IAQ solutions and technologies: review and selection for protocol development

Sultan, Z. M.; Magee, R. J.; Nilsson, G.

https://doi.org/10.4224/20374466

NRC·CNRC Institute for Research in Construction
CNRC·NRC Institut de recherche en construction
http://www.nrc-cnrc.gc.ca/irc

IAQ Solutions and Technologies: Review and Selection for Protocol Development

NRCC-54495

Sultan, Z.M.; Magee, R.J.; Nilsson, G.

March 2011

National Research Council Canada | Conseil national de recherches Canada
Canada

Table of Contents

1 Introduction

The NRC-IRC *Indoor Air Research and Development Initiative*, part of the Federal Government's Clean Air Agenda, takes a multi-faceted approach to improving indoor air quality (IAQ) in the built construction sector. One important subtask involves the development of detailed protocols for assessing the impact of technologies/ devices that claim to enhance IAQ. This research task will review, identify, develop and validate effective protocols that might be adopted by industry to improve "indoor air quality solutions and technologies" (IAQSTs), and how they are installed, used and maintained in buildings. These IAQSTs may range in scope from residential heat recovery ventilator (HRV) systems, to single room particle filtration units to Heating, Ventilating and Air-Conditioning (HVAC)-mounted air modification systems in commercial buildings. Although, IAQSTs have been advocated and adopted for the purpose of controlling indoor air pollutants in commercial and residential buildings, little research has been conducted on current status and performance. The purpose of this document is to: 1) provide the current state-of-the-art knowledge on available IAQSTs; 2) aid the Technical Advisory Committee (TAC) members to review current/developing technologies; and 3) select candidates deemed most promising or most in need of detailed evaluation protocol development. It is envisaged that three to four IAQSTs (depending on technology complexity) will be selected in consultation with TAC for full test protocol development.

Much of what we do in a day takes place indoors. In buildings, the quality of the air we breathe depends on various processes that influence indoor pollutant exposures. These processes include ventilation, pollutants source strengths control and other removal mechanisms such as deposition and air cleaning. Dilution of indoor pollutants by ventilation is the most widely applied strategy to reduce exposure and provide good indoor air quality. However, this approach may not be the most energy efficient strategy and applicable in some situations (e.g. mold infestation). Alternative to ventilation, various indoor air quality solutions and technologies (IAQSTs) is receiving increased consideration to control indoor air pollutants in buildings.

Many IAQSTs are strongly marketed by manufacturers and are increasingly used by consumers. From the manufacturers' perspectives, many IAQSTs are promoted as being capable of removing indoor pollutants thus improving the overall IAQ. Unsubstantiated claims were also made with regards to performance, health benefits and energy savings of IAQSTs (Consumers Union, 1985; EPA, 1997). From the consumer's perspectives, IAQSTs are used primarily for their perceived health, economical and environmental benefits and also to conform to IAQ regulatory guidelines (Consumers Union, 1985; EPA, 1997; NEMI, 2002; Rideal, 2005). Anecdotal evidence has shown that the sale and marketing of IAQSTs has increased considerably. A recent survey in the United States revealed that 30% of households own at least one type of air cleaning device (AHAM, 2002) while about 10% of California residents own air cleaners that deliberately release ozone (Waring et al, 2008). Industry survey reported that mold remediation has become an important topic among building owners and insurance providers and that duct cleaning services amount to about US$1.4 billion (CAD 1.35 billion) worth of market value (NEMI 2002). The filter industry noted the world's market size was estimated to be over US$20 billion and forecasted a conservative estimate for the overall industry growth to exceed 34% from the year 2004 through to 2009 (Rideal, 2005). In the large growing consumer market

of China, air purification market size has increased from 8 to 21.5 million RMB (CAD 1.2 to 3.2 million) from 2003 to 2007 (Zhang et al, 2008).

A wide variety of IAQSTs are available. To relate the processes of the myriad IAQSTs in controlling indoor air pollutants, a mass-balanced equation representing three important parameters is used:

$$\frac{d(C_i V)}{dt} = E - \left[Q_o \left(C_i - C_o \right) \right] - \left[C_i \left(\beta V + Q_r \eta_r \right) + C_o \eta_s \right] \qquad \text{Equation 1}$$

where, C_o and C_i are the indoor and outdoor pollutant concentrations (µg/m^3), Q_o and Q_r are the building outdoor and recirculation flow rates (m^3/h), η_s and η_r are removal efficiencies of filter at the mechanical supply and recirculation flow, β (h^{-1}) is the first-order loss-rate coefficient via deposition onto room surfaces, E (µg/h) is the emission source strength operating and V is the interior volume (m^3) and t is the time. Broadly, equation 1 states that the rate of indoor pollutant accumulation is equal to the rate of indoor source emission minus the rate of dilution by ventilation minus the rate of reduction by filtration and deposition.

Now, energy demands of ventilation constitute a significant proportion of total building energy consumption (EIA, 2003). Further, it is anticipated that energy demands would increase in the coming years thus making dilution by ventilation an expensive resort. Concomitantly, more sustainable technologies that reduce pollutants by filtration and deposition are currently being sought and gaining widespread acceptance (Sanchez et al. 2008). In keeping with the above, IAQ solutions and technologies associated with efforts to reduce indoor pollutant accumulation, increase filtration and deposition rates are expected to have a strategic and important role in the future.

The challenges of the building sustainability, energy efficiency and the public's request for better, healthier and more productive indoor environments are huge. Despite the potential advantages of IAQSTs, they are often marketed and used without first being tested if they are effective. Questions are being asked about benefits and risks[1] associated with their use. IAQSTs must not compromise occupants' health and cause negative environmental impacts. To meet the needs of consumers and to support industry requirements for targeted technology development, the findings of both technology review and protocol development efforts will be used to provide a foundation for creation of scientifically sound technology labeling systems. In this document, a broad overview of IAQST applications, target contaminants and their health relevance, performance indices and effectiveness, market demand, product labeling potential, manufacturer's claims, associated standards, guidelines and assessment protocols and knowledge gaps is summarized and tabulated. The IAQSTs are categorized in terms of applications into residential and commercial buildings. Since numerous IAQSTs are available, ranking criteria based on merit and feasibility scores and the use of an IAQ solution technology evaluation matrix for assessment protocol development is proposed. Based on the scores, all the IAQSTs will be ranked to reflect their level of importance. The top three or four IAQSTs will then be recommended for full test protocol development.

[1] Risks associated with IAQSTs include increased energy with use, high noise levels and creation of environmental footprint and hazardous products over their service lifetime.

2 Materials and Methods

2.1 Technology review: Literature and Environmental Scan

This study considers IAQSTs that are currently in existence and commercially available. The definition of an IAQ solution here is any activity, device and material that is used and/or performed to improve indoor air quality which does not rely on ventilation and/or ventilation strategy. Thus, ventilation systems such as displacement, personalised and other novel strategies of ventilation are not considered here. Based on these criteria, we focused on portable air cleaners, in-duct filtration devices, heating/energy recovery ventilation systems, ventilation system duct cleaning and building disinfection limited in scope to the commercial and residential building applications. Scientific literature, standards and guidelines, published in journals and conference proceedings were searched through a number of electronic databases including Airbase from the Air Infiltration and Ventilation Center, Applied Science and Technology Index; Canadian Mortgage and Housing Corporation (CMHC) database; Current Contents; Inspec; Medline; PubMed; and Sciencedirect. A search using the key terms air cleaner, air-purification, filtration, heating or energy recovery ventilation systems, duct cleaning, mold remediation, water damage remediation, cleaning and building disinfection was also performed. A similar search was done manually for American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) IAQ Conference Proceedings; ASHRAE Journal; ASHRAE Transactions publications. To determine benefits claimed by manufacturers including those suitable for commercial applications, an environmental scan of websites and brochures of different IAQSTs were performed.

2.2 Description of IAQ Solutions and Technologies

Although it is beyond the scope of this document to provide detailed descriptions of “solutions” and “technologies” employed by individual IAQSTs, a brief description of the basic principles will be provided. The performance indices used to evaluate how well they operate in the field or laboratory will be described. The health benefits or risk associated with their use as well as environmental impacts will also be discussed.

2.3 Criteria for selection of IAQ Solutions Technologies

2.3.1 Merit and Feasibility Criteria

We based the IAQSTs selection for protocol development and test evaluation using several criteria. These criteria are not purely made up of scientific or health considerations but also incorporate feasibility considerations to include NRC-IRC logistical capabilities and project timelines. Each criterion is grouped into either merit or feasibility criteria.

For merit criteria, the IAQSTs are first evaluated in terms of their capabilities to remove health relevant target contaminants. Target contaminant of the IAQST must have a realistic impact on indoor

environment which may also include an unintentional negative impact. For example, some IAQSTs operations result in ozone formation or creation of harmful secondary products which include irritants or allergens. The selection criteria for IAQSTs do not provide scores to devices/technologies based on published or claimed health benefit of IAQSTs. Rather, the approach used here is meant to give scores to health relevant pollutants that are targeted by IAQSTs, placing particular importance on those associated with mortality over morbidity outcomes and more morbidity outcomes over lesser ones. These pollutant levels associations with health outcomes must be well documented in medical literature.

The IAQSTs are next evaluated in terms of the measurable effect of the target contaminant using currently available analytical methodologies, or techniques that may reasonably be developed within time frame of current project. To ensure that the protocol development is not a repetition, IAQSTs are given various scores in terms of whether current assessment protocols are non-existent, lacking or incomplete. IAQSTs where protocols are available and widely accepted will not be evaluated.

The next criterion by which the IAQSTs are evaluated is product availability. Since the final deliverable of this task is the assessment of an existing product via the new protocol, hence the target "product" must be clearly defined and suitable for assessment. Here, high scores will be given to commercially available IAQST products that are widely used.

The IAQSTs are also evaluated in terms of whether the proposed assessment protocol for a particular IAQST is able to provide data suitable for future product labeling. Product labeling could incorporate labels dealing with health needs, green products, and energy efficiency or at least fulfill building regulation requirements.

Lastly, we look at whether the development of the proposed protocol may possibly lead to research partnership opportunities. High scores were given to IAQSTs that can potentially involve support and/or collaboration with stakeholders in terms of information sharing and future development of new or enhanced technologies.

For feasibility criteria, the IAQSTs were first evaluated to determine if it is possible to develop assessment protocols within project timeline. An IAQST was not selected at all if it could not be evaluated in the allotted time.

The next criterion to be evaluated is the assessment of cost to complete evaluation of the protocol vis-à-vis project budget. This criterion relates to the cost in terms of human resources, facility upgrades, instrumentation, operations and maintenance, and target technology purchasing and installation.

Lastly, the IAQSTs are evaluated to determine if NRC-IRC's infrastructure and analytical capabilities are suitable to perform the protocol evaluation within the project budget and timeline.

Using the above criteria, scores ranging from 1 (lowest) to 10 (highest) were given based on different criteria descriptions.

Merit Scores

- ***Health relevance of targeted contaminants:***

Description	Score
Target contaminants are associated with premature mortality outcomes:	10
Target contaminants are associated with carcinogenic outcomes:	9
Target contaminants are associated with mutagenic outcomes:	8
Target contaminants are associated with toxic outcomes:	7
Morbidity outcomes in more than 5 target contaminants:	6
Morbidity outcomes for target contaminants ≥3 but ≤ 5:	5
Morbidity outcomes for target contaminants > 1 but ≤ 3:	3
Morbidity outcomes for target contaminants = 1:	2
No Morbidity outcomes for target contaminants:	1

- ***Measurable (positive) impact:***

Description	Score
Methods available for all target contaminants:	10
Methods not available for health relevant contaminant – new methods can be developed:	8
Methods not available for negative impact contaminant – new methods can be developed:	6
Methods not available for health relevant & negative impact contaminant – new ones can be developed:	4
Methods not available for health relevant contaminant – new methods difficult to be developed:	3
Methods not available for negative impact contaminant - new methods difficult to be developed:	2
Methods not available for health relevant and negative impact contaminant:	1

- ***Potential (negative) impact:***

Description	Score
Device generates ozone and potential secondary by-products via chemical reactions:	10
Device generates pollutant causing known health effects:	9
Device creates environment causing known health effects:	8
Use of device is associated with large amount of energy consumption:	7
Use of device is associated with generation of greenhouse gas:	6
Device creates environment causing adverse thermal comfort:	4
Use of device is associated with poor acoustical environment:	3
Device creates environment/condition reducing perceived air quality:	2
No reported negative impact:	1

- ***Protocol development need:***

Description	Score
Protocols non-existent and can be developed:	10
Protocols incomplete and enhancement can be performed:	8
Protocols non-existent and new protocol development difficult:	6
Protocols incomplete and enhancement difficult:	4
Protocols exist and widely accepted:	X[2]

- ***Product availability:***

Description	Score
Commercially available and widely used in both residential and commercial building stock:	10
Commercially available and widely used in either residential or commercial building stock:	8
Commercially available, has potential to be widely used and strongly marketed by vendors:	6
New technology/service which is commercially available, has potential to be widely	
used and strongly marketed by vendors:	4
New technology/service which is commercially available:	2

- ***Labeling support:***

Description	Score
Labels for all types (A, B, C and D):	10
Labels for types A, B and D:	8
Labels for types A, C and D:	6
Labels for types B or C and D:	4
Labels for type D:	2

Different label types include:

A) 'Best' IAQ for special needs (e.g. for asthmatic children – provide healthy environment);
B) Green product (e.g. energy saving potential from excessive ventilation designed to dilute indoor contaminants);
C) Energy saving potential only; and
D) Fulfill minimum requirements of building regulations.

- ***Research partnership opportunities:***

Description	Score
Ready partner [F, $, E]:	10
Ready partner [F] or [S] or [$] or [E]:	8
Potential partner [F] and [E] and/or [$]:	6
Potential partner [F] and/or [E]:	4

[2] X : a veto score in which IAQST receiving this score will not be considered for evaluation for protocol development and test evaluation. For technologies which are deemed to be potentially dangerous, these should be evaluated if budget or time permits.

Potential partner [S] and/or [E]:	2

Partner provides – expertise (information sharing) [E], facilities and/or equipment [F], monetary funding [$], support [S]

Feasibility Scores

- ***Time:***

Description	Score
Report and protocol can be completed on schedule:	10
Protocol can be completed on schedule:	8
Report and protocol may be completed on schedule:	6
Protocol may be completed on schedule:	4
Report and protocol difficult to be completed on schedule:	X

- ***Cost:***

Description	Score
No partners NRC has to carry 100% of the cost that is within project budget:	10
Confirmed in kind contributions to cover some of the cost that will exceed project budget:	6
No partners - NRC has to carry 100% of the cost but the cost may exceed project budget:	2
No partners - NRC has to carry 100% of the cost but the cost is higher than project budget:	X

- ***Infrastructure capabilities:***

Description	Score
All infrastructures is available at NRC-IRC:	10
Most infrastructures is available at NRC-IRC - only minor upgrades needed:	8
Some infrastructures available at NRC-IRC - major upgrades needed:	6
Only bare infrastructures available at NRC-IRC - major upgrades needed:	4
No infrastructure available - major set-up needed:	2

- ***Analytical capabilities:***

Description	Score
All analytical needs are available in NRC-IRC:	10
Most analytical needs are available in NRC-IRC - minor upgrades needed:	8
Some analytical needs are available in NRC-IRC - major upgrades needed:	6
Bare analytical capabilities - major upgrades needed:	4
No analytical capabilities - major set-up needed:	2

2.3.2 IAQ Solution Technology (IAQST) Evaluation Matrix

An IAQST Evaluation Matrix developed in NRC-IRC is used to select three or four IAQSTs for protocol development and test evaluation. The IAQST Evaluation Matrix is a simple table where the criteria scores are grouped. The evaluation matrix provides a quick view of the likelihood and the priority with which each of the IAQST will be selected. A sample IAQST evaluation matrix is given in Figure 1.

1.1 Indoor Air Quality Solutions Technology A				
Merit	**H**	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

Figure 1 IAQST Evaluation Matrix of an Indoor Air Quality Solutions Technology A.

The total merit scores are considered as follows: Low (L) – Less than 50; Medium (M) – 50 to 62; and High (H) – Over 62. The total feasibility scores are considered as follows: Low (L) – Less than 2; Medium (M) – 26 to 32; and High (H) – Over 32.

Once the total scores have been placed in the evaluation matrix, the status of the IAQST priority becomes clear. Each IAQST shown in the table can be categorized as follows.

Strong Pass: IAQSTs that fall in the cell marked with '*V*' are the most critical and must be. The project team should develop and evaluate the IAQST protocol.

Pass but less priority then *V*: Denoted with '*IV*' in the evaluation matrix, also calls for protocol development and test evaluation. However, priority is lower than that of "strong pass".

Medium Pass: IAQSTs that fall in one of the cells marked as '*III*' should be considered for protocol development and test evaluation, but only if more technologies are required.

Poor Pass: IAQSTs that fall in the cells marked with '*II*' are of lower importance and do not have enough merit and feasibility scores for protocol development and test evaluation.

Fail: IAQSTs that fall in the cells marked with '*I*' will not be considered.

3 Results

3.1 Characterization of IAQ solutions and technologies

Table 1 presents the various IAQ solutions, their technologies, target pollutants/parameters and building applications. Based on equation 1, IAQSTs can be classified into 2 categories: 1) source removal/reduction; and 2) exposure reduction. For source removal/reduction IAQSTs, the solution involves the reduction or removal of indoor pollutant accumulation sources. On the other hand, exposure reduction IAQSTs deal with controlling the indoor pollutants concentration using filtration and deposition principles. Based on the different types of IAQSTs found, IAQ solutions can be grouped into portable air cleaners, filtration systems, exchangers, professional cleaning, passive panels and building disinfection.

Table 1Indoor air quality solutions and technologies

IAQ Solutions	Description	Technologies	Target pollutants or parameters	Building applications
Emission type (Source removal methods)				
Professional Cleaning (PCL)	Non-routine professional cleaning of building materials and HVAC systems.	i. General Duct Cleaning (GDC) ii. General Duct Cleaning with Biocides (GDCB) iii. Carpet and Upholstery Cleaning (CUC) iv. Water Damage Restoration and Mold Remediation and (WMR)	i. Dust and debris ii. Particles iii. Bacteria & fungi iv. Pollen. v. Allergens vi. Virus vii. Volatile organic compounds (VOCs) viii. Formaldehyde ix. Surface microbials x. Polycyclic aromatic hydrocarbon (PAH)	Commercial and residential
Building Disinfection (BD)	Services involve in the release of high concentrations of strong oxidant or biocide into the indoor environment to destroy or inactivate the harmful micro organisms.	i. Liquid agents[1] ii. Foams and gels iii. Gaseous and vapour agents	i. Bacteria & Fungi ii. Surface microbials iii. Certain volatile organic compounds (VOCs)	Commercial

Table 1 continued

IAQ Solutions	Description	Technologies	Target pollutants or parameters	Building applications
Air purification and Deposition type (Exposure reduction methods)				
Portable Air Cleaners (PAC)	Devices intended to remove gaseous and particulate pollutants in a single room or specific areas.	i. Mechanical Filtration (MF) ii. Electronic Cleaners a. Electrostatic precipitators (ESP) b. Ionic Generators (IG) c. Ion source with charged media filter (ISM) iii. Gas Phase Filtration (GP) a. Physical adsorption b. Chemisorption iv. Photocatalytic oxidation (PCO) v. Ultraviolet Germicidal Irradiation (UVGI) vi. Ozone generator (OG) vii. Nanotechnology (Nano)	i. Particles ii. Bacteria & fungi iii. Pollen. iv. Allergens v. Virus vi. Volatile organic compounds (VOCs) vii. Formaldehyde viii. Ozone	Residential
Filtration System (FS)	In-duct air cleaning systems used in forced-air heating, ventilation, and air conditioning systems (HVAC) to remove gaseous and particulate pollutants at a building scale.	i. Mechanical Filtration (MF) ii. Anti-microbial coated filters (AMCF) iii. Electronic Cleaners (EC) a. Electrostatic precipitators (ESP) b. Ionic Generators (IG) c. Ion source with charged media filter (ISM) d. Plasmacluster ion (PCI) iv. Gas Phase Filtration (GP) a. Physical adsorption b. Chemisorption v. Photocatalytic oxidation (PCO) vi. Ultraviolet Germicidal Irradiation (UVGI) vii. Biofiltration (BF) viii. Nanotechnology (Nano)	i. Particles ii. Bacteria & fungi iii. Pollen. iv. Allergens v. Virus vi. Volatile organic compounds (VOCs) vii. Formaldehyde viii. Ozone	Commercial and residential
Exchangers (EX)	Devices used to facilitate counter-flow heat/enthalpy exchange between the inbound and outbound airflow within a ventilation system. These could be air-to-air heat/energy recovery ventilators (HRV/ERV) or rotating desiccant wheels (RDW).	i. Heat/Energy Transfer Modules (HTM/ETM) together with a. Mechanical Filtration (MF) b. Electronic Cleaners c. Gas Phase Filtration (GP) d. Ultraviolet Germicidal Irradiation (UVGI) ii. Dry Desiccant wheel (DDW) iii. Wet Desiccant wheel (WDW)	Filtration system in residential exchangers i. Same as PAC and FS except viii. Desiccant wheel i. Volatile organic compounds (VOCs) ii. Formaldehyde	RDW-Commercial HRV/ERV-Residential
Passive Panel (PP)	Passive panels (PP) are coatings applied to an indoor wall with large deposition velocities of contaminants.	i. Gas phase physical adsorption ii. Anti-microbial coating (AMC) a. Leaching based b. Non-leaching based iii. Photocatalytic oxidation (PCO) iv. Nanotechnology coating (Nano)	i. Same as PAC and FS ii. Surface microbials	Commercial

[1]The oxidants may exist in mixtures.

3.1.1 Source removal/reduction IAQSTs

Professional Cleaning (PCL) include non-routine cleaning of indoor surfaces such as carpets, upholsteries and various components of the ventilation systems, and water damage restoration and mold remediation. Included in the services are the use of various cleaning agents, fragrances and biocides. Soiling of carpet and upholsteries over time can accumulate dusts within the fabrics where their subsequent resuspension can increase exposure of particulate matter. Presumably, this may cause adverse health effects especially among sensitive occupants. It has been reported that people living in indoor environments with greater fleece characteristics have higher risks of asthma, allergies and sick building syndrome (Wargocki et al., 1999; Jaakkola et al., 2006). Professional water damage restoration and mold remediation has been the response by concerns of dampness and/or mold exposures in indoor environments. Many international scientific organizations have conducted reviews on the links between increased prevalence and incidence of asthma, allergies, respiratory symptoms and infections among building occupants with presence of dampness or mold on the interior surface (Bornehag et al. 2001). Duct cleaning refers to the cleaning of various heating and cooling system components of ventilation air systems. The main objectives are to improve the general indoor air quality via the removal of accumulated dusts and mold growths on the interior surfaces of the ventilation systems, prevent clogging of ducts and improve the efficiency of the ventilation system (Brosseau et al., 2000a; 2000b). It can be divided into general duct cleaning (dirt/dust) or general duct cleaning with biocides (dirt/dust and biocontamination). Biocides used include, but not limited to, essential oils, polyacrylate copolymer containing zinc oxide and borates, acrylic coating containing decabromodiphenyl oxide and antimony trioxide, acrylic primer containing a phosphated quaternary amine complex, glutaraldehyde and even ozone (EPA, 1997; 2006; Foarde & Menetrez, 2002; Godish, 2003; Sondossi, 2004).

Building disinfection (BD) services conventionally involves the release of high concentrations of strong chemical agents or biocide into the indoor environment to destroy or inactivate the harmful microorganisms such as legionella or even biological warfare agent (EPA, 2005; Hubbard, 2006). When a disinfectant is vaporized or applied to an indoor environment, it comes into contact with all of the materials indoor, as well as with the biological pollutants it is meant to destroy. The technologies can be classified into liquids, foams and gels, and gases and vapors. Typical gaseous agents for building disinfection include, among others, ozone, chlorine dioxide, methyl bromide and hydrogen peroxide, glutaraldehyde-based, phenol-based, iodophore-based, quaternary ammonium-based and alcohol/quaternary-based products (Godish, 2003; Sondossi, 2004; Hubbard, 2006). Surface type application (liquids, foams and gels) oxidants include hypochlorite, aqueous hydrogen peroxide and chlorine dioxide and enzymatic foams (EPA, 2005).

3.1.2 Exposure reduction IAQSTs

Portable air cleaning (PAC) devices are room units intended to remove gaseous and particulate pollutants in a single room or specific areas. Most PACs contain a fan to mechanically draw in the airborne pollutants into a filtration device (using one or more of air cleaning technologies described below) and circulate the cleaned air out into the room. Generally PAC are designed and marketed to

reduce concentrations of particulate matter (PM) such as tobacco smoke, pollen, dust mites, animal allergens, and diesel exhaust particles (Batterman et al., 2005). The widespread use and effectiveness of PAC in ameliorating asthma and allergies has been the topic of various discussions (see section 3.3.2).

In-duct air cleaning systems are filtration systems (FS) designed and used solely as a physically integrated part of a forced-air heating, ventilation, and air conditioning systems (HVAC) in residential and commercial buildings to remove pollutants at a building scale. Since indoor air pollutant removal takes place within the HVAC system and not within the room, FS are ineffective for pollutants that deposit on the indoor surfaces. Depending on the types of technologies used for FS, airborne pollutant removal includes particulates such as dust, pollen, mold, and bacteria as well as gas phase contaminants such as VOCs, ozone, nitrogen dioxide and formaldehyde.

Passive panels (PP) are coatings applied to an indoor wall to reduce indoor chemical and biological exposures. By replacing surfaces that have a pollutant low deposition velocity with ones that have a larger deposition velocity, lower indoor air concentrations of pollutants can be achieved (Kunkel et al., 2010; Sekine and Nishimura, 2001). Some passive panels rely on special coatings that not only inactivate biological pollutants but prevent their growth and proliferation on the surfaces (Dubosc et al., 2001). Others rely on the activation and emission of reactive chemicals into the air to remove airborne biological and chemical pollutants (Taoda et al. 2006). Modifications of building materials such as composite sheets and wall papers with photocatalysts (Ichiura et al., 2003; Taoda et al. 2006) showed that these materials have the potential to be placed on walls and ceilings for the removal of various indoor pollutants. Indoor passive panels have the potential to improve indoor air quality without much reliance on energy.

Exchangers are devices used in a ventilation system to facilitate counter-flow heat/enthalpy exchange between the inbound and outbound airflow. These could be air-to-air heat/energy exchangers or rotating desiccant wheels. A heat recovery ventilator (HRV) is designed to increase ventilation by introducing outdoor air while at same time use the heated or cooled air being exhausted to warm or cool the incoming air. An energy recovery ventilator (ERV) works by exchanging moisture between the two air streams. Filtration devices incorporated in HRV/ERV have the ability to remove gaseous and particulate pollutants while the reduction of relative humidity levels from HRV/ERV use have the potential to create unfavorable microenvironments that enable dust mite proliferation and mold growth (Wright, 2007). HRV/ERV use has been associated with the threat of pollutant transfer from the exhaust to the supply air. While HRV/ERV is conventionally used in residential buildings, in many commercial buildings, the counter-flow heat exchange process involves the use of rotating wheel. For enthalpy exchange using rotating wheels, it is accomplished through the use of wet or dry desiccants, transferring moisture through the process of adsorption. This process is predominately driven by the difference in the partial pressure of vapor within the opposing air-streams.

3.1.3 IAQ solutions, their technologies and target pollutants.

As summarized in Table 2, different technologies can address indoor pollutants concentrations by various physical, chemical and biological mechanisms. Typically, source removal/reduction

technologies involve mechanical removal and/or strong chemicals agents. Concentration reduction technologies include mechanical filters, electronic cleaners, gas phase filtration, photocatalytic oxidation, ultraviolet germicidal irradiation, anti-microbial coatings, heat and energy transfer modules in conjunction with filtration devices and desiccant wheels. Among these technologies, mechanical filters, electronic cleaners, gas phase filtration, photocatalytic oxidation, ultraviolet germicidal irradiation are used in portable air cleaners, filtration system and heat or energy recovery ventilators (Table 1). In addition, two technologies (gas phase physical adsorption and photocatalytic oxidation) are applied in all concentration reduction IAQ solutions.

Table 2 shows that the common indoor pollutant that all technologies seem to directly or indirectly address is airborne particles. This includes inanimate as well as animate particles such as bacteria, fungi, virus and allergens. For source removal/reduction technologies, the aim is to reduce airborne particles concentrations via removal of deposited dusts or microorganisms on building surface materials which can be resuspended when agitated (Corsi et al., 2008). Concentration reduction technologies remove particles as they come in contact or approach the devices via various physical and chemical mechanisms. In HRV/ERV devices, incorporated filtration devices have the ability to remove airborne pollutants (Marsik and Johnson, 2008). It is also noted that most technologies target indoor gaseous pollutants such as volatile organic compounds (VOCs) and formaldehyde. These include biofiltration, physical and chemical adsorption, photocatalytic oxidation and agents used in professional cleaning. It has been reported that VOCs concentrations can be adsorbed on desiccant wheels behaving the same way a gas phase adsorption filter does (Fang et al., 2008). Nanotechnology is a new emerging technology that entails the application of reactive nanomaterials for transformation and detoxification of pollutants (EPA, 2007).

