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Testing Effectiveness of Duct Cleaning and Its Impact on Airborne Particles, Mold and Biocide Levels in Commercial Office Buildings

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1 Introduction
1.1 Purpose

This protocol is a test method to evaluate the effectiveness of duct cleaning (DC) and impact of DC activities on indoor air quality (IAQ) of commercial office buildings. The intent of this protocol is to provide standardized IAQ monitoring and sampling methods that can be used both pre and post DC activities to ensure that building occupants and operators have consistent and reliable data to make the necessary decisions regarding post cleaning building occupancy. Although the protocol's primary objective is to standardize the IAQ evaluation methods, it also includes testing surface cleanliness of HVAC systems.

1.2 Scope

There is a wide variety of DC techniques which include contact vacuuming, compressed air cleaning or mechanical brushing together with vacuum collection (Holopainen et al., 2003; HVCA, 2005), hand washing, water jet spray and chemical disinfection (Luoma et al, 1993; Brosseau et al., 2000). Chemical treatment involves the use of biocides and sealants to coat and encapsulate duct surfaces (Luoma et al, 1993; EPA, 1997) while some DC techniques introduce ozone as part of the disinfection process (EPA, 1997). DC activities have been reported to increase airborne particles concentrations during, as well as, after the process. A recent scientific review has reported that pollutants emitted from the DC activities or application of chemical treatment can pose harmful exposures to occupants within the building (Zuraimi, 2010).

Regardless of the DC technique used, there will be a positive or negative impact on the IAQ[1] of the building. The protocol provides a test method to evaluate concentrations of airborne biocides, as well as airborne dust and mold associated with DC. The protocol also describes a method to evaluate the performance of DC services in reducing dust/debris contaminants on internal surfaces of ducts via a combination of measurement and visual inspection.

[1] In this protocol the term IAQ relates to the indoor air concentrations of pollutants that are associated with DC activities and known or suspected to affect people's comfort, environmental satisfaction, health, or work or school performance. This protocol does not address thermal and humidity conditions, although they are important not only for comfort and satisfaction of the occupants, prevalence rates of building related health symptoms and work performance, but they also influence IAQ, because these conditions can also affect pollutant emission rates, the growth of microrganisms on building surfaces, the survival of house dust mites and mold, which are a source of allergens.

The protocol is not meant to be used for the following situations or applications: cleaning for residential, industrial, healthcare and marine buildings, mixed use spaces, and restaurant associated ventilation systems with kitchen extraction systems. All IAQ measurements should be conducted by an indoor environment professional with a background in Industrial Hygiene and have HVAC systems experience. It does not provide guidelines for health and safety for DC service workers.

1.3 Description of Test Protocol

For this test protocol, two main themes were chosen by the TAC for determining performance of DC: 1) assessing airborne pollutant concentrations indoor; and 2) assessing duct surface cleanliness.

The test protocol has three objectives:

1) adopting standardized and consistent pre- and post-DC measurements for comparison;

2) providing an on-site evaluation in commercial building where DC service is performed; and

3) measuring indoor concentrations of pollutants associated with DC intended to protect building occupants from possible health effects.

In order to determine the concentrations of airborne pollutants, the DC company shall be required to provide a declaration of the use of biocides and/or any other chemical treatments. If biocides are being used, the test protocol calls for targeted measurements. Airborne biocide measurements are not necessary when no use of biocidal products or any chemical treatments have been declared.

To determine that DC activities do not cause elevated indoor concentrations of airborne particles and mold spores, measurements shall be performed in the affected indoor space as well as outdoors as reference. Sole measurements of their indoor concentrations are not sufficient, as outdoor sources can contribute to indoor concentrations through ventilation and infiltration.

For the assessment of surface cleanliness, post-cleaning evaluation of the HVAC systems shall be performed. Surface dust/debris contamination shall be assessed by a combination of measurement and visual techniques. Post cleaning surface dust levels must meet the National Air Duct Cleaners Association's (NADCA) objective guideline of 0.75mg/100cm^2 for the main supply air duct (NADCA, 2006). For porous surface and curved or round ducts, cleanliness level by visual inspection have to be considered sufficient for the moment, as there is currently no practical method to quantify the dust levels on these kind of surfaces. Post-cleaning visual inspection of selected sections of the HVAC system shall ensure that the surfaces are visibly free of dust/debris contamination.

If the surface cleanliness and/or airborne concentrations do not meet the criteria of the protocol, re-cleaning is to be performed. All results shall be clearly documented, preferably using the forms given in the appendices.

2 Definitions and Acronyms

2.1 Definitions

Some terms are defined below for the purposes of this protocol. When definitions are not provided, common usage shall apply.

air flow rate: the volumetric flow rate in the test duct.

airborne particles: solid or liquid suspended aerosols.

biocide: an agent that inactivates or kills or suppresses growth of microorganisms.

concentration: the ratio of the mass or volume of a particular substance to the mass or volume of another substance. For airborne pollutants, the concentration is given as milligrams per cubic meter, parts per million by volume or parts per billion by volume. For surface dust, the concentration is given as milligrams per a 100 square centimeter.

constant air volume system: an air handling system involving a continuous amount of air flow.

contact vacuum: a DC collection device, usually portable, that uses a brush nozzle attached to the end of its inlet hose. The brush head is applied directly to a surface for cleaning.

DC induced airborne pollutants: Airborne pollutants emitted by DC activities, e.g. biocides, particles or mold.

debris: non-adhered substances not intended to be present on the duct surfaces or in the HVAC system.

duct: a conduit for distribution and extraction of air, excluding plenums.

duct cleaning:	the removal of surface dusts and particles to a level defined by this protocol.
filter:	a porous sheet often made of either fibrous or membrane materials for removal of particles from an air stream.
HVAC:	the heating, ventilating, and air conditioning system which includes, but is not limited to, the interior surface of the air distribution system for conditioned spaces and/or occupied zones, grilles and air-handling unit (AHU) components.
inspection:	to gather information for identification of sampling locations and possible issues that may confound the results of testing by an indoor environment professional with a background in Industrial Hygiene and have HVAC systems experience.
non-adhered substances:	any material not intended to be present on the surface of the duct, and which can be removed by contact vacuum.
non-porous duct surface:	any internal surface of the duct that cannot be penetrated by water or air.
porous duct surface:	any internal surface of the duct that is can be penetrated by water or air.
shall be:	mandatory requirement for compliance with this protocol.
sealant:	fastener, coating, or filler used to seal against air leakage.
visibly clean:	a condition in which the interior duct surfaces are free of non-adhered substances and debris.
visual inspection:	visual examination with the naked eye of the cleanliness of the internal duct surface.

2.2 Acronyms and Abbreviations

ACGIH	American Conference of Government Industrial Hygienists
AHU	Air Handling Unit
ASHRAE	American Society for Heating, Refrigerating and Air-conditioning Engineers
ASTM	American Society for Testing and Materials
BAS	Building Automation System
CAV	Constant Air Volume
CCTV	Closed-Circuit Television

CEN	European Committee for Standardization
DC	Duct Cleaning
EC	Elemental Carbon
EPA	United States Environmental Protection Agency
HVAC	Heating, Ventilating and Air Conditioning
HVCA	The Heating and Ventilating Contractors' Association
LTS	Long Term Samples
MSDS	Materials Safety Data Sheet
NADCA	National Air Duct Cleaners Association
NIOSH	National Institute of Occupational, Safety and Health
NMAM	NIOSH Manual of Analytical Methods
OEHHA	Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Agency
PEL	Permissible Exposure Limits
PMRA	Pest Management Regulatory Agency
ppb	Parts per Billion by volume
ppm	Parts per Million by volume
PVC	Polyvinyl Chloride
REL	Recommended Exposure Limits
STS	Short Term Samples
TLV	Threshold Limit Values
VAV	Variable Air Volume
VOCs	Volatile Organic Compounds

3 Test Parameters and Measurements

3.1 Test Method Procedures

In order to perform the test method of this protocol, the following procedure is recommended (see Figure 1). The building is first characterized by walkthrough inspection and information gathering as described in Section 3.1.1 and Appendix A. DC characterization via surface cleanliness evaluation and airborne pollutant concentration measurements for pre- and post-DC periods is next performed (Sections 3.1.2). The results of the pre- and post-DC evaluations are then documented and compared using the criteria set in this protocol (Section 3.1.3). The acceptable limits and methods of measurements are included in Section 3.2 and Table E.1.

3.1.1 Walkthrough Inspection and Information Gathering

A walkthrough inspection of the premises and HVAC system shall be conducted before the pre-DC measurements. The walkthrough shall be conducted by an indoor environment professional with a background in Industrial Hygiene and have HVAC systems experience. The main objectives of the walkthrough are to:

a) select and determine the sampling location points; and
b) identify possible issues that may confound the results of testing. These include, but are not restricted to, indoor and outdoor pollutant sources, building envelope conditions, potential issues related to the HVAC system and its operations, and office cleaning and maintenance routines.

A sample checklist for a walkthrough inspection is provided in Appendix A.

With respect to DC techniques, the types/technologies (e.g. compressed air and mechanical brushing) used by the DC company shall be noted. Work protocols adopted by DC companies shall be reviewed prior to the test evaluation.

