:
    - GREENGUARD certification for chemical emissions from building materials, finishes, and furnishings
    - GREENGUARD certification for chemical and particle emission from electronic equipment
- Secondarily (involves IAQ but not the entire focus):
  - USGBC's LEED for New Construction
  - USGBC's LEED for Homes

ASHRAE Standard 62.1-2010



1. PURPOSE

1.1 The purpose of this standard is to specify minimum ventilation rates and other measures intended to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects.

1.2 This standard is intended for regulatory application to new buildings, additions to existing buildings, and those changes to existing buildings that are identified in the body of the standard.

1.3 This standard is intended to be used to guide the improvement of indoor air quality in existing buildings.

2. SCOPE

2.1 This standard applies to all spaces intended for human occupancy except those within single-family houses, multi-family structures of three stories or fewer above grade, vehicles, and aircraft.

2.2 This standard defines requirements for ventilation and air-cleaning system design, installation, commissioning, and operation and maintenance.

ASHRAE Standard 62.1-2010

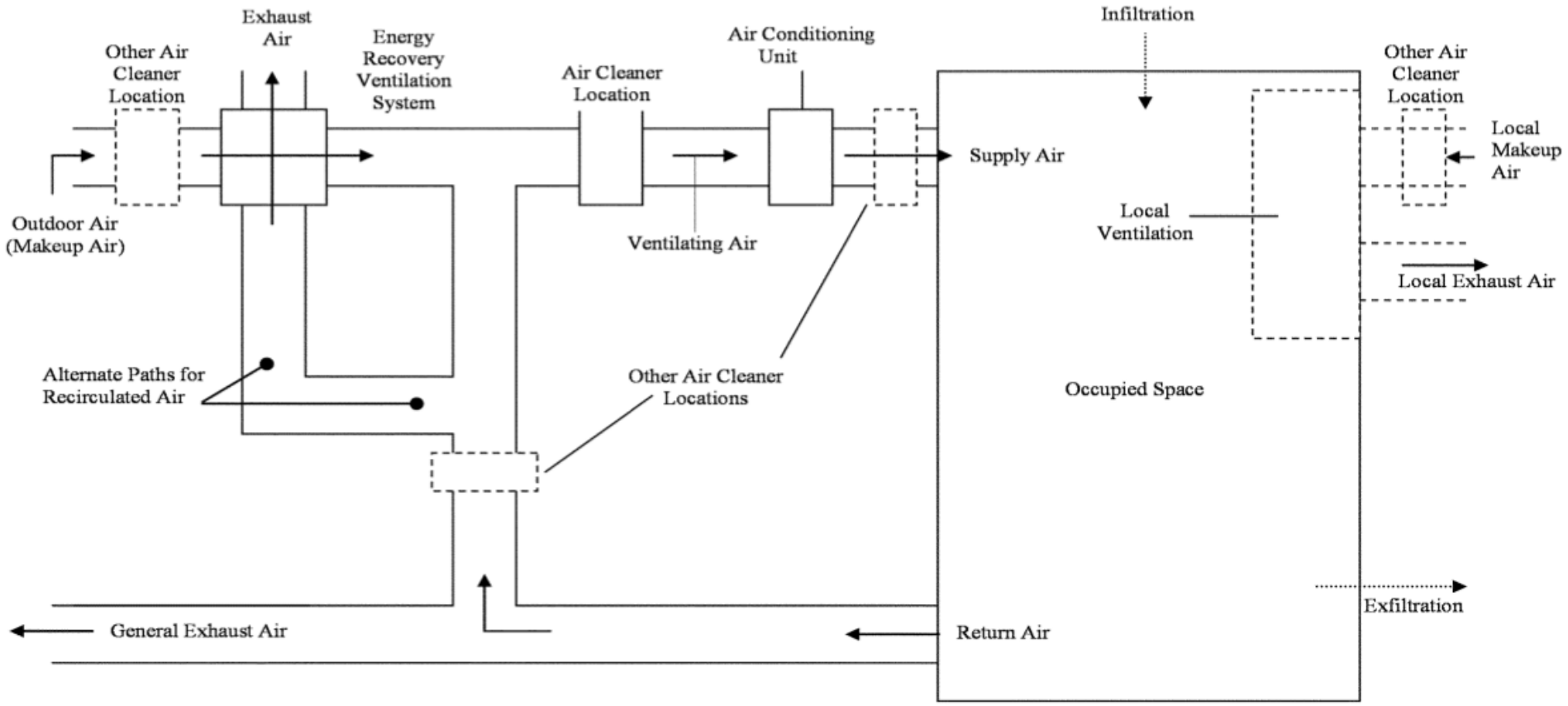


Figure 3.1 Ventilation system.

ASHRAE Standard 62.1-2010

TABLE 5-1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Class 2 air exhaust/relief outlet (Note 1)	10 (3)
Class 3 air exhaust/relief outlet (Note 1)	15 (5)
Class 4 air exhaust/relief outlet (Note 2)	30 (10)
Plumbing vents terminating less than 3 ft (1 m) above the level of the outdoor air intake	10 (3)
Plumbing vents terminating at least 3 ft (1 m) above the level of the outdoor air intake	3 (1)
Vents, chimneys, and flues from combustion appliances and equipment (Note 3)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 4)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 4)	25 (7.5)
Driveway, street, or parking place (Note 4)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 5 and 6)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

ASHRAE Standard 62.1-2010

TABLE 5-2 Airstreams

Description	Air Class
Diazo printing equipment discharge	4
Commercial kitchen grease hoods	4
Commercial kitchen hoods other than grease	3
Laboratory hoods	4
Residential kitchen vented hoods	3
Hydraulic elevator machine room	2

- Class 1: Air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odor.
- Class 2: Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odors. Class 2 air also includes air that is not necessarily harmful or objectionable but that is inappropriate for transfer or recirculation to spaces used for different purposes.
- Class 3: Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor.
- Class 4: Air with highly objectionable fumes or gases or with potentially dangerous particles, bioaerosols, or gases, at concentrations high enough to be considered harmful.

ASHRAE Standard 62.1-2010

Ventilation rate procedure

6.2.2.1 Breathing Zone Outdoor Airflow. The outdoor airflow required in the breathing zone of the occupiable space or spaces in a *ventilation zone*, i.e., the breathing zone outdoor airflow (V_{bz}), shall be no less than the value determined in accordance with Equation 6-1.

$$V_{bz} = R_p \cdot P_z + R_a \cdot A_z \qquad (6\text{-}1)$$

where

A_z = zone floor area: the net occupiable floor area of the *ventilation zone* ft^2 (m^2)

P_z = zone population: the number of people in the *ventilation zone* during typical usage.

R_p = outdoor airflow rate required per person as determined from Table 6-1

Note: These values are based on adapted occupants.

