Indoor Air Quality Assessment
CHBE building Second floor

Bojosi Gamontle, Jackie Law, Navid Taherdin

University of British Columbia

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Reported by:

School of Environmental Health
OCCH 502 students

Navid Taherdin
Bojosi Gamontle
Jackie Law

Supervisor:
Karen Bartlett, PhD

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Executive Summary

The Chemical and Biological Engineering (CHBE) building was selected for study from a number of buildings on the University of British Columbia campus whose occupants have made complaints about poor indoor air quality.

As part of the training in the Occupational and Environmental Hygiene graduate program, students conducted an indoor environmental quality survey and performed field measurements for potential indoor air pollutants based on the result of the survey. Six occupants of the second floor answered survey questions regarding their perception of the quality of the indoor environment; the primary complaints were of chemical odours, particularly in the morning. Lack of ability to control temperature, and temperature fluctuation, was also noted by some respondents.

Areas were chosen for sampling based on availability and in consultation with the safety program officer for the building. Assessment of airflow patterns and spot checks for bioaerosols, ultrafine particulate matter (≤ 1 µm), carbon dioxide, and volatile organic chemicals (VOCs) was conducted on March 16, 2010. A twenty-four hour sample for carbon dioxide were taken March 16 – 17.

Field measurement results showed that the level of indoor air contaminates in all sampling locations were in compliance with WorkSafe BC and ASHRAE 62.1 indoor air guidelines. However, the assessment of air flow patterns and generation of ultrafine particulate matter, may have contributed to subjective complaints by occupants

Improvements to air flow patterns to enable fresh air delivery into occupied spaces, filtration of ultrafine particulate matter, and local control of room temperature may result in higher occupant satisfaction in this building.

Introduction

Considering the fact that office workers spend one third of their day time inside office buildings, indoor air quality is recognized as a contributing factor in the health and comfort of this population. Poor indoor air quality may result in headaches, shortness of breath, coughing, nausea, hypersensitivity and allergies, and decreased productivity in office workers. Indoor air contaminants can be generated from activities of building occupants, or building materials and furnishings, or can be brought into the building through the ventilation system. Some common examples of indoor air contaminants include bioeffluents of building occupants including carbon dioxide (CO_2), volatile organic compounds (VOCs) from workplace furnishings, cleaners and solvents, microbial contaminants such as molds and bacteria from damp areas and stagnant water, and ultrafine particulate matter generated from office equipment such as photocopiers and laser printers, or from vehicular air pollution entrained from outside sources. (1) (2)

In office buildings the heating, ventilating, and air conditioning (HVAC) system is designed to provide appropriate temperature and humidity, distribute outdoor air to occupants, filter contaminants and control pressure relationships between rooms. Inadequate ventilation can increase indoor pollutant levels by not providing enough fresh air to dilute emissions from indoor sources. According to the American Society of Heating, refrigerating, and Air-Conditioning Engineers (ASHRAE) standard 62.1 (2007), acceptable indoor air quality is defined as air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which the substantial majority (80% or more) of the people exposed do not express dissatisfaction. (3) (4)

For this project, the concentration of the following indoor environmental quality markers were considered: CO_2, VOCs, ultrafine particulate matter, and airborne bioaerosols (bacteria and mold) were measured in three personal office rooms (2.53, 2.27, 2.13), reception (2.18), photocopy room (2.24), lunch room (2.12), entrance hall (ground level) and outdoor areas. We also evaluated the performance of the ventilations ducts in all rooms that we conducted sampling.

Methods

Bioaerosols:

Mold and bacteria samples were taken based on the NOISH 0501 method using an Andersen N-6 sampler. (5) In this method, air is drawn through the sampling head at 28.3 litres per minute (LPM) and samples collected on agar culture media. Tryptic Soy Agar (TSA) and Malt Extract Agar (MEA) were used for bacteria and mold sampling, respectively. Seven pairs of mold and bacteria samples from six indoor and one outdoor locations were taken.