3.1.2 DC Characterization

Figure 2 illustrates the schematic flowchart for procedures to characterize DC. Two sets of assessment shall be made: 1) surface cleanliness; and 2) airborne concentration.

For assessment of surface cleanliness, the air duct in the HVAC system is first ascertained whether it is round or circular in shape or whether the interior surface is comprised of porous material. If the air ducts are round or circular in shape or interior surface comprised of porous materials, only visual inspections are possible (Appendix B). Both visual inspections and objective measurements using the vacuum test method (Appendix B) are needed if the air duct has a flat and non-porous interior surface.

Airborne biocide measurements are not necessary when biocidal products or chemical treatments are not used. Airborne pollutants sampling shall be conducted on an eight-hour basis as far as practicable. If there are no standards requiring eight-hour sampling, other sampling strategies based on established standards can be followed (Appendix C). Assessment of concentrations shall be made for airborne particles and mold (Appendix D).

Airborne concentration assessment shall be performed for pre- and post-DC periods (Appendix E). Although surface cleanliness assessment shall be performed after DC, pre-DC assessment is recommended. All assessment results shall be clearly documented.

3.1.3 Data Analysis: Comparison Criteria

The results for DC characterization will be analyzed by comparing the pre- and post-DC assessments with the recommended guidelines given in Section 3.2.2 and 3.2.3 (Table E.1). If assessment results revealed that the DC did not meet some or all criteria of this protocol, re-cleaning is to be performed (Appendix G).

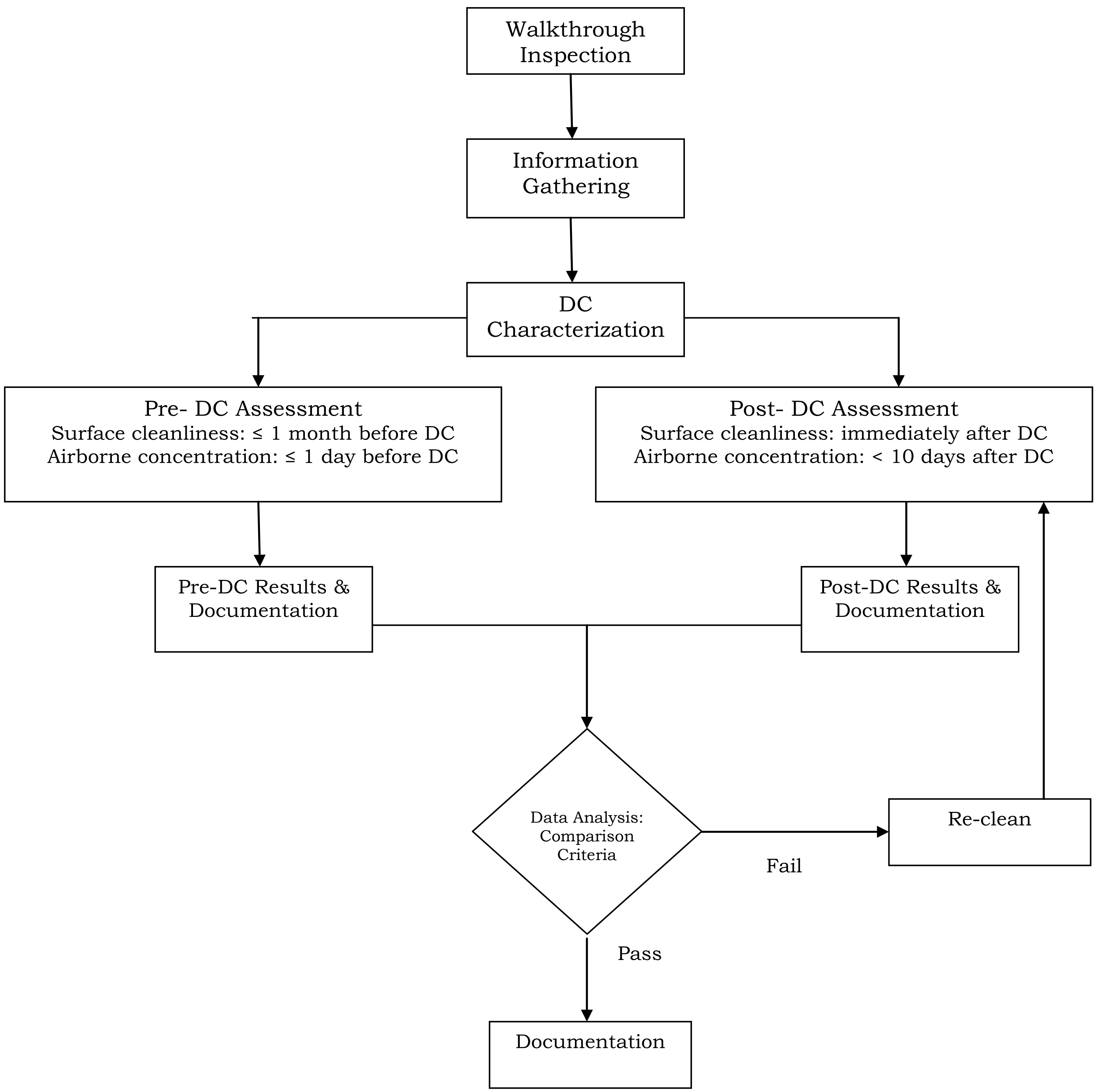

Figure 1 General overview of the procedures for the test method

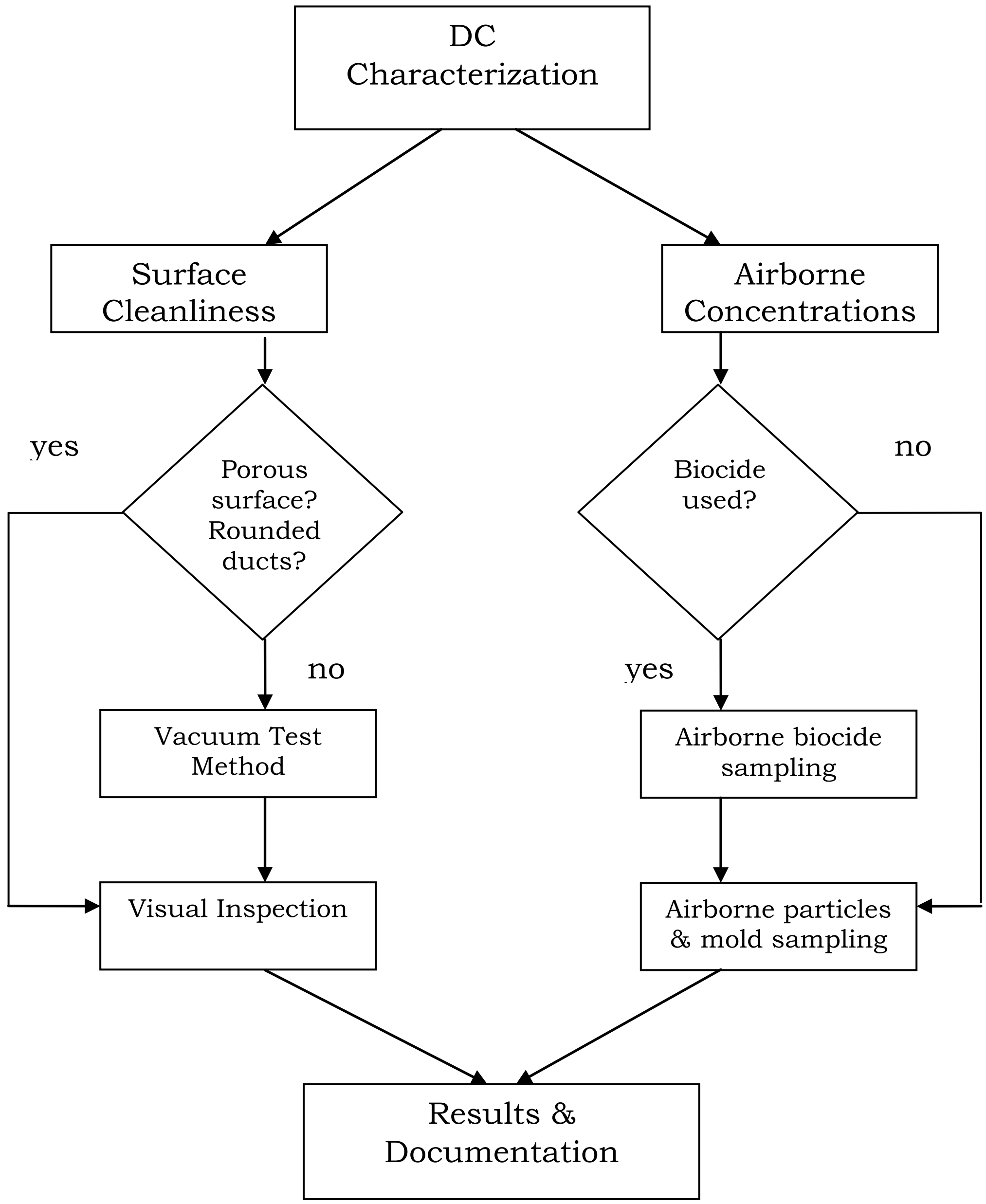

Figure 2 Schematic flow chart for procedures in the DC characterization for pre- and post-DC assessments.