R_a = outdoor airflow rate required per unit area as determined from Table 6-1

ASHRAE Standard 62.1-2010: VRP

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/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	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
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1

ASHRAE Standard 62.1-2010: VRP

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

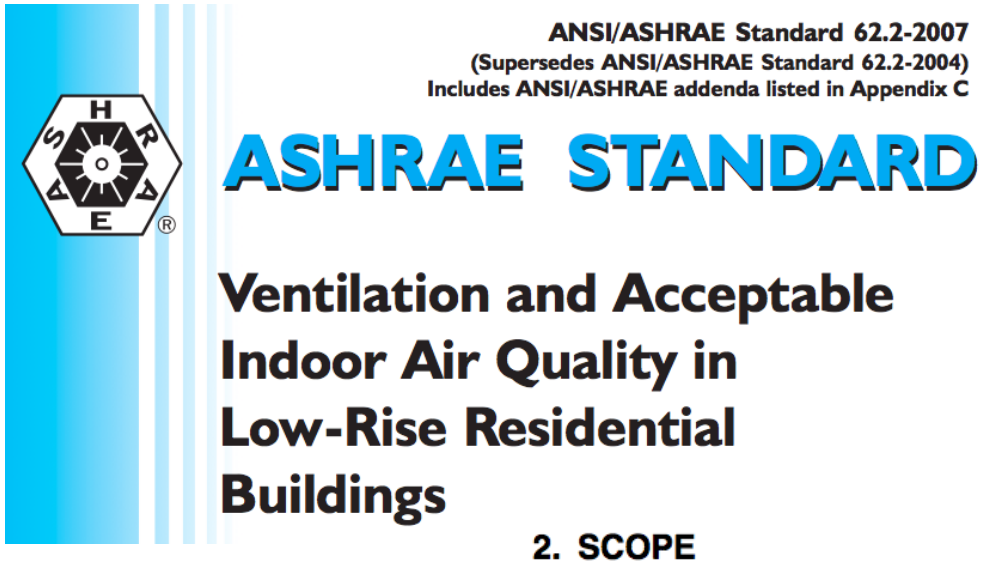
Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1
General manufacturing (excludes heavy industrial and processes using chemicals)	10	5.0	0.18	0.9		7	36	18	3

ASHRAE Standard 62.1-2010: Required exhaust flows

TABLE 6-4 Minimum Exhaust Rates

Occupancy Category	Exhaust Rate, cfm/unit	Exhaust Rate, cfm/ft^2	Notes	Exhaust Rate, L/s·unit	Exhaust Rate, L/s·m^2	Air Class
Arenas	–	0.50	B	–	–	1
Art classrooms	–	0.70		–	3.5	2
Auto repair rooms	–	1.50	A	–	7.5	2
Barber shops	–	0.50		–	2.5	2
Beauty and nail salons	–	0.60		–	3.0	2
Cells with toilet	–	1.00		–	5.0	2
Copy, printing rooms	–	0.50		–	2.5	2
Darkrooms	–	1.00		–	5.0	2
Educational science laboratories	–	1.00		–	5.0	2
Janitor closets, trash rooms, recycling	–	1.00		–	5.0	3
Kitchenettes	–	0.30		–	1.5	2
Kitchens—commercial	–	0.70		–	3.5	2
Locker/dressing rooms	–	0.25		–	1.25	2
Locker rooms	–	0.50		–	2.5	2
Paint spray booths	–	–	F	–	–	4
Parking garages	–	0.75	C	–	3.7	2
Pet shops (animal areas)	–	0.90		–	4.5	2
Refrigerating machinery rooms	–	–	F	–	–	3
Residential kitchens	50/100	–	G	25/50	–	2
Soiled laundry storage rooms	–	1.00	F	–	5.0	3
Storage rooms, chemical	–	1.50	F	–	7.5	4

ASHRAE Standard 62.2-2010 (actually showing 2007)



ANSI/ASHRAE Standard 62.2-2007
(Supersedes ANSI/ASHRAE Standard 62.2-2004)
Includes ANSI/ASHRAE addenda listed in Appendix C

ASHRAE STANDARD

Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

1. PURPOSE

This standard defines the roles of and minimum requirements for mechanical and natural ventilation systems and the building envelope intended to provide acceptable indoor air quality (IAQ) in low-rise residential buildings.

2. SCOPE

This standard applies to spaces intended for human occupancy within single-family houses and multifamily structures of three stories or fewer above grade, including manufactured and modular houses. This standard does not apply to transient housing such as hotels, motels, nursing homes, dormitories, or jails.

2.1 This standard considers chemical, physical, and biological contaminants that can affect air quality. Thermal comfort requirements are not included in this standard (see *ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy*).

2.2 While acceptable indoor air quality is the goal of this standard, it will not necessarily be achieved even if all requirements are met

ASHRAE Standard 62.2-2010

4. WHOLE-BUILDING VENTILATION

4.1 Ventilation Rate. A mechanical exhaust system, supply system, or combination thereof shall be installed for each dwelling unit to provide whole-building ventilation with outdoor air each hour at no less than the rate specified in Tables 4.1a and 4.1b or, equivalently, Equations 4.1a and 4.1b, based on the floor area of the conditioned space and number of bedrooms.

$$Q_{fan} = 0.01A_{floor} + 7.5(N_{br} + 1) \qquad (4.1a)$$

where

Q_{fan} = fan flow rate, cfm
A_{floor} = floor area, ft^2
N_{br} = number of bedrooms; not to be less than one

$$Q_{fan} = 0.05A_{floor} + 3.5(N_{br} + 1) \qquad (4.1b)$$

where

Q_{fan} = fan flow rate, L/s
A_{floor} = floor area, m^2
N_{br} = number of bedrooms; not to be less than one

TABLE 4.1a (I-P)
Ventilation Air Requirements, cfm

Floor Area (ft^2)	Bedrooms				
	0–1	2–3	4–5	6–7	>7
<1500	30	45	60	75	90
1501–3000	45	60	75	90	105
3001–4500	60	75	90	105	120
4501–6000	75	90	105	120	135
6001–7500	90	105	120	135	150
>7500	105	120	135	150	165

TABLE 4.1b (SI)
Ventilation Air Requirements, L/s

Floor Area (m^2)	Bedrooms				
	0–1	2–3	4–5	6–7	>7
<139	14	21	28	35	42
139.1–279	21	28	35	42	50
279.1–418	28	35	42	50	57
418.1–557	35	42	50	57	64
557.1–697	42	50	57	64	71
>697	50	57	64	71	78