Table 2 Technologies employed to reduce indoor exposures to pollutants

Technologies	Mechanism and target pollutants[1]
Mechanical filter	Inertial impaction, interception, diffusion and electrostatic attraction of living and inanimate particles particles onto the fibrous media (Hinds, 1999)
Photocatalytic oxidation (PCO)	Shining ultraviolet light (UV) onto a catalytic surface composed of a titanium oxide (TiO_2) to form highly reactive species (hydroxyl radicals, ozone, ions) to react with VOCs to form CO_2 and water (Mo et al., 2009). The highly reactive species and/or UV light also inactivates virus, bacteria and fungi (Lin and Li , 2003; Grinshpun et al., 2007)
Electronic	Ionic generators: Negative ion generating devices charge airborne particles causing them to accumulate into bigger particles and deposit (due to the higher deposition rate, electrostatic attraction and migration velocity) on various indoor surfaces including occupants (Daniels, 2002; Waring et al., 2008). The ions produce create reactive oxidative species (ROS) which can oxidise VOCs and denature the microbial constituents of microorganisms (Daniels, 2002). Electrostatic precipitators: Through high voltage, electronic charge is provided to airborne particles which are then attracted to oppositely charged collecting plates (Zuraimi and Tham, 2009). Ionic generators with charged filter: Ion generators charge airborne particles to be collected on low efficiency filter media with an electrical charge (Myers and Arnold, 2003). Plasmacluster ion: Ion generator uses an alternating plasma discharge to split water molecules into oppositely charged hydrogen and oxygen ions. The collision of hydrogen with oxygen ions forms OH radicals that react with proteins/polysaccharides in the cell wall or surface structure of the airborne microbials thus damaging it (S.H.A.R.P. Electronics, 2005).
Gas phase filtration	Physical adsorption: The removal process of VOCs and ozone via attraction to the adsorbents surface, both outer surface and inner pore surface, of a media (e.g. activated charcoal) by physical forces (Van der Waals forces) (Underhill, 2000). Chemisorption: The removal process of low molecular weight aldehydes (e.g. formaldehyde), organic (formic acid) and inorganic acids (e.g. NO) via binding to the surface of a solid by forces whose energy levels approximate those of a chemical bond (Underhill, 2000).
Ultraviolet germicidal irradiation (UVGI)	Involves the sterilization method by irradiating the short wavelength of UV light (UVC) to destroy the nucleic acids in micro- organisms such as bacteria, fungi and viruses (Brickner et al., 2003).
Nanotechnology	Nanomaterials have properties that enable both chemical reduction and catalysis to mitigate the pollutants of concern. They can be used in mold remediation, applied as coatings in filters of FS and PAC, PP and internal of ventilation system during duct cleaning. Nanotechnology is also employed in surface excitation by ultraviolet radiation and particle aggregation used in FS and PAC (Sharpe, 2006). For biological contaminants, nanoparticles interacts with elements of the bacterial membrane, causing a structural change, dissipation of the proton motive force and finally to cell death (Yoon et al., 2008; EPA, 2007).
Biofiltration	The removal process of VOCs via metabolism using naturally occurring microorganisms immobilized in the form of a biofilm on a porous substrate such as soil, compost, peat, bark, synthetic substances or their combination to their primary components - carbon dioxide and water, plus additional biomass and innocuous metabolic products (Darlington et al., 2000; Chen et al., 2005).
Microbial coating	Coatings with anti-microbial properties placed on surfaces (e.g. media filters, walls) with the objectives of reducing the concentration of airborne microorganisms in the indoor air and potential of the surface becoming a source for microbial contamination (Pyankov et al., 2008; Chen and Poon, 2009).
Heat/Energy transfer modules	Opposing air streams are sent through alternating layers of aluminium plates or polypropylene cores (HRV). In ERV, the core is made of a paper based permeable material that allows some moisture transfer. HRV and ERV usually incorporate filtration systems to remove airborne pollutants (Marsik and Johnson, 2008). The reduction of relative humidity levels from HRV/ERV use has the potential to create micro-environments unfavorable for dust mite proliferation and mold growth (Howieson et al., 2003; Wright, 2007).

Table 2 continued

Technologies	Mechanism and target pollutants[1]
Desiccants	The rotating wheel cylinder filled with an air permeable material of large surface area can adsorb gaseous contaminants such as VOCs (Fang et al., 2008). Liquid desiccants absorb VOCs via simple hydrolysis, catalyzed hydrolysis, or catalyzed oxidation (Chung et al., 1993; Munro et al., 1999) resulting from action of the desiccant itself or desiccant enhanced by added metal salts or catalytic surfaces. Particles in the air stream are washed down by desiccant while microorganisms (e.g. vegetative cells) can be killed on contact with desiccant solution due to the biocidal effects of salts and dehydration.
Liquid decontamination agents	Liquid solutions are applied directly on a surface contaminated with a biological or chemical agent (EPA, 2005).
Foams and gel decontamination agents	Foam and gel agents works by enhancing the surface removal of biological or chemical contaminants through delivering them in a matrix that can be applied onto vertical and horizontal surfaces. Wall application using this technology ensures sufficient contact time to effectively treat the surface biological contaminant (Buttner et al., 2004; EPA, 2005). Some enzymatic foams decontaminate chemical and biological agents through catalysis.
Gaseous and vapour decontamination agents	The agents are vaporised and released to an indoor environment where it reacts and oxidised certain classes of airborne organic compounds and airborne micro-organisms (Hubbard, 2006; Korzun et al., 2008). The oxidants also come into contact with all of the materials indoor to oxidise adsorbed organic compounds, as well as bacteria, fungi and viruses (Hubbard, 2006; EPA, 2005).
Duct cleaning	Conventional duct cleaning involves the use of high-efficiency particle air (HEPA) vacuum equipment that exhausts particles from the ventilation system (Brosseau et al., 2000a; NAIMA, 2007). Mechanical dislodgement of deposited dusts via well-controlled brushing of duct surfaces or compressed air spray or the use metal “skipper” balls in conjunction with vacuum cleaning is used (NAIMA, 2007). For biocontamination duct cleaning, an additional procedure of coating with biocides is applied to remove fungal and bacterial deposits (Brosseau et al., 2000b).
Cleaning	Accumulated dry particle removal using a powerful, industrial grade vacuum cleaning equipment after pile preparation. For ground-in particles that are not easily removed, use of detergents and solvents to suspend, emulsify, peptize or saponify particles of various solubilities at an elevated temperature and mechanical agitation. Particle extraction follows by either absorption, wet or dry vacuuming and rinsing methods (IICRC, 2000; 2002). Some sources are associated with odors and/or VOCs released from micro-organisms, commonly known as microbial volatile organic compounds (MVOC).
Water damage restoration / Mold remediation	Extraction pumps used to remove standing water, followed drying pressure equipments for drying surfaces and dehumidification equipments (refrigerant dehumidification or desiccant dehumidification) to remove moisture in the air. Biocides are used in conjunction with the above restoration process to remove microbial amplifiers or prevent their growth (IICRC, 2006; 2008). Sometimes, methods involving controlled heat application to a structure are applied to kill mold spores and vegetative structures while abrasive cleaning methods are applied to dislodge mold sources (IICRC, 2008).

[1]Unless otherwise described, particles given in this table include both living and inanimate.

3.2 IAQST Performance Indices

In discussing IAQST performance, we adopt the description provided by Miller-Leiden et al (1996) in differentiating the concept of efficiencies and effectiveness. In this context, efficiency describes the likelihood of the IAQST to remove the pollutant from the air or source matrix at the specific location where the technology is applied. Effectiveness describes the impact of the IAQST on indoor air concentrations in actual settings. Thus, effectiveness is more relevant when discussing human pollutant exposure, dose and subsequent health risk and impact (Miller-Leiden et al. 1996).

3.2.1 Efficiencies of IAQSTs

For duct cleaning, North America Insulation Manufacturers Association (NAIMA) has summarized in its recommended practice, three types of most commonly used cleaning techniques: contact vacuum, air washing, and power brushing (NAIMA, 2007). Verification of cleaning efficiencies includes visual inspection, objectively evaluating the deposit thickness test (DTT) and vacuum test (VT) (NADCA, 2006; HVCA 2005; NAIMA, 2007), wipe test (Ito et al., 1996) and optical method (Holopainen et al., 2002). Indeed, considering the various methods adopted in these published studies, only crude comparisons can be made. Ito et al (1996) recorded 4-11 mg/m2 of dust before cleaning and 1-2 mg/m2 after cleaning using wiping method. Kulp et al (1997) measured pre-cleaning dust deposits using VT ranging from 0.2 to 3.6 g/m2 reduced to less than 0.2 g/m2 after cleaning in nine residential homes. Holopainen et al (2003) reported that mechanical brush cleaning reduced the amount of dust deposits in new Finnish buildings from 0.6 - 0.9 g/m2 (before cleaning) to 0.1 - 0.2 g/m2 (after cleaning) while compressed air cleaning reduced dust amounts from 5.4 to 0.3 g/m2. These values translate to a reduction of accumulated dust left on the duct surfaces ranging from 6 to 44% (Holopainen et al., 2003; Ito et al., 1996; Kulp et al., 1997).

Published studies on upholstery and carpet cleaning reports on the reduction of dust, lead, bacteria, fungi, allergen and even polycyclic aromatic hydrocarbons (PAHs) deposits. No performance index was identified except determining the percentage reduction of deposits after cleaning. Franke et al (1997) reported after cleaning reductions of 40 and 84% respectively for fungi and bacteria in carpets. Adilah et al., (1997) noted regular vacuuming can lower allergen levels in carpets substantially while HEPA vacuuming can be more effective than conventional vacuuming (Popplewell et al., 2000; Yu et al., 2009). In a study among low-income urban Seattle homes, Vojta et al (2001) documented that by vacuuming, group 1 mite allergen levels decreased by 43% from a base level of 70 ug/g. However, the levels rose back to 60ug/g after 4 weeks. They also reported that by combining vacuuming and dry steam cleaning, the allergen levels decreased by 28% over the same period. This concurs with Yiin et al's (2008) report of mean percent reductions for lead loadings of 29 and 39% for vacuuming and vacuuming and dry steam cleaning combination respectively. They also reported that the characteristics of the carpets may have affected cleaning efficiency where level-loop carpets appeared to be more "cleanable" than cut-pile carpets, regardless of the cleaning method used. Roberts et al. (2005) mentioned that after starting surface carpet dust has been removed, further decrease by 84% to 99% can be achieved if deep dust was removed using an inbuilt "dirt finder" device. Yu et al (2009) noted larger reductions in loading of dust (64.4%), PAH (69.1%), and dust mite allergens (85.5%) by dry steam cleaning together with repetitive HEPA vacuuming compared to regular HEPA vacuuming alone: dust (55.5%), PAHs (58.6%), and HDM allergens (80.8%).

It is unclear what constitutes an efficient mold remediation, water damage restoration or building disinfection (Seiler et al., 1987; Haverinen-Shaughnessy et al. 2008). From a technical viewpoint, efficient or successful remediation relied on 'best engineering judgement' and/or considered sufficient if proper evaluation of existing damage, elimination of the causes of damage and removal and replacement of damaged materials are addressed (IICRC 2006, 2008; Shaughnessy and Morey, 1999). These assessments are judgemental and do not allow for a statistical statement as to the confidence in the decontamination process. Although, experimental studies on cleaning efficiencies

on realistic building materials has been conducted (Hubbard, 2006; Wilson et al., 2004; Rastogi et al., 2009), no objective measure related to pollutant removal efficiency in the field has been identified (Haverinen-Shaughnessy et al. 2008). For example during actual building disinfection, the gaseous agent interacts with various interior building materials in addition to the biological contaminants it is intended to address. This interaction when coupled with building ventilation can lower indoor concentration of gaseous agents which in turns lowers the capacity to disinfect the biological contaminant.

Portable air cleaners are often rated with a clean air delivery rate (CADR). The CADR is the product of device flow rate and single pass efficiency - the higher the value the better the performance. CADR is normally computed in a chamber or controlled room environment and has been consistently used to compare PAC devices (AHAM, 2006a). CADR provides a more representative performance characterization in a real environment rather than a measure of the single pass efficiency alone (Waring et al., 2008; Daisey et al., 1989) because it considers both the room mixing and single pass efficiency of the technology. Although CADRs have been computed for various indoor contaminants (environmental tobacco smoke (ETS), pollen, Arizona road dust, incense smoke), it can be broadly categorized into particle or gaseous dependent. Studies on various portable air cleaners (Shaughnessy et al.,1994; Grinshpun et al., 2007) have noted small or insignificant difference in particle removal performance for the same general particle size range regardless of whether they were biological or inanimate particles. For particles, it can be summarized that efficacy of technologies follow the trend of HEPA<ESP<ionisers<ozone generators. Reported CADRs for particles associated with ETS range from 277–407m3/h for HEPA PAC, 197–499m3/h for ESP PAC, 2–51m3/h for ion generators (Shaughnessy et al., 1994; Offermann et al., 1985) and 80 m3/h for ozone generator (Shaughnessy et al., 1994). There are few particle resolved CADR values reported for ultrafine, fine and coarse particles (Waring et al., 2008). For gaseous contaminants, the values vary depending on compounds and technologies: CADRs for toluene range from 3-163 m3/h for activated carbon (Daisey et al., 1989; Chen et al., 2005); CADRs for dichloromethane did not vary statistically from zero for activated carbon but recorded 2 m3/h for activated carbon with potassium permanganate (Daisey et al., 1989); CADRs for nitrogen dioxide range from 0-72 m3/h (Daisey et al., 1989; Shaughnessy et al., 1994). Current information suggests that PAC sorption technology performance is the best for general removal of indoor VOCs, with chemisorption technology performing better for more volatile gaseous contaminants (Daisey et al., 1989; Chen et al., 2005; Shaughnessy et al., 1994). Performance of PCO PAC devices is reported to be ineffective due to poor product designs (Chen et al. 2005; Mo et al. 2009). Chen et al (2005) reported that PAC with PCO, ionizers and ozone generating technologies did not significantly remove the challenge VOCs except for limonene.

Filtration systems (FS) in HVAC have been widely studied, and the common performance index used has been the single-pass removal efficiency. Several studies have measured particle resolved efficiencies for various filters using standard aerosol challenge in test rigs (Hanley et al., 1994; Raynor and Chae, 2003) and in situ using naturally occurring aerosols (Zuraimi and Tham, 2009). Filter efficiency curves are typically V shaped with the lowest efficiency at about 0.3 microns. ESP filters typically have removal efficiencies up to 100% for particles greater than one micron (Zuraimi and Tham, 2009) while HEPA filters have efficiencies of at least 99.97% for all particle sizes (Hanley et al., 1994). Researchers have found reasonable concurrence in the removal efficiencies of standard

challenge aerosols with biological active aerosols (Maus and Umhauer, 1997), although removal for all bioaerosol types has not been evaluated. Typical single pass efficiencies of FS together with the size ranges of various aerosols are illustrated in Figure 2. Single pass gaseous pollutants removal efficiencies for FS have been evaluated using sorption and PCO technologies (Weschler et al., 1994; Tham et al., 2004; Hodgson et al., 2007; Howard-Reed et al. 2008). After 37 months of servicing, Weschler et al (1994) recorded ozone removal efficiencies ranging from 90-95% for charcoal filters protected from submicron particles and 60% for similar filter with accumulated dusts. Tham et al (2004) reported single pass efficiencies for large amount of VOCs using activated carbon in a tropical office building – efficiencies range from 43–93% for the alcohols, 16–91% for carbonyl compounds, 28–54% for terpenes, 22 to 85% for the aromatics, 22 - 81% for alkanes, 46–66% for the halogenated compounds, 62–96% for the esters and 54–65% for the cyclic compounds. Howard-Reed et al (2008) noted decane removal efficiencies in a test house experiment ranging from 40-73% using a combination of pleated fiber matrix containing activated carbon, alumina, and potassium permanganate. Hodgson et al (2007) studied removal efficiencies of VOCs mixtures, characteristic of office buildings and cleaning products, at realistic concentrations using PCO. The removal efficiencies follow the trend: alcohols and glycol ethers > aldehydes, ketones, and terpene hydrocarbons > aromatic and alkane hydrocarbons > halogenated aliphatic hydrocarbons. Formaldehyde was noted as a by-product of PCO where output/input ratios range from 1.9 to 7.2.

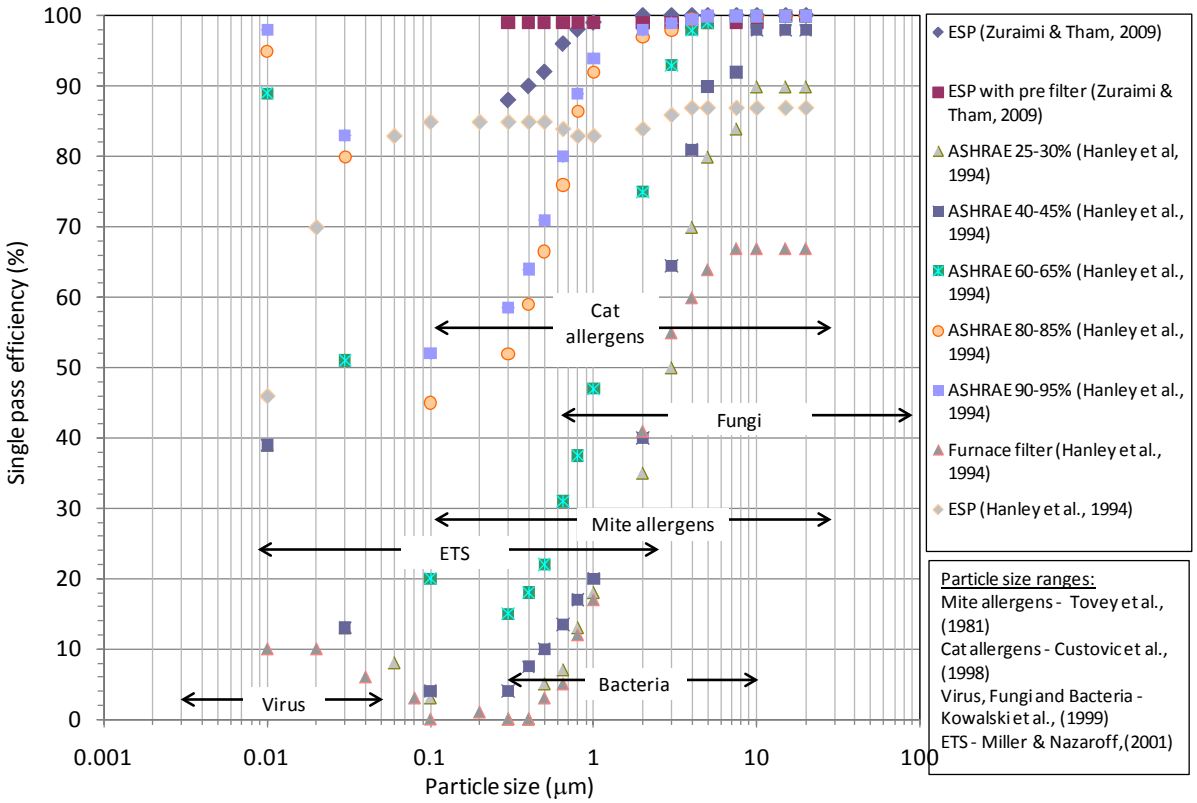

Figure 2 Efficiency of some filtration system technologies and size ranges of various indoor aerosols.

Materials used in dry and wet desiccant wheels normally used for dehumidification have been shown to remove gases other than water vapor from air in both experimental and in-situ studies. For experimental studies on dry desiccant wheels, Popescu and Ghosh (1999) reported that by using solid desiccant mixture of silica gel, molecular sieve and hydrophobic molecular sieve, simultaneous removal of moisture and some pollutants (1,1,1-trichloroethane, toluene, carbon dioxide, formaldehyde) can be observed. They noted removal efficiency as high as 80% for the three VOCs while a 40% reduction was noted for carbon dioxide. Kuo and Hines (1988) reported that silica gel can be effectively used to remove methyl chloride, methylene chloride, chloroform, carbon tetrachloride, 1,1,1-trichloroethane and tetrachloroethylene from indoor air. An in-situ study using a proton transfer reaction mass spectrometer, Fang et al. (2008) reported air purification effects of silica gel rotors. They evaluated VOC (formaldehyde, ethanol, toluene, and 1,2-dichloroethane) removal capabilities where average removal efficiencies reached 94% or higher for all the monitored VOCs. Hines et al. (1993) reported that the total number of particles decreased from 4.8-6.0x10^3 to 1.3-3.0x10^3 particles/cm^3 for solid adsorbents such as silica gel, molecular sieve and activated carbon. Liquid desiccants such as lithium chloride (LiCl) salt and triethylene glycol (TEG) solution have been shown to be effective in collecting particulate matter, volatile organic compounds and performing a biocidal function on bioaerosols. Chung et al. (1993) documented that 40% LiCl solution has a removal efficiency of 20% for formaldehyde and toluene and about 3% for carbon dioxide and 1,1,1-trichloroethane. Using 95% TEG solution however improved the removal efficiencies of these compounds by 30, 100, 56 and 100% respectively. The better efficiencies of TEG are due to its better solubility with the organic compounds. Hines et al (1993) reported a reduction of 10% in ETS particle counts using both liquid desiccants and more than 90% and 92% of the microorganisms (Escherichia coli, Bacillus subtilis, Pseudomonas aeroginosa, Staphylococcus aureus and Aspergillus niger) for 40% LiCl and 98% TEG solutions respectively using in-vitro tests. Interestingly, while solid silica gel and molecular sieve are capable to remove these microorganisms from the air, the activated carbon was found to be ineffective.

Although HRV/ERV can incorporate filter media within their devices, little research has been performed to evaluate their removal efficiencies of particles and/or VOCs.

3.2.2 Effectiveness of IAQSTs

The effectiveness can be described by the following equation (Nazaroff, 2000; Miller-Leiden et al. 1996):

$$\varepsilon = 1 - \frac{C_{i,A}}{C_{i,B}} \qquad \text{Equation 2}$$

where ε is the IAQST effectiveness, $C_{i,B}$ and $C_{i,A}$ is the indoor pollutant concentrations before and after IAQST respectively. Because co-varying outdoor pollutant concentrations can have an influence on the indoor pollutant concentrations, the effectiveness of IAQSTs must be accurately quantified by considering this confounding variable in equation 2. A simple method is by normalizing the indoor concentrations with outdoor concentrations. There is no 'gold' standard for what is considered to be a

minimum effectiveness value. Although, 80% effectiveness has been recommended for PACs (AHAM, 2006a), IAQST effectiveness should be considered as being pollutant dependent, taking into account the pollutant's virulence or hazardous effects. For instance, 90% effectiveness for removal of a highly infectious airborne agent may not be sufficient.

Figure 3 illustrates the summary effectiveness of various IAQSTs. It is observed that source removal/reduction IAQSTs effectiveness vary widely. Although, the data by Garrison et al. (1993) provided duct cleaning effectiveness of fungal spores removal between 63 and 91%, the intervention includes the post-cleaning installation of electrostatic precipitators in the houses. The calculated effectiveness for residential duct cleaning study by Ahmad et al. (2001) range from -363 to 77%. For mold remediation, computed effectiveness vary from -239 to 76% (Meklin et al., 2005). These values cohere with qualitative data reported in other papers documenting both positive and negative outcomes. Chew et al (2006) noted that post-intervention bioaerosol levels in studied Katrina hit houses were lower except endotoxin in one of the houses, which was moderately elevated, and culturable mold in another, which had post-intervention levels similar to those collected pre-intervention. Haverinen-Shaughnessy et al., (2008) noted improvement in microbial levels in a case building, partial improvement in two and no improvement in two case buildings. Where post-intervention outcome involves partial or no success or even negative, the authors attributed these to inadequate address of all damage moisture surfaces, improper remediation work being performed and the lack of prescriptive guidelines. Calculated cleaning effectiveness determined from the study by Franke et al (1997) range from 40 to 95% depending on pollutants. The only exception is oxygenated VOCs (ε:-133%) presumably due to the use of these compounds during decontamination.

Calculated filtration system effectiveness for removal of particles and oxides of nitrogen range from -117% to 94% and 22 to 56% respectively. Comparison within studies showed that compared to conventional media filters, removal effectiveness for enhanced filtration and electrostatic precipitators (ESP) tend to be higher for smaller particles (Fisk et al., 2000; Krzyzanowski and Reagor, 1990: Zuraimi & Tham, 2009). Particle removal greater than 2 microns was less effective. Comparison between studies revealed that effectiveness does not depend solely on technology single pass efficiencies. Consider the studies by Krzyzanowski and Reagor (1990) which improved the filter performance from 65% ASHRAE dust spot efficiency to 85% and Zuraimi and Tham (2009) which changed the filters from about 70% ASHRAE dust spot efficiency to ESP. Although removal efficiencies of ESP is higher than that of 85% ASHRAE dust spot efficiency filters, the effectiveness computed for Krzyzanowski and Reagor (1990) are higher. For PAC, industrial standards recommend performance of 80% effectiveness in reducing steady-state particle concentrations. However, it can be seen that only one study reported PAC effectiveness higher than 80% (Henderson et al., 2005). For other studies, calculated effectiveness range from –26[3] (Berry et al., 2007) to 73% (Reisman et al., 1990) for particles and –36 to 10% (Batterman et al., 2005) for VOCs.

[3] Negative value for effectiveness indicates the IAQST is a source pollutant.

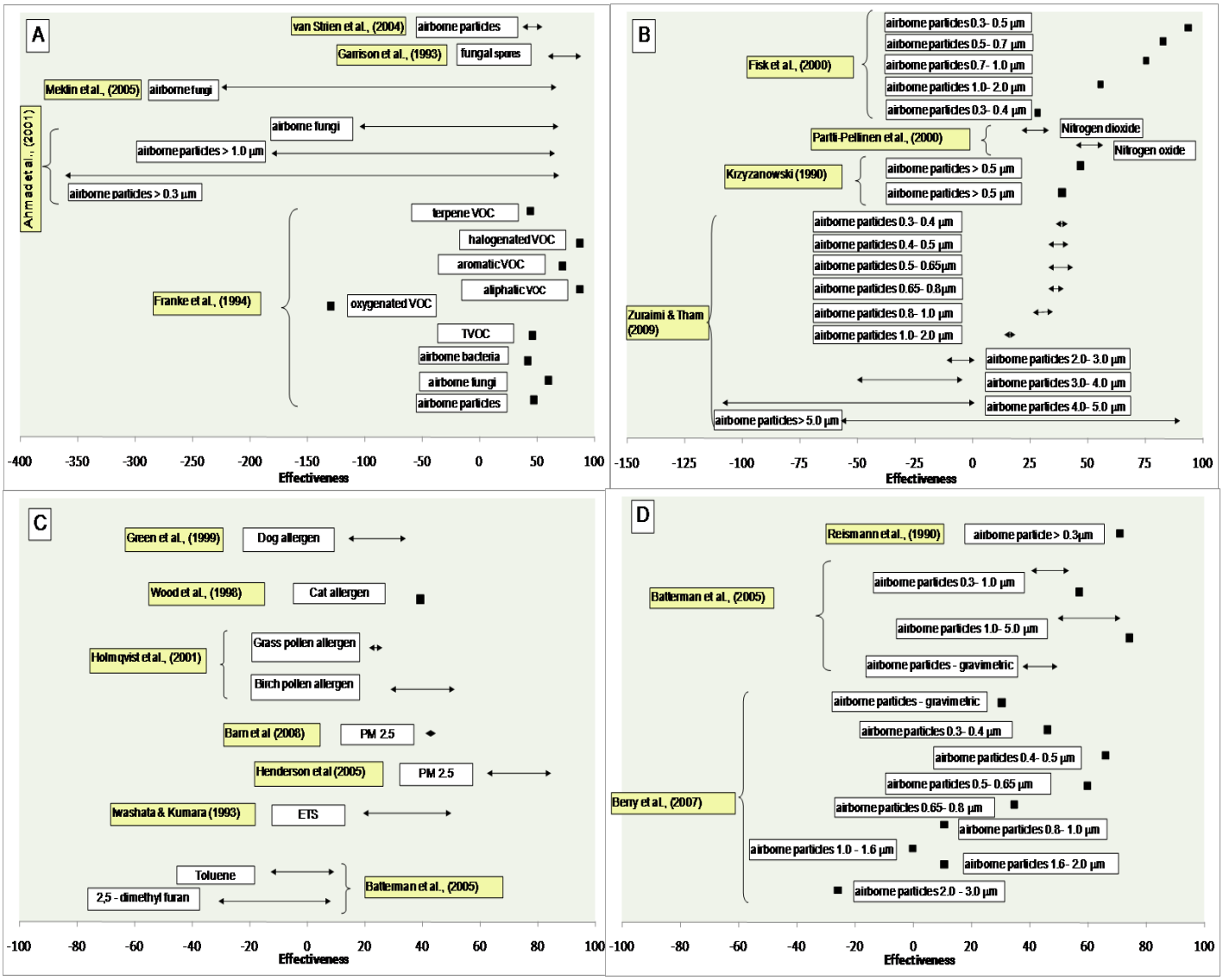

Figure 3 Effectiveness of IAQSTs evaluated from field studies – (A) professional cleaning; (B) filtration system; (C) & (D) portable air cleaners.