3.2 Measurements

3.2.1 Sampling Location, Position and Density[2]

All assessment measurements shall be conducted within the HVAC system or the indoor space where DC is performed. The selection of sampling floors for DC characterization depends on the scale of proposed DC. For a multi-storey building, the recommended percentage of floors to be sampled randomly is given in Table 1.

Table 1 Recommended percentage of floors to be sampled for air and surface samplings in a building undergoing DC

Number of occupied floors in a building undergoing DC	Percentage of randomly selected floors to be tested
< 5	50% of floors*
5-10	40% of floors*
11-20	30% of floors*
21-30	20% of floors*
31-40	7 floors or 20 % of floors, whichever is higher
> 40	9 floors or 20% of floors, whichever is higher

* round off to whole number

Within each randomly selected floor to be tested, the sampling requirements for surface cleanliness and airborne concentration assessments shall be as follows:

1) The *visual inspection* for surface cleanliness assessment shall include at least:

   (A) Supply air ductwork, including all terminal devices and units;
   (B) Return and recirculation air ductwork, including all components;
   (C) Exhaust air ductwork, including all components; and
   (D) Fresh air ductwork.

   The sampling requirement for surface cleanliness assessment using the *Vacuum Test method* (see Section 3.2.2) shall include at least the main supply air duct (NADCA, 2006).

2) The sampling requirements for the airborne concentration assessment are as follows:

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[2] See Appendix A.2 for rationale and issues associated with sampling locations, position and density.

(A) Indoor : For each selected floor, at least one sample shall be taken from each separated area serviced by a separate air handling unit (AHU) or fan coil unit or any air-conditioning or air distribution system. The number of indoor sampling locations shall not be less than one per 2300 m^2 for each tested floor (LEED-NC, 2005). The indoor sample shall be collected in the middle of the occupied space (away from the walls) at a breathing zone height of 1.1 to 1.5 meters.

(B) Outdoor: Outdoor sampling shall be taken at the fresh air (outdoor air) intake of the air handling unit or the nearest accessible point to the fresh air (outdoor air) intake. Only one outdoor sampling location is needed.

3.2.2 Surface Cleanliness

Surface cleanliness evaluation shall be performed with the HVAC system turned off. Pre-DC assessment can be performed at the earliest 1 month and latest immediately before DC. Post-DC assessment shall be performed immediately after DC before the HVAC system is turned on to prevent post-cleaning interference.

The preferred method for this protocol is the Vacuum Test method whereby a gravimetric result is achieved as given in Appendix B. A surface is considered cleaned if, following the Vacuum Test, the dust concentration is less than 0.75 mg/100 cm^2. Gravimetric measurements can be performed on site. This method is suitable for square or rectangular sheet metal duct types only.

For systems with round or circular in shape ducts or internally lined porous surface, it is not possible to obtain samples using the Vacuum Test method. Here, cleanliness level by visual inspection must be considered sufficient due to a lack of a suitable sampling method. The surface is considered visibly cleaned when it is free from non-adhered substances and debris.

3.2.3 Airborne Concentrations

Airborne concentration measurements may include pre- and post-DC assessments of airborne particles biocides, and mold as required per sections 3.2.3.1 to 3.2.3.3. Airborne biocide measurements are not necessary if biocidal products and chemical treatments are not used. Table C.3 provides a sample declaration form that can be used.

Airborne concentration measurements of particles, mold and biocides, which are used (Table E.1) shall be performed with the HVAC system in operation. Pre-DC assessments shall be performed at the latest 24 hours before DC. Depending on office occupancy needs, post-DC assessment shall be performed not later than 10 days after DC. Measurements can be performed when the tested zone is occupied or unoccupied (Appendix F). To ensure comparability of the data regarding the pre- and post-DC sampling and provide stable conditions, the ventilation routine shall not be changed between the two sampling assessments (Appendix E).

For airborne biocides, sampling shall be performed when there are neither indoor cleaning activities nor cleaning products use. Indoor cleaning and use of cleaning products can be resumed as soon as the 8 hour air sampling has been completed. Measurements for outdoor concentrations shall be performed for airborne particles and mold and selected biocides (see Table E.1). Measurements for outdoor concentration of biocides with no known sources of outdoor origin are not required.

3.2.3.1 Airborne Biocides

Considering the various types of biocides that are being used for DC (Table C.1), the protocol requires a two step approach to assess compliance with the protocol:

The first step involves the screening of biocides obtained from DC company. The chemicals in the biocides shall be only those that have been regulated for use specifically for HVAC cleaning application in Canada by the Pest Management Regulatory Agency (PMRA) of Health Canada through the Pest Control Products Act:

(http://www.hc-sc.gc.ca/ahc-asc/branch-dirgen/pmra-arla/index-eng.php).

The DC company shall provide the registration number of the biocidal product, and commit to strictly follow the detailed directions that appear on the label or in attached leaflets that come with the register.

The second step involves airborne biocide concentration measurements. Depending on the target biocides, airborne concentration measurements are required to consider indoor and outdoor sources contributions and pre- and post-DC assessments (Table C.1). Measurement of airborne biocide concentrations shall be made on an 8-hour basis (Appendix C). Alternatively, sampling strategies based on established standards can be followed.

Table C.3 provides a sample declaration form that can be used.

3.2.3.2 Airborne Particles

This protocol requires the determination of the concentrations of total airborne particle mass for the assessment of airborne particles. The preferred method for this protocol is the NIOSH NMAM method 0500 (NIOSH, 1994b). If another method is used, the equivalency has to be demonstrated. Post DC airborne particle concentrations measured indoors shall not exceed 1 mg/m^3 and post-DC concentration index shall not exceed the pre-DC concentration index. See Appendix E for calculation of the concentration index.

3.2.3.3 Airborne Mold

This protocol requires the determination of the concentrations of the total airborne mold count[3] (ACGIH, 1989; Kleinheinz et al., 2006). The preferred method for this protocol is the ASTM method D 7391 (ASTM, 2009), using the slit sampler cassettes by Zefon Air-O-Cell (Zefon, 2004; Kleinheinz et al., 2006). If another method is used, the equivalency has to be demonstrated. The post-DC concentration index shall not exceed pre-DC concentration index. See Appendix E for calculation of the concentration index.

3.3 Data Analysis: Comparison Criteria

The surface cleanliness and airborne concentrations assessments shall be determined by comparing the various post-DC concentrations or their concentration indices with the criteria given in Table E.1.

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[3] Currently, there is no consensus on a standard against which to measure levels of airborne mold in the indoor environment (ACGIH, 1989; Rao et al., 1996; Kleinheinz et al., 2006). Industrial standard practice for airborne mold exposure assessment has typically used total fungal spore counts (ACGIH, 1989; Kleinheinz et al., 2006).

3.4 Re-cleaning

If the surface cleanliness and/or airborne concentration assessments do not meet the criteria given in Table E.1, re-cleaning is to be performed. Post-DC measurements and data analysis are then repeated so that acceptable duct surface cleanliness and indoor air quality can be proven (Appendix G).

4 Reporting Results

On completion of the test method, a report shall be provided, favorably using the documents given in the appendix. This report shall clearly state the following information:

a. DC work plan;
b. Pre- and post-DC assessments dates;
c. Pre- and post- DC visual surface assessments results;
d. Pre- and post- DC surface dust measurements results (if applicable);
e. Data on ventilation routine for pre- and post-DC assessments;
f. Declaration of chemicals use/non-use for cleaning or biocidal treatment;
g. Data on chemicals used for cleaning or biocidal treatment (if applicable);
h. Concentrations and/or indoor-outdoor concentration ratios of airborne biocides (if applicable);
i. Concentrations and/or indoor-outdoor concentration ratios of total airborne particles and mold;
j. Building re-cleaning dates (if applicable); and
k. Repeat post-DC assessments dates and results (if applicable).

A sample form that can be used along with the report is given in Appendix E.

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APPENDIX A

SAMPLING

A.1 Sample Checklist for Walkthrough Inspection

A walkthrough inspection shall include the office premises, its air-conditioning system(s) and any other ventilation installations where DC is conducted. The purpose of the inspection is to select and determine sampling location points and identify possible issues that may confound the test results. These include, but are not restricted to, potential indoor and outdoor pollutant sources, building envelope conditions, potential issues related to the HVAC system(s) and its operations, and office cleaning and maintenance routines. The checklist below can be used for the walkthrough.