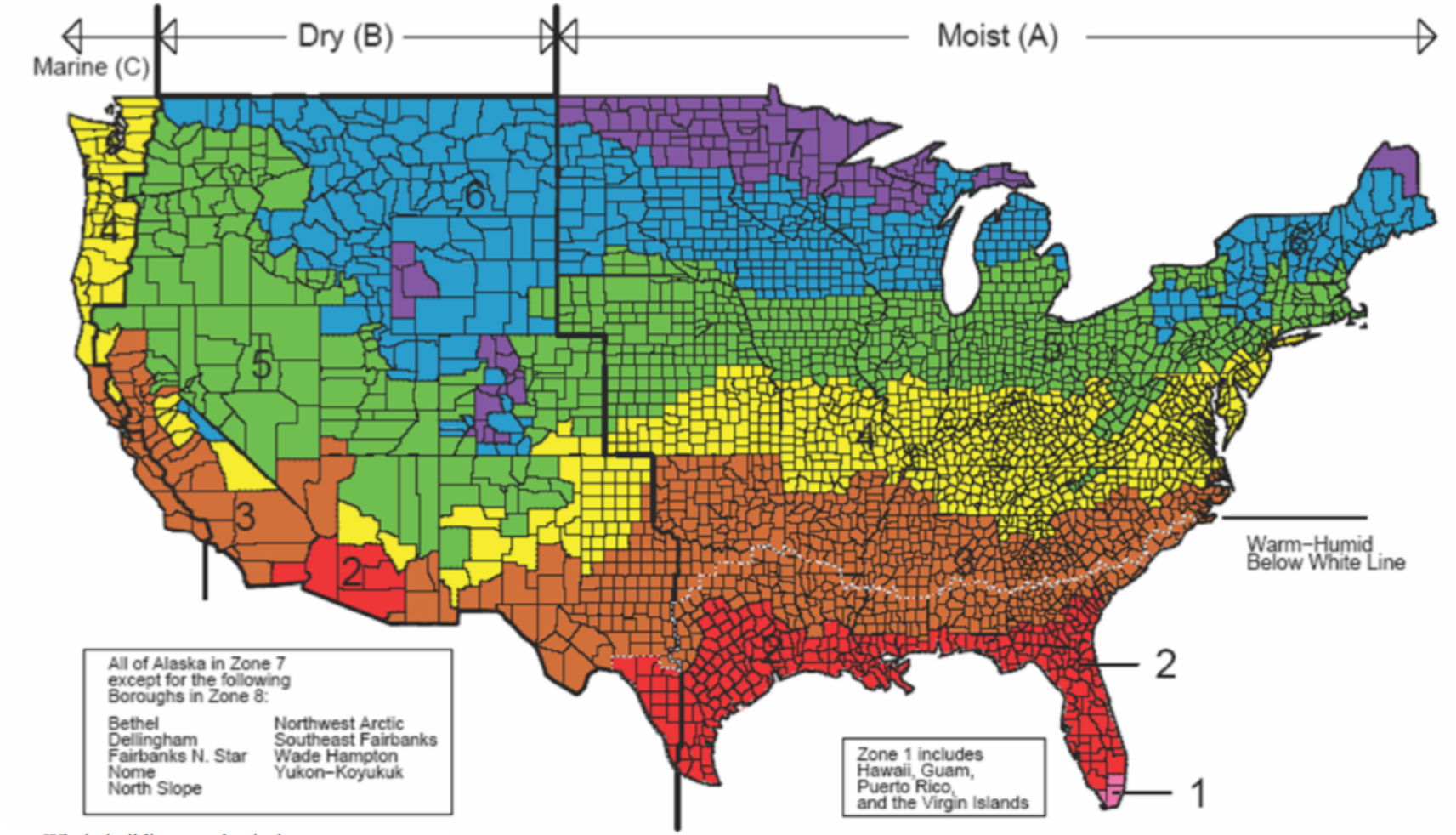
ASHRAE Standard 62.2-2010

Exceptions: Whole-building mechanical systems are not required provided that at least one of the following conditions is met:

a. the building is in zone 3B or 3C of the IECC 2004 Climate Zone Map (see Figure 8.2),
b. the building has no mechanical cooling and is in zone 1 or 2 of the IECC 2004 Climate Zone Map (see Figure 8.2), or
c. the building is thermally conditioned for human occupancy for less than 876 hours per year,

and if the authority having jurisdiction determines that window operation is a locally permissible method of providing ventilation.

ASHRAE Standard 62.2-2010



Exceptions: Whole-building mechanical systems are not required provided that at least one of the following conditions is met:

a. the building is in zone 3B or 3C of the IECC 2004 Climate Zone Map (see Figure 8.2),

b. the building has no mechanical cooling and is in zone 1 or 2 of the IECC 2004 Climate Zone Map (see Figure 8.2), or

ASHRAE Standard 62.2-2010

4.4 Delivered Ventilation. The delivered ventilation rate shall be calculated as the larger of the total supply or total exhaust and shall be no less than specified in Section 4.1 during each hour of operation.

Exception: The effective ventilation rate of an intermittent system is the combination of its delivered capacity, its daily fractional on-time, and the ventilation effectiveness from Table 4.2.

$$Q_f = Q_r / (\varepsilon f) \qquad (4.2)$$

where

Q_f = fan flow rate

Q_r = ventilation air requirement (from Table 4.1a or 4.1b)

ε = ventilation effectiveness (from Table 4.2)

f = fractional on time

TABLE 4.2
Ventilation Effectiveness for Intermittent Fans

Daily Fractional On-Time, f	Ventilation Effectiveness, ε
$f \leq 35\%$	0.33
$35\% \leq f < 60\%$	0.50
$60\% \leq f < 80\%$	0.75
$80\% \leq f$	1.0

ASHRAE Standard 62.2-2010

5. LOCAL EXHAUST

5.1 Local Mechanical Exhaust. A local mechanical exhaust system shall be installed in each kitchen and bathroom. Each local ventilation system shall be either one of the following two:

1. an intermittent mechanical exhaust system meeting the requirements of Section 5.2 or
2. a continuous mechanical exhaust system meeting the requirements of Section 5.3.

Exception: *Alternative Ventilation*. Other design methods may be used to provide the required exhaust rates when approved by a licensed design professional.

TABLE 5.2
Continuous Local Ventilation Exhaust Airflow Rates

Application	Airflow	Notes
Kitchen	5 ach	Based on kitchen volume.
Bathroom	20 cfm (10 L/s)	

TABLE 5.1 Intermittent Local Ventilation Exhaust Airflow Rates

Application	Airflow	Notes
Kitchen	100 cfm (50 L/s)	Vented range hood (including appliance-range hood combinations) required if exhaust fan flow rate is less than 5 kitchen ach.
Bathroom	50 cfm (25 L/s)	

ASHRAE Standard 62.2-2010

6.5 Garages. When an occupiable space adjoins a garage, the design must prevent migration of contaminants to the adjoining occupiable space. Doors between garages and occupiable spaces shall be gasketed or made substantially airtight with weather stripping. HVAC systems that include air handlers or return ducts located in garages shall have total air leakage of no more than 6% of total fan flow when measured at 0.1 in. w.c. (25 Pa) using California Title 24[5] or equivalent.

6.3 Clothes Dryers. Clothes dryers shall be exhausted directly to the outdoors.

6.7 Minimum Filtration. Mechanical systems that supply air to an occupiable space through ductwork exceeding 10 ft (3 m) in length and through a thermal conditioning component, except evaporative coolers, shall be provided with a filter having a designated minimum efficiency of MERV 6 or better when tested in accordance with *ANSI/ASHRAE Standard 52.2, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.*[6] The system shall be designed such that all recirculated and mechanically supplied outdoor air is filtered before passing through the thermal conditioning components. The filter shall be located and installed in such a manner as to facilitate access and regular service by the owner. The filter shall be selected and sized to operate at a clean pressure drop no greater than 0.1 in. w.c. (25 Pa) unless the equipment is designed or selected to accommodate any additional pressure drop imposed by the filter selection (i.e., greater than 0.1 in. w.c. [25 Pa]).

Green building rating systems and IAQ/IEQ

LEED 2009 FOR NEW CONSTRUCTION AND MAJOR RENOVATIONS

System of 110 possible points;

- Site (26)
- Water (10)
- Energy and atmosphere (35)
- Materials and resources (14)
- Indoor environmental quality (15)
- Innovation in design (6)
- Regional priorities (4)

15/110 = 14% related to IEQ

LEED® for Homes Rating System

System of 136 possible points;

- Innovation and design (11)
- Location and linkages (10)
- Sustainable sites (22)
- Water efficiency (15)
- Energy and atmosphere (38)
- Materials and resources (16)
- Indoor environmental quality (21)
- Awareness and education (3)

21/136 = 15% related to IEQ

LEED-NC 2009: IEQ

Indoor Environmental Quality		15 Possible Points
☑ Prerequisite 1	Minimum Indoor Air Quality Performance	Required
☑ Prerequisite 2	Environmental Tobacco Smoke (ETS) Control	Required
☐ Credit 1	Outdoor Air Delivery Monitoring	1
☐ Credit 2	Increased Ventilation	1
☐ Credit 3.1	Construction Indoor Air Quality Management Plan—During Construction	1
☐ Credit 3.2	Construction Indoor Air Quality Management Plan—Before Occupancy	1
☐ Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
☐ Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
☐ Credit 4.3	Low-Emitting Materials—Flooring Systems	1
☐ Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
☐ Credit 5	Indoor Chemical and Pollutant Source Control	1
☐ Credit 6.1	Controllability of Systems—Lighting	1
☐ Credit 6.2	Controllability of Systems—Thermal Comfort	1
☐ Credit 7.1	Thermal Comfort—Design	1
☐ Credit 7.2	Thermal Comfort—Verification	1
☐ Credit 8.1	Daylight and Views—Daylight	1
☐ Credit 8.2	Daylight and Views—Views	1

LEED-NC 2009: IEQ

INDOOR ENVIRONMENTAL QUALITY

IEQ Prerequisite 1: Minimum Indoor Air Quality Performance

Required

Intent

To establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants.