3.3 Health Benefits of IAQSTs

Many reports can be found in the medical and environmental health journals attempting to provide a positive link between the use of IAQSTs and health. This section will summarize the available scientific evidence regarding the effectiveness of IAQSTs to provide significant relief for people with asthma, allergies, respiratory symptoms and diseases, sick building syndrome and other building related illness. Studies that attempt to associate IAQST with reduction in biomarkers of health outcome and/or bioaccumulation of pollutants are also included. Only studies where health impact of IAQSTs is independently assessed and not in conjunction with other intervention variables are considered here.

3.3.1 Professional Cleaning

Despite carpet is an excellent reservoirs for dusts and asthma triggering agents, no studies have determined health benefits of carpet and upholstery cleaning each by themselves in isolation from other interventions (Platts-Mills et al., 2000). Still, a few research studies have shown that airborne dust levels can actually be lower in carpeted rooms as compared those to non-carpeted ones. This unusual finding has been observed in situations where the carpet has been maintained with an aggressive vacuuming schedule (Hilts et al., 1995; Lioy et al., 1998; Roberts et al., 2004) and that the reduction may be due to the "sink" capacity of carpets to hold particulates as they settle from the air (Foarde and Berry, 2004). In studies where lead dust levels were monitored, successful dust lead reductions via repetitive carpet vacuuming (Hilts et al., 1995; Lioy et al., 1998; Roberts et al., 2004) had no effect on reducing children's blood lead levels (Hilts et al., 1995; Yiin et al., 2003).

Analyses of the United States Environmental Protection Agency (USEPA) Base study involving 97 representative buildings in the US (Mendell et al., 2008) showed that although cleanliness/condition of air handler components was not associated with symptoms, HVAC maintenance factors such as infrequent cleaning of cooling coils and drain pans were associated with increased odds ratios (probability) for building occupants to experience headache, eye symptoms, lower respiratory symptoms and fatigue/difficulty concentrating symptoms. Also, lack of a regular maintenance schedule was associated with substantial increases in eye symptoms and upper respiratory symptoms, along with possible increases in lower respiratory symptoms and cough. Still, very little research has been conducted to show that ventilation duct cleaning can actually improve occupant's health. Zuraimi et al (2008) reported that there was no difference in occupants sick building syndrome (SBS) symptoms recorded before and after cleaning performed in tropical office buildings. They noted however, that when the subjects were stratified into healthy and allergic subjects, the latter group reported significant improvements in perception of still, stuffy and dusty air, tiredness and difficulty to concentrate. This suggests that sensitive subjects are more perceptible to the benefits of duct cleaning.

Some studies have published the results for the effects of water damage repairs and mold remediation in buildings on occupant's health. Rylander (1997) documented changes in symptoms and airway responsiveness among persons who worked in a day-care center before and after renovation to remove microbial growth problems. He noted the number of persons who had airway responsiveness problems decreased after the renovation. Savilahti et al. (2000) reported a study involving Finnish children from two suburban elementary schools exposed to moisture damage. Remediation led to significant reduction in prevalence of respiratory symptoms and infections. Haverinen-Shaughnessy et al (2004) documented a 5 year follow-up study on the self-reported health status of students after comprehensive moisture damage repairs in a school. They reported a consistent decrease in trends for the prevalence of sinusitis, nocturnal cough, and asthma among the subjects. In another study, effects of renovation on symptom prevalence were reported in two moisture-damaged schools and in two non-damaged schools with longitudinal cross-sectional surveys before and after repairs (Meklin et al. 2005). The authors studied the symptoms prevalence of over 1300 schoolchildren using questionnaires before and after repairs. They noted a significant decrease in the prevalence of 10 of the 12 symptoms studied among schoolchildren attending one of the

damaged schools. The improved symptoms include stuffy nose, rhinitis, sore throat, hoarseness, cough with and without phlegm, nocturnal cough, eye symptoms, fatigue and headache. Slight improvement in symptoms prevalence (rhinitis, sore throat, cough with phlegm, eye symptoms and fatigue) was noted in the other school with partial repairs. This study underscores the importance of even minor repair measures in improving some health outcomes and that a comprehensive repair is needed for a remediation to be completely successful. However, other studies have shown that health outcomes still do not improve after a repair was deemed as "technically successful" (Haverinen-Shaughnessy et al. 2008).

3.3.2 Portable air cleaners, filtration systems and HRVs

Studies relating to PAC use and improvement in health outcomes were mostly focused on asthma and allergic patients, using a HEPA PAC as an intervention and adopting a well planned randomized controlled trial (RCT) design. Kooistra et al (1978) studied 20 patients with hay fever or asthma for 8 weeks and reported no significant differences in daytime sneezing, nasal congestion, itchy eyes, or medication use. Interestingly, nocturnal symptoms were reduced when no filter was in place. In another study, a HEPA PAC was placed in the bedroom for 8 weeks of 29 patients with rhinitis or asthma, with a randomly selected active and placebo filter, each for 4 weeks (Reisman et al. 1990). They found no difference in congestion, discharge, eye irritation, cough, airway twitching, asthma, or medication use. van der Heide et al (1997) followed 45 asthmatic and allergic teenage and adult subjects for 6 months in a non-crossover RCT design study. They recorded no differences in FEV1, FVC and PEF, serum IgE, eosinophils, skin tests and airway hyperresponsiveness with PAC use. In a later study (van der Heide et al. 1999), they studied moderate asthmatic children with elevated levels of serum cat- or dog-specific IgE (i.e. allergic to dog or cats). The authors noted that although airway hyperresponsiveness did improve, there was no change in peak expiratory flow rates and no difference in wheezing, dyspnea, cough, or medication use with the HEPA PAC in place. Warburton et al (1994) noted no differences in cough, phlegm, wheezing, breathlessness, chest tightness, nocturnal wakening, or bronchodilator use among 12 asthmatics when the PAC was utilized. Another study followed cat-allergic adults with asthma or allergic rhinitis in a non-crossover RCT design for 3 months (Wood et al. 1998). When the HEPA PAC was used, there was no difference in congestion, rhinorrhea, sneezing, cough, wheezing, chest tightness, sleeping difficulty, or medication use. Although operating the device managed to reduce the airborne cat allergens, the dustborne allergen levels remained unchanged. Sulser et al (2009) studied 36 asthmatic children who are sensitized to cat and/or dog allergen and exposed to high levels of cat and/or dog allergen. The authors did not find significant change in FEV1, medication use and serum ECP levels when the PAC was used. Again, dustborne allergens remained the same despite decrease in airborne allergen levels with the PAC in operation. In summary, the vast majority of these studies showed that HEPA PACs operation is not associated with a reduction of symptoms or clinical outcomes of asthma and allergies among children or adult subjects.

There are sparse reports documenting health benefits of FS and HRV. Mendell et al (2002) performed a double-blind crossover study in an office building. They reported that although enhanced filtration reduced fine particle concentrations by 94%, there was little association with reduced sick building syndrome symptoms among building occupants. Menzies et al (2003) conducted a double blind,

multiple crossover trial study evaluating the effects of UVGI of drip pans and cooling coils within office buildings ventilation systems on work-related symptoms among 771 occupants. The use of UVGI was associated with significantly fewer work related symptoms, respiratory and mucosal symptoms than was non-use. Work-related mucosal symptoms reduction among sensitive subjects (atopic) and never-smokers were the highest. In a randomized double-blind placebo-controlled trial to evaluate the effect of domestic mechanical heat recovery ventilation on asthma control of 119 patients allergic to the house dust mite, there was a clinically significant improvement in asthma and rhinitis symptoms and fewer admissions to hospital with asthma among subjects when there was a mechanical ventilation and heat recovery device installed in the home (Wright, 2007). This health improvement is not related to allergen exposure reduction and clinical effects were not sustained for greater than one year. In a recent study, Kovesi et al (2009) documented a randomized double-blind, placebo controlled trial to evaluate the effects of home HRV on respiratory illnesses among young Inuit children. They noted that the HRV use was associated with a reduced probability of wheeze and rhinitis symptoms.

3.4 Health Benefits of IAQSTs

Table 3 provides the summary of various negative health and environmental impacts associated with the use of IAQSTs. Created negative impacts can be due to the intrinsic and extrinsic generation of pollutants from the use of IAQSTs. Pollutant generation through the use of IAQSTs can be intentional or otherwise. Negative impacts also include excessive energy usage, excessive noise and creation of harmful agents (e.g. ozone, ultrafine particles).

Table 3 Summary of negative health and environmental impacts of some IAQSTs

IAQSTs[1]	Negative impacts	Ref[2]
IG, ESP, PCO used in PAC and FS.	The use of these devices unintentionally emits ozone which is a harmful pollutant. Further, the ozone generated can react with other co-occuring gaseous compounds and surfaces indoors to form harmful byproducts formaldehyde and ultrafine and fine particles.	a,c,d, e
OG used as PAC	Intentional emission of ozone.	b
PCO used in PP	The use of PCO has been associated with ozone emissions with subsequent hetero and homogeneous chemical reactions indoors to form formaldehyde and ultrafine and fine particles.	d, e
PAC	Excessive noise and energy consumption with use of PAC with high flow rates.	f, g
UVGI used in PAC and FS	UV lights can create the same harmful effects to the skin and eyes of humans if no protection is in place. Enhancement of VOC emissions from building materials due to UV irradiation. Some UV lamps produce ozone which can undergo reactions to form formaldehyde and ultrafine particles.	h
GPF used in FS	Microorganisms prefer to adhere to solid supports made of carbon materials, thus, carbon filters have high biocompatibility where microorganism may multiply and become a source of bioaerosols indoors.	i
IG in PAC and FS	Charged particles become attracted to and deposit on surfaces where they may cause soiling problems. Human exposure to ions released indoors is unknown.	j, k
ESP used in FS	Collected particles on plates can be re-entrained into the air stream into the indoor air	l
AMC used in PCL, FS and PP.	Anti-microbial coatings can contain chemicals that are terpene based (e.g. tea tree oil, essential oils). These can react with outdoor ozone coming into the HVAC systems and form harmful by-products. Under certain conditions, an exudate can form on the surface of coating (leaching). Some leachates are toxic chemicals, and washing cycles dilute these so that they are efficient for only a relatively short period.	e, m, n
Chemicals used in BD and PCL	Chemicals used may be toxic and/or ecotoxic. Building interiors may contain large surfaces composed of complex materials, material compatibility to how the decontaminant vapors impact building materials within an enclosed building interior space is	n, o
BF used in FS	Concerns that potted biofilters can be a source of microbial spores and MVOCs and thus create health problems.	p
Pollution migration in PCL	Increased exposure from disturbance of settled dusts leading to peak concentrations of dusts/bioaerosols in indoor environments during duct cleaning, mold remediation and carpet cleaning	q, r, s
Nano used in PCL, FS and PP	The human health impacts of nano-particles are still largely unknown, but some studies and cases indicate that the nanomaterial has the potential to initiate adverse biological responses that can lead to toxicological outcomes. Ecotoxicological effects of various manufactured nanomaterials includes effects on microbes, plants, invertebrates and fish.	t, u

[1] Refer to Table 2 for description of IAQST

[2]References: a- Waring et al. (2008), b-Hubbard (2006), c – Boelter & Davidson (1997), d – Mo et al., (2009), e – Weschler (2000), f –Hacker and Sparrow (2005), g – Offerman et al (1985), h – Salthammer et al (2002); i – Park and Jang (2003), j- Wu et al (2006), k – Daniels (2002), l – Zuraimi & Tham (2009), m- Heaton et al. (1991), n- Sondossi (2004), o - Godish (2003), p – Darlington et al (2000), q- Ahmed et al. (2001), r- Chew et al. (2006), s – Corsi et al (2008), t - Boxall et al. (2007), u – Nel et al (2006)

Carpet and upholstery cleaning can generate pollution through resuspension of dust disturbed during cleaning and generation of volatile organics during cleaning product use. For example during vacuuming events, particulate matter and airborne allergens can be resuspended, increasing their exposure levels many fold from pre-cleaning levels (Corsi et al., 2008). Koh et al (2009) reported that asthmatic children were more likely to be sensitized to dust mites and have higher eosinophil cationic protein (biomarker for allergic inflammation) if the floor was vacuumed in the home. Carpet cleaning typically incorporates chemical action using detergents, fragrances and solvents at an elevated temperature to maximize the extraction of contaminants and material preservation (IICRC, 2002). Chemical agents used in carpet cleaning may pose health hazards to building occupants and cleaners themselves, as well as environmental impacts and materials degradation (Wolkoff et al. 1998; Hubbard, 2006). Nazaroff and Weschler (2004) noted that although a fraction of the chemicals emitted from cleaning products may pose a direct health concern, the inhaled mass of chemical agents would approach average exposure levels of concern. Various health effects of exposures (via inhalation, ingestion, dermal contact) to cleaning chemicals range from mild skin irritation and respiratory effects to long term cancer development (Nazaroff and Weschler, 2004; Wolkoff et al, 1998). A case study reported an incident where residential carpet-cleaning caused a woman to experience an acute asthma attack, seizures, and unconsciousness from exceedingly high exposures to a sodium tripolyphosphate (TSP) solution (Lynch, 2000). Kreiss et al (1982) reported carpet shampoo residue exposures were associated with respiratory irritation among most employees in an office building and among all staff members and most children in a day-care center. A case-control study (Rauch et al., 1991) revealed that patients with Kawasaki syndrome are more likely to have had a history of exposure to shampooed or spot-cleaned carpets compared to matched control subjects.

Duct cleaning has been reported to increase indoor particle and bioaerosol concentrations during and after cleaning activities (Ahmed et al., 2001). Further, fine particles concentrations were higher not only during cleaning but also for 2 weeks after. These suggest that dirt, debris and other pollutants may become airborne as a result of disturbances caused by the cleaning processes. Better removal via filtration and higher deposition rates of bigger particles onto surfaces may reduce indoor concentrations after cleaning, but fine particles remained airborne for longer periods (Ahmed et al., 2001; Zuraimi et al., 2008). Increased exposure to fine particles has been linked to morbidity and mortality outcomes (Schwartz and Neas, 1999; Schwartz et al., 2000). In keeping with the above, there has been little research on the microbial load contained in dust that has been re-suspended. The risk to workers or building occupants exposed to resuspended particles may be different depending on the microbial composition (Nevalainen & Seuri, 2005). Application of sealants onto duct surfaces with the goal of preventing dust particles from being released into the air may affect the acoustical and fire retarding characteristics of duct materials. Also, the potential toxicity of these products during service life is still unclear (EPA, 1997). Zuraimi (2010) has reported that although epidemiological studies indicate suggestive evidence that improperly maintained ducts are associated with higher risks of symptoms among building occupants, this review finds insufficient evidence that duct cleaning can alleviate occupant's symptoms.

For bio-contaminant duct cleaning, an additional procedure of coating the interior of the duct with biocides is common practice. The primary concern with the use of biocides in duct cleaning is the potential for human exposure to these products and health risks to workers and building occupants. Compared to other hard surface treatments, application of biocides to a ventilation system usually requires larger amounts to be applied to the components. Post-treatment ventilation system

operation may increase the spread of the biocides throughout the building. Although there is little evidence on harmful exposure to these biocides during duct cleaning in non-industrial buildings, data from occupational settings suggest that peak exposure levels of about 60 $\mu g/m^3$ of glutaraldehyde during such activities can influence workers symptoms and respiratory conditions (Vyas et al., 2000). The USEPA noted that exposures to airborne biocides which have not been approved for use in ventilation systems may cause health effects that are as detrimental or worse than the health effects caused by the exposure to the bio-contaminants that the biocides are intended to control (EPA, 2006).

Similarly, biocides used during water damage restoration, mold remediation, building disinfection and passive panels can be toxic to human health and environment, and owing to their corrosive nature, can degrade indoor materials (EPA, 2001; 2005; Wolkoff et al., 1998; Sondossi, 2004). Where indoor areas need mold contamination clean-up, killing the mold would not eliminate the associated health risk as mold constituents are still allergenic. Further, some dead molds are potentially toxic (EPA, 2001). Excessive use of biocides may produce mirco-organisms with non-specific mechanism of cross-resistance to other biocides (Russell, 2003; Sondossi, 2004). Biocides used in paints have the potential to leach out from the paint matrix. The resulting exposure can be hazardous considering the large painted surface areas on walls and ceilings. A study showed that isothiazolone fungicide is able to migrate through the paint matrix replenishing fungicide lost from the surface (Heaton et al., 1991). Considering most biocides are regarded as hazardous materials, there is little information on the proper disposal of biocide during the decontamination processes to prevent biocides from entering surface and ground water, wastewater treatment systems or the environment in general.

Ozone is commonly used in duct cleaning, water damage restoration, mold remediation and building disinfection (Hubbard, 2006; EPA, 2001). Further, several concentration reduction IAQSTs have been shown to increase indoor ozone concentrations during their use either intentionally or non-intentionally (Table 3). For example, ESP, ionizers, ozone generators, PCOs can generate incidental ozone (Chen et al., 2005; Waring et al., 2008; Mo et al., 2009). Now, controlled exposure studies of healthy and asthmatic human subjects have shown that high ozone exposures can produce significant adverse effects on pulmonary function, and causes lung inflammation, tissue damage, and airway hyperresponsiveness (Bernstein et al., 2008). In addition, ozone emitted indoors can react with co-occuring VOCs containing unsaturated carbon–carbon double bonds which are commonly found in indoor air (Weschler, 2000). Reactions of ozone with some of these gaseous compounds such as limonene can be much faster than the removal rate of ozone via ventilation and other processes (Weschler, 2000). Under such a scenario, the homogeneous reaction between ozone and limonene provides a large source of secondary pollutants such as formaldehyde, together with ultrafine particles, and other airborne irritant compounds (Nazaroff and Weschler, 2004). Indeed, some of these reaction products are listed as toxic air contaminants, and can irritate the mucous membranes and respiratory tract or cause other health impacts. In keeping with the above, surface reactions of ozone can also play an important role in increasing occupant exposures to these harmful secondary by-products. Wang and Morrison (2006) reported that ozone reaction with indoor surfaces of a residential building can be a source of formaldehyde of up to 6.75 $\mu g\ m^{-2}\ h^{-1}$. In buildings with mechanical ventilation systems, clean as well as dirty media filters have been observed to be important locations for ultrafine particle formation via surface oxidation processes to occur (Fadeyi et al., 2009).

Although very new, there are increasing efforts to use nanotechnology as an environmental technology to improve IAQ exposure reduction technologies and cleanup processes during water damage restoration and mold remediation and duct cleaning (EPA, 2007, Yoon et al., 2008). However, potential risks are poorly understood and might lead to unintended consequences. Although the indoor environment contains many natural particles at the nano-scale (Weichenthal et al., 2007), manufactured nanoparticles may act differently since they are designed to have specific surface properties and chemistries that are not likely to be found in natural particles (Handy et al., 2008). The properties of manufactured nanoparticles enhance novel physico-chemical and possibly toxicological properties compared to natural particles (Nel et al., 2006). Boxall et al. (2007) has reported a range of ecotoxicological effects of various manufactured nanomaterials which includes effects on microbes, plants, invertebrates and fish. In keeping with the above, airborne particle coating and aggregation, surface treatments and excitation by ultraviolet (UV) radiation (PCO) can potentially modify the effects of particle size in the indoor environments. Nel et al (2006) has suggested that some nanoparticles could exert their toxic effects as aggregates or through the release of toxic chemicals. Considering that the aggregates are fractal-like, they may exhibit some of the properties of the discrete nanoparticles, including specific surface area and reactivity. These are attributed to the fact that these particles have been manufactured at the nanoscale in order to harness particular nanoscale properties.

There has been little study on the impact of IAQSTs on energy and resource use and other indoor comfort factors. Fisk et al (2000) noted concerns from facility managers that high efficiency filters in the supply airstreams of HVAC systems can lead to excessive airflow resistance and consume too much energy. Their modeling analyses showed that the average of the initial and recommended-final pressure drops did not increase significantly with increasing filter efficiency rating up to ASHRAE dust spot efficiency of 90%. Sanchez et al. (2008) reported that improving energy efficiency of PACs would achieve an estimate savings of $29 million and 0.05 TgC equivalent of carbon avoidance for the years up to 2006. They projected that the savings could amount to $519 million and 1.17 TgC equivalent of carbon avoidance for subsequent years up to 2015. Hacker and Sparrow (2005) reported that although tested PACs managed to reduce indoor particle concentrations, in terms of acoustical performance most exceeded the ASHRAE-recommended value of 40 dBA for a quiet residential area.

3.5 Protocols applicable to IAQSTs

IAQST protocols discussed here include standards and guidelines. In the interest of brevity, the main protocols provided in this report are based on their comprehensive evaluation, wide acceptance and common use (Table 4). The list should be representative of the types of protocols that exist. For the purposes of discussion, a “standard” is defined as a requirement and a “guideline” is defined as a recommendation.

3.5.1 Performance evaluation protocols

It is noted that most protocols relating to source removal/reduction IAQSTs are in-situ evaluations of efficiencies in removing pollutants from the substrate. There are few laboratory based evaluations to compare removal performance of various technologies under controlled standardized conditions. Indeed, disclaimers are often included making clear that the protocols are meant to provide guidance on cleaning techniques and not to compare them.

Table 4 Main IAQSTs Protocols

IAQST Protocols: Standard / Guideline; Setting	Target indoor pollutant/parameter	Pollutant related performance index & testing evaluation	Pollutant / parameter related requirements
Professional Cleaning (PCL): General duct cleaning with/without biocide			
NADCA: Assessment, cleaning and restoration of HVAC systems. (Standard); In-situ (ACR, 2006)	Surface dust and debris	Cleanliness verification 1) Visual inspection 2) Surface comparison test 3) NADCA vacuum test.	No adhered substances and debris on surface. No visible difference after contact vacuuming. Debris net weight ≤ 0.75 mg/100 cm^2.
NADCA: Assessment, cleaning and restoration of HVAC systems. (Guideline); In-situ (ACR, 2006)	Airborne particle (0.3, 0.5, 0.7, 1.0, 2.0 & 5 μm) Fungal spores sampling Surface sampling	1) %: Air sampling at the supply outlets and return ducts. 2) Air sampling at the ambient, supply air and return air. 3) Sticky tape mounted to a slide sampling at the air-handling unit, return and supply ducts.	% increase or decrease of difference in concentrations of supply and return air divided by return air concentration. Concentrations to be reported - no establishments of limits. Presence of spores and/or hyphal elements - no establishments of concentration limits.
Professional Cleaning (PCL): Carpet and upholstery cleaning			
IICRC S100: Standard reference guide for professional carpet cleaning (Standard); In-situ (IICRC, 2002)	Carpet particulate soil and biopollutants.	…	…
IICRC S100: Standard reference guide for professional carpet cleaning (Guideline); Lab testing of cut samples. In-situ (IICRC, 2002)	Standard soil[1]	△E: Before and after evaluation	Carpet is soiled uniformedly and the results were evaluated using spectrophotometer.
IICRC S300: standard and reference guide for professional upholstery cleaning (Standard); In-situ (IICRC, 2000)	Soil	…	…
Professional Cleaning (PCL): Water Damage Restoration and Mold Remediation and (WMR)			
ANSI-IICRC S500-2006: Standard and reference guide for professional water damage restoration. (Standard); In-situ situ (IICRC, 2006)	Water damage restoration	Post restoration verification: return to an acceptable or non-contaminated environment.	…
IICRC S520-2008: Standard and reference guide for professional mold remediation (Standard); In-situ situ (IICRC, 2008)	Mold contamination	Post remedial evaluation: Return to "normal condition (1) and acceptable visible removal of mold and olfactory removal of malodour.	…
Exchangers (EX)			
ANSI-ASHRAE 84: Method of testing air-to-air heat/energy exchangers (Standard); Test rig (ASHRAE, 2008b)	Temperature, humidity.	Exhaust air transfer ratio (EATR): Measurements of temperature, humidity and mass flow rates of device.	…
CSA C439-00 (R2005): Standard Laboratory Methods of Test for Rating the Performance of Heat/Energy-Recovery Ventilators. (CSA, 2005)	Temperature, humidity.	Same as ASHARE 84 including leakage characteristics of device	…

Table 4 continued

Portable Air Cleaners (PAC)			
ANSI-AHAM AC-1 2006: Method for measuring performance of portable household electric room air cleaners (Standard); Test chamber (AHAM, 2006a)	Environmental tobacco smoke, Arizone road dust, Pollen	CADR (clean air delivery rate): First order decay constant with and without PAC operation.	Recommended room size for an 80% PAC effectiveness performance.
ANSI-UL Standard 867: Electrostatic air cleaners, Fourth edition (Standard); Test chamber (UL, 2007)	Ozone	Measurements of ozone emissions	Average concentration ≤ 50ppb
AHAM AC-2 2006: Method for sound testing of portable household electric room air cleaners (Standard); Test chamber (AHAM, 2006b)	Noise	A-weighted sound power level Loudness	…
USEPA Energy star program requirements for air cleaners (Standard); Test chamber (EPA-DOE, 2004)	Energy consumption and standby power	CADR/Watt	Minimum performance requirement: 2.0 CADR/Watt (Dust) for PAC with minimum CADR 50 cfm (Dust). Ozone production ≤ 50ppb.
AHAM AC-3-2009: Method for measuring the performance Of portable household electric room air cleaners following accelerated particulate loading (Standard); Test chamber (AHAM 2009).	Environmental tobacco smoke, Arizona road dust, Pollen	Initial and final (after dust loading) CADR values % change in initial and final CADR values	...
Filtration System (FS)			
ANSI-ASHRAE 52.1: Gravimetric and dust-spot procedures for testing air-cleaning devices used in general ventilation for removing particulate matter (Standard); Test rig (ASHRAE, 1992)	Airborne particles	1) Atmospheric dust spot efficiency (%): Light transmission measurements of target papers at upstream and downstream. 2) Arrestance (%): Gravimetric ratio of test dusts removed by filter to total dust fed. 3) Dust holding capacity (g): Product of test dust fed with average arrestance.	… … …
ANSI-ASHRAE 52.2: Method of testing general ventilation air cleaning devices for removal efficiency by particle size (Standard); Test rig (ASHRAE, 2008a)	Airborne particles (12 size ranges from 0.30 to 10μm)	Minimum Efficiency Reporting Value (MERV): Concentration measurements at upstream and downstream points six times, beginning with a clean filter and then after the addition of standard synthetic ASHRAE dust loadings for five additional measurement cycles.	The lowest values over six test cycles at each particle size are used to determine the Composite Minimum Efficiency Curve. Averaging the Composite Minimum Efficiency into 3 size groups (E1, E2, E3) will provide the average Particle Size Efficiency (PSE), and the resulting three percentages are then used to determine the MERV.
EN779:2002 Particulate filters for general ventilation: Determination of the filtration performance (Standard); Test rig (EN, 2002)	Airborne particles (DEHS-Diethyl Hexyl Sebacate : 0.2 to 3.0μm) Loading dust (Arizona road dust)	1) Efficiency (%): Concentration measurements at upstream and downstream 2) Arrestance (%): same as 52.1 3) Dust holding capacity (g): same as 52.1	Classification into G classes based on average arrestance of synthetic dust and F classes based on average filtration efficiency of 0.4μm particles.

Table 4 continued

EN1822:2009. High Efficiency air filters (HEPA and ULPA) (Standard); Test rig (EN, 2009).	Airborne particles (6 size classes: from 0.05 to 0.4μm)	1) minimum efficiency 2) particle size at the minimum efficiency (MPPS)	Classification into H10-H14 or U15-U17 based on the efficiency and penetration.
Indoor Passive Panel (PP)			
ISO 16000-23: Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials (Standard); Test chamber (ISO, 2009a)	Formaldehyde	1) Sorption flux 2) Total mass per area of sorption 3) Equivalent ventilation rate per area.	...
ISO 16000-24: Performance test for evaluating the reduction of volatile organic compound (except formaldehyde) concentrations by sorptive building materials (Standard); Test chamber (ISO, 2009b)	Volatile organic compound	1) Sorption flux 2) Total mass per area of sorption 3) Equivalent ventilation rate per area.	...

[1] Standard soil obtained from American Association of Textile Chemist and Colorist (AATCC)

The Institute for Inspection, Cleaning and Restoration Certificate (IICRC) establishes standards for professional on-location cleaning of carpets (IICRC S100), upholstery (IICRC S300), water damage restoration (ANSI-IICRC S500-2006) and mold remediation (IICRC S520). These standards are procedural in nature, focus on approaches to on-site sampling, remediation and preventative maintenance and have limited objective assessments. The duct cleaning protocols on the other hand, can be part qualitative and part quantitative: National Air Duct Cleaning Association (NADCA) (ACR, 2006) promotes numerical verification of surface cleanliness but also relies on subjective visual assessments for surface cleanliness. It also provides guidance in terms of recommendations for cleaning frequency, HVAC system inspection procedures during cleaning and restoration activities and selection of cleaning methods. The NADCA protocol has been adopted in some parts by other standards agencies such as the Heating and Ventilating Contractor's Association (HVCA TR/19) and European Committee for Standardization (prEN 15780). Non-mandatory quantitative evaluation protocols are also included in the appendices of some standards: ACR (2006) includes guideline of an in-situ concentration assessment of airborne particles, airborne fungal spore and surface fungal before and after duct cleaning; IICRC S100 includes analytical measurements of cleaned carpet samples. Despite carpet cleanliness assessment is considered in IICRC S100, the protocol gives very limited consideration to other objective evaluations related to IAQ. The ACR guidance on in-situ concentration assessment doesn't consider confounding factors such as outdoor contribution, other sources and/or ventilation variations. No protocols for assessing performance of building disinfection were found.