Table A.1 Walkthrough Checklist

Category	Question	Yes
Ventilation issues	Are the outside air dampers open?	
	Does the BAS show that the design make up air is still being provided?	
HVAC issues	Is there any damaged, dirty or missing ductwork?	
	Is the ductwork circular or rounded?	
	Is the ductwork lined with porous materials?	
	Are there missing filters in the HVAC units? If not are they being bypassed?	
	Are the filters in the HVAC units dirty?	
	Are evaporator coils dirty?	
	Are the drain pans of HVAC units holding water?	
	Is the make-up air intake located near an exhaust discharge or such that moisture can enter it?	
	Are exhaust fans operating?	
	Are there any cleaning chemicals or disinfectants stored in the mechanical room?	
	Does the door to the mechanical room have a self-closer?	
	Are HVAC grilles and diffusers and the areas adjacent to them discolored and/or soiled?	
	In plenum ceiling systems, are there any ceiling tiles that are broken or misaligned causing a gap?	
Mold/Moisture related issues	Any staining/discoloration of walls?	
	Any staining/discoloration of acoustical ceiling tiles?	
	Any staining/discoloration of flooring materials?	
	Any standing water in the bathroom fixture or janitor sinks?	
	Any moisture/condensation issues on doors or windows?	
	Are there any musty / moldy smell in the office space?	
Cleaning and maintenance issues	Through cleaning maintenance records, have detergents, pesticides or other chemicals been used in the building?	

	Are there open containers or spilled materials in the janitor's closet?	
	Is the building cleaned regularly?	
	Are the carpets vacuum-cleaned regularly?	
Building envelope issues	Are there any missing or damaged exterior components (e.g. doors, holes or spalling in wall)?	
	Are gutters & downspouts disconnected, damaged or missing?	
	Are any roofing materials missing?	
	Is there apparent damage to the foundation?	
Pollutant sources issues	Are there occupants smoking in any room or area?	
	Are there building materials (furniture, furnishings, carpets, etc) or office equipment emitting noticeable odors?	
	Are renovation works being undertaken in any part of the building?	
	Is there a kitchen/pantry where cooking is done?	
	Are there soiled dishes in the kitchen/pantry?	
	Are there perishables in the refrigerator that are deteriorated?	
	Are horizontal surfaces dirty?	
	Are there spilled copier chemicals in the copier room?	
	Is the outdoor air intake duct near the cooling tower in this building or adjacent buildings?	
	Is there any construction work going on near the building?	
	Are heavy industries located near the building?	
	Are there nearby sources of traffic pollution (car park, roads, loading docks)?	

A.2 Number of Samples and Rationales

A balance has to be attained to reach a compromise between the costs of environmental sampling and obtaining an adequate number of samples for an accurate assessment[4].

Within the floor of the building, if the floor can be categorized into *x* separated areas that are being serviced by *x* different AHUs or fan coil units or any air-conditioning or air distribution systems [5], then the number of indoor samples to be taken shall be *x*. However the number of indoor sampling locations shall not be less than one per 2300 m^2 for each tested floor (LEED-NC, 2005).

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[4] Despite the costs associated with environmental sampling, a thorough investigation of a building has been shown to provide useful solutions related to IAQ issues (Gammage et al., 1989; EPA, 1991). A thorough investigation typically includes the collection of appropriate number of samples obtained through statistical methods (ASTM, 2001). As such, the protocol recommends sampling requirements that is based on a statistical approach similar to that adopted elsewhere (SS, 2009).

[5] The rationale of taking an indoor airborne sample from a separated area serviced by a separate air handling unit (AHU) or fan coil unit or any air-conditioning or air distribution system is primarily to obtain an air sample that is not mixed with air that is coming from adjacent areas. Air sample that is mixed may not represent the impact of DC performed in the separated area and its use may lead to a bias.

To allow cost reductions associated with a large number of sampling points, this protocol does not restrict the use of alternate sampling strategies (ASTM, 2001). For example, aggregating outdoor samples in two or more samples can be combined to reduce costs in a multi-story building investigation. In this case, several sets of samplers for indoor airborne pollutant measurements can be deployed simultaneously in several floors while only a single outdoor sampler is deployed during the same period.

We recommend that airborne concentration assessments to be conducted not later than 10 days after DC[6].

[6] This is based on experiences of Auger (1994) and Ahmed et al. (2001) who even 7 days after DC still recorded elevated post DC airborne particles. Zuraimi et al. (2008) reported elevated indoor $PM_{2.5}$ concentrations even after 14 days. The midpoint between 7 and 14 days is being used for this protocol.

APPENDIX B

DUCT SURFACE CLEANLINESS ASSESSMENTS

Ideally visual inspections should be supported by objective measurements. Surface cleanliness of square or rectangular air ducts with non-porous surfaces can be objectively assessed with methods described in section B.1. However, for porous surfaces, or curved or round ducts, visual inspections have to be considered sufficient, due to the lack of validated methods.

Post-DC assessment shall be performed, whereas pre-DC assessment is recommended. Post-DC assessment for duct surface cleanliness shall be performed immediately after DC before the HVAC system is turned on again, to prevent post-cleaning interference[7]. Pre-DC assessment provides a point of reference for comparing with post-DC assessment.

B.1 Visual Inspection

Visual inspection using the naked eye shall be made at the selected sampling points. For recording purposes, this may be assisted by the use of equipments such as cameras, endoscopes and robotic CCTV. All visual inspection shall be performed when the HVAC system serving the measurement floor is shut down with outdoor intake and exhaust air dampers fully closed.

The interior surface of the duct is considered visibly clean, when compared to pre-DC condition, there is a visual improvement in the surface cleanliness and post DC interior surfaces are free from non-adhered substances/debris.

B.2 Surface Dust/Debris Measurements

The yearly accumulation rate for dust in commercial supply air ducting is about 1 g/m^2 (Zuraimi, 2010). A review found that mean dust concentrations on duct surfaces range from 0.2 to 13.2 g/m^2 (Zuraimi, 2010). The review also noted dust levels measured as high as 158 g/m^2. For objective assessment of

[7] Post cleaning interference can arise after the HVAC is turned on resulting in airborne particles from indoor or outdoor air depositing on duct surfaces. Also, loose debris or dust left on duct surfaces due to ineffective DC may be transported to other HVAC sections or into the indoor environment after the HVAC is turned on. Since the intention is to evaluate surface cleanliness that is attributed only to DC, evaluation conducted after the HVAC is turned on may confound the measurements.

dust/debris contamination, the vacuum test method shall be followed for measurements of dust levels on the duct surface (NADCA, 2006)[8].

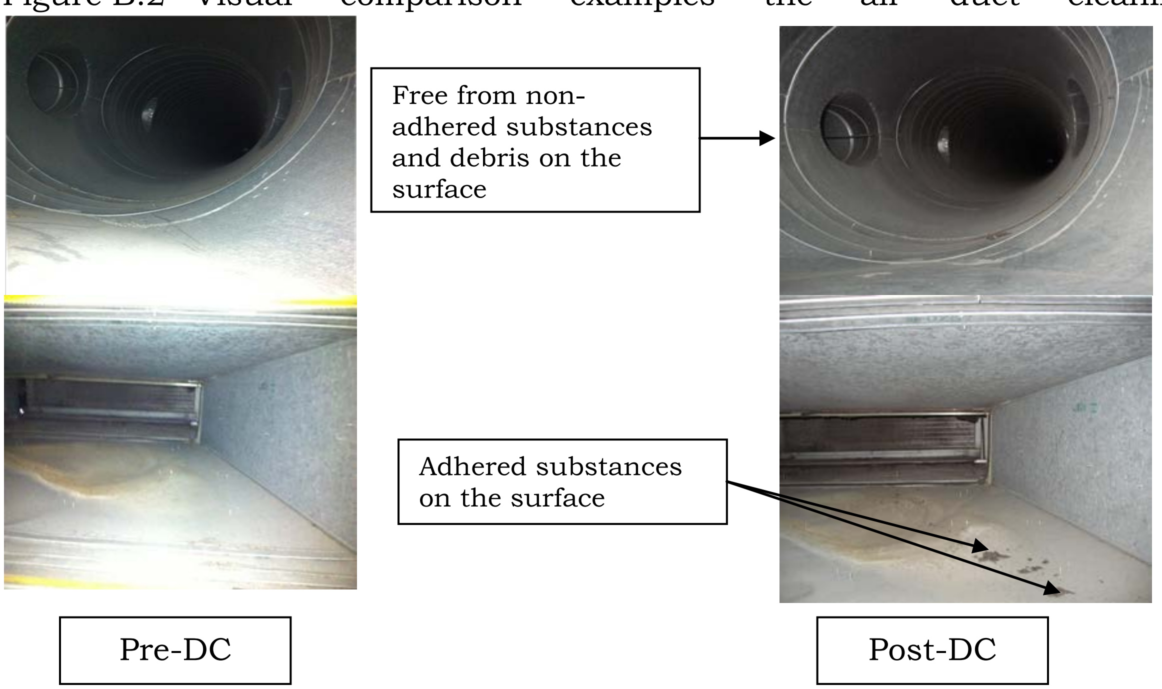
This vacuum test method shall be conducted when the HVAC system is not in operation. A template (Figure B.1) shall be secured flat against the duct surface. A cassette containing pre-weighed filter media (37mm mixed cellulose ester; 0.8 microns pore size) attached to an air pump shall be used to vacuum the open area of the template. According to NADCA (2006), each template's openings must be vacuumed twice (once in each direction) and at any time, the cassette should not touch the duct surface. The pump shall have a flow of 15 L min^{-1} and a flow gauge with a ± 3% accuracy shall be used to monitor the airflow during the sampling period. Variations in flow exceeding 0.5 L min^{-1} require the sample to be declared inaccurate and a new sample to be obtained. A weighing balance with a scale sensitivity equal to or better than 0.7 mg is to be used to measure the filter weight. Analysis based on the National Institute for Occupational Safety and Health (NIOSH) Method 0500 (total nuisance dust) is to be used (NISOH, 1994b). Surface dust results are to be reported in milligrams per 100 square centimeters (mg/100 cm^2) of sampling area. For this protocol, post-DC dust levels collected on the filter media shall not exceed the recommended guidelines of 0.75 mg/100 cm^2.