Requirements

CASE 1. Mechanically Ventilated Spaces

Mechanical ventilation systems must be designed using the ventilation rate procedure as defined by ASHRAE 62.1-2007, or the applicable local code, whichever is more stringent.

OPTION 1. ASHRAE Standard 62.1-2007 or Non-U.S. Equivalent

Meet the minimum requirements of Sections 4 through 7 of ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality (with errata but without addenda). Projects outside the U.S. may use a local equivalent to Sections 4 through 7 of ASHRAE Standard 62.1-2007.

LEED-NC 2009: IEQ

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

Required

Intent

To prevent or minimize exposure of building occupants, indoor surfaces and ventilation air distribution systems to environmental tobacco smoke (ETS).

Requirements

OPTION 1

Prohibit smoking in the building.

Prohibit on-property smoking within 25 feet (8 meters) of entries, outdoor air intakes and operable windows. Provide signage to allow smoking in designated areas, prohibit smoking in designated areas or prohibit smoking on the entire property.

LEED-NC 2009: IEQ

IEQ Credit 1: Outdoor Air Delivery Monitoring

1 Point

Intent

To provide capacity for ventilation system monitoring to help promote occupant comfort and well-being.

Requirements

Install permanent monitoring systems to ensure that ventilation systems maintain design minimum requirements. Configure all monitoring equipment to generate an alarm when airflow values or carbon dioxide (CO_2) levels vary by 10% or more from the design values via either a building automation system alarm to the building operator or a visual or audible alert to the building occupants

AND

CASE 1. Mechanically Ventilated Spaces

Monitor CO_2 concentrations within all densely occupied spaces i.e., those with a design occupant density of 25 people or more per 1,000 square feet (95 square meters). CO_2 monitors must be between 3 and 6 feet (between 1 and 2 meters) above the floor.

Provide a direct outdoor airflow measurement device capable of measuring the minimum outdoor air intake flow with an accuracy of plus or minus 15% of the design minimum outdoor air rate, based on the value determined in IEQ Prerequisite 1: Minimum Indoor Air Quality Performance, for mechanical ventilation systems where 20% or more of the design supply airflow serves nondensely occupied spaces.

LEED-NC 2009: IEQ

IEQ Credit 2: Increased Ventilation

1 Point

Intent

To provide additional outdoor air ventilation to improve indoor air quality (IAQ) and promote occupant comfort, well-being and productivity.

Requirements

CASE 1. Mechanically Ventilated Spaces

OPTION 1. ASHRAE Standard 62.1-2007 or Non-U.S. Equivalent

Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above the minimum rates required by ASHRAE Standard 62.1-2007 (with errata but without addenda[1]) as determined by IEQ Prerequisite 1: Minimum Indoor Air Quality Performance. Projects outside the U.S. may use a local equivalent to ASHRAE Standard 62.1-2007 if the same is used for IEQ Prerequisite 1: Minimum Indoor Air Quality Performance.

LEED-NC 2009: IEQ

IEQ Credit 3.1: Construction Indoor Air Quality Management Plan—During Construction

1 Point

Intent

To reduce indoor air quality (IAQ) problems resulting from construction or renovation and promote the comfort and well-being of construction workers and building occupants.

Requirements

Develop and implement an IAQ management plan for the construction and preoccupancy phases of the building as follows:

- During construction, meet or exceed the recommended control measures of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines For Occupied Buildings Under Construction, 2nd Edition 2007, ANSI/SMACNA 008-2008 (Chapter 3).
- Protect stored on-site and installed absorptive materials from moisture damage.
- If permanently installed air handlers are used during construction, filtration media must be used at each return air grille that meets one of the following criteria below. Replace all filtration media immediately prior to occupancy.
    - Filtration media with a Minimum Efficiency Reporting Value (MERV) of 8 as determined by ASHRAE Standard 52.2-1999 (with errata but without addenda).
    - Filtration media is Class F5 or higher, as defined by CEN Standard EN 779-2002, Particulate air filters for general ventilation, Determination of the filtration performance.
    - Filtration media with a minimum dust spot efficiency of 30% or higher and greater than 90% arrestance on a particle size of 3–10 μg.

LEED-NC 2009: IEQ

IEQ Credit 3.2: Construction Indoor Air Quality Management Plan—Before Occupancy

1 Point

Intent

To reduce indoor air quality (IAQ) problems resulting from construction or renovation to promote the comfort and well-being of construction workers and building occupants.

Requirements

Develop an IAQ management plan and implement it after all finishes have been installed and the building has been completely cleaned before occupancy.

OPTION 1. Flush-Out[1]

PATH 1

After construction ends, prior to occupancy and with all interior finishes installed, install new filtration media and , perform a building flush-out by supplying a total air volume of 14,000 cubic feet of outdoor air per square foot (4,500 cubic meters of outdoor air per square meter) of floor area while maintaining an internal temperature of at least 60° F (15°C) and relative humidity no higher than 60%.

OPTION 2. Air Testing

Conduct baseline IAQ testing after construction ends and prior to occupancy using testing protocols consistent with the EPA Co
listed in the tabl
requirements fr

Demonstrate that the contaminant maximum concentration levels listed below are not exceeded:

Contaminant	Maximum Concentration	EPA Compendium method	ISO method
Formaldehyde	27 parts per billion	IP-6	ISO 16000-3
Particulates (PM10)	50 micrograms per cubic meter	IP-10	ISO 7708
Total volatile organic compounds (TVOCs)	500 micrograms per cubic meter	IP-1	ISO 16000-6
4-Phenylcyclohexene (4-PCH)*	6.5 micrograms per cubic meter	IP-1	ISO 16000-6
Carbon monoxide (CO)	9 part per million and no greater than 2 parts per million above outdoor levels	IP-3	ISO 4224

* This test is only required if carpets and fabrics with styrene butadiene rubber (SBR) latex backing are installed as part of the base building systems.

LEED-NC 2009: IEQ

IEQ Credit 4.1: Low-Emitting Materials—Adhesives and Sealants

1 Point

Intent

To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Requirements

All adhesives and sealants used on the interior of the building (i.e., inside of the weatherproofing system and applied on-site) must comply with the following requirements as applicable to the project scope[1]:

- Adhesives, Sealants and Sealant Primers must comply with South Coast Air Quality Management District (SCAQMD) Rule #1168. Volatile organic compound (VOC) limits listed in the table below correspond to an effective date of July 1, 2005 and rule amendment date of January 7, 2005.