Conversely, most concentration reduction IAQSTs protocols deal with quantitative evaluation of devices in controlled chamber or test rig environments. For PAC, the commonly used protocol (ANSI-AHAM AC-1) utilizes environmental tobacco smoke, dust and pollen as challenge aerosols to obtain device clean air delivery rate (CADR) values (AHAM 2006a). Although AHAM AC-1 has no performance requirements, it relates PAC performance obtained in chamber settings to actual service conditions by recommending room sizes to achieve 80% indoor concentration reduction under steady state conditions. The AHAM AC-3 protocol extends the AC-1 protocol by evaluating long term particle removal performance. Concerns relating to noise generated by PACs are evaluated using the AHAM

AC-2 protocol. AC-2 provides sound rating comprised of a set of sound levels that includes A-weighted sound power level and loudness. The current AHAM protocols deal with only particle removal whereas current PAC configurations include hybrid technologies that include among others, VOC removal. Currently, there is no PAC protocol assessing removal performance for gaseous contaminants and ultrafine particles.

ASHRAE 52.1, 52.2 and EN779:2002 discuss ducted FS standards on removal efficiencies, particle arrestance and dust holding capacity as a function of particle diameter. ASHRAE 52.2 provides the Minimum Efficiency Reporting Value (MERV) performance index expressing removal efficiency as a function of specific particle sizes. EN779:2002 provides ratings based on average arrestance of loading dust (class G filters) and filtration efficiency of 0.4 micron particles (class F filters). The EN1822:2009 certifies a HEPA or ULPA filter's absolute minimum efficiency for all particles and is primarily used to certify air filters for clean room applications. Although the efficiency of HEPA filters has been traditionally measured at 0.3 µm, many particles in the air are much smaller. The EN 1822 protocol identifies the particle size that penetrates the filter most easily, known as the Most Penetrating Particle Size (MPPS), and challenges the filter with only these particles, creating an absolutely worst-case scenario. ASHRAE is currently developing protocols for gaseous contaminant filters for HVAC system (ASHRAE 145.2P and 145.3P).

The common protocols relating to HRV/ERV (ASHRAE 84 and CSA 439) do not address the removal of indoor air pollutants although device performance assessment includes evaluating exhaust (pollutant) air transfer ratio. Despite the use of filtration devices in HRV/ERV, there are no protocols in place to determine contaminant removal performance in HRV/ERV. There is currently no protocol for assessing performance of indoor passive panels dealing with biological pollutants.

3.5.2 Safety, health and environmental related protocols

To consider IAQSTs as a sustainable tool, focus should be placed on increasing the efficiency of the device/service and their resource use (energy, water, and materials) while simultaneously reducing any negative impacts on human health, comfort and environment. Here, negative impacts associated with IAQSTs include energy efficiency, noise levels and minimizing the creation of environmental footprint of products and hazardous products over their service lifetime. Although very few, there are several protocols intended to help customers identify device/services with higher or lower negative health and environmental impacts which may lead to future innovation or even product/service banning.

Environmental impacts of source removal/reduction IAQSTs is addressed by considering emissions of cleaning products and biocides, waste handling and disposal. Cleaning agents and biocide used for PCL are associated with adverse health outcomes and environmental impacts. Currently, protocols dealing with cleaning agents and biocides typically rely on materials safety data sheet (MSDS) to provide information on hazardous effects and on the safe handling of the agents. Within the MSDS however, suppliers typically do not distinguish whether specific ingredients in a chemical mixture are harmful or not. Further, existing requirements for MSDS information on chemicals causing adverse health effects such as sensitization is inadequate (Wolkoff et al., 1998). However, comprehensive green or environmentally preferable cleaning guidelines are available. These protocols are aimed at reducing human exposures to toxic or hazardous chemicals and the release of polluting chemicals into the

environment. These include the USEPA Design for the Environment (DfE) Formulator Initiative (EPA, 2009), GreenSeal's GS-37 Standard (Green Seal, 2009) and Ecologo Program Certification Criteria Document (EcoLogo, 2007; 2008). These protocols encourage suppliers to develop products with demanding environmental, health and safety specifications. Performance requirements include screening all ingredients for potential health (acute toxicity, irritation, carcinogens, mutagens, reproductive toxins, asthma causing, skin sensitizer and absorption) and environmental effects (pH requirements, prohibited and ozone depleting compounds, VOCs and hazardous air pollutants content limit, bioaccumulation/biodegradation, flammability, packaging, life cycle review).

Many chemical agents and biocides used in PCL are classified as pesticides (Godish, 2003; Sondossi, 2004). Suppliers have become more aggressive in promoting use of biocides with end-users in applications that have human contact, therefore implying a health benefit. Still, from the IAQST perspective, there are no protocols for biocide use in non-industrial settings. The EPA and Health Canada register and regulate antimicrobial pesticides, including industrial biocides under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and Pest Control Products Act respectively. A product must be registered for a specific use before it can be legally used for that purpose. For example in the US, to register an industrial biocide, product suppliers must meet EPA requirements to show that it will not cause unreasonable adverse effects on human health and the environment and the product labeling and composition comply with requirements of FIFRA. Biocides that are currently used during duct cleaning do not bear specific directions for HVAC application as no products are registered as biocides for use on fiberglass duct boards or fiberglass lined ducts[4] (EPA, 2006).

For concentration reduction IAQSTs, the UL standard 867 regulates PAC ozone emissions for electrostatic air cleaners to (UL, 2007). The standard recommends a threshold limit of 50ppb for ozone concentration. The USEPA Energy Star program allows consumer to identify and purchase energy efficient PACs: it maintains limit values for standby power and CADR/Watt for PAC with no ozone emissions (as determined by UL standard 867). Sanchez et al (2008) reported that through 2006, the Energy Star label on PACs resulted in 3 PJ of primary energy savings and avoided 0.05 TgCeq equivalent. They projected that Energy Star label on PACs will save 69 PJ and avoid 1.17 TgCeq equivalent over the period 2007-2015. Currently, there are various working groups developing protocols to limit ozone emissions and establish energy efficiency index for FS. The California Air Resources Board (CARB) is developing test methods and measuring ozone emission rates in the laboratory and in the field for "in duct electronic air cleaners". The ISO/TC142 "cleaning equipment for air and other gases" at International Organization for Standardization is involved in developing protocols relating to sustainability of particulate air filters and calculation and classification of energy performance of air cleaners.

An internal NRC case report has documented volatile organic compounds (VOC) emissions (formaldehyde and styrene) from HEPA filters used in an HRV device (Magee et al., 2011). Currently, there is no protocol that addresses IAQSTs as a potential for source of VOCs or limits their emissions. The use of high power vacuum, wet and dry cleaning, elevated temperature during professional cleaning has not been considered as one of the major environmental issues. Protocols dealing with efficiency of water and energy use for source removal IAQSTs are not available.

[4] Some biocides are used purely for sanitizing the insides of bare sheet metals of air ducts (EPA, 1997).

3.6 IAQSTs Ranking and Selection for Protocol Development

3.6.1 Summary of IAQST Technology Review, Environmental Scan and Evaluation Matrix

Appendix A provides the detailed technology reviews, environmental scans, merit and feasibility scores and evaluation matrices for all the IAQSTs identified. There are 28 and 23 IAQSTs for residential and commercial buildings application respectively (Tables 5 and 6).

Table 5 IAQST for residential buildings applications

No	IAQ Solutions Technologies	Merit Scores	Feasibility Scores
1	Room units HEPA or mechanical filters (particles)	59	34
2	Portable Air Cleaners – Room units ESP or electrostatic precipitators (particles)	64	34
3	Portable Air Cleaners – Room units (gas phase sorption)	57	36
4	Portable Air Cleaners – Room units (Ion Generation)	54	34
5	Portable Air Cleaners – Room units (PCO - Photocatalytic oxidation)	53	36
6	Portable Air Cleaners – Room units (portable ozone generators)	54	36
7	Portable Air Cleaners – Room units (Germicidal UV)	57	34
8	Portable Air Cleaners – Room units (Hybrid technologies)	64	34
9	In-Duct Filtration Systems - Particulate matter (Mechanical, HEPA)	X	24
10	In-Duct Filtration Systems - Particulate matter (Electret, Charged Media)	50	26
11	In-Duct Filtration Systems - Particulate matter (Electrostatic Precipitation)	56	26
12	In-Duct Filtration Systems - Particulate matter (Ion generators)	52	26
13	In-Duct Filtration Systems – Germicidal UV	55	30
14	In-Duct Filtration Systems – Anti-microbial coated filters	58	26
15	In-Duct Filtration Systems – Gas phase (sorption)	59	26
16	In-Duct Filtration Systems – Gas phase (photocatalytic oxidation)	56	26
17	HRV & ERV	64	38
18	Professional Cleaning – Carpet and Upholstery Cleaning	58	34
19	Professional Cleaning – Water Damage Restoration and Mold Remediation	58	22
20	Professional Cleaning – General Duct Cleaning	65	30
21	Professional Cleaning – General Duct Cleaning with Biodecontamination	67	30
22	Building Disinfection via Chemical Cleaning- Ozone	54	32
23	Building Disinfection via Chemical Cleaning- Hydrogen Peroxide Vapors	50	32
24	Building Disinfection via Chemical Cleaning- Aerosolized Chlorine Dioxide	54	32
25	Indoor Passive Panels – Activated carbon media on indoor wall	58	36
26	Indoor Passive Panels – Leaching anti-microbial coating on indoor wall	59	36
27	Indoor Passive Panels – Non-leaching anti-microbial coating on indoor wall	59	36
28	Indoor Passive Panels – PCO (photocatalytic oxidation) coating on indoor wall	60	36

Table 6 IAQST for commercial buildings applications

No	IAQ Solutions Technologies	Merit Scores	Feasibility Scores
1	In-Duct Filtration Systems - Particulate matter (Mechanical, HEPA)	X	24
2	In-Duct Filtration Systems - Particulate matter (Electret, Charged Media)	50	26
3	In-Duct Filtration Systems - Particulate matter (Electrostatic Precipitation)	56	26
4	In-Duct Filtration Systems - Particulate matter (Ion generators)	52	26
5	In-Duct Filtration Systems – Germicidal UV	55	30
6	In-Duct Filtration Systems – Anti-microbial coated filters	58	26
7	In-Duct Filtration Systems – Gas phase (sorption)	59	26
8	In-Duct Filtration Systems – Gas phase (photocatalytic oxidation)	56	26
9	Dessiccant Wheel-Dry	51	26
10	Dessiccant Wheel-Wet	51	26
11	HRV & ERV	64	38
12	Professional Cleaning – Carpet and Upholstery Cleaning	58	34
13	Professional Cleaning – Water Damage Restoration and Mold Remediation	58	22
14	Professional Cleaning – General Duct Cleaning	65	30
15	Professional Cleaning– General Duct Cleaning with Biodecontamination	67	30
16	Building Disinfection via Chemical Cleaning- Ozone	54	32
17	Building Disinfection via Chemical Cleaning- Hydrogen Peroxide Vapors	50	32
18	Building Disinfection via Chemical Cleaning- Aerosolized Chlorine Dioxide	54	32
19	Building Disinfection via Chemical Cleaning- Aerosolized Methyl Bromiode	52	32
20	Indoor Passive Panels – Activated carbon media on indoor wall	58	36
21	Indoor Passive Panels – Leaching anti-microbial coating on indoor wall	59	36
22	Indoor Passive Panels – Non-leaching anti-microbial coating on indoor wall	59	36
23	Indoor Passive Panels – PCO (photocatalytic oxidation) coating on indoor wall	60	36

3.6.2 IAQST Ranking and Selection

Table 6 provides the top 5 IAQSTs for residential and commercial building application which have been ranked based on their scores. Based on the ranking, it is recommended that the top 2 IAQ solutions and their technologies from residential and commercial applications be considered. For residential building IAQSTs, these are HRV/ERV and portable air cleaners while for commercial building IAQSTs, these are HRV/ERV and general duct cleaning with and without biodecontamination.

Comparing the cumulative merit and feasibility scores, the order of importance follows the trend: HRV/ERV > portable air cleaners > general duct cleaning with and without biodecontamination > indoor passive panels. It is recommended that these top 3 or 4 technologies be selected (depending on time schedules) for protocol development.

Table 6 Top 5 IAQSTs for residential and commercial buildings applications

No	Ranked IAQ Solutions Technologies	Merit Scores	Feasibility Scores
Residential Buildings Application			
1	HRV & ERV	64	38
2	Portable Air Cleaners – Room units ESP or electrostatic precipitators (particles)	64	34
3	Portable Air Cleaners – Room units (Hybrid technologies)	64	34
4	Professional Cleaning – General Duct Cleaning with Biodecontamination	67	30
5	Indoor Passive Panels – PCO (photocatalytic oxidation) coating on indoor wall	60	36
Commercial Buildings Application			
1	HRV & ERV	64	38
2	Professional Cleaning– General Duct Cleaning with Biodecontamination	67	30
3	Indoor Passive Panels – PCO (photocatalytic oxidation) coating on indoor wall	60	36
4	Professional Cleaning – General Duct Cleaning	65	30
5	Indoor Passive Panels – Non-leaching/leaching anti-microbial coating on indoor wall	59	36

4 Summary and conclusion

IAQSTs have the potential to generate benefits by reducing indoor pollutants. Performance of IAQSTs can be established by evaluating its efficiencies and effectiveness. Depending on IAQST classifications, efficiencies are normally determined by the pollutant removal at the source or in the air. This performance index is useful to compare one IAQST with the others. However, the numerical efficiency values are not similar to its performance in reducing indoor pollutant concentrations in actual settings. The effectiveness performance index of IAQST is thus more relevant to human exposure and health. However, reviewed effectiveness showed performance ranging from negative 239% to 95% while very few studies reported values above 80%.

Very little research has provided conclusive evidence of health benefits associated with the use of IAQSTs. Currently, sparse research conducted on HRV and UVGI used in ventilation systems has been shown to alleviate health symptoms of building occupants while research on mold remediation have provided conflicting results. However, more than 10 articles present evidence of no improvement of health symptoms with IAQST use. IAQSTs also generate risks, including exposing building occupants to migrating pollutants during cleaning activities, inhalation of ozone, its byproducts of chemical reactions and chemical constituents of cleaning products or biocides. Cleaning products and biocides used can also cause negative environmental impacts such as toxicity to aquatic life, ozone depletion, bioaccumulation and biodegradation if not properly disposed.

Adequacy of IAQST protocols associated with 1) performance and 2) safety, health and environment has been reviewed. Most of the source removal/reduction IAQSTs protocols focus on approaches to sampling, remediation, and preventative maintenance with little emphasis on assessment performance of IAQ impact. Various guidelines on cleaning products and biocides use, emissions control, waste handling and disposal are available but their application for IAQST have not been utilized. Performance indices within most protocols are not based on the expected reduction in indoor concentrations in actual settings.

The NRC research team has identified more than 50 IAQSTs for residential and commercial building applications. Using an evaluation matrix that is based on merit and feasibility criteria, these IAQSTs were evaluated and then ranked based on their scores. Comparing the cumulative merit and feasibility scores, the order of importance follows the trend: HRV/ERV > portable air cleaners > general duct cleaning with and without biodecontamination > indoor passive panels. It is recommended that top 3 or 4 technologies be selected for protocol development and test evaluation for this research activity in the NRC-IRC *Indoor Air Research and Development Initiative*.

5 References

AHAM 2002. In-house survey of homes in the United States. Association of Home Appliance Manufacturers. Washington, D.C.

AHAM, 2006a. Method for measuring performance of portable household electric room air cleaners (ANSI-AHAM AC-1-2006). Association of Home Appliance Manufacturers. Washington, D.C.

AHAM, 2006b. Method for sound testing of portable household electric room air cleaners (AHAM AC-2-2006). Association of Home Appliance Manufacturers. Washington, D.C.

AHAM 2009. Method for measuring the performance Of portable household electric room air cleaners following accelerated particulate loading (AHAM AC-3-2009). Association of Home Appliance Manufacturers. Washington, D.C.

AHRI, 2005. Performance rating of air-to-air exchangers for energy recovery ventilation. (ANSI-AHRI 1060-2005). Air-conditioning, Heating and Refrigerating Institute. Arlington, VA.

ASHRAE, 1991. Method of testing air-to-air heat exchangers. (ANSI-ASHRAE Std 84-1991) American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ASHRAE, 1992. Gravimetric and dust spot procedures for testing air-cleaning devices in general ventilation for removing particulate matter. (ANSI-ASHRAE Std 52.1) American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ASHRAE, 2007. Method of testing for rating desiccant dehumidifiers utilizing heat for the regeneration process. (ANSI-ASHRAE Std 139) American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ASHRAE, 2008a. Method of testing general ventilation air cleaning devices for removal efficiency by particle size. (ANSI-ASHRAE Std 52.2-2008) American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ASHRAE, 2008b. Method of testing air-to-air heat/energy exchangers (ANSI-ASHRAE Std 84-2008). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ASHRAE, 2008c. Laboratory test method for assessing the performance of gas-phase air cleaning systems: loss granular media (ANSI-ASHRAE Std 145.1-2008). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ASHRAE, 2011a. Laboratory Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Air Cleaning Devices (ASHRAE SPC 145.2P Draft). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ASHRAE, 2011b. Field Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Installed Systems (ASHRAE SPC 145.3P Draft). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ASTM 2001. Standard test method for air cleaning performance of a high-efficiency particulate air-filter system. (ASTM F1471). American Society for Testing and Materials, West Conshohocken, PA.

Adilah N, Fitzharris P, Crane J, Siebers RW. 1997. The effect of frequent vacuum cleaning on the house dust mite allergen, Der p 1 in carpets: a pilot study. New Zealand Medical Journal. 28; 110, 1056: 438-439.

Ahmad I, Tansel B, Mitrani JD. 2001. Effectiveness of HVAC Duct Cleaning Procedures in Improving Indoor Air Quality. Environmental Monitoring and Assessment. 72, 3: 265-276.

Axley JW. 1994. Tools for the analysis of gas phase air cleaning systems in building. ASHRAE Transactions. 100: 1130-1146.

Bahnfleth WP, Kowalski WJ, Freihaut J. 2005. Standard and guideline requirements for UVGI air treatment systems. Proceedings of Indoor Air 2005. 3464-3468.

Batterman S, Godwin C, Jia C. 2005. Long duration tests of room air filters in cigarette smokers' homes. Environmental Science and Technology. 39, 18: 7260-7268.

Barnes CS, Dowling P, Van Osdol T, Portnoy J. 2007. Comparison of indoor fungal spore levels before and after professional home remediation. Annals of Allergy and Asthma Immunology. 98, 3: 262-268.

Bernstein JA, Alexis N, Bacchus H, Bernstein IL, Fritz P, Horner E, Li N, Mason S, Nel A, Oullette J, Reijula K, Reponen T, Seltzer J, Smith A, Tarlo SM. 2008. The health effects of non-industrial indoor air pollution. Journal of Allergy and Clinical Immunology. 121, 3: 585-591.

Berry D; Mainelis G; Fennell D. 2007. Effect of an Ionic Air Cleaner on Indoor/Outdoor Particle Ratios in a Residential Environment. Aerosol Science and Technology. 41, 3: 315 – 328.

Boelter KJ, Davidson JH. 1997. Ozone generation by indoor, electrostatic air cleaners. Aerosol Science and Technology. 27, 6: 689-708.

Bornehag CG, Blomquist G, Gyntelberg F, Järvholm B, Malmberg P, Nordvall L, Nielsen A, Pershagen G, Sundell J. 2001. Dampness in buildings and health. Nordic interdisciplinary review of the scientific evidence on associations between exposure to "dampness" in buildings and health effects (NORDDAMP). Indoor Air. 11, 2: 72-86.

Boeniger MF. 1995. Use of Ozone Generating Devices to Improve Indoor Air Quality. American Industrial Hygiene Association Journal, 56, 6: 590 - 598

Boxall ABA, Tiede K, Chaudhry Q. 2007. Engineered nanomaterials in soils and water: how do they behave and could they pose a risk to human health? Nanomedicine. 2, 6: 919-927.

Brosseau LM, Vesley D, Kuehn TH, Melson J, Han HS. 2000a Methods and criteria for cleaning contaminated ducts and air-handling equipment. ASHRAE Transaction, 106: 188-189.

Brosseau LM, Vesley D, Kuehn TH, Melson J, Han HS 2000b. Duct cleaning: a review of associated health effects and results of company and expert surveys. ASHRAE Transaction. 106: 180–187.

Brickner PW, Vincent RL, First M, Nardell E, Megan M, Kaufman W. 2003. The application of ultraviolet germicidal irradiation to control transmission of airborne disease: bioterrorism countermeasure. Public Health Reports. 118: 99-114.

Buttner MP, Cruz P, Stetzenbach LD, Klima-Comba AK, Stevens VL, Cronin TD. 2004. Determination of the efficacy of two building decontamination strategies by surface sampling with culture and quantitative PCR analysis. Applied and Environmental Microbiology. 70, 8: 4740-4747.

CSA, 2008. Fans and Ventilators (CSA C22.2 No. 113-08). Canadian Standards Association. Toronto.

CSA, 2009. Standard laboratory methods of test for rating the performance of heat/energy recovery ventilators. (CAN/CSA-C439-09). Canadian Standards Association. Toronto.

Chen W, Zhang JS, Zhang. 2005. Performance of air cleaners for removal multiple volatile organic compounds in indoor air. ASHRAE Transactions. 1101-1114.

Chen WH, Zhang JS. 2008. UV-PCO device for indoor VOCs removal: Investigation on multiple compounds effect. Building and Environment. 43: 246-252.

Chen J, Poon CS. 2009. Photocatalytic construction and building materials: From fundamentals to applications. Building and Environment. 44, 9: 1899-1906.

Chew GL, Wilson J, Rabito FA, Grimsley F, Iqbal S, Reponen T, Muilenberg ML, Thorne PS, Dearborn DG, Morley RL. 2006. Mold and endotoxin levels in the aftermath of Hurricane Katrina: a pilot project of homes in New Orleans undergoing renovation. Environmental Health Perspectives. 114, 12: 1883-1889.

Chung TW, Ghosh TK, Hines AL, Novosel D. 1993. Removal of selected pollutants from air during dehumidification by lithium chloride and triethylene glycol solutions. ASHRAE transactions. Part 1: 834-841.

Consumers Union of U.S., Inc.: Air cleaners. Consumer Reports 50:7–11 (1985, Jan.)

Corsi RL, Walker MB, Liljestrand HM, Hubbard HF, Poppendieck DG. 2007. Methyl bromide as a building disinfectant: interaction with indoor materials and resulting byproduct formation. Journal of Air and Waste Management Association. 57, 5: 576-585.

Corsi RL, Siegel JA, Chiang C. 2008. Particle resuspension during the use of vacuum cleaners on residential carpet. Journal of Occupational and Environmental Hygiene, 5: 232-238.

Daisey JM, Hodgson AT. 1989. Initial efficiencies of air cleaners for the removal of nitrogen dioxide and volatile organic compounds. Atmos.Environment. 23, 9: 1885-1892.

Daniels SL. 2002. On the ionization of air for removal of noxious effluvia. IEEE Transactions on Plasma Science. 30: 1471–1481.

Darlington A, Chan M, Malloch D, Pilger C, Dixon MA. 2000. The biofiltration of indoor air: implications for air quality. Indoor Air. 10: 39-46.

Dubosc A, Escadeillas G, Blanc PJ. 2001. Characterization of biological stains on external concrete walls and influence of concrete as underlying material, Cement and Concrete Research. 31, 11: 1613–1617.

EIA 2003. Preliminary End-Use Consumption Estimates (with CBECS data) - Energy Information Agency (EIA) Report.

EN, 2002. Particulate filters for general ventilation: Determination of the filtration performance. (EN 779:2002). Brussels. European Committee for Standardization.

EN, 2008. Ventilation for buildings - Ductwork - Cleanliness of ventilation systems. (prEN 15780:2008). Brussels. European Committee for Standardization.

EN, 2009. High Efficiency air filters (HEPA and ULPA). (EN1822:2009). Brussels. European Committee for Standardization.

EPA, 1997. Should You Have the Air Ducts in Your Home Cleaned? EPA-402-K-97-002. Research Triangle Park: U.S. Environmental Protection Agency, Indoor Environment Division, Office of Air and Radiation.

EPA, 2001. Mold Remediation in Schools and Commercial Buildings. Investigating, Evaluating, and Remediating Moisture and Mold Problems. EPA-402-K-01-001. Research Triangle Park: U.S. Environmental Protection Agency, Indoor Environment Division, Office of Air and Radiation.

EPA, 2005. Building Decontamination Alternatives. EPA/600/R-05/036. Research Triangle Park: U.S. Environmental Protection Agency, Office of Research and Development.

EPA, 2006. Pesticide Registration (PR) Notice 2006-A Draft: Draft Pesticide Registration Notice Use of Antimicrobial Pesticide Products in Heating, Ventilation, Air Conditioning and Refrigeration Systems (HVAC&R). U.S. Environmental Protection Agency, Office of Pesticide Programs. http://www.epa.gov/opppmsd1/PR_Notices/prdraft_hvacr_2006.htm

EPA. 2007. Nanotechnology White Paper. U.S. Environmental Protection Agency Report U.S. EPA 100/B-07/001, Washington, DC.

EPA, 2009. USEPA Design for the Environment (DfE) Formulator Initiative. U.S. Environmental Protection Agency. http://www.epa.gov/dfe/index.htm

EcoLogo 2007. EcoLogo^{CM} Program Certification Criteria Document: Product: Disinfectants and Disinfectant-Cleaners (CCD-166).

EcoLogo 2008. EcoLogo^{CM} Program Certification Criteria Document: Carpet and Upholstery Care Products (CCD-148).

Esswein EJ, Boeniger MF. 1994. Effects of an ozone-generating air-purifying device on reducing concentrations of formaldehyde in air. Applied Occupational and Environmental Hygiene. 9, 2: 139-146.

Howieson SG, Lawson A, McSharry C, Morris G, McKenzie E, Jackson J. 2003. Domestic ventilation rates, indoor humidity and dust mite allergens: are our homes causing the asthma pandemic? Building Services Engineering Research Technology. 24, 3: 137-147.

Fadeyi MO, Weschler CJ, Tham KW. 2009. The impact of recirculation, ventilation and filters on secondary organic aerosols generated by indoor chemistry Atmospheric Environment. 43, 22-23: 3538-3547.

Fang L, Zhang G, Wisthaler A. 2008. Desiccant wheels as gas-phase absorption (GPA) air cleaners: evaluation by PTR-MS and sensory assessment. Indoor Air. 18, 5: 375-385.

Fisk WJ, Faulkner D, Sullivan D, Mendell MJ. 2000. Particle concentrations and sizes with normal and high efficiency air filtration in a sealed air-conditioned office building. Aerosol Science and Technology. 32: 527-544.

Foarde KK, Menetrez MY. 2002. Evaluating the potential efficacy of three antifungal sealants of duct liner and galvanized steel as used in HVAC systems. Journal of Industrial Microbiology & Biotechnology 29: 38 –43.

Foarde KK, Hanley JT. 2001. Determine the efficacy of antimicrobial treatments of fibrous air filter. ASHARE Transactions. 107: 156-170.

Foarde K, Berry M. 2004. Comparison of biocontaminant levels associated with hard vs. carpet floors in nonproblem schools: results of a year long study. Journal of Exposure Analysis and Environmental Epidemiology. 14 Suppl 1: S41-8.

Foarde K, van Osdell D, Steiber R. 1997a. Investigation of gas-phase ozone as a potential biocide. Applied Occupational and Environmental Hygiene. 12, 8: 535-542.

Foarde K, VanOsdell D, Meyers E, Chang J. 1997b. Investigation of contact vacuuming for remediation of fungally contaminated ducted surfaces. Environment International. 23: 751-762.

Franke DL, Cole EC, Leese KE, Foarde KK, Berry MA. 1997. Cleaning for Improved Indoor Air Quality: an Initial Assessment of Effectiveness. Indoor Air. 7, 1: 41-54.

Garrison RA, Robertson LD, Koehn RD, Wynn SR. 1993. Effect of heating-ventilation-air conditioning system sanitation on airborne fungal populations in residential environments. Ann Allergy. 71, 6: 548-556.

Green Seal 2009. Green Seal™ Environmental Standard for General-Purpose, Bathroom, Glass, and Carpet Cleaners Used for Industrial and Institutional Purposes. (GS-37) Washington DC.

Godish T. Air Quality, Fourth Edition, Lewis Publishers. US. 2003.