In view of the difficulty in measuring surface dust using the vacuum test method, it is accepted that air ducts lined with porous materials or with round or curved surfaces undergo only visual inspection.

[8] The vacuum test method is considered to be an effective and reliable method for determining the amount of dust in air ducts (Fransson et al., 1995). The effectiveness of the method has been reported by Holopainen et al. (2002) by demonstrating the highest amount of dust collected when compared to other methods.

Figure B.1 NADCA template placed on the interior dust surface.

Figure B.2 Visual comparison examples the air duct cleanliness.



APPENDIX C

AIRBORNE BIOCIDES

Table C.1 provides information of the various types of biocides used for DC, their characteristics and safe concentrations.

Table C.1 Characteristics of some common biocides which are used for DC.

Biocide	Safe concentrat-ions[2]	Sporicidal activity	Mechanism of action	Health effects	Sources[1]
Hypochlorites of sodium (NaOCl) or calcium ($Ca(ClO_2)$).	NaOCl: <2 mg/m^3; NaOH: <2 mg/m^3; Cl: 0.5 ppm $Ca(ClO_2)$: NA; $Ca(OH)_2$: 5 mg/m^3	yes	Enzymatic inactivation	Irritation, corrosion	No outdoor source; indoor sources are from cleaning products
Hydrogen peroxide	1.4 mg/m^3	yes	Free hydroxyl radicals	Irritation	Insignificant outdoor source; indoor sources are from cleaning products
Quaternary ammonium compounds	NA	no	Increased cell membrane permeability	Irritation, toxicity	No outdoor source; indoor sources are from cleaning products
Alcohols (ethanol, 2-propanol)	Ethanol: 1000 ppm 2-propanol: 400 ppm	no	Protein denaturation	None reported	No outdoor source; numerous indoor sources
Phenols	Phenol: 20 mg/m^3	no	Protein denaturation	Irritation, toxicity, corrosion	Insignificant outdoor source; numerous indoor sources
Glutaraldehyde	0.2 ppm (ceiling)	yes	Modification of proteins	Irritation, toxicity,	No indoor or outdoor sources
Iodinated compounds	NA	yes	Iodination and protein oxidation	Dermal, mucus membrane irritation	No indoor or outdoor sources
Formaldehyde	0.5 ppm	yes	Modification of DNA and cellular proteins	Irritation, toxicity, odour, maybe carcinogenic	Insignificant outdoor source; numerous indoor sources

[1] Wolkoff et al (1998), Nazaroff and Weschler (2004); [2] values are derived from 8 hour time weighted average (TWA) obtained from ACGIH or OSHA unless specified, NA: not available.

C.1 Declaration of Biocide Use or Non-Use

The use of liquid products like chemicals or biocides on surfaces of ducts during DC may lead to vaporization into the air stream ventilating the indoor air environment. Some of the emissions may be harmful to occupant health even when they are used according to the recommendations. All products used as biocides must comply with the national, regional and local standards and laws regulating their use.

DC companies shall declare that biocidal materials they are using are properly registered for use in HVAC systems by Health Canada and are also applied in accordance with their registration listing <u>specifically</u> for HVAC applications (http://www.hc-sc.gc.ca/ahc-asc/branch-dirgen/pmra-arla/index-eng.php).
DC companies shall provide and make available the Materials Safety Data Sheets (MSDS) or other relevant health and safety documents related to biocidal materials use in the DC report.

If only mechanical cleaning is used for DC, i.e. no biocidal materials are applied, a declaration of no biocide use shall be explicitly made.

C.2 Biocides without or insignificant indoor and outdoor sources

These biocides include glutaraldehyde, hypochlorites, hydrogen peroxide, quaternary ammonium compounds and iodinated compounds. For some biocides, methods are available to assess their airborne concentrations. The methods and/or standards to evaluate airborne concentrations of these biocides are briefly provided below.

Similar to airborne particles and mold sampling, airborne biocide sampling can be performed at the latest 24 hours before DC and not later than 10 days after DC. Airborne biocide concentration sampling shall be performed with the HVAC system in operation. There shall be no indoor cleaning activities and their product use during airborne biocide concentration sampling only in the area where the sampling is conducted.

In a test floor, indoor samplings for pre- and post-DC measurements shall be performed. The indoor sample shall be collected in the middle of the occupied office space (away from the walls) at a breathing zone height of 1.1 to 1.5 meters.

C.2.1 Glutaraldehyde

While there is currently no OSHA Permissible Exposure Limits (PEL) for glutaraldehyde[9], they recommend 10 and 2 ppb target concentrations for short -(STS) and long -(LTS) term samples respectively (NIOSH, 1994a). The durations for the STS and LTS are 15 and 120 minutes respectively. The NIOSH Recommended Exposure Limits (REL) for glutaraldehyde is a ceiling limit of 0.2 ppm; the ACGIH threshold limit values (TLV) for glutaraldehyde is a ceiling limit of 50 ppb. DC companies are encouraged to follow the NIOSH RELs, the ACGIH TLVs, or whichever is the more protective criterion.

The procedures from NIOSH Manual of Analytical Methods (NMAM) 2532.1 (NIOSH, 1994a) or OSHA Method 64 for sampling and analysis of glutaraldehde (OSHA, 1998) shall be followed.

C.2.2 Hypochloroites

Hypochlorites[10] are powerful oxidizing and bleaching agents. Those that are used for DC typically comes in aqueous mixtures containing sodium hypochlorite (NaOCl) or calcium hypochlorite ($Ca(ClO_2)$) as active cleaning agents. If hypochlorites are used in DC, concentrations of hypochlorites of sodium (NaOCl) or calcium ($Ca(OCl)_2$), their products from volatization (NaOH, Cl, $Ca(OH)_2$) shall be measured. Table C.2 provides the recommended safe concentrations and the methods of measurements for DC associated hypochlorites and their compounds that can be used for this protocol.

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[9] Glutaraldehyde (1,5-Pentadial) is an organic compound (with the formula CH2(CH2CHO)2) belonging to the aldehyde group. It is a pungent, colorless and oily liquid. Glutaraldehyde is commonly used in DC, and may be used in concentrated form, as an aqueous solution (from 0.1% to 50% glutaraldehyde), or as a mixture Trade names for glutaraldehyde-containing mixtures include Cidex®, Sonacide®, Sporicidin®, Hospex®, Omnicide®, Metricide®, Rapicide® and Wavicide®. Exposure to glutaraldehyde is normally through inhalation or skin contact. Health effects that may occur as a result of glutaraldehyde exposure include, throat and lung irritation, asthma and difficulty breathing, contact and/or allergic dermatitis, nasal irritation, sneezing, wheezing, burning eyes and conjunctivitis.

[10] Calcium hypochlorite is a white or greyish-white powder which contains about 35-37% active chlorine. Its bleaching powder is partially soluble in water, the hypochlorite dissolving and being responsible for oxidizing and bleaching powers. Available chlorine is a measure of the oxidizing power of the hypochlorite ion. Typical chemical products derived from $Ca(ClO_2)$ include calcium hydroxide ($Ca\ (OH)_2$), chlorine gas (Cl_2), calcium carbonate ($Ca(CO_3)_2$), calcium chloride ($CaCl_2$) and hypochloric acid (HOCl).
Sodium hypochlorite is a greenish-yellow liquid. For DC application, it is the hypochlorite ion in basic solution that is the active ingredient. This is typically about 5 to 6 percent NaOCl. During cleaning, the OCl^- ion is reduced to chloride and hydroxide ions and forms sodium chloride (NaCl) and sodium hydroxide (NaOH).
Oxidation reactions of hypochlorite solutions are corrosive, can burn skin and cause eye damage at high concentrations. A recent European study indicated that sodium hypochlorite and organic chemicals (e.g., surfactants, fragrances) contained in several household cleaning products can react to generate chlorinated volatile organic compounds (VOCs) (Odabasi, 2008).

Table C.2 DC associated hypochlorites and their compounds, recommended safe concentrations and methods of measurements.

Compound	Safe concentrations[2]	Method	Organization
$NaOCl$	<2 mg/m^3 STEL	OSHA chemical sampling information	AIHA
$Ca(OCl)_2$	NA	NA	NA
$NaOH$	<2 mg/m^3	OSHA method ID-121; NIOSH method 7401	OSHA; NIOSH
Cl	<0.5 ppm TWA	OSHA method ID-202; NIOSH method 6011	OSHA; NIOSH
$Ca(OH)_2$	<5 mg/m^3 TWA	NIOSH method 7401	NIOSH

TWA: time weighted average; STEL: short term exposure limit (15 mins).

