

**BLDG 475/6751 Indoor Air Quality (& Ventilation)**  
**Department of Building, Civil & Environmental Engineering**  
**Faculty of Engineering and Computer Science**  
**Concordia University**

**Assignment #2**

1. The samples of two different carpets were tested for VOC emissions in 20m<sup>3</sup> environmental chamber made of stainless steel. Dynamic tests were conducted under the following conditions:

- Temperature: 23°C
- Relative humidity: 50%
- Air exchange rate: 1 hr<sup>-1</sup>
- Loading factor: 0.44 m<sup>2</sup>/m<sup>3</sup>

The following test results (chamber concentrations in ug/m<sup>3</sup>) for 4-phenylcyclohexene (4-PCH) were obtained.

Time [hr]	Carpet A	Carpet B
3.0	42.8	48.5
6.0	44.0	44.7
12.0	40.4	36.5
24.0	37.0	34.8
48.0	34.3	29.8
72.0	31.2	29.4
96.0	30.8	25.2
120.0	28.6	23.8
144.0	26.6	21.6
168.0	26.8	20.9

- a) Using the mass balance equation, determine the emission rates of each carpet (as a function of time)
- b) After one-week of airing out, each carpet was installed wall-to-wall in an identical open-plan office with constant volume ventilation system. The area of the office is 2000 ft<sup>2</sup> (185.8 m<sup>2</sup>) and the number of expected occupants is 10. Assuming the carpets are the only source of 4-PCH, estimate the 4-PCH concentrations of both offices in **ppm or ppb unit**. Consider two ventilation cases: one complying ASHRAE Standard 62.1 Ventilation Rate Procedure (VRP) and the other is 30% more than VRP to comply LEED v.4 BD&C EQ credit "Enhanced Indoor Air Quality Strategies".

2. Evaluate the effect of “flush-out” option of LEED v4 BD&C EQ credit “Indoor Air Quality Assessment” Option 1-Flush Out using IA-Quest for an office space:

- Size: 15 m × 20 m × 3.2 m
- Number of occupants: 25
- Occupancy hours: 08:00 – 18:00, 7 days a week
- Outdoor air ventilation rate
  - Flush out period: 500 liter/sec
  - After occupancy: minimum ventilation rate set by ASHRAE Standard 62.1 VRP
- Window & door area : 40 m<sup>2</sup>
- Office finishing materials
  - Wall-to-wall carpet with adhesive on concrete slab (Crp7a)
  - Latex paint (PT7) on plain gypsum board (GB1) for all wall finishing except window & door area
  - Cellulose acoustical ceiling tiles (ACT3)
- Considered contaminants: toluene and TVOC
  - Toluene: initial room concentration 0.2 mg/m<sup>3</sup>; outdoor air concentration 0.01 mg/m<sup>3</sup>
  - TVOC: initial room concentration 2.0 mg/m<sup>3</sup>; outdoor air concentration 0.1 mg/m<sup>3</sup>

Simulate the following three cases for 60 days and

- (a) Draw **two figures (one for toluene and the other for TVOC)** comparing the concentration profiles (**Concentration vs. time curves**) of three cases.
- (b) Determine **the highest & the lowest TVOC concentrations** during occupancy for each case on the **day 30, 40, 50 & 60**. Compare with **toluene and TVOC concentration limits** set in LEED v4 BD&C EQ Credit “Indoor Air Quality Assessment” Option 2-Air Testing.
- (c) Examine the simulation results of three cases and discuss the **limitations of IA-Quest**.

### **Case 1: Flush-out path 1**

- (a) The space is ventilated constantly at 500 liter/sec of outdoor air for flush-out until the total 4,267,140 liters of outdoor air per square meter of gross floor area is delivered
- (b) After the flush-out period, the building is occupied and regular ventilation schedule is applied:
  - 07:00 – 18:00 period with the ventilation rate equals to the minimum requirement of ASHRAE 62.1 VRP
  - Overnight the ventilation system is turned off.