Grinshpun SA, Mainelis G, Trunov M, Adhikari A, Reponen T, Willeke K. 2005. Evaluation of ionic air purifiers for reducing aerosol exposure in confined indoor spaces. Indoor Air. 15: 235-245.

Grinshpun SA, Adhikari A, Honda T, Kim KY, Toivola M, Ramchander Rao KS, Reponen T. 2007. Control of aerosol contaminants in indoor air: Combining the particle concentration reduction with microbial inactivation. Environmental Science and Technology. 41, 2: 606–612.

HVCA 2005. Guide to good practice: Internal cleanliness of ventilation systems. (HVCA TR19). Heating and Ventilating Contractors' Association (HVCA). London. UK.

Hacker DW, Sparrow EM. 2005. Use of air-cleaning devices to create airborne particle-free spaces intended to alleviate allergic rhinitis and asthma during sleep. Indoor Air. 15, 6: 420-431.

Handy RD, von der Kammer F, Lead JR, Hassellöv M, Owen R, Crane M. 2008. The ecotoxicology and chemistry of manufactured nanoparticles. Ecotoxicology. 17: 287-314.

Hanley JT, Ensor DS, Smith DD, Sparks LE. 1994. Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners. Indoor Air, 4, 3: 169-178

Hanley JT, Owen MK. 2005. Development of a new conditioning aerosol for testing electret filters. ASHRAE Transactions. 110; 1115-1125.

Haverinen-Shaughnessy U, Pekkanen J, Nevalainen A, Moschandreas D, Husman T. 2004. Estimating effects of moisture damage repairs on students' health-a long-term intervention study. Journal of Exposure Analysis and Environmental Epidemiology. 14 Suppl 1: S58-64.

Haverinen-Shaughnessy U, Hyvärinen A, Putus T, Nevalainen A. 2008. Monitoring success of remediation: seven case studies of moisture and mold damaged buildings. Science of the Total Environment. 25; 399, 1-3: 19-27.

Heaton PE, Butler GM, Milne A, Callow ME. 1991. Studies on biocide release and performance of novel anti-fungal paints. Biofouling: The Journal of Bioadhesion and Biofilm Research. 3, 1: 35 – 43.

Henderson DE, Milford JB, Miller SL. 2005. Prescribed burns and wildfires in Colorado: impacts of mitigation measures on indoor air particulate matter. Journal of Air and Waste Management Association. 55, 10: 1516-1526.

Hilts SR, Hertzman C, Marion SA. 1995. A controlled trial of the effect of HEPA vacuuming on childhood lead exposure. Canadian Journal of Public Health. 86, 5: 345-350.

Hines AL, Ghosh TK, Loyalka SK, Warder RC. 1993. Investigation of Co-Sorption of Gases and Vapors as a Means to Enhance Indoor Air Quality – Phase 2: A Summary of Pollutant Removal Capabilities of Solid and Liquid Desiccants from Indoor Air, Chicago, Report of Gas Research Institute: GRI-92/0157.1.

Hinds WC. Aerosol technology: Properties, behaviour, and measurement of airborne particles. New York: John Wiley & Sons; 1999

Hodgson AT, Destaillats H, Sullivan DP, Fisk WJ. 2007. Performance of ultraviolet photocatalytic oxidation for indoor air cleaning applications. Indoor Air 17, 4: 305-316

Holopainen R, Asikainen V, Pasanen P, Seppänen O. 2002. The field comparison of three measuring techniques for evaluation of the surface dust level in ventilation ducts. Indoor Air. 12, 1: 47-54.

Holopainen R, Asikainen V, Tuomainen M, Björkroth M, Pasanen P, Seppänen O. 2003. Effectiveness of duct cleaning methods on newly installed duct surfaces. Indoor Air. 13. 3: 212-222

Howard-Reed C, Nabinger SJ , Emmerich SJ. 2008. Characterizing gaseous air cleaner performance in the field. Building and Environment. 43, 3: 368-377.

Hubbard HF. 2006. Building disinfection chemistry: heterogeneous consumption of gaseous disinfecting agents and resulting by-product formation. PhD thesis. The University of Texas at Austin.

Huttunen K, Rintala H, Hirvonen MR, Vepsäläinen A, Hyvärinen A, Meklin T, Toivola M, Nevalainen A. 2008. Indoor air particles and bioaerosols before and after renovation of moisture-damaged buildings: The effect on biological activity and microbial flora. Environmental Research. 107: 291-298.

IICRC, 2000. Standard and reference guide for professional upholstery cleaning (IICRC-S300-2000). Institute of Inspection, Cleaning and Restoration Certification (IICRC). Vancouver Washington.

IICRC, 2002. Standard reference guide for professional carpet cleaning (IICRC-S100-2002). Institute of Inspection, Cleaning and Restoration Certification (IICRC). Vancouver Washington.

IICRC, 2006 Standard and reference guide for professional water damage restoration (IICRC-S500-2006). Institute of Inspection, Cleaning and Restoration Certification (IICRC). Vancouver Washington.

IICRC 2008 Standard and reference guide for professional mold remediation (ANSI/IICRC-S520-2008). Institute of Inspection, Cleaning and Restoration Certification (IICRC). Vancouver Washington.

IEST, 2004. Electrostatic charge in cleanrooms and other controlled environments (IEST-RP-CC022.2). Institute of Environmental Sciences and Technology. Arlington Heights, Illinois.

IEST, 2005. HEPA and ULPA filters (IEST-RP-CC001.4). Institute of Environmental Sciences and Technology. Arlington Heights, Illinois.

IEST, 2009a. Testing HEPA and ULPA filter media (IEST-RP-CC021.2). Institute of Environmental Sciences and Technology. Arlington Heights, Illinois.

IEST, 2009b. HEPA and ULPA filter leak testing (IEST-RP-CC034.3). Institute of Environmental Sciences and Technology. Arlington Heights, Illinois.

ISO, 2009a. Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials. (ISO/FDIS 16000-23: 2009 (E)). International Organization for Standardization. Geneva, Switzerland.

ISO, 2009b. Performance test for evaluating the reduction of volatile organic compound (except formaldehyde) concentrations by sorptive building materials. (ISO/FDIS 16000-23: 2009 (E)). International Organization for Standardization. Geneva, Switzerland.

IUVA, 2006a. General guideline for UVGI air and surface disinfection systems. (IUVA-G01A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org. Draft.

IUVA, 2006b. Guideline for design and installation of UVGI air disinfection systems in new building construction. (IUVA-G02A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org Draft.

IUVA, 2006c. Guideline for design and installation of UVGI in-duct air disinfection systems. (IUVA-G03A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org. Draft.

IUVA, 2006d. Guideline for the design and installation of UVGI cooling coil surface disinfection systems. (IUVA-G04A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org Draft.

IUVA, 2006e. Guideline for the design and installation of UVGI unitary recirculation air disinfection systems. (IUVA-G05A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org Draft.

IUVA, 2006f. Standard for the testing and commissioning of UVGI in-duct air treatment systems. (IUVA-S01A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org . Draft.

IUVA, 2006g. Standard for the testing and commissioning of UVGI cooling coil disinfection systems. (IUVA-S02A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org . Draft.

IUVA, 2006h. Standard for the testing and commissioning of UVGI unitary recirculation unit systems. (IUVA-S03A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org . Draft.

IUVA, 2006i. Standard for the testing and commissioning of upper room UVGI systems. (IUVA-S04A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org . Draft.

IUVA, 2006j. Standard for the testing of UVGI surface disinfection systems. (IUVA-S05A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org . Draft.

IUVA, 2006k. Standard for laboratory testing of UVGI air and surface rate constants. IUVA-S06A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org. Draft.

IUVA, 2006l. Standard for the evaluation and testing of building protection factors. (IUVA-S07A-2006) International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org . Draft.

Ichiura H, Kitaoka T, Tanaka H. 2003. Removal of indoor pollutants under UV irradiation by a compsite TiO2-zeolite sheet prepared using a papermaking technique, Chemosphere. 50, 1: 79–83.

Ito H., Yoshizawa S., Kumagai K., Shizaka K., Kimura K., Ishikawa K. and Iwata T. 1996. Dust Deposit Evaluation of Air Conditioning Duct. In: Yoshizawa, S., Kimura, K., Ikeda, K., Tanabe, S. and Iwata, T. (eds.) Proceedings of Indoor Air '96, Nagoya, The 7th International Conference on Indoor Air Quality and Climate, Vol. 3: 965–970.

Jaakkola JJ, Ieromnimon A, Jaakkola MS. 2006. Interior surface materials and asthma in adults: a population-based incident case-control study. American Journal of Epidemiology. 15, 164, 8: 742-749.

Klapes NA, Vasely D. 1990. Vapor-phase hydrogen peroxide as a surface decontaminant and sterilser. Applied and Environmental Microbiology. 56: 503-506.

Koh GCH, Shek LP, Kee J, Tai BC, Wee A, Ng V, Koh D. 2009. An association between floor vacuuming and dust mite and cockroach sensitization and serum eosinophil cationic protein in young asthmatics. Indoor Air. 19, 6: 468-473.

Kooistra JB, Pasch R, Reed CE. 1978. The effects of air cleaners on hay fever symptoms in air-conditioned homes. Journal of Allergy and Clinical Immunology. 61, 5: 315-319.

Korzun W, Hall J, Sauer R. 2008. The effect of ozone on common environmental fungi. Clinical Laboratroy Science. 21, 2: 107-111.

Kowalski WJ. 2003. Immune Building Systems Technology. McGraw-Hill, New York.

Kovesi T, Zaloum C, Stocco C, Fugler D, Dales RE, Ni A, Barrowman N, Gilbert NL, Miller D. 2009. Heat Recovery Ventilators Prevent Respiratory Disorders in Inuit Children. Indoor Air. 19, 6: 489-499.

Kreiss K, Gonzalez MG, Conright KL, Scheere AR. 1982. Respiratory irritation due to carpet shampoo: two outbreaks. Environment International. 8: 337–341.

Kulp R, Fortmann R, Gentry C, VanOsdell D, Foarde K, Hebert T, Krell R, Cochrane C. 1997. Evaluating residential air duct cleaning and ia: results of a field study conducted in nine single family dwellings. In: Woods, J.E., Grimsrud, D.T. and Boschi, N. (eds) Proceedings of Healthy Buildings/IAQ'97, Washington DC, USA,The 5th Healthy Buildings Conference, Vol. 1, pp. 605–610.

Kunkel D, Gall E, Siegel J, Novoselac A, Morrison GC, Corsi RL. 2010. Passive reduction of human exposure to indoor ozone. Building and Environment. 45, 2: 445-452.

Kuo SL, Hines AL. 1988. Adsorption of chlorinated hydrocarbon pollutants on silica gel. Separation Science Technology. 23: 293–303.

Krzyzanowski ME, Reagor BT. 1990. The Effect of Ventilation Parameters and Compartmentalization on Airborne Particle Counts in Electronic Equipment Offices, Proceedings of Indoor Air'90, The 5th International Conference on Indoor Air Quality and Climate, Vol. 2, 409-414, International Conference on Indoor Air Quality and Climate, Ottawa.

Levetin E, Shaughnessy R, Rogers CA, Scheir R. 2001. Effectiveness of germicidal UV radiation for reducing fungal contamination within Air-Handling units. Applied and Environmental Microbiology. 67: 3712-3715.

Lin CY, Li CS. 2003. Inactivation of microorganisms on the photocatalytic surfaces in air. Aerosol Science and Technology. 37: 939–946.

Lioy PJ, Yiin LM, Adgate J, Weisel C, Rhoads GG. 1998. The effectiveness of a home cleaning intervention strategy in reducing potential dust and lead exposures. Journal of Exposure Analysis and Environmental Epidemiology. 8, 1: 17-35.

Luoma M, Pasanen A-L, Pasanen P, Fan Y. 1993. Duct cleaning – a literature survey. Air Infiltration Review. 14: 1-5.

Lynch RM. 2000. Modeling of exposure to carpet-cleaning chemicals preceding irritant-induced asthma in one patient. Environmental Health Perspectives. 108: 911–913.

Magee R, Nilsson G, Zuraimi MS. 2011. Test evaluation of HRV protocol. Institute for Research in Construction, National Research Council Canada. Internal report.

Mainelis G, a, Adhikari A, Willeke K, Lee S-A, Reponen T, Grinshpun SA.. 2002. Collection of airborne microorganisms by a new electrostatic precipitator. Journal of Aerosol Science. 33: 1417-1432.

Marsik T, Johnson R. 2008. Use of simulink to evaluate the air-quality and energy performance of HRV-equipped residences in Fairbanks, Alaska. Energy and Buildings. 40, 8: 1605-1613.

Maus R, Umhauer H. 1997. Collection efficiencies of coarse and fine dust filter media for airborne biological particles. Journal of Aerosol Science. 28, 3: 401-415.

Meklin T, Potus T, Pekkanen J, Hyvärinen A, Hirvonen MR, Nevalainen A. 2005. Effects of moisture-damage repairs on microbial exposure and symptoms in schoolchildren. Indoor Air. 15 Suppl 10: 40-47.

Mendell MJ, Fisk WJ, Petersen MR, Hines CJ, Dong M, Faulkner D, Deddens JA, Ruder AM, Sullivan D, Boeniger MF. 2002. Indoor particles and symptoms among office workers: results from a double-blind cross-over study. Epidemiology. 13, 3: 296-304.

Mendell MJ, Lei-Gomez Q, Mirer AG, Seppänen O, Brunner G. 2008. Risk factors in heating, ventilating, and air-conditioning systems for occupant symptoms in US office buildings: the US EPA BASE study. Indoor Air. 18, 4: 301-316.

Menzies D, Popa J, Hanley JA, Rand T, Milton DK. 2003. Effect of ultraviolet germicidal lights installed in office ventilation systems on workers' health and wellbeing: double-blind multiple crossover trial. Lancet. 362, 9398: 1785-1791.

Miller SL, Nazaroff WW. 2001. Environmental tobacco smoke particles in multizone indoor environments, Atmospheric Environment. 35: 2053–2067.

Miller-Leiden S, Lobascio C, Nazaroff WW, Macher JM. 1996. Effectiveness of in-room air filtration and dilution ventilation for tuberculosis infection control. Journal of Air and Waste Management Association. 46, 9: 869-882.

Mo J, Zhang Y, Xu Q, Lamson JJ, Zhao R. 2009. Photocatalytic purification of volatile organic compounds in indoor air: A literature review. Atmospheric Environment. 43, 14: 2229-2246.

Morawska L, Agranovski V, Ristovski Z, Jamriska M. 2002. Effect of face velocity and the nature of aerosol on the collection of submicrometer particles by electrostatic precipitator. Indoor Air. 12:129-137

Munro NB, Talmage SS, Griffin GD, Waters LC, Watson AP, King JF, Hauschild V. 1999. The sources, fate, and toxicity of chemical warfare agent degradation products. Environmental Health Perspectives. 107: 933-974.

Myers DL, Arnold BD. 2003. Electret media for HVAC filtration applications. The International Nonwovens Journal. 12, 4: 43-54.

NADCA 2006. Assessment, cleaning and restoration of HVAC systems. NADCA National air duct cleaners association. Washington, D.C

NAIMA, 2007. Cleaning fibrous glass insulated air duct systems: recommended practice. North American Insulation Manufacturers Associations (NAIMA). Alexandria.

NEMI, 2002. Indoor air quality (IAQ) market research. National Energy Management Institute (NEMI). Report by Management Consultants to the Construction Industry (FMI).

Nazaroff W. 2000. Effectiveness of air cleaning devices. Proceedings of Healthy Buildings 2000, Vol. 2: 49-54.

Nazaroff WW, Weschler CJ. 2004. Cleaning products and air fresheners: exposure to primary and secondary air pollutants. Atmospheric Environment. 38, 18: 2841-2865.

Nel A, Xia T, Madler L, Li N. 2006. Toxic potential of materials at the nanolevel. Science 311: 622–627

Nevalainen A, Seuri M. 2005. Of microbes and men. Indoor Air. 15, Suppl 9: 58-64.

Offermann FJ, Sextro RG, Fisk WJ, Grimsrud DT, Nazaroff WW, Nero AV, Revzan KL, Yater J. 1985. Control of respirable particles in indoor air with portable air cleaners. Atmospheric Environment. 19, 11: 1761-1771.

Park SJ, Jang YS. 2003. Preparation and characterization of activated carbon fibers supported with silver metal for antimicrobial behavior. Journal of Colloid and Interface Science. 261: 238–243.

Platts-Mills TAE, Vaughan JW, Carter MC, Woodfolk JA. 2000. The role of intervention in established allergy: Avoidance of indoor allergens in the treatment of chronic allergic disease. Journal of Allergy and Clinical Immunology. 106, 5: 787-804

Popescu M, Ghosh TK. 1999. Dehumidification and simultaneous removal of selected pollutants from indoor air by a desiccant wheel using a 1M type desiccant, Journal of Solar Energy Engineering. 121: 1–13.

Popplewell EJ, Innes VA, Lloyd -Hughes S, Jenkins EL, Khdir K, Bryant TN, Warner JO, Warner JA. 2000. The effect of high-efficiency and standard vacuum-cleaners on mite, cat and dog allergen levels and clinical progress. Pediatrics Allergy and Immunology. 11, 3: 142-148.

Pyankov OV, Agranovski IE, Huang R, Mellins BJ. 2008. Removal of biological aerosols by oil coated filters. CLEAN. 36, 7: 609 – 614

Rastogi VK, Wallace L, Smith LS, Ryan SP, Martin B. 2009. Quantitative method to determine sporicidal decontamination of building surfaces by gaseous fumigants, and issues related to laboratory-scale studies. Applied and Environmental Microbiology. 75, 11: 3688-3694.

Rauch AM, Hurwitz ES, Schonberger LS, Glode MP, Wiggins Jr JW, Rodriguez JG, Hopkins RS. 1991. Outbreak of Kawasaki syndrome in Denver, Colorado: Association with rug and carpet cleaning. Pediatrics. 87, 5: 663-669.

Raynor PC, Chae SJ. 2003. Dust loading on electrostatistically charged filters in a standard test and a real HVAC system, Filtration and separation. 40: 35-39.

Reisman RE, Mauriello PM, Davis GB, Georgitis JW, DeMasi JM. 1990. A double-blind study of the effectiveness of a high efficiency particulate air (HEPA) filter in the treatment of patients with perennial allergic rhinitis and asthma. Journal of Allergy and Clinical Immunology. 85: 1050–1057

Rideal G. Filtration: the market place. Filtration and Separation. 2005. 30-34.

Roberts JW, Glass G, Mickelson L. 2005. A pilot study of the measurement and control of deep dust, surface dust, and lead in 10 old carpets using the 3-spot test while vacuuming. Archives of Environmental Contamination and Toxicology. 48, 1: 16-23.

Russell AD. 2002. Antibiotic and biocide resistance in bacteria: introduction. Journal of Applied Microbiology. 92 Suppl: 1S-3S.

Rylander R. 1997. Airborne (1-->3)-beta-D-glucan and airway disease in a day-care center before and after renovation. Archives of Environmental Health. 52, 4: 281-285.

S.H.A.R.P. Electronics. 2005. Sharp's plasmacluster ions effectively deactivate H5N1 avian influenza virus. Asia Pacific Biotech News. 6, 11: 469.

Salthammer T, Bednarek M, Fuhrmann F, Funaki R, Tanabe S-I. 2002. Formation of organic indoor air pollutants by UV-curing chemistry. Journal of Photochemistry and Photobiology A: Chemistry. 152, 1-3: 1-9.

Sanchez MC, Brown RE, Webber C, Homan GK. 2008. Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program. Energy Policy, 36, 6: 2098-2108.

Savilahti R, Uitti J, Laippala P, Husman T, Roto R. 2000. Respiratory morbidity among children following renovation of a water-damaged school. Archives of Environmental Health. 55, 6: 405–410.

Schwartz J, Neas LM. 2000. Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren. Epidemiology. 11, 1: 6–10.

Schwartz J, Norris G, Larson T, Sheppard L, Claiborne C, Koenig J. 1999. Episodes of high coarse particle concentrations are not associated with increased mortality. Environmental Health Perspectives. 107, 5: 339–342.

Sharpe M. 2006. Small wonders, big future: the development of environmental nanotechnology. Journal of Environmental Monitoring. 8, 2: 235-239.

Shaughnessy RJ, Oatman L. 1991. The Use of Ozone Generators for the Control of Indoor Air Contaminants in an Occupied Environment. Proceedings of the ASHRAE Conference IAQ '91. Healthy Buildings. ASHRAE, Atlanta.

Shaughnessy RJ, Morey PR. 1999. Remediation of microbial contamination. In: Macher J, Ammann HA, Burge HA, Milton DK, Morey PR, editors. Bioaerosols: Assessment and Control, Chapter 15. Cincinnati, Ohio, USA: ACGIH.

Shaughnessy R, Levetin E, Blocker J, Sublette KL. 1994. Effectiveness of portable air cleaners: Sensory testing results. Indoor Air. 4, 3: 179-188.

Shaughnessy R, Sextro R. 2006. What Is an Effective Portable Air Cleaning Device? A Review. Journal of Occupational and Environmental Hygiene, 3: 169–181.

Seiler FA, Davis HT, Kominsky JR, Ronan RJ, Kowka CD. 1987. Use of risk assessment methods in the certification of decontaminated buildings. Risk Analysis. 7, 4: 487-495.

Sekine Y, Nishimura A. 2001. Removal of formaldehyde from indoor air by passive type air-cleaning materials. Atmospheric Environment. 35, 11: 2001-2007.

Sondossi M. Biocides (Nonpublic health, nonagricultural microbials). In (Eds) Schaechter M, Lederberg J. 2004. The desk encyclopedia of microbiology. Elsevier Academic Press. Oxford, UK.

Sulser C, Schulz G, Wagner P, Sommerfeld C, Keil T, Reich A, Wahn U, Lau S. 2009. Can the use of HEPA cleaners in homes of asthmatic children and adolescents sensitized to cat and dog allergens decrease

bronchial hyperresponsiveness and allergen contents in solid dust? International Archives of Allergy and Immunology. 148, 1: 23-30.

Taoda H, Fukaya M, Watanabe E. 2006. VOC decomposition by photocatalytic wall paper, Eco-material Processing & Design VII 510–511: 22–25.

Tham KW, Zuraimi MS, Sekhar SC. 2004. Emission modelling and validation of VOCs' source strengths in air-conditioned office premises. Environment International, 30, 8: 1075-1088

UL, 2007. Standard for Safety Electrostatic Air Cleaners (ANSI-UL 867-2007) Underwriter's Laboratory.

Underhill DM. 2000. Removal of gases and vapors. In. Spengler JD, Samet JM, McCarthy JF Eds. Indoor Air Quality Handbook. New York. McGraw-Hill.

Vojta PJ, Randels SP, Stout J, Muilenberg M, Burge HA, Lynn H, Mitchell H, O'Connor GT, Zeldin DC. 2001. Effects of physical interventions on house dust mite allergen levels in carpet, bed, and upholstery dust in low-income, urban homes. Environmental Health Perspectives. 109, 8: 815-819.

van der Heide S, Kauffman HF, Dubois AE, de Monchy JG. 1997. Allergen reduction measures in houses of allergic asthmatic patients: effects of air-cleaners and allergen-impermeable mattress covers. European Respiratory Journal. 10, 6: 1217-1223.

van der Heide S, van Aalderen WM, Kauffman HF, Dubois AE, de Monchy JG. 1999. Clinical effects of air cleaners in homes of asthmatic children sensitized to pet allergens. Journal of Allergy and Clinical Immunology. 104, 2 Pt 1: 447-451

Vyas A, Pickering CA, Oldham LA, Francis HC, Fletcher AM, Merrett T, Niven RM. 2000. Survey of symptoms, respiratory function, and immunology and their relation to glutaraldehyde and other occupational exposures among endoscopy nursing staff. Occupational and Environmental Medicine. 57, 11: 752-759.

Wang H, Morrison GC. 2006. Ozone-initiated secondary emission rates of aldehydes from indoor surfaces in four homes. Environmental Science and Technology. 40, 17: 5263-5268.

Warburton CJ, Niven RM, Pickering CA, Fletcher AM, Hepworth J, Francis HC. 1994. Domiciliary air filtration units, symptoms and lung function in atopic asthmatics. Respiratory Medicine. 88, 10: 771-776.

Wargocki P, Wyon DP, Baik YK, Clausen G, Fanger PO. 1999. Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads. Indoor Air. 9, 3: 165-179.

Waring M, Siegel JA, Corsi R. 2008. Ultrafine particle removal and generation by portable air cleaners. Atmospheric Environment. 42, 5003-5014.

Weichenthal S, Dufresne A, Infante-Rivard C. 2007. Indoor ultrafine particles and childhood asthma: exploring a potential public health concern. Indoor Air. 17, 2: 81-91.

Weschler CJ. 2000. Ozone in indoor environments: concentration and chemistry. Indoor Air. 10, 4: 269-288.

Weschler CJ, Shields HC, Naik DV. 1994. Ozone removal efficiencies of activated carbon filters after more than three years of continuous service. ASHRAE Transactions. 100: 1121-1129.

Wilson SC, Brasel TL, Carriker CG, Fortenberry GD, Fogle MR, Martin JM, Wu C, Andriychuk LA, Karunasena E, Straus DC. 2004. An investigation into techniques for cleaning mold-contaminated home contents. Journal of Occupational and Environmental Hygiene. 1: 442–447.

Wolkoff P, Schneider T, Kildesø J, Degerth R, Jaroszewski M, Schunk H. 1998. Risk in cleaning: chemical and physical exposure. Science of the Total Environment. 215, 1-2: 135-156.

Wood RA, Johnson EF, Van Natta ML, Chen PH, Eggleston PA. 1998. A placebo-controlled trial of a HEPA air cleaner in the treatment of cat allergy. American Journal of Respiratory and Critical Care Medicine. 158, 1: 115-120.

Wright, G. 2007. The effect of domestic mechanical heat recovery ventilation on asthma control of patients allergic to the house dust mite. PhD thesis. University of Glasgow.

Wu CC, Lee GWM, Cheng P, Yang S, Yu KP. 2006. Effect of wall surface materials on deposition of particles with the aid of negative air ions. Aerosol Science. 37: 616–630.

Yiin LM, Lioy PJ, Rhoads GG. 2003. Impact of home carpets on childhood lead intervention study. Environmental Research. 92, 2: 161-165.

Yiin LM, Yu CH, Ashley P, Rhoads G. 2008. Cleaning efficacy of high-efficiency particulate air-filtered vacuuming and "dry steam" cleaning on carpet. Journal of Occupational and Environmental Hygiene. 5, 2: 94-99.

Yoon KY, Byeon JH, Park CW, Hwang J. 2008. Antimicrobial effect of silver particles on bacterial contamination of activated carbon fibers. Environmental Science and Technology. 15, 42, 4: 1251-1255.

Yu CH, Yiin LM, Tina Fan ZH, Rhoads GG. 2009. Evaluation of HEPA vacuum cleaning and dry steam cleaning in reducing levels of polycyclic aromatic hydrocarbons and house dust mite allergens in carpets. Journal of Environmental Monitoring. 11, 1: 205-211.

Zhang Y, J Mo J, Xu Q, Xiong J, Zhang G. 2008. Indoor VOCs: Source characteristics and air cleaning. Proceedings of Indoor Air 2008, 17-22 August 2008, Copenhagen, Denmark.

Zuraimi MS, Tham KW. 2009. Reducing particle exposures in a tropical office building using electrostatic precipitators. Building and Environment. 44, 12: 2475-2485.

Zuraimi MS, Ho JC Tham KW. 2008. A pilot study on the effects of building ventilation duct cleaning on indoor air quality and SBS symptoms of occupants. Proceedings of Indoor Air 2008. 17-22 August 2008, Copenhagen, Denmark.

Zuraimi MS. 2010. Is ventilation duct cleaning useful? A review of the scientific evidence. Indoor Air. 20: 443-529.