C.2.3 Hydrogen peroxide

Hydrogen peroxide (H_2O_2)[11] is a strong oxidizer which is commonly used as bleach. If hydrogen peroxide is used in DC, its concentration shall be measured using NIOSH or OSHA methods. NIOSH and OSHA have set a time-weighted average exposure limit of 1 ppm (1.4 mg/m^3) for hydrogen peroxide. Hydrogen peroxide can be measured by OSHA method ID-126-SG using $TiOSO_4$ in a midget fritted-glass impinger and analyzed using different pulse polarography.

C.2.4 Quaternary ammonium compounds

Quaternary ammonium compounds[12] are a large group of related organic compounds used as disinfectants and/or detergents. No OSHA PEL, NIOSH REL, or ACGIH TLV exists for quaternary ammonium compounds.

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[11] Hydrogen peroxide is a clear liquid, slightly more viscous than water that appears colorless in dilute solution. Hydrogen peroxide decomposes (disproportionates) exothermically into water and oxygen gas. Diluted hydrogen peroxide solution is used to prevent infection transmission in the hospital environment. Hydrogen peroxide vapor is registered with the US EPA as a sporicidal sterilant. Inhalation of hydrogen peroxide may produce respiratory tract irritation while dermal contact may lead skin inflammation. Hydrogen peroxide is toxic to lungs and mucous membranes.

[12] Quaternary ammonium compounds (quats) contain positively charged polyatomic ions of the structure NR_4^+, R being an alkyl group or an aryl group with an anion. Some concentrated formulations have been shown to be effective low-level disinfectants. Typically, quats do not exhibit efficacy against difficult to kill non-enveloped viruses such as norovirus, rotavirus, or polio virus. The detergent benzalkonium chloride is the most widely used quaternary ammonium compound and is found in many commercial products (Cohen 1987) such as Zephiran chloride, Zephirol, BTC, Roccal, Benirol, Enuclen, Germitol, Drapolene, Drapolex, Cequartyl, Paralkan, Germinol Rodalon and Osvan. Quaternary ammonium compounds can cause contact dermatitis, but they tend to be less irritating to hands than other substances. They can also cause nasal irritation.

C.2.5 Iodinated compounds.

Iodinated compounds are mixtures of elemental iodine or as the water-soluble triiodide anion I_3^- used as a disinfectant in DC. An example of an iodinated compound that is used for disinfectant is potassium tetraglycine triiodide. No OSHA PEL, NIOSH REL, or ACGIH TLV exists for iodinated compounds.

C.3 Biocides with indoor and/or outdoor sources

These biocides include, but not limited to, ozone, alcohols, phenols and formaldehyde.

Airborne biocide concentration samplings shall be performed with the HVAC system in operation. Measurements can be performed at the latest 24 hours before DC and before the first working day but not later than 10 days after DC. There shall be no indoor cleaning activities and their product use during airborne biocide concentration sampling.

Simultaneous indoor and outdoor samplings measurements shall be performed. In a measurement floor, an indoor sample and one outdoor sample shall be collected. Indoor sample shall be collected in the middle of the occupied office space (away from the walls) at a breathing zone height of 1.1 to 1.5 meters. Outdoor sampling shall be taken as close as possible to the fresh air (outdoor) air intake of the air handling unit or the nearest accessible point to the fresh air (outdoor) air intake.

C.3.1 Ozone

In DC, ozone[13] is used under the term "ozone shock treatment". Here, ozone is deliberately introduced with the aim to eliminate odours and reduce and remove microorganism sources from both air and surfaces (EPA, 1997). Ozone normally disintegrates in the indoor environment. If concentration measurements are to be performed, its level in the air shall be determined using an analyzer based on either chemiluminesence or UV absorption at 254

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[13] Ozone is a pollutant linked to reduced lung function, increased frequency of respiratory symptoms, and development of asthma (EPA, 1996). Ozone is regulated in the indoor air as a lung irritant by the Health Canada. Ozone-producing devices that were once marketed as being beneficial for IAQ are increasingly being banned based on health concerns, or subject to strict regulation regarding usage (as with Health Canada's Consumer Product Safety proposed regulations). The US EPA has cautioned against the use of ozone for DC as little research has been conducted to demonstrate the effectiveness of ozone when used inside ducts and some people may react negatively to the ozone, causing adverse health reactions (http://www.epa.gov/iaq/pubs/ozonegen.html).

nm. The range of measurements for the instrument shall be from 1.5 ppb to 100 ppm with accuracy of 1.5 ppb or 2% of reading and resolution of 0.1 ppb. The response time of the equipment should be no greater than 1 minute.

C.3.2 Alcohols

Alcohols, usually ethanol or isopropanol, are sometimes used as a disinfectant in DC services. Alcohols are most effective when combined with purified water to facilitate diffusion through the cell membranes of microorganisms. A mixture of 70% ethanol[14] or isopropanol[15] diluted in water is effective against a wide spectrum of bacteria, though higher concentrations are often needed to disinfect wet surfaces.

If ethanol is used in DC, it can be measured by OSHA method 100 (OSHA, 1993), NIOSH method 1400 (NIOSH, 1994e) or USEPA TO-17 (USEPA, 1999a) using sorbent tube collection and gas chromatographic analysis.If isopropyl alcohol is used in DC, it can be measured by OSHA method 109 (OSHA, 1997), NIOSH method 1400 (NIOSH, 1994e) or USEPA TO-17 (USEPA, 1999a) using sorbent tube collection and gas chromatographic analysis.

C.3.3 Phenols

Phenols[16] are active ingredients that are used in some DC disinfectants. Phenol can be measured by OSHA method 32 (OSHA, 1981), NIOSH method 2549 (NIOSH, 1994f) or USEPA TO-17 (USEPA, 1999a) using sorbent tube collection and gas chromatographic analysis.

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[14] Ethanol is a volatile, colorless liquid that has a slight odor. Ethanol kills microorganisms by denaturing their proteins and dissolving their lipids and is effective against most bacteria and fungi, and many viruses, but is ineffective against bacterial spores. NIOSH and OSHA have established 1000 ppm as a TWA.

[15] Isopropyl alcohol is a flammable, colorless liquid with an odor resembling alcohol. The air odor threshold concentration of isopropyl alcohol has been reported as 22 parts per million (ppm) parts of air. It is an irritant of the eyes and mucous membranes. NIOSH has established a recommended exposure limit (REL) for isopropyl alcohol of 400 ppm (980 mg/m^3) as a TWA.

[16] Various phenolic compounds are used as disinfectants. These include o-phenylphenol, chloroxylenol, hexachlorophene, thymol and amylmetacresol. Disinfectant strength phenols however are considered a health risk by EPA and NIOSH. OSHA recommendations state that employee exposure to phenol in the work place should be controlled to less than 20 mg/m^3 in air determined as a time-weighted average (TWA) concentration for up to a 10 hour work day or 40 hour work week. The NIOSH guidelines also limit exposure to phenols to 60 mg/m^3 of air as a ceiling concentration for any 15 minute period. Phenols generally enter the blood stream via ingestion, respiration or skin contact. Disinfectants with a concentration of 1% phenol or greater are considered an extreme skin and inhalation hazard and are moderately combustible.

C.3.4 Formaldehyde

Formaldehyde[17] measurement can be performed following ASTM D 5197-09 (ASTM, 2009), USEPA TO-11A (USEPA, 199b), NIOSH methods 2016 (NIOSH, 1994g), 2541 (NIOSH, 1994h) and 3500 (NIOSH, 1994i) and OSHA method 52 (OSHA, 1989). This typically involves the collection via derivatization of formaldehyde and analysis using HPLC or gas chromatographic systems.

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[17] Formaldehyde is a potent irritant and is classified as a probable human carcinogen (group B1) by the U.S. Environmental Protection Agency. The state of California set 9 µg/m^3 (7 ppb at 25°C) as the chronic Reference Exposure Level (REL) for formaldehyde (Office of Environmental Health Hazard Assessment; OEHHA, http://www.oehha.org/air/allrels.html). The REL is based on positive associations, especially among children with diagnosed asthma, between prolonged exposures to formaldehyde and allergic sensitization, respiratory symptoms, or decrements in lung function.

Formaldehyde can be found in the indoor air of commercial buildings due to the numerous indoors sources. Chemical reactions between oxidants such as ozone with certain volatile organic compounds (VOCs) in the air and on surfaces of indoor environments can produce formaldehyde (Morrison and Nazaroff, 2002; Weschler, 2000). During DC, some of these oxidants are used which may increase formaldehyde concentration.