### **Case 2: Flush-out path 2**

- (a) The space is ventilated constantly at 500 liter/s of outdoor air for flush-out before occupancy until 1,066,260 liters of outdoor air per square meter of gross floor area is delivered.
- (b) Then, the building is occupied, and the flush-out is continued following the Path 2 until total (including pre-occupancy flush-out) 4,267,140 liters of outdoor air per square meter of gross floor area is delivered:
  - 05:00 – 18:00 period with 500 liter/sec
  - Overnight the ventilation system is turned off.
- (c) Once the flush-out is finished, the regular ventilation schedule is applied:
  - 07:00 – 18:00 period with the ventilation rate equals to the minimum requirement of ASHRAE 62.1 VRP
  - Overnight the ventilation system is turned off.

### **Case 3: No flush-out**

The building is ventilated using the regular ventilation schedule:

- 07:00 – 18:00 period with the ventilation rate equals to the minimum requirement of ASHRAE 62.1 VRP
- Overnight the ventilation system is turned off.

**TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone (Continued)**  
 (Table 6.2.2.1 shall be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate		Area Outdoor Air Rate		Notes	Default Values			
	$R_p$		$R_a$			Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft <sup>2</sup>	L/s·m <sup>2</sup>		#/1000 ft <sup>2</sup> or #/100 m <sup>2</sup>	cfm/person	L/s·person	
<b>General</b>									
Break rooms	5	2.5	0.06	0.3	H	25	7	3.5	1
Coffee stations	5	2.5	0.06	0.3	H	20	8	4	1
Conference/meeting	5	2.5	0.06	0.3	H	50	6	3.1	1
Corridors	—	—	0.06	0.3	H	—			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
<b>Hotels, Motels, Resorts, Dormitories</b>									
Bedroom/living room	5	2.5	0.06	0.3	H	10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3	H	20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3	H	30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3	H	120	6	2.8	1
<b>Office Buildings</b>									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3	H	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	H	5	17	8.5	1
Reception areas	5	2.5	0.06	0.3	H	30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3	H	60	6	3.0	1

**GENERAL NOTES FOR TABLE 6.2.2.1**

- 1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
- 2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
- 3 **Air density:** Volumetric airflow rates are based on dry air density of 0.075 lb<sub>air</sub>/ft<sup>3</sup> (1.2 kg<sub>air</sub>/m<sup>3</sup>) at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates shall be permitted to be adjusted for actual density.
- 4 **Default occupant density:** The default occupant density shall be used where the actual occupant density is not known.
- 5 **Default combined outdoor air rate (per person):** Rate is based on the default occupant density.
- 6 **Unlisted occupancies:** Where the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

**ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1**

- A For high-school and college libraries, the values shown for "Public Assembly Spaces—Libraries" shall be used.
- B Rate may not be sufficient where stored materials include those having potentially harmful emissions.
- C Rate does not allow for humidity control. "Deck area" refers to the area surrounding the pool that is capable of being wetted during pool use or when the pool is occupied. Deck area that is not expected to be wetted shall be designated as an occupancy category.
- D Rate does not include special exhaust for stage effects such as dry ice vapors and smoke.
- E Where combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation, source control, or both shall be provided.
- F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
- G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.
- H Ventilation air for this occupancy category shall be permitted to be reduced to zero when the space is in occupied-standby mode.

## EQ CREDIT: ENHANCED INDOOR AIR QUALITY STRATEGIES

BD&C

1–2 points

This credit applies to

- New Construction (1–2 points)
- Core & Shell (1–2 points)
- Schools (1–2 points)
- Retail (1–2 points)
- Data Centers (1–2 points)
- Warehouses & Distribution Centers (1–2 points)
- Hospitality (1–2 points)
- Healthcare (1–2 points)

### Intent

To promote occupants' comfort, well-being, and productivity by improving indoor air quality.

### Requirements

**NC, CS, SCHOOLS, RETAIL, DATA CENTERS, WAREHOUSES & DISTRIBUTION CENTERS, HOSPITALITY, HEALTHCARE**

#### Option 1. Enhanced IAQ Strategies (1 point)

Comply with the following requirements, as applicable.

Mechanically ventilated spaces:

- A. entryway systems;
- B. interior cross-contamination prevention; and
- C. filtration.