Appendix A

A.1 Residential Applications

A.1.1 Portable Air Cleaners – Room units HEPA or mechanical filters (particles)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Room level removal of particle contamination via portable air cleaning device using particle impaction.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1*, *Der f 1*, *Fel d 1*, *Can f 1*, *Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Mainly residential application although it can be used in commercial buildings	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiency (%) • Clean air delivery rate (CADR)	10
Potential negative impacts (eg. harmful by-products?)	• Some PACs are associated with causing poor acoustical environment.	3
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of contaminants/allergens and alleviating health problems.	10
Commercial examples (potential candidates for testing with new protocol)	• ***Holmes® HEPA-type tower air purifier*** • ***LifeLong™ HEPA-Type Tower Air Cleaner*** (http://www.jardenstore.com/products.aspx?pgsz=9&bid=14&cid=1701) • ***Honeywell 50250 Enviracaire ® True HEPA Round Air Purifier*** Honeywell (http://www.honeywellpurifiers.com/)	
Existing assessment protocols (scope/coverage)	• **AHAM AC-1-2006a** *Method for Measuring Performance of Portable Household Electric Room Air Cleaners* • **AHAM AC-2-2006b** *Method to determine the sound rating of portable household electric room air cleaners* • **AHAM AC-3-2009** *Method for Measuring The Performance Of Portable Household Electric Room Air Cleaners Following Accelerated Particulate Loading*	
Protocol Gaps (Gaps or weaknesses)	• Lack of standardized air cleaner **field** testing protocols or test representing actual home conditions. • No assessment of ultrafine particles. • CADR tested only for House Dust, Tobacco smoke, Pollen (i.e. Particles) – no protocols for other particle related pollutants that are always claimed to be efficiently removed by the manufacturers (e.g. Mold, Dust mite allergens, Cat dander) • Initial efficiencies evaluated only - contaminant loading is not taken into accounts. Efficiencies/CADR values are often calculated over an extended periods when time and thus contaminant loadings, are factor s influencing efficiencies/CADR.	10
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10

IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for contaminant level monitoring) • Ventilation and Walls Research house. • CCHT	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system • Particle monitoring: Grimm system • Particle monitoring: TSI DustTrak • TSI aerosol generator • Gas analyser	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • ETS generator fabrication • Disinfection measures of facilities	6
New Facilities/equipment required: b) ***analytical***	• Particle monitor: TSI APS system • Particle generator • Bioaerosol generator • Andersen 6-stage viable samplers • SMPS neutralizers parts • Andersen 8-stage non-viable samplers (for allergen sampling)	8
New Facilities/equipment required: c) technology	• Purchase of selected PAC for testing	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities?	• HRAI/HVI	6
Related Scientific Literature / review information	• Shaughnessy RJ, Sextro RG. What is considered an effective air cleaning device. J Occup Environ Hyg. 2006; 3(4): 169-81 • Ensor, D.S. ; Viner, A.S. ; Hanley, J.T. ; Lawless, P.A. ; Ramanathan, K. (1988) Air-cleaner technologies for indoor air pollution; ASHRAE Journal., 111-129 (1988) • Offermann et al. Control of respirable particles in indoor air with portable air cleaners. Atmospheric Environment, 1985, 19: 1761-1771.	
	Merit Total:	**59 (H)**
	Feasibility Total:	**34 (H)**

A.1.1 Portable Air Cleaners – Room units HEPA or mechanical filters (particles)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.2 Portable Air Cleaners – Room units ESP or electrostatic precipitators (particles)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Room level removal of particle contamination via portable air cleaning device using electrostatic principles.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Mainly residential application although it can be used in commercial buildings	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiency (%) • Clean air delivery rate (CADR)	10
Potential negative impacts (eg. harmful by-products?)	• ESP technology can generate ozone which in turn create harmful by-products via reaction with unsaturated volatiles into formaldehyde, other aldehydes and secondary organic aerosols. • Some PACs are associated with causing poor acoustical environment.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of contaminants/allergens and alleviating health problems	10
Commercial examples (potential candidates for testing with new protocol)	• ***C-90B Electronic Air Cleaner*** – Friedrich (http://www.air-purifier-direct.com/Images/common/Media/Friedrich_C-90A_Electronic_Air_Cleaner_Brochure.pdf)	
Existing assessment protocols (scope/coverage)	• **AHAM AC-1-2006a** *Method for Measuring Performance of Portable Household Electric Room Air Cleaners* • **AHAM AC-2-2006b** *Method to determine the sound rating of portable household electric room air cleaners* • **AHAM AC-3-2009** *Method for Measuring The Performance Of Portable Household Electric Room Air Cleaners Following Accelerated Particulate Loading* • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• Lack of standardized air cleaner **field** testing protocols or test representing actual home conditions. • No assessment of ultrafine particles. • CADR tested only for House Dust, Tobacco smoke, Pollen (i.e. Particles) – no protocols for other particle related pollutants that are always claimed to be efficiently removed by the manufacturers (e.g. Mold, Dust mite allergens, Cat dander) • Initial efficiencies evaluated only - contaminant loading is not taken into accounts. Efficiencies/CADR values are often calculated over an extended periods when time and thus contaminant loadings, are factor s influencing efficiencies/CADR. • Measurements of ozone and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test protocols	8
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for contaminant level monitoring) • Ventilation and Walls Research house • CCHT	

IRC Research Facilities: b) ***analytical*** (availability, status)	• Same as 3.1 • GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • ETS generator fabrication • Disinfection measures of facilities	6
New Facilities/equipment required: b) ***analytical***	• Same as 3.1	8
New Facilities/equipment required: c) technology	• Purchase of selected PAC for testing	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities?	• HRAI/HVI	6
Related Scientific Literature / review information	• Shaughnessy RJ, Sextro RG. What is considered an "effective" air cleaning device. J Occup Environ Hyg. 2006; 3(4): 169-81 • Boelter KJ, Davidson JH. Ozone Generation by Indoor, Electrostatic Air Cleaners. Aerosol Science and Technology 1997; 27: 689-708. • Offermann et al. Control of respirable particles in indoor air with portable air cleaners. Atmospheric Environment, 1985, 19: 1761-1771. • Daisey JM, Hodgson AT. Initial efficiencies of air cleaners for the removal of nitrogen dioxide and volatile organic compounds. Atmospheric Environment. 1989; 23:1885-1892.	
	Merit Total:	64 (H)
	Feasibility Total:	34 (H)

A.1.2 Portable Air Cleaners – Room units ESP or electrostatic precipitators (particles)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.3 Portable Air Cleaners – Room units (Gas Phase Sorption) [5]

Description and Review Aspect	Review	Score
Technology Description/ Scope	Room level removal of gaseous pollutant contamination via portable air cleaning device using sorption principles.	
Target Contaminant (s)	1. VOCs and high molecular weight aldehydes 2. Ozone 3. Nitrogen dioxide 4. ETS	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms, carcinogenic and toxic for some VOCs • Premature mortality and morbidity (e.g. asthma, allergies, respiratory and diseases) • Asthma, allergies and respiratory symptoms • Premature mortality and morbidity (e.g. asthma, allergies, respiratory and diseases)	10
Application (Comm'l/Resid'l)	Mainly residential application although it can be used in commercial buildings	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiency (%) • Clean air delivery rate (CADR)	10
Potential negative impacts (eg. harmful by-products?)	• Some PACs are associated with causing poor acoustical environment.	3
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of contaminants and alleviating health problems	8
Commercial examples (potential candidates for testing with new protocol)	• ***BPA Smoke Muncher Smoke Eater*** (http://www.smokeeaters.org/carbon/) • ***IQAir Multigas GCX Smoke Eater*** • ***HealthMate 400 Air Purifier*** Austin Air Company (http://www.achooallergy.com/austinhealthmate.asp)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• Lack of standardized gaseous air cleaner chamber and field testing protocols. • Multiple instead of single challenge of VOCs • CADR for room air cleaner is only for Dust, Tobacco smoke, pollen and not gaseous pollutants • Initial effectiveness assessed only: Contaminant loading is not taken into account in assessments - Efficiencies/CADR values are often calculated over an extended periods when time and thus contaminant loadings, are factor s influencing efficiencies/CADR. • Regeneration of filtration device not considered.	10
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for contaminant level monitoring) • Ventilation and Walls Research house • CCHT	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Same as 3.1 • API ozone monitor • Dasibi ozone generator (for calibration and ozone generation)	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • ETS generator fabrication • Disinfection measures of facilities • VOC generation system	8

[5] Gas phase sorption can be by physical adsorption (e.g activated carbon, charcoal etc) or chemisorption (impregnated with $KMnO_4$)

New Facilities/equipment required: b) ***analytical***	• Particle monitor: TSI APS system	8
New Facilities/equipment required: c) technology	Purchase of selected PAC for testing	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities?	• HRAI	6
Related Scientific Literature / review information	• Nazaroff. Effectiveness of air cleaning technologies. Healthy Buildings Conference 2000. Vol. 2, pp. 49–54, • Daisey et al. Initial efficiencies of air cleaners for the removal of nitrogen dioxide and volatile organic compounds, Atmospheric Environment 1989, 23, 1885-1892. • Howard-Reed etal - Gaseous *Air Cleaners - Characterizing field performance*. Building and Environment. 2008; 43, 3: 368-377 • Chen et al. Performance of air cleaners for removing multiple volatile organic compounds in indoor air. ASHRAE Transactions 2005. 1101-1114.	
	Merit Total:	**57 (M)**
	Feasibility Total:	**36 (H)**

A.1.3 Portable Air Cleaners – Room units (gas phase sorption)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.4 Portable Air Cleaners – Room units (Ion Generation)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Room level removal of pollutant contamination via portable air cleaners using ionizers relying on plasma decomposition principle.	
Target Contaminant (s)	1. VOCs 2. odours 3. Airborne bacteria 4. Airborne mould spores 5. Pollen 6. Particulate matter 7. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms, carcinogenic and toxic for some VOCs • Discomfort • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma, allergies and respiratory symptoms • Premature mortality and morbidity (e.g. asthma, allergies, respiratory and diseases) • Asthma and allergies	10
Application (Comm'l/Resid'l)	Mainly residential although there are commercial (hotels, theatres, conference centres etc) applications	
Measurable (positive) impact	• Removal efficiency (%) • Clean air delivery rate (CADR) • CRF (concentration reduction factor) (Mayya et al., 2004)	8
Potential negative impacts (eg. harmful by-products?)	• Technique involves provision of an energetic source (via electron beams or electric discharges) of active chemical species such as ozone (O3), oxygen atoms [O(1D) and O(3P)], hydroxyl radicals, and free electrons, • ozone formation and subsequently its by-products of reactions with unsaturated organics: assessment protocol should screen for formation of ozone, irritants, etc. • hydrogen peroxide formation • Some PACs are associated with causing poor acoustical environment.	10
Technology: Maturity / Development Stage	Multiple products in market with claimed benefit in reducing indoor levels of contaminants and alleviating health problems	8
Commercial examples (potential candidates for testing with new protocol)	• ***Wein VI-2500 High Density Negative Ionizer*** (http://www.weinproducts.com/Wein_VI-2500_Vortex_High_Intensity_Negative_Ionizer.html) • ***ION house*** (http://www.n-ion.com/e/recommended-negative-ion-generator.html) • ***PLASMA AIR PURIFIER*** (http://www.himfr.com/d-p11397601207200600-PLASMA_AIR_PURIFIER/)	
Existing assessment protocols (scope/coverage)	• **AHAM AC-1-2006a** *Method for Measuring Performance of Portable Household Electric Room Air Cleaners* • **AHAM AC-2-2006b** *Method to determine the sound rating of portable household electric room air cleaners* • **AHAM AC-3-2009** *Method for Measuring The Performance Of Portable Household Electric Room Air Cleaners Following Accelerated Particulate Loading* • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition	
Protocol Gaps (Gaps or weaknesses)	• Lack of standardized air cleaner field testing protocols or test representing actual home conditions. • No assessment of ultrafine particles. • CADR tested only for House Dust, Tobacco smoke, Pollen (i.e. Particles) – no protocols for other particle related pollutants that are always claimed to be efficiently removed by the manufacturers (e.g. Mold, Dust mite allergens, Cat dander) • Initial efficiencies evaluated only - contaminant loading is not taken into accounts. Efficiencies/CADR values are often calculated over an extended periods when time and thus contaminant loadings, are factor s influencing efficiencies/CADR. • Measurements of ozone and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test	8

	protocols	
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• full scale chambers • CCHT • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Same as 3.1 • Same as 3.3	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • ETS generator fabrication • Disinfection measures of facilities • VOC generation system	6
New Facilities/equipment required: b) ***analytical***	• Same as 3.1 • Same as 3.3	8
New Facilities/equipment required: c) technology	• Purchase of selected PAC for testing	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	• HRAI/HVI	6
Related Scientific Literature / review information	• Daniels. On the ionization of air for removal of noxious effluvia. IEEE Transactions on plasma Science 2002; 30: 1471-1481. • Grinshpun et al. Evaluation of ionic air purifiers for reducing aerosol exposure in confined indoor spaces. Indoor Air 2005; 15 : 235-245. • Shaughnessy et al. Effectiveness of portable indoor air cleaners: Sensory testing results. Indoor Air 1994; 4: 179-188. • Offermann et al. Control of respirable particles in indoor air with portable air cleaners. Atmospheric Environment, 1985, 19: 1761-1771.	
	Merit Total:	54 (M)
	Feasibility Total:	34 (H)

A.1.4 Portable Air Cleaners – Room units (Ion Generation)				
Merit	**H**	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.5 Portable Air Cleaners – Room units (PCO - Photocatalytic oxidation)

Description and Review Aspect	Review	Score
Technology Description/ Scope	The technology exposes ultraviolet light to a catalyst (TiO_2) to produce primarily hydroxyl radicals (OH). These hydroxyl radicals are extremely reactive and can oxidize or "break down" typical VOC's in indoor environments.	
Target Contaminant (s)	1. VOCs 2. Formaldehyde 3. Bacteria 4. Fungi	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms, carcinogenic and toxic for some VOCs • Asthma, allergies and respiratory symptoms	9
Application (Comm'l/Resid'l)	Mainly residential application although it can be used in commercial buildings	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiency (%) • Clean air delivery rate (CADR)	10
Potential negative impacts (eg. harmful by-products?)	• PCO-UV technology can create ozone and its harmful by-products reactions via degradation of volatiles into formaldehyde, other aldehydes and secondary organic aerosols. • Some PACs are associated with causing poor acoustical environment.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of contaminants and alleviating health problems	4
Commercial examples (potential candidates for testing with new protocol)	• ***NANO O2™*** (http://www.nanoo2.com/) • ***S-980 PCO / HEPA Air Purifier*** by Airsopure (http://www.air-purifier-home.com/airsopure/) • ***3000Xtreme*** (http://www.negative-ion-generators.com/store/product_info.php?cPath=25_48&products_id=88)	
Existing assessment protocols (scope/coverage)	• **AHAM AC-1-2006a** *Method for Measuring Performance of Portable Household Electric Room Air Cleaners* • **AHAM AC-2-2006b** *Method to determine the sound rating of portable household electric room air cleaners* • **AHAM AC-3-2009** *Method for Measuring The Performance Of Portable Household Electric Room Air Cleaners Following Accelerated Particulate Loading* • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• Lack of standardized gaseous air cleaner chamber and field testing protocols. • Multiple instead of single challenge of VOCs • CADR for room air cleaner is only for Dust, Tobacco smoke, pollen and not gaseous pollutants • Initial effectiveness assessed only: Contaminant loading is not taken into account in assessments - Efficiencies/CADR values are often calculated over an extended periods when time and thus contaminant loadings, are factor s influencing efficiencies/CADR. • Measurements of ozone and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test protocols	10
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chambers • CCHT • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Same as 3.3	

New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • ETS generator fabrication • Disinfection measures of facilities • VOC generation system	8
New Facilities/equipment required: b) ***analytical***	• Same as 3.3	8
New Facilities/equipment required: c) technology	Purchase of selected PAC for testing	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	• HRAI/HVI	6
Related Scientific Literature / review information	• Zhang et al. A model for analyzing the performance of photocatalytic air cleaner in removing volatile organic compounds. Atmospheric Environment 2003; 37: 3395-3399. • Lin & Li. Inactivation of microorganisms on the photocatalytic surfaces in air. Aerosol Science & Tehchnology 2003; 37: 939-946. • Mo et al. Photocatalytic purification of volatile organic compounds in indoor air: A literature review. Atmospheric Environment 2009. 43, 14: 2229-2246.	
	Merit Total:	**53 (M)**
	Feasibility Total:	**36 (H)**

A.1.5 Portable Air Cleaners – Room units (PCO - Photocatalytic oxidation)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.6 Portable Air Cleaners – Room units (Portable Ozone Generators)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Room level removal of gaseous pollutant using ozone generating device.	
Target Contaminant (s)	1. VOCs 2. odours 3. Airborne bacteria 4. Airborne mould spores 5. Pollen 6. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms, carcinogenic and toxic for some VOCs • Discomfort • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	9
Application (Comm'l/Resid'l)	Mainly residential application although it can be used in commercial buildings	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies (%) • Clean Air Delivery Rate (CADR)	10
Potential negative impacts (eg. harmful by-products?)	• Ozone is a harmful pollutant and can react with unsaturated organics to form harmful by-products such as formaldehyde and fine PM • Some PACs are associated with causing poor acoustical environment.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of contaminants and alleviating health problems	4
Commercial examples (potential candidates for testing with new protocol)	• ***LA-2SPX*** Lightning Air portable natural fresh ozone air purifier cleaner treatment systems by Applied ozone systems (http://www.appliedozone.com/purifiers.html) • ***The clair ozone generator*** by Ecozone (http://www.ecozone.co.il/English/Article.aspx?Item=66&Section=63)	
Existing assessment protocols (scope/coverage)	• **AHAM AC-1-2006a** *Method for Measuring Performance of Portable Household Electric Room Air Cleaners* • **AHAM AC-2-2006b** *Method to determine the sound rating of portable household electric room air cleaners* • **AHAM AC-3-2009** *Method for Measuring The Performance Of Portable Household Electric Room Air Cleaners Following Accelerated Particulate Loading* • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• Lack of standardized gaseous air cleaner chamber and field testing protocols. • Multiple instead of single challenge of VOCs • CADR for room air cleaner is only for Dust, Tobacco smoke, pollen and not gaseous pollutants • Measurements of ozone reaction by-products with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test protocols	10
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chambers • CCHT • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Same as 3.1 • Same as 3.3	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols.	8

	• ETS generator fabrication • Disinfection measures of facilities • VOC generation system	
New Facilities/equipment required: b) ***analytical***	• Same as 3.1 • Same as 3.3	8
New Facilities/equipment required: c) technology	Purchase of selected PAC for testing	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	• HRAI/HVI	6
Related Scientific Literature / review information	• Weschler. Ozone in Indoor Environments: Concentration and Chemistry. Indoor Air 2000; 10: 269-288. • Hubbard 2006. Building disinfection chemistry: heterogeneous consumption of gaseous disinfecting agents and resulting by-product formation. PhD thesis. The University of Texas at Austin. • Foarde et al. Investigation of gas-phase ozone as a potential biocide, Applied Occupational and Environmental Hygiene 1997a; 12: 535–542 • Boeniger MF. Use of ozone generating devices to improve indoor air quality. AIHA J 1995; 56: 590-598.	
	Merit Total:	54 (M)
	Feasibility Total:	36 (H)

A.1.6 Portable Air Cleaners – Room units (portable ozone generators)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.7 Portable Air Cleaners – Room units (Germicidal UV)

Description and Review Aspect	Review	Score
Technology Description/ Scope	The technology exposes ultraviolet light to kill microbes that are uniquely vulnerable to the effects of light at wavelengths at or near 2537 Angstroms due to the resonance of this wavelength with molecular structures.	
Target Contaminant (s)	1. Airborne Bacteria 2. Airborne Fungi 3. Virus	
Health Impact of target contaminant(s)	• 1 - Asthma and respiratory symptoms and mutagenic outcomes • 2 - Asthma, allergies, respiratory symptoms and mutagenic outcomes • 3 – Respiratory infections	7
Application (Comm'l/Resid'l)	Mainly residential application although it can be used in commercial buildings (hospitals, clinics)	
Measurable (positive) impact (ie. basis for technol. labeling)	• Clean air delivery rate (CADR) • Removal efficiencies (before vs after of air, surface swabs and settle plate samples) • UVGI Rating Value (URV) - a scale for rating UVGI air treatment systems based on the dose produced. • Germicidal dose – portion of exposure to the UV spectrum that is germicidal. • Building Protection Factor (BPF) – to define the effectiveness of a building air cleaning system in terms of % of occupants theoretically protected from infection	10
Potential negative impacts (eg. harmful by-products?)	• UV technology can create the same harmful effects to the skin and eyes of humans if no protection is in place. • Some UVGI devices produce ozone which is a pollutant associated with negative health outcomes and capable of producing harmful by-products such as formaldehyde and SOA. • Some PACs are associated with causing poor acoustical environment.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of bacteria, fungi, virus and alleviating health problems.	6
Commercial examples (potential candidates for testing with new protocol)	• ***UV Air Purifier Cleaners*** (http://www.peakpureair.com/ultraviolet.htm) • ***Mobile Germicidal UV Room Sterilizers*** (http://www.americanairandwater.com/port/portable.htm) • ***Honeywell HCM300T UV Tower Humidifier*** Honeywell (http://www.nextag.com/Honeywell-HCM300T-UV-Tower-512345138/prices-html)	
Existing assessment protocols (scope/coverage)	• **IUVA-GO1A** General Guideline for UVGI Air and Surface Disinfection Systems (Draft) • **IUVA-SO6A** Standard for Laboratory Testing of UVGI Air and Surface Rate Constants (Draft)	
Protocol Gaps (Gaps or weaknesses)	• Lack of standardized air cleaner field and chamber testing protocols. • Standardized UV methods are in draft format. • Ozone emissions of UV devices is not assessed • Endotoxins, exotoxins and mycotoxins exposure reductions are not addressed.	10
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chambers • CCHT • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system • Particle monitoring: Grimm system • TSI aerosol generator	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • Disinfection measures of facilities	6
New Facilities/equipment	• Particle monitor: TSI APS system (same as 3.1)	8

required: b) ***analytical***	• Andersen 6-stage viable samplers (same as 3.1)	
New Facilities/equipment required: c) technology	Purchase of selected PAC for testing	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	• HRAI	4
Related Scientific Literature / review information	• Brickner et al. The application of ultraviolet germicidal irradiation to control transmission of airborne disease: Bioterrorism countermeasure. Public Health Reports 2003; 118: 99-118. • Bahnfleth et al. Standard and guideline requirements for UVGI air treatment systems. Proceedings of Indoor Air 2005. 3464-3468.	
	Merit Total:	57 (M)
	Feasibility Total:	34 (H)

A.1.7 Portable Air Cleaners – Room units (Germicidal UV)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.8 Portable Air Cleaners – Room units (Hybrid technologies)

Description and Review Aspect	Review	Score
Technology Description/ Scope	The PAC uses a combination of various technologies (e.g. HEPA, UV, gas phase sorption and ionizer in the cleaning device).	
Target Contaminant (s)	1. VOCs and high molecular weight aldehydes 2. Ozone 3. Particulate matter (outdoor combustion) 4. Particulate matter (ETS) 5. Airborne bacteria 6. Airborne mould spores 7. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• The most important health outcome addressed by this technology is premature mortality associated with PM and ozone exposure.	10
Application (Comm'l/Resid'l)	Commercial and residential applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiency • Clean air delivery rate (CADR) • UVGI Rating Value (URV) - a scale for rating UVGI air treatment systems based on the dose produced. • Germicidal dose – portion of exposure to the UV spectrum that is germicidal. • Building Protection Factor (BPF) – to define the effectiveness of a building air cleaning system in terms of % of occupants theoretically protected from infection	10
Potential negative impacts (eg. harmful by-products?)	• Potential emissions of ozone and its byproducts from ionizer device maybe adsorbed by the gas phase adsorbent provided the latter is placed after the ionizer. • UV exposure maybe harmful if inadequate protection in device is not provided. • Some PACs are associated with causing poor acoustical environment.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of contaminants and alleviating health problems	10
Commercial examples (potential candidates for testing with new protocol)	• ***Multi-Tech XJ – 3000C*** Surround Air;A Division of Indoor Purification Systems Inc (http://www.surroundair.com/ionic-air-purifier.htm)	
Existing assessment protocols (scope/coverage)	• **AHAM AC-1-2006a** *Method for Measuring Performance of Portable Household Electric Room Air Cleaners* • **AHAM AC-2-2006b** *Method to determine the sound rating of portable household electric room air cleaners* • **AHAM AC-3-2009** *Method for Measuring The Performance Of Portable Household Electric Room Air Cleaners Following Accelerated Particulate Loading* • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007) • **IUVA-GO1A** General Guideline for UVGI Air and Surface Disinfection Systems • **IUVA-SO6A** Standard for Laboratory Testing of UVGI Air and Surface Rate Constants	
Protocol Gaps (Gaps or weaknesses)	• Lack of standardized air cleaner **field** testing protocols or test representing actual home conditions. • No assessment of particles lower than 90nm. • CADR tested only for House Dust, Tobacco smoke, Pollen (i.e. Particles) – no protocols for other particle related pollutants that are always claimed to be efficiently removed by the manufacturers (e.g. Mold, Dust mite allergens, Cat dander) • Initial efficiencies evaluated only - contaminant loading is not taken into accounts. Efficiencies/CADR values are often calculated over an extended periods when time and thus contaminant loadings, are factor s influencing efficiencies/CADR. • Measurements of ozone and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test protocols	8
Labeling support	• Has the potential to label products for best IAQ, green product, energy saving potential and fulfill min requirements of new protocol regulations	10

IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chambers • CCHT • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Same as 3.1 and 3.3	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • ETS generator fabrication • Disinfection measures of facilities • VOC generation system	6
New Facilities/equipment required: b) ***analytical***	• Same as 3.1 and 3.3	8
New Facilities/equipment required: c) technology	Purchase of selected PAC for testing	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	• HRAI/HVI	6
Related Scientific Literature / review information	• Shaughnessy RJ, Sextro RG. What is considered an "effective" air cleaning device. J Occup Environ Hyg. 2006; 3(4): 169-81	
	Merit Total:	64 (H)
	Feasibility Total:	34 (H)

A.1.8 Portable Air Cleaners – Room units (Hybrid Technologies)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.9 In-Duct Filtration Systems - Particulate matter (Mechanical, HEPA)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce aerosols in residences via impaction on fibrous media. Technology may be the same for commercial systems albeit smaller dimension devices are adopted for residential settings.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1*, *Der f 1*, *Fel d 1*, *Can f 1*, *Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact	• Particulate matter removal efficiency (of specific size classes) • MERV ratings • Penetration factor	8
Potential negative impacts (eg. harmful by-products?)	• Media and HEPA filters result in increased pressure drop. • Media and HEPA filter typically will undergo increased soiling over time – sensory pollution and formation of byproducts via reaction of sorbed organics with ozone.	7
Technology: Maturity / Development Stage	Multiple products in market with claimed benefit in reducing indoor levels of particulate contaminants	8
Commercial examples (potential candidates for testing with new protocol)	• ***Air Demon Air Filter - MERV 11*** AmericanAirFilter (http://www.americanairfilter.com/index.asp?sid=353B27171D3E47D79FB8A7815DF4EB87&action=product&id=5&deptID=5) • ***High Efficiency Air Cleaning Filter*** Honeywell (http://www.honeywellcentral.com/product/0-85267-26005-3.html) • ***Performance EZ Flex Cabinet Air Filter*** Carrier (http://www.residential.carrier.com/products/airquality/aircleaners/ezflex.shtml)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 52.1** Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter • **ASHRAE 52.2** Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size • **ASTM F1471** Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air- Filter System • **EN1822:** High Efficiency air filters (HEPA and ULPA). • **EN779:2002** Particulate filters for general ventilation: Determination of the filtration performance • **IEST-RP-CC001.4**: HEPA and ULPA Filters • **IEST-RP-CC021.2**: Testing HEPA and ULPA Filter Media • **IEST-RP-CC034.3:** HEPA and ULPA Filter Leak Testing	
Protocol Gaps (Gaps or weaknesses)	• Standards widely used and accepted	X
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical***	• M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS, Grimm and TSI DustTrak system (same as 3.1) • Aerosol generator (same as 3.1) • Ozone monitor (same as 3.3)	

Description and Review Aspect	Review	Score
	• GC-MS (same as 3.3) • HPLC (same as 3.3)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• Ozone monitors (same as 3.3) • Particle monitor: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (same as 3.1) • Andersen 8-stage non-viable samplers (for allergen sampling) (same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		2
Cost to complete evaluation:		10
Research Partnership Opportunities?		4
Related Scientific Literature / review information	• Hanley et al. Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners. Indoor Air 1994; 4: 169-178	
	Merit Total:	V
	Feasibility Total:	24 (L)

A.1.9 In-Duct Filtration Systems - Particulate matter (Mechanical, HEPA)				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.1.10 In-Duct Filtration Systems - Particulate matter (Electret, charged media)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce aerosols in residences via electrostatic attraction on charged fibrous media. Technology may be the same for commercial systems albeit smaller dimension devices are adopted for residential settings.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact (ie. basis for technol. labeling)	Particulate removal efficiency (of specific size classes and/or allergen species)	8
Potential negative impacts (eg. harmful by-products?)	• Electret or charged media filter typically will undergo increased soiling over time resulting in decreased performance.	2
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of particulate contaminants	8
Commercial examples (potential candidates for testing with new protocol)	• ***Tox Box, AirClean 1500*** Innereco Environmental Inc. (http://www.toxbox.ca/) • ***Filtrete™ Ultra Clean Air Purifier Replacement Filters for Model Series FAP02 & FAP03*** 3M (http://solutions.3m.com/wps/portal/3M/en_US/Filtrete/AirQualityProducts/ProductInformation/FiltreteProducts/AirPurifierFilters/)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 52.2** Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size • **EN1822** standard for filtration • **EN779:2002** Particulate filters for general ventilation: Determination of the filtration performance • **IEST-RP-CC022.2:** Electrostatic Charge in Cleanrooms and Other Controlled Environments • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• The use of DOP and other challenge aerosols inn testing (health concerns and unrepresentative) • No assessment of particles below 80nm.	4
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS APS, DustTrak and Grimm system (same as 3.1) • Aerosol generator (same as 3.1) • Ozone monitor (same as 3.3) • GC-MS (same as 3.3) • HPLC (same as 3.3)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4