Architectural Applications	VOC Limit (g/L less water)	Specialty Applications	VOC Limit (g/L less water)
Indoor carpet adhesives	50	PVC welding	510
Carpet pad adhesives	50	CPVC welding	490
Wood flooring adhesives	100	ABS welding	325
Rubber floor adhesives	60	Plastic cement welding	250
Subfloor adhesives	50	Adhesive primer for plastic	550
Ceramic tile adhesives	65	Contact adhesive	80
VCT and asphalt adhesives	50	Special purpose contact adhesive	250
Drywall and panel adhesives	50	Structural wood member adhesive	140
Cove base adhesives	50	Sheet applied rubber lining operations	850
Multipurpose construction adhesives	70	Top and trim adhesive	250
Structural glazing adhesives	100		

IEQ Credit 4.2: Low-Emitting Materials—Paints and Coatings

1 Point

IEQ Credit 4.3: Low-Emitting Materials—Flooring Systems

1 Point

LEED for Homes 2008: IEQ

Indoor Environmental Quality (EQ) (Minimum of 6 EQ Points Required)				OR		Y / Pts	No	Maybe
1. ENERGY STAR with IAP		1	ENERGY STAR with Indoor Air Package		13			
2. Combustion Venting		2.1	Basic Combustion Venting Measures	EQ 1	Prerequisite			
		2.2	Enhanced Combustion Venting Measures	EQ 1	2			
3. Moisture Control		3	Moisture Load Control	EQ 1	1			
4. Outdoor Air Ventilation	✍	4.1	Basic Outdoor Air Ventilation	EQ 1	Prerequisite			
		4.2	Enhanced Outdoor Air Ventilation		2			
		4.3	Third-Party Performance Testing	EQ 1	1			
5. Local Exhaust	✍	5.1	Basic Local Exhaust	EQ 1	Prerequisite			
		5.2	Enhanced Local Exhaust		1			
		5.3	Third-Party Performance Testing		1			
6. Distribution of Space Heating and Cooling	✍	6.1	Room-by-Room Load Calculations	EQ 1	Prerequisite			
		6.2	Return Air Flow / Room by Room Controls	EQ 1	1			
		6.3	Third-Party Performance Test / Multiple Zones	EQ 1	2			
7. Air Filtering		7.1	Good Filters	EQ 1	Prerequisite			
		7.2	Better Filters		1			
		7.3	Best Filters	EQ 7.2	2			
8. Contaminant Control	✍	8.1	Indoor Contaminant Control during Construction	EQ 1	1			
		8.2	Indoor Contaminant Control		2			
	✍	8.3	Preoccupancy Flush	EQ 1	1			
9. Radon Protection	✍	9.1	Radon-Resistant Construction in High-Risk Areas	EQ 1	Prerequisite			
	✍	9.2	Radon-Resistant Construction in Moderate-Risk Areas	EQ 1	1			
10. Garage Pollutant Protection		10.1	No HVAC in Garage	EQ 1	Prerequisite			
		10.2	Minimize Pollutants from Garage	EQ 1	2			
		10.3	Exhaust Fan in Garage	EQ 1	1			
		10.4	Detached Garage or No Garage	EQ 1, 10.2, 10.3	3			
				Sub-Total for EQ Category:	***21***		***0***	

LEED for Homes 2008: IEQ

EQ 2: Combustion Venting
Maximum points: 2

Intent

Minimize the leakage of combustion gases into the occupied space of the home.

Requirements

Prerequisites

2.1 Basic Combustion Venting Measures. Meet all the following requirements.

a) No unvented combustion appliances (e.g., decorative logs) are allowed.

b) A carbon monoxide (CO) monitor must be installed on each floor.

c) All fireplaces and woodstoves must have doors.

d) Space and water heating equipment that involves combustion must meet one of the following. Space heating systems in homes located in IECC-2007 climate zone 1 or 2 are exempt.

i. it must be designed and installed with closed combustion (i.e., sealed supply air and exhaust ducting);

ii. it must be designed and installed with power-vented exhaust; or

iii. it must be located in a detached utility building or open-air facility.

Credits

2.2 Enhanced Combustion Venting Measures (maximum 2 points). Install no fireplace or woodstove, or design and install a fireplace or woodstove according to the requirements in **Table 29**.

LEED for Homes 2008: IEQ

EQ 3: Moisture Control
Maximum points: 1

Intent

Control indoor moisture levels to provide comfort, reduce the risk of mold, and increase the durability of the home.

Requirements

Prerequisites

None.

Credits

3. **Moisture Load Control (1 point).** Install dehumidification equipment with sufficient latent capacity to maintain relative humidity at or below 60%. This must be achieved through one of the following:
   a) Additional dehumidification system(s).
   b) A central HVAC system equipped with additional controls to operate in dehumidification mode.

   Note: LEED for Homes does not encourage active dehumidification for all projects. Work with the HVAC contractor to determine whether this credit is appropriate and/or necessary.

LEED for Homes 2008: IEQ

EQ 4: Outdoor Air Ventilation
Maximum points: 3

Intent

Reduce occupant exposure to indoor pollutants by ventilating with outdoor air.

Requirements

Prerequisites

4.1 Basic Outdoor Air Ventilation. Design and install a whole building ventilation system that complies with ASHRAE Standard 62.2-2007. A summary of alternatives is provided below, but the HVAC contractor should review and follow the requirements of ASHRAE Standard 62.2-2007, Sections 4 and 7.

a) Mild climate exemption. A home built in a climate with fewer than than 4,500 infiltration degree-days[3] is exempt from this prerequisite.

b) Continuous ventilation. Meet the ventilation requirements in **Table 30** below.

c) Intermittent ventilation. Use Equation 4.2 of ASHRAE Standard 62.2-2007 to demonstrate adequate ventilation air flow.

d) Passive ventilation. Have a passive ventilation system approved and verified by a licensed HVAC engineer as providing ventilation equivalent to that achieved by continuous ventilation systems as described in **Table 30**.

Credits

4.2 Enhanced Outdoor Air Ventilation (2 points). Meet one of the following:

a) In mild climates (fewer than 4,500 infiltration degree-days), install a whole-building active ventilation system that complies with ASHRAE Standard 62.2-2007.

OR

b) Install a system that provides heat transfer between the incoming outdoor air stream and the exhaust air stream, such as a heat-recovery ventilator (HRV) or energy-recovery ventilator (ERV). The heat recovery system must be listed by a certified testing lab (e.g., UL, ETL).

4.3 Third-Party Performance Testing (1 point). Have a third-party test the flow rate of air brought into the home, and verify that the requirements of ASHRAE Standard 62.2-2007 are met. In exhaust-only ventilation systems, install exhaust ducts according to Table 7.1 of ASHRAE Standard 62.2-2007, and either test the flow rate out of the home or conduct air flow tests to ensure back-pressure of ≤ 0.20 inches w.c.

LEED for Homes 2008: IEQ

EQ 5: Local Exhaust
Maximum points: 2

Intent

Reduce moisture and exposure to indoor pollutants in kitchens and bathrooms.

Requirements

Prerequisites

5.1 Basic Local Exhaust. Meet all the following requirements:

a) Design and install local exhaust systems in all bathrooms (including half-baths) and the kitchen to meet the requirements of Section 5 of ASHRAE Standard 62.2-2007. Sample requirements that relate to minimum intermittent local exhaust flow rates are shown in **Table 31**, below.

b) Design and install the fans and ducts to meet the requirements of Section 7 of ASHRAE Standard 62.2-2007.

c) Exhaust air to the outdoors (i.e., exhaust to attics or interstitial spaces is not permitted).

d) Use ENERGY STAR labeled bathroom exhaust fans (except for exhaust fans serving multiple bathrooms).

Credits

5.2 Enhanced Local Exhaust (1 point). Use one of the following strategies in every bathroom to control the use of the local exhaust fan:

a) An occupancy sensor.

b) An automatic humidistat controller.

c) An automatic timer to operate the fan for a timed interval after occupant leaves the room.

d) A continuously operating exhaust fan.

5.3 Third-Party Performance Testing (1 point). Perform a third-party test of each exhaust air flow rate for compliance with the requirements in Section 5 of ASHRAE Standard 62.2-2007.

LEED for Homes 2008: IEQ

EQ 6: Distribution of Space Heating and Cooling
Maximum points: 3

Intent

Provide appropriate distribution of space heating and cooling in the home to improve thermal comfort and energy performance.

Requirements

A. Forced-Air Systems:

Prerequisites

6.1 Room-by-Room Load Calculations. Perform design calculations (using ACCA Manuals J and D, the ASHRAE Handbook of Fundamentals, or an equivalent computation procedure) and install ducts accordingly.