Table C.3 Sample declaration for biocide use or non-use

Building Characteristics									
Building Name:									
Street Address:									
City:				State:			PO:		
Floor:									
Zone:					Zone:				
DC Date/Time:									
Declaration									
Biocide Use[1]		Yes/No							
If Yes, if biocide material/s properly registered for use in HVAC systems by Health Canada and used in accordance with their registration listing specifically for HVAC applications[2]								Yes/No	
If Yes, does biocide materials use comply to all national, regional and local standards/regulations for protecting safety and health of building occupants [2]								Yes/No	
List biocidal materials[3]								Registration No.	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
[1] if No, then no airborne biocide measurements are to be tested in the protocol									
[2] include documents as evidence									
[3]include MSDS or other relevant health and safety documents									

APPENDIX D

AIRBORNE PARTICLES AND MOLD

Sampling for airborne particles and mold concentrations shall be performed with the HVAC system in operation. There shall be no indoor cleaning activities and their product use during air sampling.

D.1 Total Airborne Particle

Simultaneous indoor and outdoor 8 hour samplings following the NIOSH NMAM method 0500 (NIOSH, 1994b) shall be performed. For a test floor, a blank sample shall be used to accompany indoor and outdoor samples. The indoor sample shall be collected in the middle of the occupied office space (away from the walls) at a breathing zone height of 1.1 to 1.5 meters. Outdoor sampling shall be taken as close as possible to the fresh air (outdoor) air intake of the air handling unit or the nearest accessible point to the fresh air (outdoor) air intake. Total airborne particle samples collected on filters shall be gravimetrically measured and concentrations determined immediately as per NIOSH method 0500.

D.2 Total Airborne Mold Counts

Simultaneous indoor and outdoor 10 minute samplings following the ASTM method D 7391 (ASTM, 2009) shall be performed[18]. For a test floor, a blank sample shall be used to accompany indoor and outdoor samples. The indoor sample shall be collected in the middle of the occupied office space (away from the walls) at a breathing zone height of 1.1 to 1.5 meters. The outdoor sample shall be taken as close as possible to the fresh air (outdoor) air intake of the air handling unit or the nearest accessible point to the fresh air (outdoor) air intake. Total airborne mold samples shall be enumerated and the concentrations determined immediately as per method described by elsewhere (Zefon, 2004; http://www.zefon.com/analytical/download/aocug.pdf).

[18] Industrial standard practice for mold exposure assessment has typically used total mold spore counts using the Zefon air-o-cell sampler (Kleinheinz et al., 2006).

APPENDIX E

PRE- AND POST-DC COMPARISON

E.1 HVAC Setting – Ventilation Routine and Stability

To ensure consistent data for pre- and post-DC comparison and provide stable conditions, the ventilation routine shall not be changed between the two sampling assessments.

The HVAC system shall at least be set with the minimum outdoor air rate delivered to the indoor environments defined by ASHRAE 62.1-2004. It shall be ensured that the thermal comfort requirements defined by ASHRAE 55-2004 are met. For constant volume systems, a specific outdoor air damper position shall be set. For variable air volume systems, the outdoor air flow variation option shall be disabled to maintain HVAC stability. The ventilation routine is assumed to have not changed if the above scenarios are maintained during the pre- and post-DC measurements.

For HVAC systems equipped with airflow monitoring system(s) that provide feedback on ventilation performance, the monitoring equipment can be configured to generate an alarm when the outdoor air rates vary by more than 10% from the set-point during the pre- and post-DC measurements. If monitoring records revealed that the outdoor air rates during the pre- and post – DC measurements are greater than 10% from the set-point, section E4 is to be considered for pre- and post-DC comparison calculations.

E.2 Assessing the Stability of Outdoor Concentrations

To ensure reliable data for pre- and post-DC comparison, pre- and post-DC outdoor concentrations of airborne biocides with known outdoor origin (Table C.1) and particles and mold should be measured. If, pre- and post-DC outdoor concentrations vary by more than 10%, section E4 is to be considered for pre- and post-DC comparison calculations.

E.3 Airborne Concentration Indices for Stable Conditions

If pre- and post-DC outdoor air rates and/or pre- and post-DC outdoor airborne pollutant concentrations do not vary by more than 10% (determined in Sections E1 and E2), then the conditions are considered stable. In this case, a comparison of the airborne pollutants indoor concentration obtained from pre- and post- DC measurements is to be performed.

See Figure E.1 for a quick guide on computing relevant concentration indices for pre-and post-DC comparison.

E.4 Airborne Concentration Indices for Non-Stable Conditions

If pre- and post-DC outdoor air rates and/or pre- and post-DC outdoor airborne pollutant concentrations vary by more than 10% (as determined in Sections E1 and E2), then the conditions are not considered stable for pre- and post-DC comparison using the indoor pollutant concentrations only. In this case, a comparison of the airborne pollutants' indoor-outdoor concentration ratios obtained from pre- and post-DC measurements is to be performed. Indoor-outdoor concentration ratios of the pollutant measured during pre- and post-DC are to be calculated using the following equation:

Indoor-Outdoor Pollutant Concentration Ratio =
Indoor Pollutant Concentration/Outdoor Pollutant Concentration (Eqn1)

Under non-stable conditions, the post-DC indoor-outdoor concentration ratio of the respective airborne pollutant shall not exceed the pre-DC indoor-outdoor concentration ratio.

See Figure E.1 for a quick guide on computing relevant concentration indices for pre-and post-DC comparison.

E.5 Data Analysis: Comparison Criteria

The surface cleanliness and airborne concentrations assessments shall be analyzed by comparing the various post-DC concentrations or their concentration indices with the criteria given in Table E.1.

E.6 Sample Form

A sample form for the report is provided in Table E.2.

Table E.1 Recommended Levels for Acceptable Surface Cleanliness and Airborne Concentrations

Parameter	Maximal Levels	Sample Locations	Sampling time
Surface cleanliness			
Surface dust	< 0.75 $mg/100\ cm^2$ or visibly cleaned when it is free from non-adhered substances and debris	Main supply air duct (A) Supply air duct, including all terminal devices and units. (B) Recirculation air duct, including all components. (C) Exhaust air duct, including all components. (D) Fresh air duct.	post DC
Airborne concentrations			
Hypochlorites[1, 3] of sodium ($NaOCl$) or calcium ($Ca(ClO_2)$).	$NaOCl$: <2 mg/m^3; $NaOH$: <2 mg/m^3; Cl : < 0.5 ppm; $Ca(ClO_2)$: NA; $Ca(OH)_2$: < 5 mg/m^3	Indoors	post DC
Hydrogen peroxide[1, 3]	< 1.4 mg/m^3	Indoors	post DC
Glutaraldehyde[1, 3]	< 0.2 ppm (ceiling)	Indoors	post DC
Iodinated compounds[1, 3]	Post DC < pre DC concentrations	Indoors	Pre & post DC
Quaternary ammonium compounds[1, 3]	Post DC < pre DC concentrations	Indoors	Pre & post DC
Alcohols[1, 3] (ethanol, 2-propanol)	Ethanol: < 1000 ppm; 2-propanol: < 400 ppm post DC indoor concentration & Post DC concentration index ≤ pre DC concentration index[2]	Indoors and outdoors	Pre & post DC
Phenols[1, 3]	Phenol: < 20 mg/m^3 post DC indoor concentration & Post DC concentration index ≤ pre DC concentration index[2]	Indoors and outdoors	Pre & post DC
Formaldehyde[1, 3]	< 0.04 ppm post DC indoor concentration & Post DC concentration index ≤ pre DC concentration index[2]	Indoors and outdoors	Pre & post DC
Ozone[1, 3]	< 0.02 ppm post DC indoor concentration & Post DC concentration index ≤ pre DC concentration index[2]	Indoors and outdoors	Pre & post DC
Airborne particles	< 1 mg/m^3 post DC indoor concentration & Post DC concentration index ≤ pre DC concentration index[2]	Indoors and outdoors	Pre & post DC
Airborne mold	Post DC concentration index ≤ pre DC concentration index[2]	Indoors and outdoors	Pre & post DC

[1]Airborne biocides are to be measured only when biocides have been used for DC; [2]Concentration index is either indoor concentrations or indoor-outdoor concentration ratios depending on ventilation routine and/or pre-and post- outdoor concentrations stability (Appendix E); [3]Safe concentrations criteria (Table C.1).