Naturally ventilated spaces:

- A. entryway systems; and
- D. natural ventilation design calculations.

Mixed-mode systems:

- A. entryway systems;
- B. interior cross-contamination prevention;
- C. filtration;
- D. natural ventilation design calculations; and
- E. mixed-mode design calculations.

#### **A. Entryway Systems**

Install permanent entryway systems at least 10 feet (3 meters) long in the primary direction of travel to capture dirt and particulates entering the building at regularly used exterior entrances. Acceptable entryway systems include permanently installed grates, grilles, slotted systems that allow for cleaning underneath, rollout mats, and any other materials manufactured as entryway systems with equivalent or better performance. Maintain all on a weekly basis.

#### Warehouses & Distribution Centers only

Entryway systems are not required at doors leading from the exterior to the loading dock or garage but must be installed between these spaces and adjacent office areas.

#### Healthcare only

In addition to the entryway system, provide pressurized entryway vestibules at high-volume building entrances.

**B. Interior Cross-Contamination Prevention**

Sufficiently exhaust each space where hazardous gases or chemicals may be present or used (e.g., garages, housekeeping and laundry areas, copying and printing rooms), using the exhaust rates determined in EQ Prerequisite Minimum Indoor Air Quality Performance or a minimum of 0.50 cfm per square foot (2.54 l/s per square meter), to create negative pressure with respect to adjacent spaces when the doors to the room are closed. For each of these spaces, provide self-closing doors and deck-to-deck partitions or a hard-lid ceiling.

**C. Filtration**

Each ventilation system that supplies outdoor air to occupied spaces must have particle filters or air-cleaning devices that meet one of the following filtration media requirements:

- minimum efficiency reporting value (MERV) of 13 or higher, in accordance with ASHRAE Standard 52.2–2007; or
- Class F7 or higher as defined by CEN Standard EN 779–2002, Particulate Air Filters for General Ventilation, Determination of the Filtration Performance.

Replace all air filtration media after completion of construction and before occupancy.

Data Centers only

The above filtration media requirements are required only for ventilation systems serving regularly occupied spaces.

**D. Natural Ventilation Design Calculations**

Demonstrate that the system design for occupied spaces employs the appropriate strategies in Chartered Institution of Building Services Engineers (CIBSE) Applications Manual AM10, March 2005, Natural Ventilation in Non-Domestic Buildings, Section 2.4.

**E. Mixed-Mode Design Calculations**

Demonstrate that the system design for occupied spaces complies with CIBSE Applications Manual 13–2000, Mixed Mode Ventilation.

**Option 2. Additional Enhanced IAQ Strategies (1 point)**

Comply with the following requirements, as applicable.

Mechanically ventilated spaces (select one):

- A. exterior contamination prevention;
- B. increased ventilation;
- C. carbon dioxide monitoring; or
- D. additional source control and monitoring.

Naturally ventilated spaces (select one):

- A. exterior contamination prevention;
- D. additional source control and monitoring; or
- E. natural ventilation room by room calculations.

Mixed-mode systems (select one):

- A. exterior contamination prevention;
- B. increased ventilation;
- D. additional source control and monitoring; or
- E. natural ventilation room-by-room calculations.

**A. Exterior Contamination Prevention**

Design the project to minimize and control the entry of pollutants into the building. Ensure through the results of computational fluid dynamics modeling, Gaussian dispersion analyses, wind tunnel

modeling, or tracer gas modeling that outdoor air contaminant concentrations at outdoor air intakes are below the thresholds listed in Table 1 (or local equivalent for projects outside the U.S., whichever is more stringent).

Table 1. Maximum concentrations of pollutants at outdoor air intakes

Pollutants	Maximum concentration	Standard
Those regulated by National Ambient Air Quality Standards (NAAQS)	Allowable annual average OR 8-hour or 24-hour average where an annual standard does not exist OR Rolling 3-month average	National Ambient Air Quality Standards (NAAQS)

**B. Increased Ventilation**

Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above the minimum rates as determined in EQ Prerequisite Minimum Indoor Air Quality Performance.