Credits

6.2 Return Air Flow (1 point). Ensure that every room (except baths, kitchens, closets, pantries, and laundry rooms) has adequate return air flow through the use of multiple returns, transfer grilles, or jump ducts. Meet one of the following requirements:

a) Size the opening to 1 square inch per cfm of supply (this area may include free area undercut below door).

b) Demonstrate that the pressure differential between closed rooms and adjacent spaces with return is no greater than 2.5 Pa (0.01 inch w.c.).

6.3 Third-Party Performance Test (2 points). Have the total supply air flow rates in each room tested using a flow hood with doors closed, or one of the other acceptable methods cited by the ACCA Quality Installation Specifications. Supply air flow rates must be within +/- 15% (or +/- 10 cfm) of calculated values from ACCA Manual J (as required by EA 6.1).

LEED for Homes 2008

EQ 7: Air Filtering
Maximum points: 2

Intent

Reduce particulate matter from the air supply system.

Requirements

A. Forced-Air Systems:

Prerequisites

7.1 Good Filters. Install air filters with a minimum efficiency reporting value (MERV) ≥ 8 and ensure that air handlers can maintain adequate pressure and air flow. Air filter housings must be airtight to prevent bypass or leakage.

Credits

7.2 Better Filters (1 point). Install air filters ≥ MERV 10 and ensure that air handlers can maintain adequate pressure and air flow. Air filter housings must be airtight to prevent bypass or leakage.

OR

7.3 Best Filters (2 points). Install air filters ≥ MERV 13 and ensure that air handlers can maintain adequate pressure and air flow. Air filter housings must be airtight to prevent bypass or leakage.

LEED for Homes 2008

EQ 8: Contaminant Control
Maximum points: 4

Intent

Reduce occupants' and construction workers' exposure to indoor airborne contaminants through source control and removal.

Requirements

Prerequisites

None.

Credits

8.1 Indoor Contaminant Control during Construction (1 point). Upon installation, seal all permanent ducts and vents to minimize contamination during construction. Remove any seals after all phases of construction are completed.

8.2 Indoor Contaminant Control (1 point each, maximum 2 points). Select from the following measures:

a) Design and install permanent walk-off mats at each entry that are at least 4 feet in length and allow accessibility for cleaning (e.g., grating with catch basin).

b) Design a shoe removal and storage space near the primary entryway, separated from living areas. This space may not have wall-to-wall carpeting, and it must be large enough to accommodate a bench and at least two pairs of shoes per bedroom.

c) Install a central vacuum system with exhaust to the outdoors. Ensure that the exhaust is not near any ventilation air intake.

8.3 Preoccupancy Flush (1 point). Flush the home with fresh air, according to the following guidelines:

a) Flush prior to occupancy but after all phases of construction are completed.

b) Flush the entire home, keeping all interior doors open.

c) Flush for 48 total hours; the hours may be nonconsecutive, if necessary.

d) Keep all windows open and run a fan (e.g., HVAC system fan) continuously or flush the home with all HVAC fans and exhaust fans operating continuously at the highest flow rate.

e) Use additional fans to circulate air within the home.

f) Replace or clean HVAC air filter afterward, as necessary.

LEED for Homes 2008

EQ 9: Radon Protection
Maximum points: 1

Intent

Reduce occupant exposure to radon gas and other soil gas contaminants.

Requirements

Prerequisites

9.1 Radon-Resistant Construction in High-Risk Areas. If the home is in EPA Radon Zone 1, design and build the home with radon-resistant construction techniques as prescribed by EPA, the International Residential Code, Washington State Ventilation and Indoor Air Quality Code, or some equivalent code or standard.

Credits

9.2 Radon-Resistant Construction in Moderate-Risk Areas (1 point). If the home is outside EPA Radon Zone 1, design and build the home with radon-resistant construction techniques as prescribed by EPA, the International Residential Code, Washington State Ventilation and Indoor Air Quality Code, or some equivalent code or standard.

Note: Radon-resistant construction does not guarantee that occupants will not be exposed to radon. The Surgeon General and EPA recommend that every home in the country be tested for radon. Information about radon testing is available at the EPA Web site, at www.epa.gov/radon/radontest.html.

LEED for Homes 2008

EQ 10: Garage Pollutant Protection
Maximum points: 3

Intent

Reduce occupant exposure to indoor pollutants originating from an adjacent garage.

Requirements

Prerequisites

10.1 No HVAC in Garage. Place all air-handling equipment and ductwork outside the fire-rated envelope of the garage.

Credits

10.2 Minimize Pollutants from Garage (2 points). Tightly seal shared surfaces between garage and conditioned spaces, including all of the following:

a) In conditioned spaces above the garage:

i) seal all penetrations;

ii) seal all connecting floor and ceiling joist bays; and

iii) paint walls and ceilings (carbon monoxide can penetrate unfinished drywall through diffusion).

b) In conditioned spaces next to the garage:

i) weather-strip all doors;

ii) place carbon monoxide detectors in adjacent rooms that share a door with the garage;

iii) seal all penetrations; and

iv) seal all cracks at the base of the walls.

AND/OR

10.3 Exhaust Fan in Garage (1 point). Install an exhaust fan in the garage that is rated for continuous operation and designed to be operated in one of the following ways. Nonducted exhaust fans must be 70 cfm or greater, and ducted exhaust fans must be 100 cfm or greater.

a) Fan must run continuously; or

b) Fan must be designed with an automatic timer control linked to an occupant sensor, light switch, garage door opening-closing mechanism, carbon monoxide sensor, or equivalent. The timer must be set to provide at least three air changes each time the fan is turned on.