Mold samples were incubated at room temperature for 7 days. Having determined the total number of colony-forming units, positive hole correction factor was applied to the numbers. (6) Positive hole correction factor (CFU) was divided by the total volume of air (m^3) to obtain the mold concentrations in CFU/m^3. Fungal colonies were identified using tape lift technique and phase contrast microscopy at 400 times magnification.

Bacteria samples were incubated at 35±2 °C temperature for 48 hours. The same procedure as mold was followed to calculate the bacteria concentrations. The gram stain method was used to identify the bacterial colonies and differentiate Gram positive bacteria from Gram negative.

Comfort parameters: carbon dioxide, temperature and relative humidity
TSI Q-Trak® real-time data-logging analyzer
The Q-trak was used to conduct spot checks for carbon dioxide, temperature and relative humidity. In addition, a 24-hour continues measurement was conducted in the reception room (2.18).

Ultrafine particulate matter:
TSI P-Trak® Ultrafine Particle Counter
The P-trak was used to measure airborne particles in the range of 0.02 to 1 micrometer (µm). Comparison measurements of outdoor air were conducted at the entrance door facing East Mall the side entrance facing Health Sciences Mall.

Total Volatile Organic Compounds (TVOC):
ppbRAE®
The highly sensitive Photo-ionized Detector (PID) of this device provides true parts-per-billion (ppb) detection for total VOCs concentration. Spot check measurements were done using the ppbRAE® in all sampling areas.

Air flow visualization:
Smoke tube
The smoke tube generates non-toxic smoke of approximately the same density as air and is used to visualize the air flow patterns of the ventilation system. Pressure differentials (positive or negative) in rooms compared to hallways were visualized.

Results

Mold and Bacteria

Analysis of mold and bacteria samples was done in School of Environmental Health laboratory. Mold concentrations in all indoor sampling locations were found to be below 30 CFU/m^3 and outdoor concentration was 363 CFU/m^3. Table 1 summarizes the measured mold and bacteria concentrations in all sampling areas. Detailed results of all sampling locations and more information about types of identified fungal and bacteria species can be found in appendix 1.

Table 1. Bioaerosol concentrations in selected CHBE areas March 16, 2010.

Location	2.53	2.18	2.13	2.27	2.12	Entrance Hall	Outdoor
Mold concentration (CFU/m^3)	4	18	25	4	7	30	363
Bacteria concentration (CFU/m^3)	84	72	47	47	4	32	30

There are no exposure limits for bioaerosols. Guidelines and recommended acceptable exposure levels for mold have been proposed by various agencies and are listed in Table 2.

Table 2. Bioaerosol (mould) contaminants guidelines [7]

Organization	Recommendations
ACGIH	< 100 CFU/m^3 = OK Indoor/outdoor < 1 = OK if similar taxa
National Health and Welfare, Canada	Toxigenic, pathogenic fungi not acceptable in indoor air. ≥ 50 CFU/m^3 if one species = investigate ≤ 150 CFU/m^3 if mixture of species = OK ≤ 500 CFU/m^3 if common tree/leaf fungi = OK in summer
USOSHA	≥ 1000 CFU/m^3 = indicates contamination

There was no evidence of an indoor source of mould due to water damage of building materials. Indoor mold concentrations were less than one-tenth that of the outdoor air, and reflected the the fungal genera found in outdoor air.

Bacterial concentrations in this study were used as a surrogate of the bioeffluents created by the occupants themselves. Humans are sources of epithelial cells which are colonized by normal skin flora and are regularly shed into the environment. Other bioeffluents which are difficult to measure, but which can be experienced as objectionable air quality, include body odour, pheromones, or scented products including perfumes, etc. Air handling systems should remove bioeffluents by dilution ventilation if room air is well mixed with fresh outdoor air as required by ASHRAE 62.1 guidelines.