**C. Carbon Dioxide Monitoring**

Monitor CO<sub>2</sub> concentrations within all densely occupied spaces. CO<sub>2</sub> monitors must be between 3 and 6 feet (900 and 1 800 millimeters) above the floor. CO<sub>2</sub> monitors must have an audible or visual indicator or alert the building automation system if the sensed CO<sub>2</sub> concentration exceeds the setpoint by more than 10%. Calculate appropriate CO<sub>2</sub> setpoints using methods in ASHRAE 62.1–2010, Appendix C.

**D. Additional Source Control and Monitoring**

For spaces where air contaminants are likely, evaluate potential sources of additional air contaminants besides CO<sub>2</sub>. Develop and implement a materials-handling plan to reduce the likelihood of contaminant release. Install monitoring systems with sensors designed to detect the specific contaminants. An alarm must indicate any unusual or unsafe conditions.

**E. Natural Ventilation Room-by-Room Calculations**

Follow CIBSE AM10, Section 4, Design Calculations, to predict that room-by-room airflows will provide effective natural ventilation.

## EQ CREDIT: INDOOR AIR QUALITY ASSESSMENT

BD&C

1–2 points

This credit applies to

- New Construction (1–2 points)
- Schools (1–2 points)
- Retail (1–2 points)
- Data Centers (1–2 points)
- Warehouses & Distribution Centers (1–2 points)
- Hospitality (1–2 points)
- Healthcare (1–2 points)

**Intent**

To establish better quality indoor air in the building after construction and during occupancy.

**Requirements**

**NC, SCHOOLS, RETAIL, DATA CENTERS, WAREHOUSES & DISTRIBUTION CENTERS, HOSPITALITY, HEALTHCARE**

Select one of the following two options, to be implemented after construction ends and the building has been completely cleaned. All interior finishes, such as millwork, doors, paint, carpet, acoustic tiles, and movable furnishings (e.g., workstations, partitions), must be installed, and major VOC punch list items must be finished. The options cannot be combined.

**Option 1. Flush-Out (1 point)**

**Path 1. Before Occupancy**

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 (4 267 140 liters of outdoor air per square meter) of gross floor area while maintaining an internal temperature of at least 60°F (15°C) and no higher than 80°F (27°C) and relative humidity no higher than 60%.

OR

**Path 2. During Occupancy**

If occupancy is desired before the flush-out is completed, the space may be occupied only after delivery of a minimum of 3,500 cubic feet of outdoor air per square foot (1 066 260 liters of outdoor air per square meter) of gross floor area while maintaining an internal temperature of at least 60°F (15°C) and no higher than 80°F (27°C) and relative humidity no higher than 60%.

Once the space is occupied, it must be ventilated at a minimum rate of 0.30 cubic foot per minute (cfm) per square foot of outdoor air (1.5 liters per second per square meter of outside air) or the design minimum outdoor air rate determined in EQ Prerequisite Minimum Indoor Air Quality Performance, whichever is greater. During each day of the flush-out period, ventilation must begin at least three hours before occupancy and continue during occupancy. These conditions must be maintained until a total of 14,000 cubic feet per square foot of outdoor air (4 270 liters of outdoor air per square meter) has been delivered to the space.

OR

**Option 2. Air Testing (2 points)**

After construction ends and before occupancy, but under ventilation conditions typical for occupancy, conduct baseline IAQ testing using protocols consistent with the methods listed in Table 1 for all occupied spaces. Use current versions of ASTM standard methods, EPA compendium methods, or ISO methods, as indicated. Laboratories that conduct the tests for chemical analysis of formaldehyde and volatile



organic compounds must be accredited under ISO/IEC 17025 for the test methods they use. Retail projects may conduct the testing within 14 days of occupancy.

Demonstrate that contaminants do not exceed the concentration levels listed in Table 1.