OR

10.4 Detached Garage or No Garage (3 points).

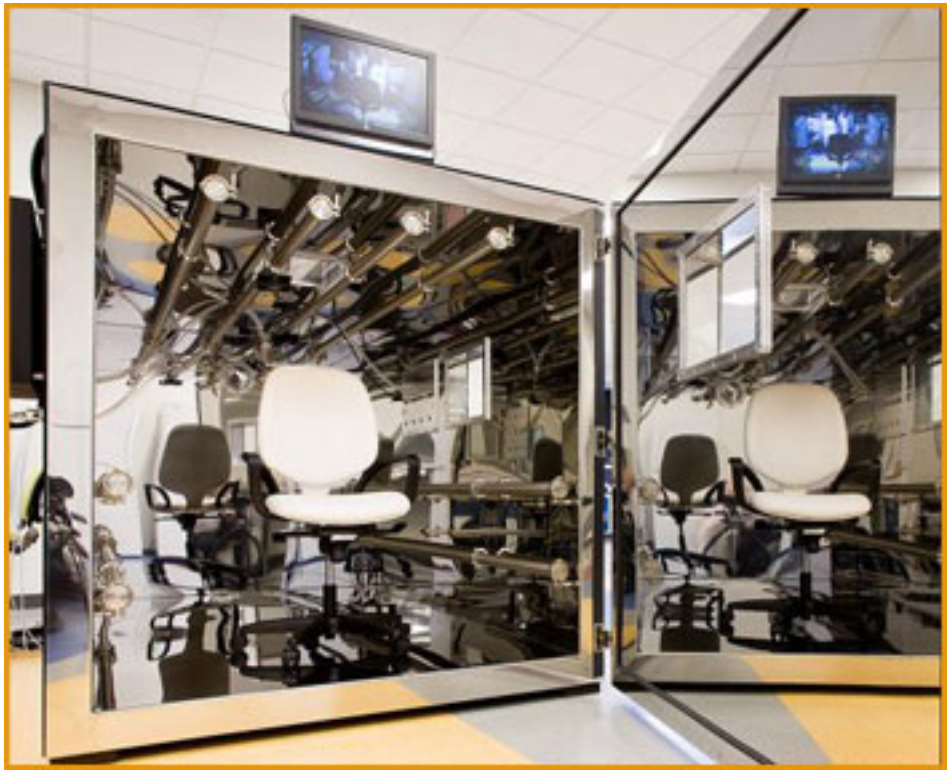
Emissions standards

GREENGUARD CERTIFICATION
FROM UL ENVIRONMENT

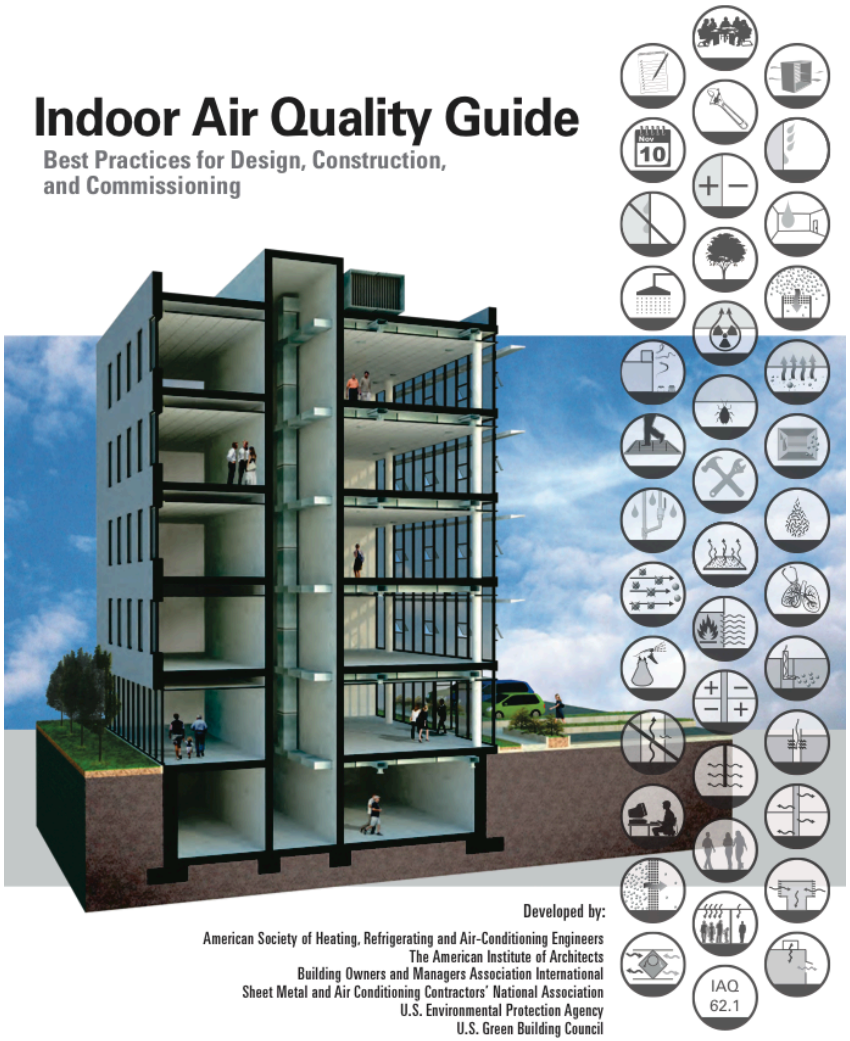
GREENGUARD Certification Program For Chemical Emissions For Building Materials, Finishes And Furnish

GREENGUARD Certification Program for Chemical and Particle Emissions for Electronic Equipment

GREENGUARD Certification Program for Chemical Emissions for Cleaners and Cleaning Maintenance System

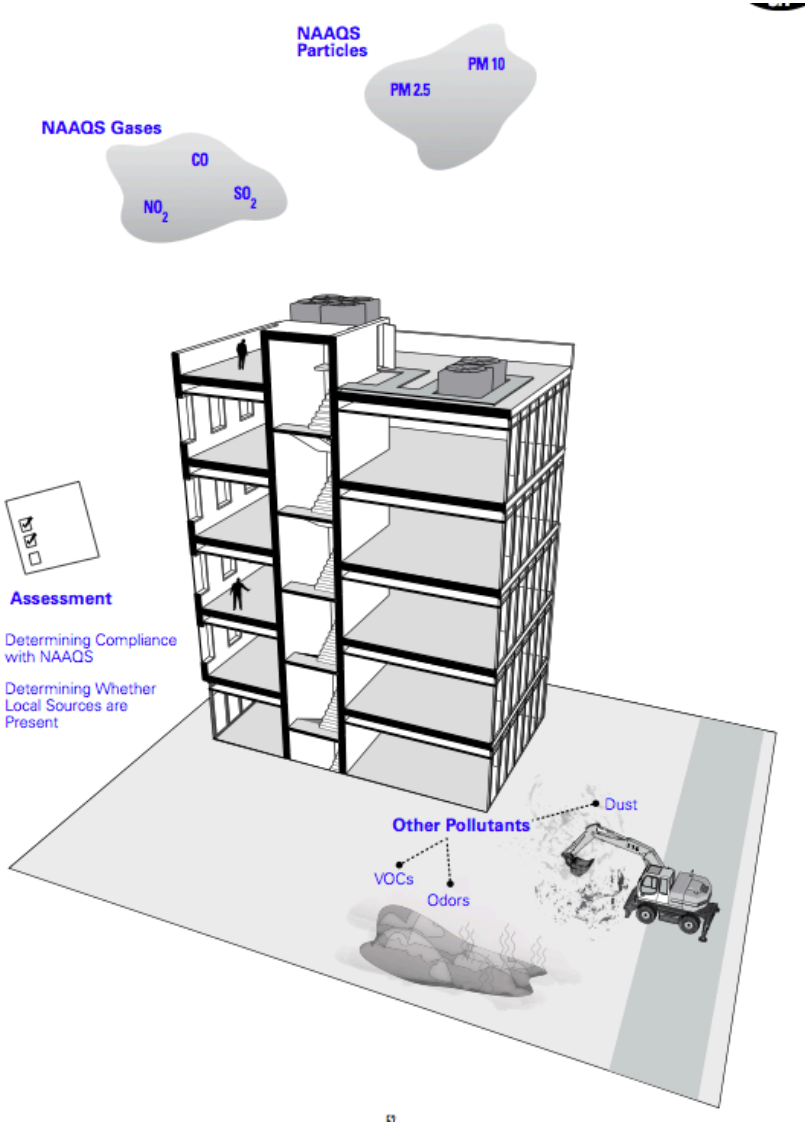


ASHRAE IAQ Guide



ASHRAE IAQ Guide

ASHRAE IAQ Guide



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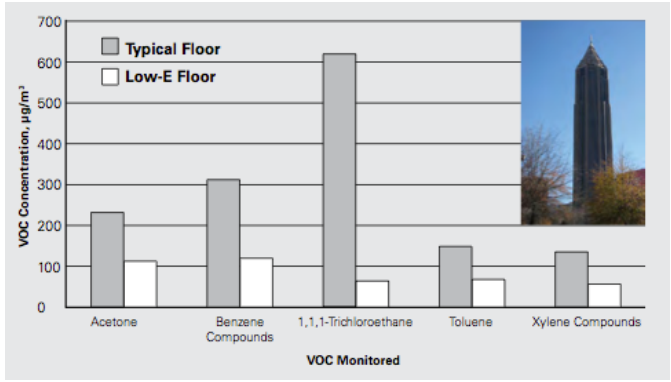
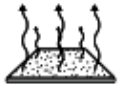
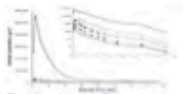