Carbon dioxide (CO_2), relative humidity and temperature

Spot check measurements of carbon dioxide are presented in Table 3. The concentration of outdoor CO_2 varies with the amount of pollution in the area, and on the sampling day was around 325 ppm. The concentrations of carbon dioxide in all sampling locations except the photocopy room were below the level of concern outlined by ASHARE 62.1 and adopted by WorkSafe BC. The photocopy room had a CO_2 concentration of 1200 ppm which indicates poor air circulation. The photocopy room will be discussed further in results for ultrafine particulate matter and evaluation of air flow patterns. The 24-hour monitoring of the reception room (2.18) showed that the CO_2 levels retuned to ambient CO_2 concentrations during the unoccupied portion the 24-hr period (Appendix 2) on this occasion. Anecdotal information from occupants indicated that the HVAC system is not operating overnight.

Table 3. Measured CO_2 concentrations in selected locations of CHBE March 16, 2010.

Location	2.53	2.18	2.13	2.27	2.12	Entrance Hall	Copy room
CO_2 concentration (ppm)	511	619	425	523	406	324	1200

According to ASHRAE Standard 55-1992, relative humidity levels below 25% are associated with increased discomfort and humidity levels above 60% can result in condensation within the building structure and the subsequent development of moulds and fungi. The recommended range of relative humidity for comfort of workers using computers or wearing contact lenses is between 30 and 60 %. [(4)]

WorkSafe BC has also adopted the ASHRAE 55-1992 temperature comfort ranges of 20 to 25 °C [(1)]. Table 4 reports temperature and relative humidity. Note that the photocopy room has a lower relative humidity than other rooms. Low relative humidity results in occupant discomfort in a variety of symptoms including dry skin, dry or itching eyes, tendency for paper cuts, etc.

Table 4. Measured temperature and relative humidity in the CHBE building March 16, 2010.

Location	2.53	2.18	2.13	2.27	2.12	Entrance Hall	Copy room
Temperature (°C)	22	23	21	22	21	20	21
Relative Humidity (%)	31	30	28	27	29	34	24

Ultrafine Particles

The P-Trak® measures the number of particles ≤ 1 µm per cubic centimeter (PT/CC). The source of ultrafine particles may be from an outdoor source, e.g. vehicular pollution, or from indoor sources such as photocopiers or laser printers. The results of particulate measurements are summarized in the table 5.

Table 5. Ultrafine particulate concentrations in the CHBE building March 16, 2010.

Location	2.02	2.13	2.27	2.18	Entrance Hall	Copy room	Outdoor
Particulate concentration (PT/CC)	650-750	1000-1300	2500-2600	1200-1500	1600-1700	8000-9000	1500-2000
Ratio indoor : outdoor	0.4	0.66	1.46	0.77	0.94	4.86	1

The building itself should attenuate the infiltration of ultrafine particulate from outdoor air through use of filters in the ventilation air stream or by the building envelope. It is generally acceptable if the ultrafine particulate matter in indoor air is no more than 20% of the outdoor particulate matter. Table 5 reports the ambient particle count and ratios of indoor to outdoor particle concentration. The location of the outdoor concentration used was near the air intake tunnel on the south side of the building. Ratios are below 1.0 for all rooms except the photocopy room and room 2.27. The concentration in the photocopy room was determined while the photocopier was in use. During the time that the machine was not working, the value decreased to about 5000 (PT/CC) with an equivalent ratio of 2.85. Further work would be required to address the higher ratio in room 2.27.

An additional outdoor measurement reflects the contribution of vehicular exhaust to ultrafine particulate matter, with a measurement at the East Mall entrance (e.g. close to road) averaging 8000 particles per cubic centimeter. In context, the photocopy room was producing as much or greater concentration of ultrafine particulate matter as being subjected to vehicular exhaust particulate matter.

Total Volatile Organic Compounds (TVOCs)

The results of the Total VOCs as measured by the ppbRAE® were low and are presented in Table 6. There is no consensus standard for indoor concentration of Total VOCs in the US or Canada. For individual component analysis, ASHRAE Standard 62-1989 and WorkSafe BC recommend using a value of $1/10^{th}$ the occupational exposure limits for non-industrial indoor air. However, the European Union has promoted a target guideline value for TVOC of 300 ppb. [(4)]

Table 6, Measured TVOC concentrations in the CHBE building, March 16, 2010.