Table 1. Maximum concentration levels, by contaminant and testing method


Contaminant		Maximum concentration	ASTM and U.S. EPA methods	ISO method	
Particulates	PM10 (for all buildings)	50 µg/m <sup>3</sup> Healthcare only: 20 µg/m <sup>3</sup>	EPA Compendium Method IP-10	ISO 7708	
	PM2.5 (for buildings in EPA nonattainment areas for PM2.5, or local equivalent)	15 µg/m <sup>3</sup>			
Ozone (for buildings in EPA nonattainment areas for Ozone, or local equivalent)		0.075 ppm	ASTM D5149 - 02	ISO 13964	
Carbon monoxide (CO)		9 ppm; no more than 2 ppm above outdoor levels	EPA Compendium Method IP-3	ISO 4224	
Total volatile organic compounds (TVOCs)		500 µg/m <sup>3</sup> Healthcare only: 200 µg/m <sup>3</sup>	EPA TO-1, TO-17, or EPA Compendium Method IP-1	ISO 16000-6	
Formaldehyde		27 ppb Healthcare only: 16.3 ppb	ASTM D5197, EPA TO-11, or EPA Compendium Method IP-6	ISO 16000-3	
Target volatile organic compounds*	1	Acetaldehyde	140 µg/m <sup>3</sup>	ASTM D5197; EPA TO-1, TO-17, or EPA Compendium Method IP-1	ISO 16000-3, ISO 16000-6
	2	Benzene	3 µg/m <sup>3</sup>		
	3	Carbon disulfide	800 µg/m <sup>3</sup>		
	4	Carbon tetrachloride	40 µg/m <sup>3</sup>		
	5	Chlorobenzene	1000 µg/m <sup>3</sup>		
	6	Chloroform	300 µg/m <sup>3</sup>		
	7	Dichlorobenzene (1,4-)	800 µg/m <sup>3</sup>		
	8	Dichloroethylene (1,1)	70 µg/m <sup>3</sup>		
	9	Dimethylformamide (N,N-)	80 µg/m <sup>3</sup>		
	10	Dioxane (1,4-)	3000 µg/m <sup>3</sup>		
	11	Epichlorohydrin	3 µg/m <sup>3</sup>		
	12	Ethylbenzene	2000 µg/m <sup>3</sup>		
	13	Ethylene glycol	400 µg/m <sup>3</sup>		
	14	Ethylene glycol monoethyl ether	70 µg/m <sup>3</sup>		
	15	Ethylene glycol monoethyl ether acetate	300 µg/m <sup>3</sup>		
	16	Ethylene glycol monomethyl ether	60 µg/m <sup>3</sup>		
	17	Ethylene glycol monomethyl ether acetate	90 µg/m <sup>3</sup>		

19	Hexane (n-)	7000 µg/m <sup>3</sup>		
20	Isophorone	2000 µg/m <sup>3</sup>		
21	Isopropanol	7000 µg/m <sup>3</sup>		
22	Methyl chloroform	1000 µg/m <sup>3</sup>		
23	Methylene chloride	400 µg/m <sup>3</sup>		
24	Methyl t-butyl ether	8000 µg/m <sup>3</sup>		
25	Naphthalene	9 µg/m <sup>3</sup>		
26	Phenol	200 µg/m <sup>3</sup>		
27	Propylene glycol monomethyl ether	7000 µg/m <sup>3</sup>		
28	Styrene	900 µg/m <sup>3</sup>		
29	Tetrachloroethylene (Perchloroethylene)	35 µg/m <sup>3</sup>		
30	Toluene	300 µg/m <sup>3</sup>		
31	Trichloroethylene	600 µg/m <sup>3</sup>		
32	Vinyl acetate	200 µg/m <sup>3</sup>		
33-35	Xylenes, technical mixture (m-, o-, p-xylene combined)	700 µg/m <sup>3</sup>		

ppb = parts per billion; ppm = parts per million; µg/cm = micrograms per cubic meter

\*The target volatile organic compounds are from CDPH Standard Method v1.1, Table 4-1. The Maximum concentration limits for these target compounds are the full CREL adopted by CalEPA OEHHA in effect on June 2014 <http://oehha.ca.gov/air/allrels.html>.

Conduct all measurements before occupancy but during normal occupied hours, with the building ventilation system started at the normal daily start time and operated at the minimum outdoor airflow rate for the occupied mode throughout the test.

For each sampling point where the concentration exceeds the limit, take corrective action and retest for the noncompliant contaminants at the same sampling points. Repeat until all requirements are met.