Emissions Data: Available Information



Emissions Testing



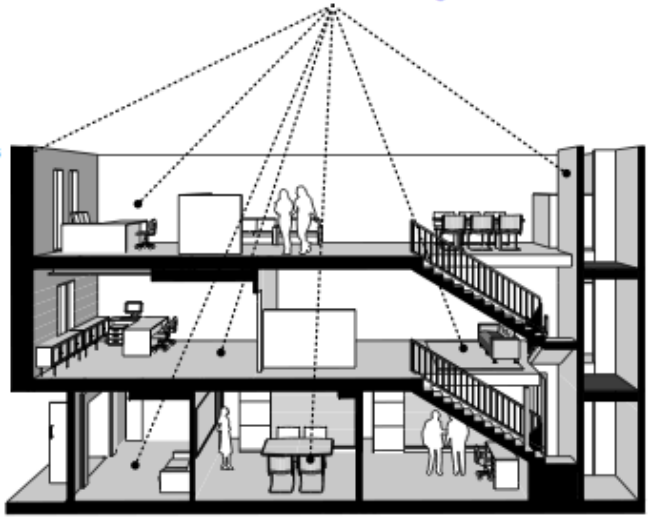
Emissions Databases

Manufacturer Supplied Information: MSDSs

Labels: Emissions-Based

Labels: Content-Based

Priority Materials/ Finishes/Furnishings



Architectural Coatings

Flooring Materials

Ceiling Tiles

PVC Materials

Insulation Materials

HVAC Components

Caulks, Sealants & Adhesives

Porous of Fleecy Materials

Flame-Retardant Materials

Structural Materials

Office Furniture Systems

Office Equipment

Composite Wood / Agrifiber Materials

ASHRAE IAQ Guide

COURSE REVIEW

Course information

Course Catalog Official Description

- Indoor air pollution sources, indoor pollutant levels, monitoring instruments and designs; indoor pollution control strategies: source control, control equipment and ventilation; energy conservation and indoor air pollution; exposure studies and population time budgets; effects of indoor air population; risk analysis; models for predicting source emission rates and their impact on indoor air environments.

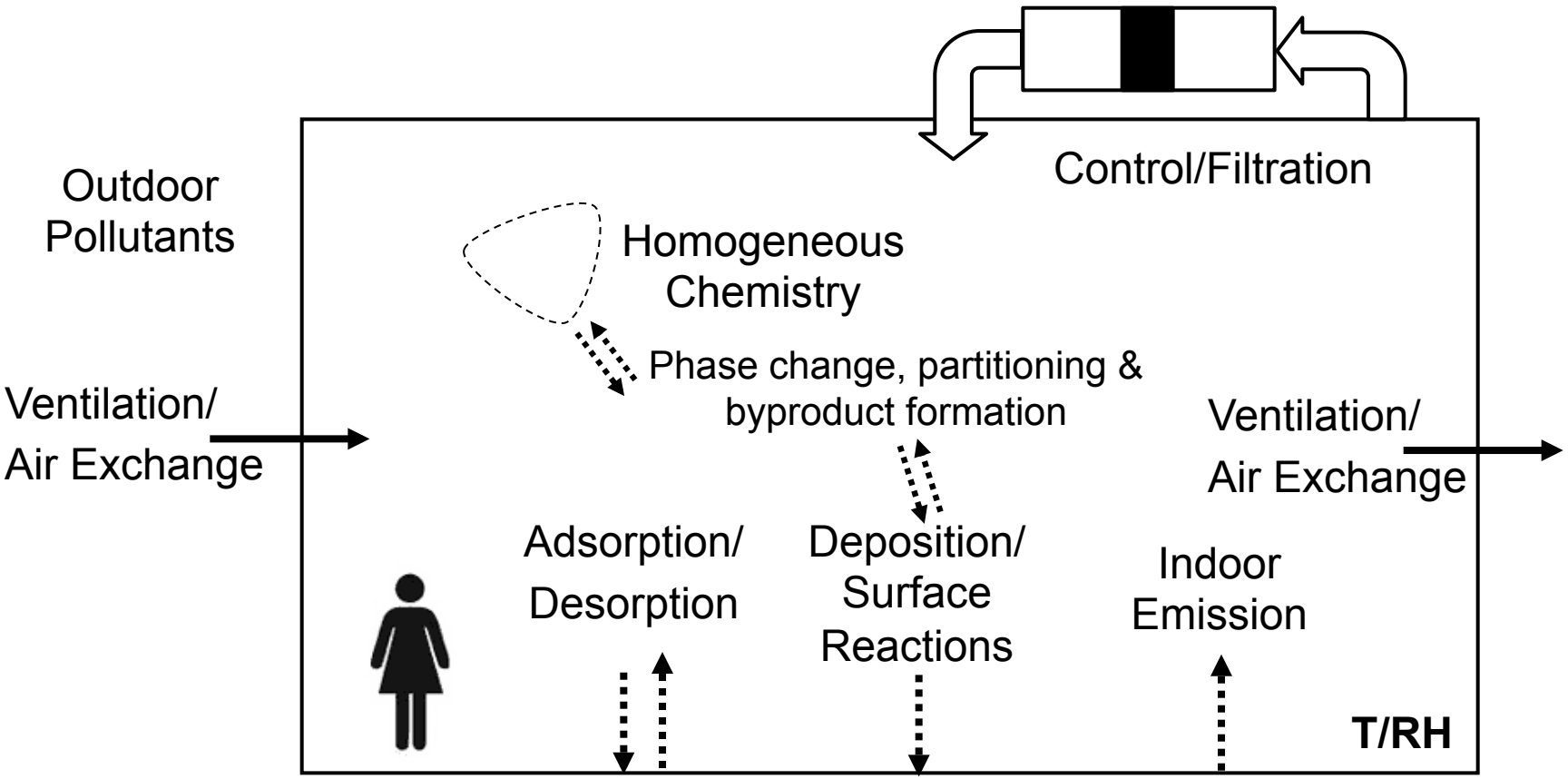
Course objectives (in my own words)

To introduce students to important concepts of indoor airborne pollutants, including their physical and chemical properties, emission sources, and removal mechanisms. By taking this course students will be able to:

1. Describe particle-phase, gas-phase, and biological pollutants found in indoor environments
2. Model indoor pollutant emission, transport, and control
3. Manipulate and perform calculations with aerosol distributions and gas-phase compounds
4. Analyze indoor pollutant control technologies and determine their effectiveness
5. Read and critically analyze articles in the technical literature on indoor air pollution
6. Prepare and review written and oral technical communication

Indoor mass balances and mechanisms

Review of course topics…



Course topics

- Introduction: Human exposure, indoor and outdoor atmospheres
- Reactor models, ventilation, and human exposure patterns
- Pollutant types and sources
- Gaseous pollutants (VOCs and others)
  - Sources, adsorption/desorption, emission models, reactive deposition, homogeneous chemistry, byproduct formation
- Particulate matter
  - Single particle physics, particle size distributions, respiratory deposition, sources, surface deposition and resuspension, filtration and air cleaners
- Biological matter
  - Dust, pollen, mold, microbes generally
- Semi-volatile organic compounds (SVOCs)
  - Pesticides, flame retardants, etc.
- Measurement techniques and sampling campaigns
- Health effects: epidemiology and physiological responses
- IAQ in developing countries
- Applications: standards and manufacturer ratings
- Infectious disease transmission and risk

Course evaluations due

- Monday November 17 through **Sunday December 7**
  - Available online now in MyIIT
- Very important that you complete the evaluation
  - It's the only way I get graded
  - It's the only way our courses get graded
  - It's one of the best ways for us to improve courses/ teaching
  - It's anonymous
- We usually only get about 50% response rate
  - We're at about 30% right now
  - Let's try to do better than this
  - If you have an internet connection you can do it right now