Location	2.02	2.13	2.27	2.18	Entrance Hall	Copy room
TVOC concentration (ppb)	<LOD	15-20	<LOD	10-120	<LOD	30-40

Visualization of air flow patterns (Smoke tube)

The airflow from supply air diffusers or into exhaust air ducts were visualized, and were found to not meet the objective of mixing fresh air in the occupied spaces of the rooms tested. The most problematic rooms were room 2.18 and the photocopy room where the air flow was short circuited, with supply air moving across the ceiling of the room and directly into the exhaust

vent without mixing in the occupied space. The photocopy room also had the highest CO_2 concentration with no resident occupants. The ventilation provided by the air handling unit is the only manner in which pollutants can be removed by dilution with fresh air, and lack of dilution ventilation results inevitably results in complaints of stuffy or stale air.
Office rooms should be maintained at positive pressure relative to the hallway to reduce infiltration of particles. Rooms 2.27, 2.13, and 2.02 were maintained at positive pressure compared to the hallways.

Summary and Recommendations

- Concentrations of bioaerosols (mold and bacteria) were at acceptable levels compared to the outdoor concentrations.
- The temperature ranges on the day of testing were acceptable, however, further investigation of temperature is suggested as 4 out of the 6 occupants who completed the survey complained about temperature extremes. On the day of testing the ambient temperate was moderate. It is possible that temperature stratification indoors may occur during periods of more extreme ambient temperatures. Provision of occupant controlled thermostats or supplemental space heating may provide greater comfort in this building.
- The relative humidity ranges were acceptable, however, in 4 rooms examined, the relative humidity levels were lower than 30% which may result in complaints of dry or itchy skin or eyes.
- All of the offices except the reception room were single occupancy rooms and were not continuously occupied, so the level of carbon dioxide taken in isolation of other observations was not a good predictor of dilution ventilation on the day of testing. The 24-hour carbon dioxide monitoring did indicate that the ventilation system was operating overnight March 16 – 17 because the carbon dioxide concentration returned to ambient background levels.
- The photocopy room is a source of ultrafine particulate matter and has inadequate dilution ventilation.
- The Total Volatile Organic Compounds were with acceptable ranges.
- Visualization of air flow patterns indicated inadequate mixing of fresh air in the occupied space. Inadequate mixing compromises the ability of the ventilation system to remove pollutants generated by occupants, furnishings, or office equipment. Complaints from occupants submitting surveys were “odours in the office in the morning”, “smell of chemicals in our office”, ”weird chemical smell, quite strong, first thing in the a.m.”,“feel like we are breathing stale, recycled air”, “stuffy” may be related to inadequate provision of fresh air, inadequate mixing, or inadequate dilution of room air.

Appendices

Appendix A

A.1 Airborne fungal testing results.