Table E.2 Sample Form for Report

Building Characteristics									
Building Name:									
Street Address:									
City:				State:			PO:		
Floor:									
Zone:					Zone:				
DC Date/Time:									
Surface Cleanlinesss Assessment									
Porous Surface:		Yes/No		Round/Circular Ducts:		Yes/No			
Pre- DC Date/Time:					Post- DC Date/Time:				
Visual Inspection:							Pre- DC Clean[1]	Post- DC Clean[1]	Surface Cleanliness Improvement
(A) Supply air ductwork, including all terminal devices and units:							Yes/No	Yes/No	Yes/No
(B) Return and recirculation air ductwork, including all components:							Yes/No	Yes/No	Yes/No
(C) Exhaust air ductwork, including all components:							Yes/No	Yes/No	Yes/No
(D) Fresh air ductwork:							Yes/No	Yes/No	Yes/No
					Overall Pass:				Yes/No
Vaccum Test Method:							Pre- DC	Post- DC	Surface Cleanliness
Concentration:									Pass
						< 0.75 mg/100 cm[2]	Yes/No	Yes/No	Yes/No
					Overall Pass:				Yes/No
Airborne Concentration Assessment									
Pre- DC Date/Time:					Post- DC Date/Time:				
Ventilation Routine Stable[2]:			Yes/No						
Airborne Biocides									
Biocide use:		Yes/No					Pre- DC	Post- DC	Stable
Outdoor Airborne Biocide Concentration[5]:									Yes/No
							Pre- DC	Post- DC	Below Safe Conc.
Indoor Airborne Biocide Concentration:									Yes/No
							Pre- DC	Post- DC	Lower Post-DC
Airborne Biocide Concentration Index[3]:									Yes/No
					Overall Pass[4]:				Yes/No
Airborne Particles									
							Pre- DC	Post- DC	Stable
Outdoor Airborne Particle Concentration:									Yes/No
							Pre- DC	Post- DC	Below Safe Conc.
Indoor Airborne Particle Concentration:									Yes/No
							Pre- DC	Post- DC	Lower Post-DC
Airborne Particle Concentration Index[3]:									Yes/No
					Overall Pass[4]:				Yes/No
Airborne Mold									
							Pre- DC	Post- DC	Stable
Outdoor Airborne Mold Concentration:									Yes/No
							Pre- DC	Post- DC	Below Safe Conc.
Indoor Airborne Mold Concentration:									Yes/No
							Pre- DC	Post- DC	Lower Post-DC
Airborne Mold Concentration Index[3]:									Yes/No
					Overall Pass[6]:				Yes/No

[1] include visual evidence (e.g. photos)

[2] include description of test method or procedure to achieve ventilation stability

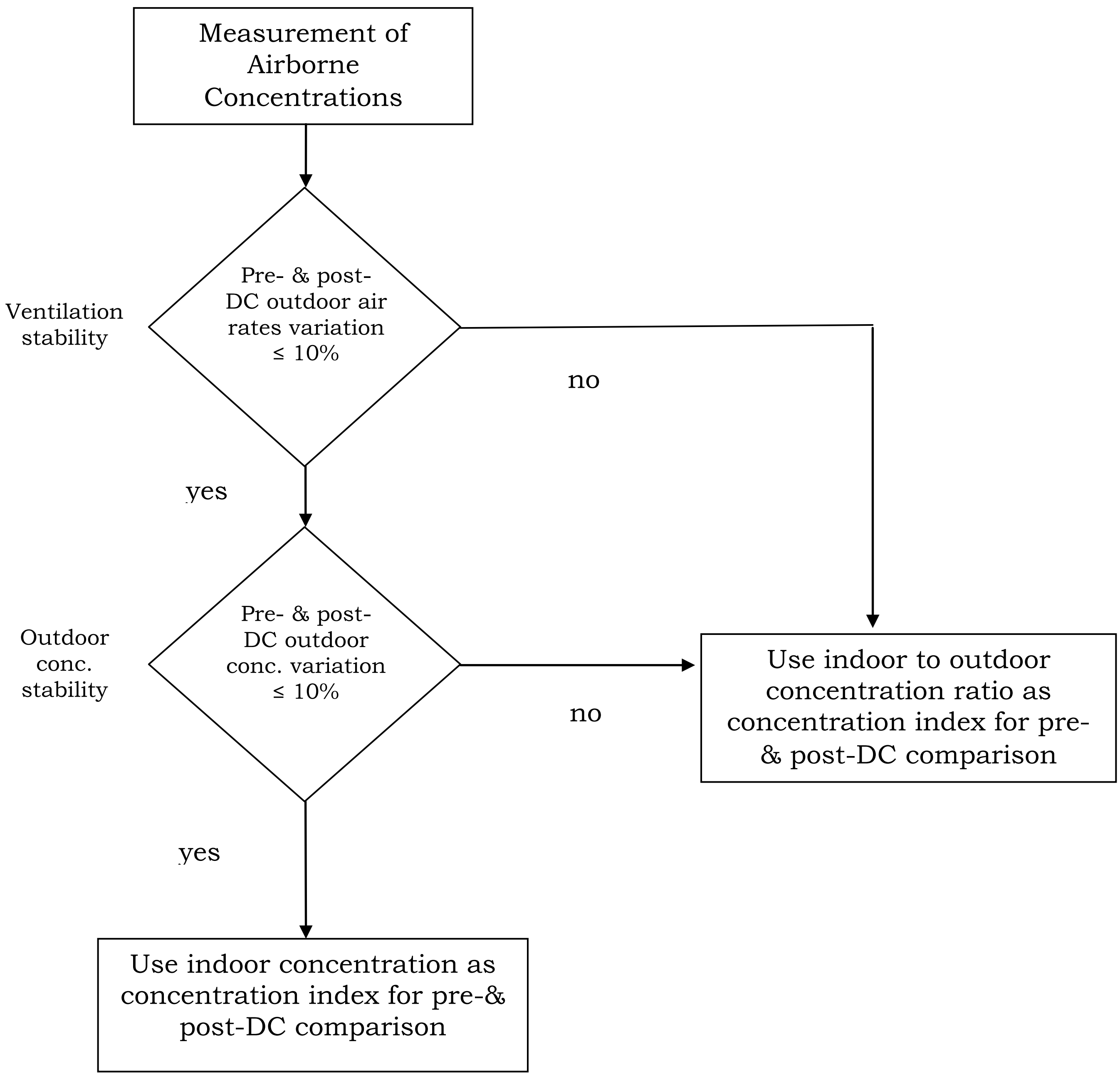
[3] if ventilation and outdoor concentration are stable, use indoor airborne concentration for airborne concentration index

[4] overall pass includes achieving concentration below safe concentration levels and lower post-DC airborne concentration index

[5] only for biocides with significant outdoor sources

[6] indoor to outdoor concentration ratios

Figure E.1 Determining concentration index of airborne biocides with known outdoor origin (Table C.1) and particles and mold for pre-and post-DC comparison.



APPENDIX F

DC WORK PLAN AND ASSESMENT SCHEDULE

F.1 DC work plan

The DC work plan shall be provided by the DC company to the building manager/owner before the DC. The work plan should include:

1. a summary of the assessment including the list of the systems and parts that requires cleaning;
2. detailed time schedule of cleaning;
3. cleaning methods to be applied;
4. description of how access will be gained to ducts and AHUs
5. list of components to be removed for cleaning and/or components to be replaced;
6. protection of the indoor environment in which the cleaning equipment is used;
7. protection and safety measures for building occupants;
8. evaluation methods for DC characterization; and
9. detailed time schedule of DC assessment;

F.2 DC work and assessment schedule

DC works shall be conducted to achieve the criteria set for this protocol without compromising building occupants' health and safety or damaging AHU, ducts and its components. As such, it is highly recommended that DC be conducted when the affected zone (separated area serviced by a separate air handling unit (AHU) or fan coil unit or any air-conditioning or air distribution system) is not occupied. However, building managers and DC operators are free to plan DC work and assessment schedules as long as the DC is conducted during non-occupied periods and that assessments are performed within the recommended period of the protocol. For example, DC work and assessments can be performed zone by zone (moving occupants temporarily), during evenings, over the weekends or during a shut down.

APPENDIX G

RE-CLEANING

If assessment results revealed that the DC did not meet all criteria of this protocol, "re-cleaning" measures shall be conducted to protect health and safety of building occupants.

Several "re-cleaning" measures can be considered:

If the surface cleanliness assessment criteria have not been met, the DC company is recommended to provide a follow up DC service as soon as possible. As such, post-DC assessment is to be conducted immediately after DC. Samples are to be taken from the same locations as in the first test.

If the airborne concentration assessment criteria have not been met, it is highly recommended that the building operator seeks advice, e.g. from an industrial hygienist, whether the affected zone in the building should be re-occupied. Prior to occupancy, the following options are to be considered:

1) if airborne particles or airborne mold levels do not meet protocol criteria, DC company is recommended to locate and remove the source of the contaminant or provide a follow up DC service whichever is appropriate. A second airborne concentration assessment is to be performed to determine criteria conformance.

2) if airborne biocide levels do not meet protocol criteria, a 'flush-out' of the affected zone of the building by supplying a total volume of 4400 m^3 (LEED-NC, 2005) of outdoor air per square meter of floor area to the space while maintaining indoor temperature and humidity conditions that meet ASHRAE Std 55 is to be performed. Measures are to be taken to ensure that there is no transfer of airborne biocides from the affected zone to other zones of the building. At the end of the 'flush-out' period, second airborne concentration assessment is to be performed to determine criteria conformance.

   If occupancy is desired prior to completion of the flush-out, the affected zone of the building may be occupied following the delivery of a minimum of 1100 m^3 [(LEED-NC, 2005) of outdoor air per square meter of floor area to the space. Once the affected zone is occupied, it is to be ventilated at a minimum rate of 5.7 CMH per square meter of floor area or that set by ASHRAE Std 62.1 whichever is greater. During each day of the flush out period, ventilation is to begin with a minimum of 3 hours prior to occupancy and continue during occupancy. These conditions are to be maintained until a total of 4400 m^3 of outdoor air per square meter of floor area has been delivered to the space. A second airborne concentration assessment is to be performed to determine criteria conformance.

When airborne concentration assessments are repeated, samples should be taken from the same locations as in the first tests.