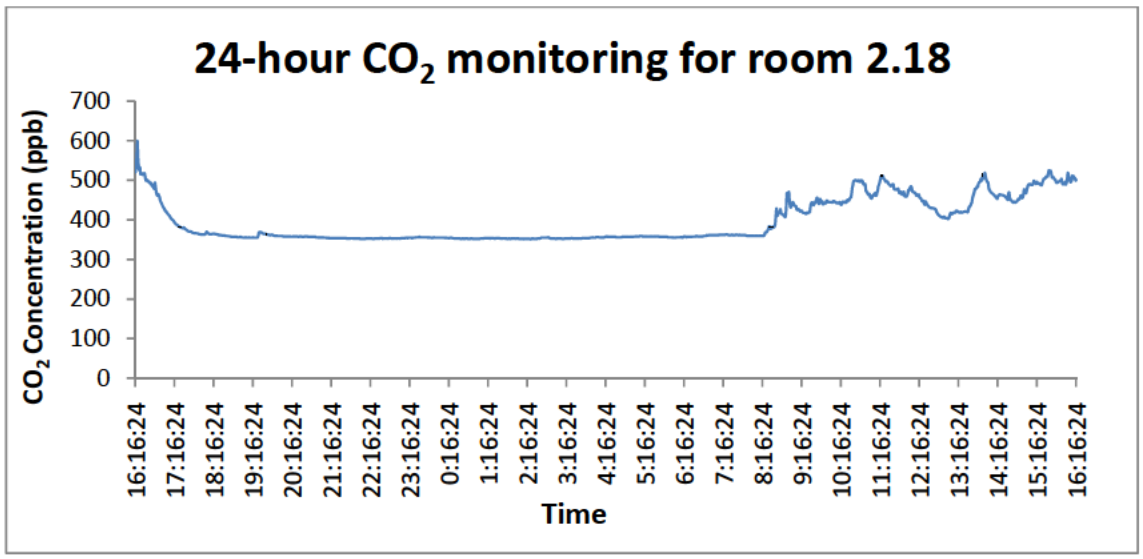
Reported by: Navid Taherdin						
Date analyzed: 25-03-2010		**Date sampled:** 16-03-2010		**Date reported:** 07-04-2010		
Incubation conditions: room temperature for 7 days						
		Proportional representation				
Room ID	**CFU/m^3**	***Botrytis***	***Cladosporium***	***Penicillium***	**Sterile Mycelia**	**Yeast**
2.53	4	-	-	-	-	100 %
2.18	11	-	33 %	-	66 %	-
2.13	18	-	20 %	40 %	20 %	20 %
2.27	4	-	-	-	100 %	-
2.12	11	-	33 %	33 %	33 %	-
First floor	53	7 %	66 %	7 %	13 %	7 %
Outdoor	298	7 %	62 %	21 %	5 %	5 %

A.2 Airborne bacterial testing results.

Reported by: Navid Taherdin					
Date analyzed: 25-03-2010		**Date sampled:** 16-03-2010		**Date reported:** 07-04-2010	
Incubation conditions: incubated at 35±2° C temperature for 48 hours, then refrigerated					
		Proportional representation			
ID	**CFU/m^3**	**Gram positive cocci**	**Gram positive rods**	**Gram negative cocci**	**Gram negative rods**
2.53	84	57 %	43 %	-	-
2.18	72	70 %	30 %	-	-
2.13	47	54 %	46 %	-	-
2.27	47	77 %	23 %	-	-
2.12	4	100 %	-	-	-
First floor	32	89 %	11 %	-	-
Outdoor	30	50 %	50 %	-	-

Appendix B

B.1 Graph of 24-hour CO_2 monitoring in room 2.18.



Appendix C

Occupant survey of the indoor environmental quality of your work space.

Please circle or tick the number on the scale that best represents how you normally perceive the air in your workspace. Note! All replies are strictly confidential. It would, however, be helpful to us if we knew approximately where in the building your workspace is – north, east, south or west side.

1) How satisfied are you with the air quality in your workspace?

Dissatisfied			Neutral			Satisfied
-3	-2	-1	0	+1	+2	+3

If you indicated a rating of -3 to -1, please tell us a little about the air in your workplace (e.g. stale air, odours, etc.)

2) Does the air in your office interfere or enhance your productivity?

Interfere			Neutral			Enhance
-3	-2	-1	0	+1	+2	+3

3) How satisfied are you with the temperature in your workspace?

Dissatisfied			Neutral			Satisfied
-3	-2	-1	0	+1	+2	+3

4) Is the temperature in your workplace:

Too cold			Just right			Too hot
-3	-2	-1	0	-1	-2	-3

5) How satisfied are you with the lighting in your workspace?

a) Amount of light

Dissatisfied			Neutral			Satisfied
-3	-2	-1	0	+1	+2	+3

b) Visual comfort

Dissatisfied			Neutral			Satisfied
-3	-2	-1	0	+1	+2	+3

c) Amount of daylight

Dissatisfied			Neutral			Satisfied
-3	-2	-1	0	+1	+2	+3

6) How satisfied are you with the general noise level in your workplace?

Dissatisfied			Neutral			Satisfied
-3	-2	-1	0	+1	+2	+3

Thank you for your sharing your experiences with us! If there is anything else you would like to comment on, please feel free to do so in the box below.

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