Description and Review Aspect	Review	Score
New Facilities/equipment required: b) ***analytical***	• Particle monitor: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (same as 3.1) • Andersen 8-stage non-viable samplers (for allergen sampling) (same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		8
Related Scientific Literature / review information	• Hanley JT, Owen MK. Development of a new conditioning aerosol for testing electret filters. ASHRAE Transactions 2005: 110; 1115-1125. • Hanley et al. Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners. Indoor Air 1994; 4: 169-178 • Myers & Arnold. Electret media for HVAC filtration applications. INJ Winter 2003: 43-54.	
	Merit Total:	50 (M)
	Feasibility Total:	26 (L)

A.1.10 In-Duct Filtration Systems - Particulate matter (Electret, Charged Media)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.11 In-Duct Filtration Systems - Particulate matter (Electrostatic precipitation)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce aerosols in residences via electrostatic precipitation in single or dual stage. Technology may be the same for commercial systems albeit smaller dimension devices are adopted for residential settings.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact (ie. basis for technol. labeling)	Particulate removal efficiency (of specific size classes and/or allergen species)	10
Potential negative impacts (eg. harmful by-products?)	• Electronic filter units can generate ozone and subsequently its by-products: assessment protocol should screen for formation of ozone, irritants, etc. • Collected particles on plates can be re-entrained into the air stream if no 'rapping' mechanism is provided.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of particulate contaminants	8
Commercial examples (potential candidates for testing with new protocol)	• ***Infinity Air Purifier*** Carrier (http://www.residential.carrier.com/products/airquality/aircleaners/purifier.shtml) • ***Honeywell F300E1001 Electronic Whole House Air Cleaner*** Honeywell (http://www.nextag.com/Honeywell-F300E1001-Electronic-Whole-500860840/prices-html?nxtg=5c810a1c0533-77E0D0BB712C0140)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 52.2** Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size • **EN1822** standard for filtration • **EN779:2002** Particulate filters for general ventilation: Determination of the filtration performance • **IEST-RP-CC022.2:** Electrostatic Charge in Cleanrooms and Other Controlled Environments • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• The use of DOP and other challenge aerosols in testing (health concerns and unrepresentative) • The adoption of ANSI/ASHRAE 52.2 is not compatible with the loading dust test. Dust contains very conductive carbon that may cause electrical shorting. • Measurements of ozone (generated by ESP) and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test protocols • Not all particles can be charged to be subsequently collected on plates. No protocol has addressed this. • No assessment of particles below 80nm.	10
Labeling support	• Has the potential to label products for green product, energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	

Description and Review Aspect	Review	Score
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS, DustTrak and Grimm system (same as 3.1) • TSI aerosol generator (same as 3.1) • Ozone monitor (same as 3.1) • GC-MS (same as 3.1) • HPLC (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	6
New Facilities/equipment required: b) ***analytical***	• Ozone monitors (same as 3.3) • Particle monitor: TSI APS system (same as 3.1) • Collison nebulizer (same as 3.1) • Andersen 6-stage viable samplers (same as 3.1) • Andersen 8-stage non-viable samplers (for allergen sampling) (same as 3.1)	4
New Facilities/equipment required: c) technology		
Time to complete evaluation:		6
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Hanley et al. Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners. Indoor Air 1994; 4: 169-178 • Morawska et al. Effect of face velocity and the nature of aerosol on the collection of submicrometer particles by electrostatic precipitator. Indoor Air 2002; 12:129-137 • Mainelis et al. Collection of airborne microorganisms by a new electrostatic precipitator. Aerosol Science 2002; 33: 1417-1432.	
	Merit Total:	56 (M)
	Feasibility Total:	26 (M)

A.1.11 In-Duct Filtration Systems - Particulate matter (Electrostatic Precipitation)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.12 In-Duct Filtration Systems - Particulate matter (Ion generators)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce aerosols via negative ions released into the airstream. Technology may be the same for commercial systems albeit smaller dimension devices are adopted for residential settings.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact (ie. basis for technol. labeling)	Particulate removal efficiency (of specific size classes and/or allergen species)	8
Potential negative impacts (eg. harmful by-products?)	• A variety of negative ion generator-type is available. The simplest types use static charges to remove particles from indoor air. They operate by charging the particles in a room, which become attracted to and deposit on walls, floors, table tops, curtains, occupants, etc., where they may cause soiling problems. • Ion generators can generate ozone and subsequently react with other VOCs to form harmful by-products: assessment protocol should screen for formation of ozone, irritants, etc.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of particulate contaminants	8
Commercial examples (potential candidates for testing with new protocol)	• ***Duct Air ionizer 720*** Allied Enterprise (http://www.buenisima.com/item547.htm)	
Existing assessment protocols (scope/coverage)	• **ASTM F1471** Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air- Filter System • **EN1822** standard for filtration • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• The use of DOP and other challenge aerosols in testing (health concerns and unrepresentative) • Measurements of ozone (generated by ion generators) and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test protocols • Not all particles can be charged and thus efficiency of device may be affected. No protocol has addressed this. • No assessment of particles below 80nm.	8
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS, DustTrak and Grimm system (same as 3.1) • TSI aerosol generator (same as 3.1) • Ozone monitor (same as 3.1) • GC-MS (same as 3.1) • HPLC (same as 3.1)	

Description and Review Aspect	Review	Score
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• Ozone monitors (same as 3.3) • Particle monitor: TSI APS system (same as 3.1) • Collison nebulizer (same as 3.1) • Andersen 6-stage viable samplers (same as 3.1) • Andersen 8-stage non-viable samplers (for allergen sampling) (same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Daniels. On the ionization of air for removal of noxious effluvia. IEEE Transactions on plasma Science 2002; 30: 1471-1481. • Wu et al. Effect of wall surface materials on deposition of particles with the aid of negative air ions. Aerosol Science 2006; 37; 616-630. • Liu et al. Effect of wire heating and configuration on ozone emission in a negative ion generator. Journal of Electrostatics 2000; 48: 81-91. • Huang et al. Removable of viable bioaerosol particles with a low efficiency HVAC filter enhanced by continuous emission of unipolar air ions. Indoor Air 2008; 8: 106-112.	
	Merit Total:	**52 (M)**
	Feasibility Total:	**26 (M)**

A.1.12 In-Duct Filtration Systems - Particulate matter (Ion generators)				
Merit	**H**	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.13 In-Duct Filtration Systems – Germicidal UV

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce bioaerosols concentrations via UV irradiation. Technology may be the same for commercial systems albeit smaller dimension devices are adopted for residential settings.	
Target Contaminant (s)	1. Airborne Bacteria 2. Airborne Fungi 3. Virus 4. Allergens	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Respiratory infections • Asthma and allergies	7
Application (Comm'l/Resid'l)	Residential applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies (upstream vs downstream of air samples) • Removal efficiencies (before vs after of air, surface swabs and settle plate samples) • UVGI Rating Value (URV) - a scale for rating UVGI air treatment systems based on the dose produced. • Germicidal dose – portion of exposure to the UV spectrum that is germicidal. • Building Protection Factor (BPF) – to define the effectiveness of a building air cleaning system in terms of % of occupants theoretically protected from infection	8
Potential negative impacts (eg. harmful by-products?)	• UV technology can create the same harmful effects to the skin and eyes of humans if no protection is in place. • Some UVGI devices produce ozone which is a pollutant associated with negative health outcomes and capable of producing harmful by-products such as formaldehyde and SOA	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor air and surface levels of bacteria, fungi, virus and alleviating health problems. Used commonly in hospital and health-care settings, but products for commercial and residential applications are available.	8
Commercial examples (potential candidates for testing with new protocol)	• ***80W UVC Induct Duel Lamp Air Sanitizer*** Ionic Zone (http://www.ioniczone.com/UVC-Induct-Air-Sanitizer-p/iz-uv72.htm) • ***Honeywell UV various models*** Honeywell (http://www.nextag.com/Honeywell-UV100E3007-UV-Surface-84802954/prices-html)	
Existing assessment protocols (scope/coverage)	• **IUVA-GO1A** General Guideline for UVGI Air and Surface Disinfection Systems (Draft) • **IUVA-GO2A** Guideline for Design and Installation of UVGI Air disinfection Systems in New Building Construction (Draft) • **IUVA-GO3A** Guideline for Design and Installation of UVGI In-Duct Air Disinfection Systems (Draft) • **IUVA-GO4A** Guideline for Design and Installation of UVGI Cooling Coil Air Disinfection Systems (Draft) • **IUVA-GO5A** Guideline for Design and Installation of UVGI Unitary Recirculation Air Disinfection Systems (Draft) • **IUVA-SO1A** Standard for the Test and Commissioning of UVGI In-Duct Air Treatment Systems (Draft) • **IUVA-SO2A** Standard for the Test and Commissioning of UVGI Cooling Coil Disinfection Systems (Draft) • **IUVA-SO3A** Standard for the Test and Commissioning of UVGI Unitary Recirculation Unit Systems (Draft) • **IUVA-SO5A** Standard for the Testing of UVGI Surface Disinfection Systems (Draft) • **IUVA-SO6A** Standard for Laboratory Testing of UVGI Air and Surface Rate Constants (Draft)	
Protocol Gaps (Gaps or weaknesses)	• Standardized UV methods are in draft format • Ozone emissions of UV devices is not assessed • Endotoxins, exotoxins and mycotoxins exposure reductions are not addressed.	8
Labeling support	• Has the potential to label products for energy saving potential and fulfill min	10

Description and Review Aspect	Review	Score
	requirements of new protocol regulations	
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chambers • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system • Particle monitoring: Grimm system • TSI aerosol generator	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Andersen 6-stage viable samplers (same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		8
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Brickner et al. The application of ultraviolet germicidal irradiation to control transmission of airborne disease: Bioterrorism countermeasure. Public Health Reports 2003; 118: 99-118. • Bahnfleth et al. Standard and guideline requirements for UVGI air treatment systems. Proceedings of Indoor Air 2005. 3464-3468. • Levetin et al. Effectiveness of germicidal UV radiation for reducing fungal contamination within Air-Handling units. Applied and Environmental Microbiology 2001; 67: 3712-3715. • Kowalski WJ. Immune building systems technology. McGraw-Hill, New York. 2003.	
	Merit Total:	55 (M)
	Feasibility Total:	30 (M)

A.1.13 In-Duct Filtration Systems – Germicidal UV

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.14 In-Duct Filtration Systems – Anti-microbial coated filters[6]

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce bioaerosols concentrations via anti-microbial coated filters. Technology may be the same for commercial systems albeit smaller dimension devices are adopted for residential settings.	
Target Contaminant (s)	1. Airborne Bacteria 2. Airborne Fungi 3. Virus	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Respiratory infections	10
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies	8
Potential negative impacts (eg. harmful by-products?)	• Dislodgement of coating agents from filter surfaces and getting into the airstream to be distributed into the indoor space (e.g. nanoparticle coating). • Anti-microbial coatings can contain chemicals that are terpene based (e.g. tea tree oil, essential oils). These can react with outdoor ozone coming into the HVAC systems and form harmful by-products. • The human health impacts of nano-silver are still largely unknown, but some studies and cases indicate that the nanomaterial has the potential to increase antibiotic resistance and potentially cause kidney and other internal problems	8
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of bacteria, fungi, virus and alleviating health problems. Used commonly in hospital and health-care settings	8
Commercial examples (potential candidates for testing with new protocol)	• ***VariCel V ULTRA: MERV 15 Double Header with Antimicrobial.*** AmericanAirFilter , AAF. (http://www.aafintl.com/Products/Replacement%20HVAC%20Filtration/High%20Efficiency%20Supported%20Pleated%20Filters/VariCel%20V/VariCel%20V.aspx)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• Current standards deal with mechanical filtration per se and not representative of protocol evaluation for anti-microbial filters. e.g. challenge aerosols are inanimate (e.g. DOP is used instead of bioaerosol). • No standardized testing protocols available	10
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chambers • CCHT • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system • Particle monitoring: Grimm system • TSI aerosol generator	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold. • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• Particle monitor: TSI APS system (same as 3.1) • Andersen 6-stage viable samplers (same as 3.1)	8
New Facilities/equipment		

[6] Most anti-microbial coatings can leach over time. Silver nano-particle is also used as an anti-microbial coating.

Description and Review Aspect	Review	Score
required: c) technology		
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Foarde KK, Hanley JT. Determine the efficacy of antimicrobial treatments of fibrous air filter. ASHRAE Transactions 2001; 107: 156-170. • Pyankov et al. Removal of biological aerosols by oil coated filters. CLEAN 2008; 36: 609-614.	
	Merit Total:	58 (M)
	Feasibility Total:	26 (M)

A.1.14 In-Duct Filtration Systems – Anti-microbial coated filters

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.15 In-Duct Filtration Systems – Gas phase (sorption) [7]

Description and Review Aspect	Review	Score
Technology Description/ Scope	Residential removal of gaseous pollutant contamination via in duct air cleaning device using adsorption principles. Technology may be the same for commercial systems albeit smaller dimension devices are adopted for residential settings.	
Target Contaminant (s)	1. VOCs 2. Ozone 3. Nitrogen dioxide	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms, carcinogenic and toxic for diff VOCs • Premature mortality and morbidity (e.g. asthma, allergies, respiratory and diseases) • Asthma, allergies and respiratory symptoms	10
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies	10
Potential negative impacts (eg. harmful by-products?)	• Microorganisms prefer to adhere to solid supports made of carbon materials,, thus, carbon filters have high biocompatibility (i.e. microorganism may multiply on carbon based filters become a source of bioaerosols.	9
Technology: Maturity / Development Stage (current market demand / potential)	• Multiple products and established in market	6
Commercial examples (potential candidates for testing with new protocol)	• ***7 Lbs CTC-80 Vapor Phase Activated Carbon*** Safety filters (http://www.safetyfilters.com/7x.html) • ***Dri-Eaz Defendair Ex Air Scrubber #F258*** Dri-Eaz (http://www.amazon.com/dp/B000PDLDXA?smid=A31AW2OZADFE8G&tag=nextag-tools-tier3-delta-20&linkCode=asn)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 145.1** Laboratory test method for assessing the performance of gas-phase air cleaning systems: loss granular media • **ASHRAE SPC 145.2P** Laboratory Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Air Cleaning Devices (proposed) • **ASHRAE SPC 145.3P** Field Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Installed Systems (proposed)	
Protocol Gaps (Gaps or weaknesses)	• Single VOCs challenge versus multiple VOCs challenge. • Breakthrough (via environmental impacts) and regeneration tests in protocols not established. • Soiling of carbon filters	10
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations (for adsorption principle)	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Porosimitry analyzer • Ozone monitor (same as 3.3) • GC-MS (same as 3.3) • HPLC (same as 3.3) • Particle monitoring: TSI SMPS, DustTrak and Grimm system (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (same as 3.3) • ozone calibrator (same as 3.3)	8

[7] Adsorption (e.g activated carbon, charcoal etc).or chemisoprtion (e.g. impregnated with $KMnO_4$)

	• NO/NO2 monitor (same as 3.3) • NO/NO2 calibrator (same as 3.3) • Particle monitoring: TSI APS system (same as 3.1)	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Howard-Reed etal – Characterizing gaseous air cleaner performance in the field. Building and Environment. 2008; 43, 3: 368-377 • Axley JW. Tools for the analysis of gas phase air cleaning systems in building. ASHRAE Transactions 1994; 100: 1130-1146. • Weschler et al. Ozone removal efficiencies of activated carbon filters after more than three years of continued service. ASHARE Transactions 1994; 100: 1121-1129. • Yoon et al. Antimicrobial effect of silver particles on bacterial contamination of activated carbon fibers. Environmental Science & Technology 2008; 42: 1251-1255.	
	Merit Total:	59 (M)
	Feasibility Total:	26 (M)

A.1.15 In-Duct Filtration Systems – Gas phase (sorption)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.16 In-Duct Filtration Systems – Gas phase (photocatalytic oxidation)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Removal of gaseous pollutant contamination in residences via in duct air cleaning device using catalytic principles. Technology may be the same for commercial systems albeit smaller dimension devices are adopted for residential settings.	
Target Contaminant (s)	1. VOCs 2. Formaldehyde 3. Ozone 4. Nitrogen dioxide	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms, carcinogenic and toxic for diff VOCs • Asthma, allergies and respiratory symptoms • Premature mortality and morbidity (e.g. asthma, allergies, respiratory and diseases) • Asthma, allergies and respiratory symptoms	10
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies	10
Potential negative impacts (eg. harmful by-products?)	• Ozone formation and subsequently its by-products of reactions with unsaturated organics: assessment protocol should screen for formation of ozone, irritants, etc.	10
Technology: Maturity / Development Stage (current market demand / potential)	• It is still a new technology that is strongly marketed by vendors	4
Commercial examples (potential candidates for testing with new protocol)	• ***Air Oasis ACT InDuct Air Purifier*** My Air Purifier (http://www.my-air-purifier.com/site/678219/product/AO-ACT) • ***AirGorilla™*** (http://www.filtrationmanufacturing.com/AirGorilla.htm)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols found for this application– the closest applicable protocol deals with gaseous pollutant removal using loose granulated media • Single VOCs challenge versus multiple VOCs challenge (cross-interferences).	10
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations (for adsorption principle)	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Ozone monitor (same as 3.3) • GC-MS (same as 3.2) • HPLC (same as 3.2) • Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (same as 3.3) • ozone calibrator (same as 3.3) • NO/NO2 monitor (same as 3.3) • NO/NO2 calibrator (same as 3.3) • Particle monitoring: TSI APS system (same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete		8

evaluation:		
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Chen & Zhang. UV-PCO device for indoor VOCs removal: Investigation on multiple compounds effect. Building and Environment 2008; 43: 246-252. • Hodgson et al. Performance of ultraviolet photocatalytic oxidation for indoor air cleaning applications. Indoor Air 2007; 17: 305-316 • Mo et al. Photocatalytic purification of volatile organic compounds in indoor air: A literature review. Atmospheric Environment 2009. 43, 14: 2229-2246.	
	Merit Total:	56 (M)
	Feasibility Total:	26 (M)

A.1.16 In-Duct Filtration Systems – Gas phase (photocatalytic oxidation)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.17 HRV & ERV

Description and Review Aspect	Review	Score
Technology Description/ Scope	Heat recovery ventilator/Energy recovery ventilator	
Target Contaminant (s)	1. All airborne contaminants via dilution 2. Moisture levels (esp w ERV systems) 3. PM levels (w optional HEPA filters) 4. Biocontaminants (w optional UV lamps …) 5. Radon (promoted use of HRVs by EPA)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity via PM (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases via moisture associated problems • Asthma, allergies and respiratory symptoms via biocontaminants • Cancer via Radon exposure • Asthma, allergies, respiratory and SBS symptoms via dilution of indoor contaminants	10
Application (Comm'l/Resid'l)	Residential application	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies • Contaminant transfer ratio	10
Potential negative impacts (eg. harmful by-products?)	• Leakage of contaminants from exhaust stream to supply stream (possibly greater risk for ERV) • Off gassing of device into supply stream (from core materials or from PVC ductwork if used) • Potential for over-drying of indoor air • With ERV – pollutant transfer across membrane reduces ventilation effectiveness • Use of HRV/ERV is associated with poor acoustical performance. • Energy costs associated with realistic (seasonal) operation (vs. standardized test conditions) • Cleanliness of components • Poor air distribution	8
Technology: Maturity / Development Stage	Multiple products in market	8
Commercial examples (potential candidates for testing with new protocol)	• Broan • Imperial Air • Lennox • Nu-Air • Nutech • Venmar	
Existing assessment protocols (scope/coverage)	• **AHRI 1060-2005** Performance *Rating of Air-To-Air Exchangers for Energy Recovery Ventilation* • **ASHRAE 84-1991** Method of Testing Air-to-Air Heat Exchangers • **CSA C439-09** *Standard Laboratory Methods of Test for Rating the Performance of Heat/Energy-Recovery Ventilators (R2005)* • **CSA C22.2 No. 113-08** *Fans and Ventilators*	
Protocol Gaps (Gaps or weaknesses)	• Climatic zones for appropriate use of HRV,ERV (Aluminium core in HRV for maximum "sensible" recovery; Energy recovery core for enhanced "latent" recovery – ERV is not recommended for climates where temp drops below 25^0C) • Current protocols are designed for "off the shelf" testing of HRV. There are no HRV protocols in place to determine effectiveness of optional IAQ sensors; indoor humidity and pollutants levels indoors (especially PM, radon); control features: adjustable flows/pressure and flow balancing systems; certified air change; ventilation effectiveness and distribution efficiency of installed system. • Cleanliness protocols of installed and used HRV are not available.	8
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D • Ventilation and Walls Research house	

Description and Review Aspect	Review	Score
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system, APS, DustTrak • Ozone monitor • Humidity Sensors • CO_2 and VOC monitoring • Allergen/biocontaminant testing if benefit claimed	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts.	10
New Facilities/equipment required: b) ***analytical***	• Same as 3.1 • Same as 3.3	8
New Facilities/equipment required: c) technology	Purchase of selected HRV/ERV units	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	Canadian manufacturers may be interested in product development opportunities (and marketing of "approved" devices)	10
Related Scientific Literature / review information	• Ouazia et al. Assessment of the enthalpy performance of houses using the nergy recovery technology. ASHRAE Transactions 2007; 112:1-11. • Zhou et al. Performance of energy recovery ventilator with various weathers and temperature set-points. Energy and Buildings 2007: 39: 1202-1210 • Marsik T, Johnson R. Use of Simulink to evaluate the air-quality and energy performance of HRV-equipped residences in Fairbanks, Alaska. Energy and Buildings 2008; 40: 1605-1613	
	Merit Total:	64 (H)
	Feasibility Total:	38 (H)

A.1.17 HRV & ERV

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.18 Professional Cleaning – Carpet and Upholstery Cleaning

Description and Review Aspect	Review	Score
Technology Description/ Scope	Professional procedures for appearance retention and soil remove of carpet and upholstery, and environmental quality indoors.	
Target Contaminant (s)	1. Debris 2. VOCs 3. Formaldehyde 4. Odors	
Health Impact of target contaminant(s)	• Asthma, allergies and respiratory diseases via debris associated exposures • Asthma and respiratory symptoms via VOCs exposures • Asthma, allergies and respiratory symptoms via formaldehyde exposures • Poor perceived air quality	9
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality • Before and after evaluation of dust deposits on carpet/upholstery surfaces	10
Potential negative impacts (eg. harmful by-products?)	• Carpet and upholstery care emissions amount to about 1.07 tonnes of VOC per day (32 tonnes per day per person) • Chemicals used maybe harmful to human health • IAQ problems associated with incomplete drying after cleaning problems	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology/Process is available with claimed benefits of improved IAQ, productivity and health outcomes	6
Commercial examples (potential candidates for testing with new protocol)	• VProcare (http://www.vprocare.com/index.asp) • Peters carpet cleaning (http://www.peterscarpetcleaning.com/index.html) • Dryex (http://www.dryex.com/index.html)	
Existing assessment protocols (scope/coverage)	• ***IICRC S100*** Standard Reference Guide for Professional Carpet Cleaninq - 2002 • ***IICRC S300*** Standard and Reference Guide for Professional Upholstery Cleaning - 2000	
Protocol Gaps (Gaps or weaknesses)	• Current protocols focus on techniques, remediation, and preventative maintenance (qualitative in nature) only and do not relate to the improvement of IAQ after cleaning activities.	8
Labeling support	• Has the potential to label products/services for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)		
IRC Research Facilities: b) ***analytical*** (availability, status)	• Ozone monitor (same as 3.3) • GC-MS (same as 3.3) • HPLC (same as 3.3) • Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Disinfection measures of facilities • Standardized contaminant dosing device	8
New Facilities/equipment required: b) ***analytical***	• ozone monitor (same as 3.3) • ozone calibrator (same as 3.3) • Particle monitoring: TSI APS system (same as 3.1)Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		
Time to complete		6

evaluation:		
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		6
Related Scientific Literature / review information	• Vojta et al. Effects of physical interventions on house dust mite allergen levels in carpet, bed, and upholstery dust in low-income, urban homes. Environmental Health Perspectives 2001; 109: 815-819. • Roberts et al. A pilot study of the measurement and control of deep dust, surface dust, and lead in 10 old carpets using the 3-spot test while vacuuming. Archives of Environmental Contamination and Toxicology 2005; 48: 16-23. • Franke et al. Cleaning for Improved Indoor Air Quality: an Initial Assessment of Effectiveness. Indoor Air 1997. 7, 1: 41-54.	
	Merit Total:	58 (M)
	Feasibility Total:	34 (M)

A.1.18 Professional Cleaning – Carpet and Upholstery Cleaning

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.19 Professional Cleaning – Water Damage Restoration and Mold Remediation

Description and Review Aspect	Review	Score
Technology Description/ Scope	Professional procedures for water damage restoration and mold remediation for improved environmental quality indoors.	
Target Contaminant (s)	1. Airborne particulate matter /debris 2. Mold 3. Bacteria 4. VOCs (mVOCs) 5. Odors	
Health Impact of target contaminant(s)	• The highest risk posed by associated contaminant is molds that are associated with toxic outcomes.	7
Application (Comm'l/Resid'l)	Residential and commercial applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality • Before and after evaluation of biological contaminations on surfaces	8
Potential negative impacts (eg. harmful by-products?)	• Although source removal is the primary means of remediation, indiscriminate use of cleaning chemicals/biocides/anti-microbial coatings of unknown health effects are regularly used. • IAQ problems associated with incomplete drying/removal (secondary problems) after restoration/remediation.	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology/Process is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• VProcare (http://www.vprocare.com/index.asp) • Peters carpet cleaning (http://www.peterscarpetcleaning.com/index.html) • Dryex (http://www.dryex.com/index.html)	
Existing assessment protocols (scope/coverage)	• ***IICRC S500*** Standard and reference guide for professional water damage restoration • ***IICRC S520*** Standard and reference guide for professional mold remediation	
Protocol Gaps (Gaps or weaknesses)	• Current protocols focus on techniques, remediation, and preventative maintenance (qualitative in nature) only and do not relate to the improvement of IAQ after cleaning activities. • Abrasive cleaning methods could aerosolize settled dust, leading to high concentrations of mold (and bacterial) spores in indoor environments. • Expectations of a remediation maybe deemed successful if it fulfilled the technical criteria but unsuccessful if level of discomfort and/or health symptoms may not have been reduced. • There is no consensus of the target contaminants reduction levels set to evaluate success of remediation.	6
Labeling support	• Has the potential to label products/services for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)		
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS (same as 3.3) • HPLC (same as 3.3) • Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Room size test • Disinfection measures of facilities • Standardized duct dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (same as 3.3) • ozone calibrator (same as 3.3)	8

	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		6
Cost to complete evaluation:		4
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		8
Related Scientific Literature / review information	• Haverinen-Shaughnessy et al. Monitoring success of remediation: Seven case studies of moisture and mold damaged buildings. Science of The Total Environment 2008; 399: 19-27. • Huttunen et al. Indoor air particles and bioaerosols before and after renovation of moisture-damaged buildings: The effect on biological activity and microbial flora. Environmental Research 2008; 107: 291-298. • Barnes et al. Comparison of indoor fungal spore levels before and after professional home remediation. Annals of Allergy Asthma Immunology 2007; 98(3): 262-268.	
	Merit Total:	58 (M)
	Feasibility Total:	22 (L)

A.1.19 Professional Cleaning – Water Damage Restoration and Mold Remediation

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.20 Professional Cleaning – General Duct Cleaning

Description and Review Aspect	Review	Score
Technology Description/ Scope	General duct cleaning technology is the mechanical removal of dirt, debris and other materials found in the ductwork and HVAC components of residences.	
Target Contaminant (s)	1. Airborne particulate matter 2. Debris 3. VOCs 4. Formaldehyde 5. Odors	
Health Impact of target contaminant(s)	• Premature mortality and morbidity via PM (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases via debris associated exposures • Asthma and respiratory symptoms via VOCs exposures • Asthma, allergies and respiratory symptoms via formaldehyde exposures • Poor perceived air quality	10
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality • Before and after evaluation of dust deposits in ductwork	10
Potential negative impacts (eg. harmful by-products?)	• Aggregated dust and debris on the ductwork by the mechanical cleaning may be aerosolized into finer particles that can remain airborne over long periods. • Mechanical cleaning may damage ductwork	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology is widely available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• Power Vac G.T.A., Ltd. (www.powervac.ca) Toronto • Enviro Plus Duct Cleaning Ltd. (www.enviroplusductcleaning.com) Brockville • Francis H.V.A.C. Services Ltd (gillesallaire@francishvac.ca) Ottawa • AWS Remediation Technologies Inc. (www.awstech.com) Ottawa	
Existing assessment protocols (scope/coverage)	• ***NADCA ACR- 2006***. Assessment, cleaning and restoration of HVAC systems. NADCA National air duct cleaners association. Washington, D.C • ***HVCA TR/17*** – Guide to good practice cleanliness of ventilation systems. HVCA Publication TR/17. • ***NAIMA***-Cleaning Fibrous Glass Insulated Air Duct Systems, Recommended Practice 1993.	
Protocol Gaps (Gaps or weaknesses)	• Protocols did not include indoor air quality evaluations.	8
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)		
IRC Research Facilities: b) ***analytical*** (availability, status)	• Ozone monitor (same as 3.3) • GC-MS (same as 3.3) • HPLC (same as 3.3) • Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard model) • Disinfection measures of facilities • Standardized duct dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3)	8

	• NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		8
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	IRSST	8
Related Scientific Literature / review information	• Ahmad et al. Effectiveness of HVAC duct cleaning procedures in improving indoor air quality. Environmental Monitoring and Assessment 2001; 72 : 265-276. • Luoma et al. Duct cleaning – a literature survey. Air Infiltration Review 1993; 14: 1-5. • Brosseau et al. Methods and criteria for cleaning contaminated ducts and air-handling equipment. ASHRAE Transactions 2000a; 106: 188-199 • Zuraimi MS. 2010. Is ventilation duct cleaning useful? A review of the scientific evidence. Indoor Air. 20: 443-529.	
	Merit Total:	65 (H)
	Feasibility Total:	30 (M)

A.1.20 Professional Cleaning – General Duct Cleaning

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.21 Professional Cleaning – General Duct Cleaning with Biodecontamination

Description and Review Aspect	Review	Score
Technology Description/ Scope	General duct cleaning technology which includes removal of dirt, debris and other materials found in the ductwork and HVAC components followed by disinfection procedures.	
Target Contaminant (s)	• Airborne bacteria • Airborne mould • Dustborne bacteria • Dustborne mould • Allergens	
Health Impact of target contaminant(s)	• Asthma, allergies and respiratory diseases via debris associated exposures	10
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality • Before and after evaluation of dust deposits in ductwork	10
Potential negative impacts (eg. harmful by-products?)	• Aggregated dust and debris on the ductwork by the mechanical cleaning may be aerosolized into finer particles that can remain airborne over long periods. • Mechanical cleaning may damage ductwork • Some biocides used may be harmful to health, can participate in surface chemistry to generate formaldehyde and harmful by-products (essential oils) • Duct cleaning could r a stir-up settled dust, including mould spores, leading to peak concentrations of mould (and bacterial) spores in indoor environments, directly after the cleaning procedure	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology is widely available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• Superior Air Duct Cleaning (http://www.superioradc.com/) Missisauga • Francis H.V.A.C. Services Ltd (gillesallaire@francishvac.ca) Ottawa • AWS Remediation Technologies Inc. (www.awstech.com) Ottawa	
Existing assessment protocols (scope/coverage)	• ***NADCA ACR- 2006***. Assessment, cleaning and restoration of HVAC systems. NADCA National air duct cleaners association. Washington, D.C • ***HVCA TR/17*** – Guide to good practice cleanliness of ventilation systems. HVCA Publication TR/17. • ***NAIMA***-Cleaning Fibrous Glass Insulated Air Duct Systems, Recommended Practice 1993.	
Protocol Gaps (Gaps or weaknesses)	• Evaluation of biocide application • Protocols did not include indoor air quality evaluations.	10
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	•	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard model) • Disinfection measures of facilities • Standardized duct dust dosing device • Standardized duct microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1)	8

	• Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		8
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	IRSST	8
Related Scientific Literature / review information	• Foarde et al. Investigation of contact vacuuming for remediation of fungally contaminated ducted surfaces. Environment International 1997b; 23: 751-762. • Foarde and Maniterez. Evaluating the potential efficacy of three antifungal sealants of duct liners and galvanized steel used in HVAC systems. Journal of Industrial Microbiology and Biotechnology 2002; 29: 38-43. • Zuraimi MS. 2010. Is ventilation duct cleaning useful? A review of the scientific evidence. Indoor Air. 20: 443-529.	
	Merit Total:	67 (H)
	Feasibility Total:	30 (M)

A.1.21 Professional Cleaning – General Duct Cleaning with Biodecontamination

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.1.22 Building Disinfection via Chemical Cleaning- Ozone

Description and Review Aspect	Review	Score
Technology Description/ Scope	Ozone vapors that intentionally produced indoors to reduce concentrations of gaseous and biological contaminants.	
Target Contaminant (s)	• Ozone • Volatile organic compounds • Formaldehyde • Airborne mould • Airborne bacteria	
Health Impact of target contaminant(s)	• The highest risk posed by ozone itself - it is associated with premature mortality and many respiratory problems.	10
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Ozone is a toxic gas with vastly different chemical and toxicological properties from oxygen. Several agencies have established health standards or recommendations to limit human exposure to ozone. • for many of the chemicals with which ozone readily react, the reaction can form a variety of harmful or irritating by-products.	10
Technology: Maturity / Development Stage (current market demand / potential)	Technology is widely available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• ***Ionic Zone 3600 mg/h Ozone Generator / 10h Timer*** Ionic Zone (http://www.ioniczone.com/ozone-generator-timer-p/iz-3600mgt.htm) • ***Empire Maintenance Industries*** (http://www.emo3.ca/) • ***BiOzone Corporation*** (http://www.biozone.com/ozone_air_purification.html)	
Existing assessment protocols (scope/coverage)	• **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• UL 867 only addressed electrostatic air cleaners	8
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	2
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1) • GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Commercial size ventilation duct test manifold • Restoration (of oxidized materials) measures of facilities • Standardized dust dosing device • Standardized microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1)	8

	• Andersen 8-stage non-viable samplers for allergen	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Foarde et al.1997a. Investigation of Gas-Phase Ozone as a Potential Biocide. Applied Occupational Environmental Hygiene. 12(8): 535-542. • Esswein, Eric J.; Boeniger, Mark F. 1994. Effects of an Ozone-Generating Air-Purifying Device on Reducing Concentrations of Formaldehyde in Air. Applied Occupational Environmental Hygiene. 9(2):139-146. • Shaughnessy, R.J.; and Oatman, L. 1991. The Use of Ozone Generators for the Control of Indoor Air Contaminants in an Occupied Environment. Proceedings of the ASHRAE Conference IAQ '91. Healthy Buildings. ASHRAE, Atlanta.	
	Merit Total:	54 (M)
	Feasibility Total:	32 (M)

A.1.22 Building Disinfection via Chemical Cleaning- Ozone				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.1.23 Building Disinfection via Chemical Cleaning- Hydrogen Peroxide Vapors

Description and Review Aspect	Review	Score
Technology Description/ Scope	Hydrogen peroxide decontamination of indoor air and surfaces using H2O2 vapors to reduce concentrations of gaseous and biological contaminants.	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Hydrogen peroxide is a mild irritant at household levels (3ppm) but may cause pulmonary irritation a more than 10ppm (typically found during disinfection). • Building interiors may contain large surfaces composed of complex materials, material compatibility to how the decontaminant vapors impact building materials within an enclosed building interior space is . • The use of h2o2 can produce building disinfection by-products such as lower carbonyls when reacted with common building materials such as vinyl composite tile, vinyl composite tile with polish, concrete, and carpet with PVC backing.	8
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• ***CLEAN AIR SYSTEMS, INC*** (http://www.cleanairsystemsinc.com/products.html) • ***BIOQUELL Inc*** (http://www.bioquell.com/)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	2
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Commercial size ventilation duct test manifold • Restoration (of oxidized materials) measures of facilities • Standardized dust dosing device • Standardized microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment		

required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Klapes and Vasely, Vapor-phase hydrogen peroxide as a surface decontaminant and sterilser, App Env Microbiol, 1990; 56:503-506. • Hubbard HF. 2006. Building disinfection chemistry: heterogeneous consumption of gaseous disinfecting agents and resulting by-product formation. PhD thesis. The University of Texas at Austin	
	Merit Total:	50 (M)
	Feasibility Total:	32 (M)

A.1.23 Building Disinfection via Chemical Cleaning- Hydrogen Peroxide Vapors				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.1.24 Building Disinfection via Chemical Cleaning - Aerosolized Chlorine Dioxide

Description and Review Aspect	Review	Score
Technology Description/ Scope	Chlorine dioxide is used to disinfect buildings contaminated with airborne biological pollutants and used as mold remediation in residences.	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Building interiors may contain large surfaces composed of complex materials, material compatibility to how the decontaminant vapors impact building materials within an enclosed building interior space is. • The use of ClO2 can corrode metal building materials. • Formation of chloroform and carbon tetrachloride after building disinfection using ClO2. These chemicals are toxic and carcinogenic.	8
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• ***Oxiperm® systems ALLDOS*** Eichler GmbH (http://www.grundfosalldos.com/e/html/09_presse/04_Chlordioxid.php) • ***Sabre Technical Services***, LLC (http://www.sabretechservices.com/)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	2
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Commercial size ventilation duct test manifold • Restoration (of oxidized materials) measures of facilities • Standardized dust dosing device • Standardized microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		
Time to complete		10

evaluation:		
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Hubbard HF. 2006. Building disinfection chemistry: heterogeneous consumption of gaseous disinfecting agents and resulting by-product formation. PhD thesis. The University of Texas at Austin	
	Merit Total:	54 (M)
	Feasibility Total:	32 (M)

A.1.24 Building Disinfection via Chemical Cleaning- Aerosolized Chlorine Dioxide

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.1.25 Indoor Passive Panels – Activated carbon media on indoor wall

Description and Review Aspect	Review	Score
Technology Description/ Scope	Activated carbon filtration media is installed on existing wall in a room to reduce exposures of VOCs, formaldehyde and ozone via passive reaction of indoor air and media surface.	
Target Contaminant (s)	• VOCs • Formaldehyde • Ozone • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the contaminants is ozone which is associated with premature mortality.	10
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Deposition velocity. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Disentanglement of loosely granulated carbon media may increase exposure to particulate matter to occupants. • Sorbed organic compounds will emit into the indoor space when saturated	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology (activated carbon media) is used mainly for induct and portable air cleaning devices which is widely available. But the application is here is via installation of pre-cut media in the indoor space and passive reaction of pollutants and media on wall.	6
Commercial examples (potential candidates for testing with new protocol)	• Gremarco Industries (http://www.gremarco.com/products.php)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 145.1** Laboratory test method for assessing the performance of gas-phase air cleaning systems: loss granular media • **ISO 16000-23** Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials • **ISO 16000-24** Performance test for evaluating the reduction of volatile organic compound (except formaldehyde) concentrations by sorptive building materials	
Protocol Gaps (Gaps or weaknesses)	• little assessment of lifetime performance	9
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Restoration (of oxidized materials) measures of facilities • Standardized VOC dosing device	8
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		

Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Kunkel et al. Passive reduction of human exposure to indoor ozone. Building and Environment. 2010. 45, 2: 445-452. • Sekine Y, Nishimura A. Removal of formaldehyde from indoor air by passive type air-cleaning materials. Atmospheric Environment 2001. 35, 11: 2001-2007.	
	Merit Total:	58 (H)
	Feasibility Total:	36 (H)

A.1.25 Indoor Passive Panels – Activated carbon media on indoor wall				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.1.26 Indoor Passive Panels – Leaching anti-microbial coating on indoor wall

Description and Review Aspect	Review	Score
Technology Description/ Scope	A biocide coating applied to on existing wall in a room to reduce exposures of bacteria, fungi, viruses and other biological agents via passive reaction of indoor air and media surface. Depending on types, coatings can leach very quickly (e.g. biocidal paints) or slowly (silver nanoparticles)	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • Viruses • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Deposition velocity.	10
Potential negative impacts (eg. harmful by-products?)	• Disentanglement of coatings via mechanical abrasion may render ineffective use of technology. • Particle pollution indoors may render the technology ineffective via surface accumulation over coating device. • Under certain conditions, an exudate can form on the surface of coating (leaching) • Some leachates are toxic chemicals, and washing cycles dilute these so that they are efficient for only a relatively short period. • The human health impacts of nano-silver are still largely unknown, but some studies and cases indicate that the nanomaterial has the potential to increase antibiotic resistance and potentially cause kidney and other internal problems. Silver is known to be toxic to fish, aquatic organisms and microorganisms.	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• General polymers (http://www.generalpolymers.com/products/technotes/4685w.pdf) • Biocote (http://www.biocote.com/default.asp)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Standardized biological dosing device • Standardized microbial dust dosing device	8
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8

New Facilities/equipment required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Dubosc et al. Characterization of biological stains on external concrete walls and influence of concrete as underlying material, Cement and Concrete Research 2001. 31, 11: 1613–1617.	
	Merit Total:	59 (M)
	Feasibility Total:	36 (H)

A.1.26 Indoor Passive Panels – Leaching anti-microbial coating on indoor wall				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.1.27 Indoor Passive Panels – Non-leaching anti-microbial coating on indoor wall

Description and Review Aspect	Review	Score
Technology Description/ Scope	A patented chemical biocide (3-Trimethoxy silyl propyl dimethyl octadecyl ammonium chloride - one end of this polymer has long molecular chain that acts like a sword and punctures the cell membranes of microbes (bacteria, mold, etc.), killing the microbes) applied to indoor walls, the coating acts like a protective layer of swords. The non-leaching chemical biocide material media is coated on existing wall in a room to reduce exposures of bacteria, fungi, viruses and other biological agents via passive reaction of indoor air and media surface.	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • Viruses • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Deposition velocity.	10
Potential negative impacts (eg. harmful by-products?)	• Disentanglement of coatings via mechanical abrasion may increase exposure to particulate matter to occupants. • Particle pollution indoors may render the technology ineffective via surface accumulation over coating device.	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• Aegis Microshield (http://aegismicrobeshield.com/impact/index.php)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Standardized biological dosing device • Standardized microbial dust dosing device	8
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10

Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information		
	Merit Total:	59 (M)
	Feasibility Total:	36 (H)

A.1.27 Indoor Passive Panels – Non-leaching anti-microbial coating on indoor wall				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.1.28 Indoor Passive Panels – PCO (photocatalytic oxidation) coating on indoor wall

Description and Review Aspect	Review	Score
Technology Description/ Scope	Titanium Dioxide (Oxide) UV-PCO coatings is applied on existing wall in a room to reduce indoor air exposures of chemical and biological agents via passive reaction of indoor air and media surface. The technology uses existing ultraviolet light in a room to the catalyst to produce primarily hydroxyl radicals (OH). These hydroxyl radicals are extremely reactive and can oxidize or "break down" typical VOC's and the cellular walls of microbes in indoor environments.	
Target Contaminant (s)	• VOCs • Formaldehyde • Airborne mould • Airborne bacteria • Viruses • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the contaminants is associated with VOCs that are carcinogenic, mutagenic or toxic related.	8
Application (Comm'l/Resid'l)	Residential and commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Deposition velocity.	10
Potential negative impacts (eg. harmful by-products?)	• Disentanglement of coatings via mechanical abrasion may increase exposure to particulate matter to occupants. • Particle pollution indoors may render the technology ineffective via surface accumulation over coating device. • PCO-UV technology can create ozone and its harmful by-products reactions via degradation of volatiles into formaldehyde, other aldehydes and secondary organic aerosols	10
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• Pureti (http://www.pureti.com/pclr_faq.html) • Enviroclean (http://www.teamenviroclean.com/home)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available • Measurements of ozone and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) has to be included in the test protocols	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	6
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Standardized biological dosing device • Standardized microbial dust dosing device • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • ETS generator fabrication	8

	• Disinfection measures of facilities • VOC generation system	
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		6
Related Scientific Literature / review information	• Taoda et al. VOC Decomposition by Photocatalytic Wall Paper. Materials Science Forum 2006; 510-511: 22-25. • Chen & Poon.. Photocatalytic construction and building materials: From fundamentals to applications. Building and Environment 2009. 44, 9: 1899-1906. • Chen et al. Photocatalytic cement-based materials: Comparison of nitrogen oxides and toluene removal potentials and evaluation of self-cleaning performance . Building and Environment 2011. In press.	
	Merit Total:	**60 (M)**
	Feasibility Total:	**36 (H)**

A.1.28 Indoor Passive Panels – PCO (photocatalytic oxidation) coating on indoor wall

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2 Commercial Applications

A.2.1 In-Duct Filtration Systems - Particulate matter (Mechanical, HEPA)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce aerosols concentrations via impaction onto fibrous media.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application	Commercial and residential applications	
Measurable (positive) impact (ie. basis for technol. labeling)	Particulate matter removal efficiency (of specific size classes)	8
Potential negative impacts (eg. harmful by-products?)	• Media and HEPA filters result in increased pressure drop and thus increased energy consumption. • Media and HEPA filter typically will undergo increased soiling over time – sensory pollution and formation of byproducts via reaction of sorbed organics with ozone.	7
Technology: Maturity / Development Stage	Multiple products in market with claimed benefit in reducing indoor levels of particulate contaminants	8
Commercial examples (potential candidates for testing with new protocol)	• ***Honeywell® HIGH EFFICIENCY FILTER*** Honeywell (http://www.longviewweb.com/honeywellfilters.htm#f100) • ***EZXCAB Performance Series*** Carrier (http://www.marinesystems.carrier.com/wcs/proddesc_display/0,2733,CLI1_DIV41_ETI4926_NBD_PRD647,00.html)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 52.1** Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter • **ASHRAE 52.2** Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size • **ASTM F1471** Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air- Filter System • **EN1822:** High Efficiency air filters (HEPA and ULPA). • **EN779:2002** Particulate filters for general ventilation: Determination of the filtration performance • **IEST-RP-CC001.4**: HEPA and ULPA Filters • **IEST-RP-CC021.2**: Testing HEPA and ULPA Filter Media • **IEST-RP-CC034.3:** HEPA and ULPA Filter Leak Testing	
Protocol Gaps (Gaps or weaknesses)	• Protocols/Standards widely used and accepted	X
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS, Grimm and TSI DustTrak system (same as 3.1) • Aerosol generator (same as 3.1) • Ozone monitor (same as 3.3) • GC-MS (same as 3.3) • HPLC (same as 3.3)	

Description and Review Aspect	Review	Score
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		2
Cost to complete evaluation:		10
Research Partnership Opportunities?		4
Related Scientific Literature / review information	• Hanley et al. Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners. Indoor Air 1994; 4: 169-178	
	Merit Total:	V
	Feasibility Total:	24 (L)

A.2.1 In-Duct Filtration Systems - Particulate matter (Mechanical: Media, HEPA)				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.2 In-Duct Filtration Systems - Particulate matter (Electret, Charged media)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filters which uses electrically charged flat or pleated fabric to attract airborne particles	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1, Der f 1, Fel d 1, Can f 1, Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Commercial and residential applications	
Measurable (positive) impact (ie. basis for technol. labeling)	Particulate removal efficiency (of specific size classes and/or allergen species)	8
Potential negative impacts (eg. harmful by-products?)	• Electret or charged media filter typically will undergo increased soiling over time – reduced performance.	2
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of particulate contaminants	8
Commercial examples (potential candidates for testing with new protocol)	• ***Polypropylene Electrostatic Air Filters & Pre-Filters*** (http://www.goodfiltercompany.com/electrostatic.html) •	
Existing assessment protocols (scope/coverage)	• **ASHRAE 52.2** Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size • **EN1822** standard for filtration • **EN779:2002** Particulate filters for general ventilation: Determination of the filtration performance • **IEST-RP-CC022.2:** Electrostatic Charge in Cleanrooms and Other Controlled Environments • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• The use of DOP and other challenge aerosols inn testing (health concerns and unrepresentative) • No assessment of particles below 80nm.	4
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS APS, DustTrak and Grimm system (same as 3.1) • Aerosol generator (same as 3.1) • Ozone monitor (same as 3.3) • GC-MS (same as 3.3) • HPLC (same as 3.3)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1)	8

Description and Review Aspect	Review	Score
New Facilities/equipment required: c) technology		
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		8
Related Scientific Literature / review information	• Hanley JT, Owen MK. Development of a new conditioning aerosol for testing electret filters. ASHRAE Transactions 2005: 110; 1115-1125. • Hanley et al. Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners. Indoor Air 1994; 4: 169-178 • Myers & Arnold. Electret media for HVAC filtration applications. INJ Winter 2003: 43-54.	
	Merit Total:	50 (M)
	Feasibility Total:	26 (L)

A.2.2 In-Duct Filtration Systems - Particulate matter (Electret, Charged Media)				
Merit	H	III	IV	V
	M	II	III	IV
	L	I	II	III
		L	M	H
		Feasibility		

A.2.3 In-Duct Filtration Systems - Particulate matter (Electrostatic precipitation)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce aerosols via electrostatic precipitation in single or dual stage.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1*, *Der f 1*, *Fel d 1*, *Can f 1*, *Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Commercial and residential applications	
Measurable (positive) impact (ie. basis for technol. labeling)	Particulate removal efficiency (of specific size classes and/or allergen species)	10
Potential negative impacts (eg. harmful by-products?)	• Electronic filter units can generate ozone and subsequently its by-products: assessment protocol should screen for formation of ozone, irritants, etc. • Collected particles on plates can be re-entrained into the air stream if no 'rapping' mechanism is provided.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of particulate contaminants	8
Commercial examples (potential candidates for testing with new protocol)	• ***Honeywell Electronic Air Cleaners*** (various models) (http://yourhome.honeywell.com/Consumer/Cultures/en-US/Products/Air+Cleaners/Electronic/Default.htm)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 52.2** Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size • **EN1822** standard for filtration • **EN779:2002** Particulate filters for general ventilation: Determination of the filtration performance • **IEST-RP-CC022.2:** Electrostatic Charge in Cleanrooms and Other Controlled Environments • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• The adoption of ANSI/ASHRAE 52.2 is not compatible with the loading dust test. Dust contains very conductive carbon that may cause electrical shorting. • The use of DOP and other challenge aerosols in testing (health concerns and unrepresentative) • Measurements of ozone (generated by ESP) and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test protocols • Not all particles can be charged to be subsequently collected on plates. No protocol has addressed this. • No assessment of particles below 80nm.	10
Labeling support	• Has the potential to label products for green product, energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability,	• Particle monitoring: TSI SMPS, DustTrak and Grimm system (same as 3.1) • TSI aerosol generator (same as 3.1)	

Description and Review Aspect	Review	Score
status)	• Ozone monitor (same as 3.1) • GC-MS (same as 3.1) • HPLC (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	6
New Facilities/equipment required: b) ***analytical***	• Ozone monitors (same as 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1)	4
New Facilities/equipment required: c) technology		
Time to complete evaluation:		6
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Hanley et al. Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners. Indoor Air 1994; 4: 169-178 • Morawska et al. Effect of face velocity and the nature of aerosol on the collection of submicrometer particles by electrostatic precipitator. Indoor Air 2002; 12:129-137 • Mainelis et al. Collection of airborne microorganisms by a new electrostatic precipitator. Aerosol Science 2002; 33: 1417-1432.	
	Merit Total:	56 (M)
	Feasibility Total:	26 (M)

A.2.3 In-Duct Filtration Systems - Particulate matter (Electrostatic Precipitation)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.4 In-Duct Filtration Systems - Particulate matter (Ion generators)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce aerosols via negative ion technologies by itself or with in conjunction with charged/non charged low efficiency filters.	
Target Contaminant (s)	1. Particulate matter (outdoor combustion) 2. Particulate matter (ETS) 3. Airborne bacteria 4. Airborne mould spores 5. Allergens (*Der p 1*, *Der f 1*, *Fel d 1*, *Can f 1*, *Bla g 1*)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases • Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Asthma and allergies	10
Application (Comm'l/Resid'l)	Commercial and residential applications	
Measurable (positive) impact (ie. basis for technol. labeling)	Particulate removal efficiency (of specific size classes and/or allergen species)	8
Potential negative impacts (eg. harmful by-products?)	• Ion generators can generate ozone and subsequently react with other VOCs to form harmful by-products: assessment protocol should screen for formation of ozone, irritants, etc. • A variety of negative ion generator-type is available. The simplest types use static charges to remove particles from indoor air. They operate by charging the particles in a room, which become attracted to and deposit on walls, floors, table tops, curtains, occupants, etc., where they may cause soiling problems.	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of particulate contaminants	8
Commercial examples (potential candidates for testing with new protocol)	• ***Duct Air ionizer 720*** Allied Enterprise (http://www.buenisima.com/item547.htm)	
Existing assessment protocols (scope/coverage)	• **ASTM F1471** Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air- Filter System • **EN1822** standard for filtration • **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• Measurements of ozone (generated by ion generators) and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) not included in the test protocols • The use of DOP and other challenge aerosols in testing (health concerns and unrepresentative) • Not all particles can be charged and thus efficiency of device may be affected. No protocol has addressed this. • No assessment of particles below 80nm.	8
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS, DustTrak and Grimm system (same as 3.1) • TSI aerosol generator (same as 3.1) • Ozone monitor (same as 3.1) • GC-MS (same as 3.1) • HPLC (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model).	4

Description and Review Aspect	Review	Score
	• ETS generator fabrication • Disinfection measures of facilities	
New Facilities/equipment required: b) ***analytical***	• Ozone monitors (same as 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers (for allergen sampling) (same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Daniels . On the ionization of air for removal of noxious effluvia. IEEE Transactions on plasma Science 2002; 30: 1471-1481. • Wu et al. Effect of wall surface materials on deposition of particles with the aid of negative air ions. Aerosol Science 2006; 37; 616-630. • Liu et al. Effect of wire heating and configuration on ozone emission in a negative ion generator. Journal of Electrostatics 2000; 48: 81-91. • Huang et al. Removable of viable bioaerosol particles with a low efficiency HVAC filter enhanced by continuous emission of unipolar air ions. Indoor Air 2008; 8: 106-112.	
	Merit Total:	52 (M)
	Feasibility Total:	26 (M)

A.2.4 In-Duct Filtration Systems - Particulate matter (Ion generators)				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.5 In-Duct Filtration Systems – Germicidal UV

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce bioaerosols concentrations via UV irradiation	
Target Contaminant (s)	1. Airborne Bacteria 1. Airborne Fungi 2. Virus 3. Allergens	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Respiratory infections • Asthma and allergies	7
Application (Comm'l/Resid'l)	Commercial and residential applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies (upstream vs downstream of air samples) • Removal efficiencies (before vs after of air, surface swabs and settle plate samples) • UVGI Rating Value (URV) - a scale for rating UVGI air treatment systems based on the dose produced. • Germicidal dose – portion of exposure to the UV spectrum that is germicidal. • Building Protection Factor (BPF) – to define the effectiveness of a building air cleaning system in terms of % of occupants theoretically protected from infection.	8
Potential negative impacts (eg. harmful by-products?)	• UV technology can create the same harmful effects to the skin and eyes of humans if no protection is in place. • Some UVGI devices produce ozone which is a pollutant associated with negative health outcomes and capable of producing harmful by-products such as formaldehyde and SOA	10
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor air and surface levels of bacteria, fungi, virus and alleviating health problems. Used commonly in hospital and health-care settings, but products for commercial and residential applications are available.	8
Commercial examples (potential candidates for testing with new protocol)	• ***80W UVC Induct Duel Lamp Air Sanitizer*** Ionic Zone (http://www.ioniczone.com/UVC-Induct-Air-Sanitizer-p/iz-uv72.htm) • ***Honeywell UV various models*** Honeywell (http://www.nextag.com/Honeywell-UV100E3007-UV-Surface-84802954/prices-html)	
Existing assessment protocols (scope/coverage)	• **IUVA-GO1A** General Guideline for UVGI Air and Surface Disinfection Systems (Draft) • **IUVA-GO2A** Guideline for Design and Installation of UVGI Air disinfection Systems in New Building Construction (Draft) • **IUVA-GO3A** Guideline for Design and Installation of UVGI In-Duct Air Disinfection Systems (Draft) • **IUVA-GO4A** Guideline for Design and Installation of UVGI Cooling Coil Air Disinfection Systems (Draft) • **IUVA-GO5A** Guideline for Design and Installation of UVGI Unitary Recirculation Air Disinfection Systems (Draft) • **IUVA-SO1A** Standard for the Test and Commissioning of UVGI In-Duct Air Treatment Systems (Draft) • **IUVA-SO2A** Standard for the Test and Commissioning of UVGI Cooling Coil Disinfection Systems (Draft) • **IUVA-SO3A** Standard for the Test and Commissioning of UVGI Unitary Recirculation Unit Systems (Draft) • **IUVA-SO5A** Standard for the Testing of UVGI Surface Disinfection Systems (Draft) • **IUVA-SO6A** Standard for Laboratory Testing of UVGI Air and Surface Rate Constants (Draft)	
Protocol Gaps (Gaps or weaknesses)	• Standardized UV methods are in draft format and have not been ratified. • Ozone emissions of UV devices is not assessed • Endotoxins, exotoxins and mycotoxins exposure reductions are not addressed.	8
Labeling support	• Has the potential to label products for energy saving potential and fulfill min	10

Description and Review Aspect	Review	Score
	requirements of new protocol regulations	
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chambers • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system • Particle monitoring: Grimm system • TSI aerosol generator	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Andersen 6-stage viable samplers (same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		8
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Brickner et al. The application of ultraviolet germicidal irradiation to control transmission of airborne disease: Bioterrorism countermeasure. Public Health Reports 2003; 118: 99-118. • Bahnfleth et al. Standard and guideline requirements for UVGI air treatment systems. Proceedings of Indoor Air 2005. 3464-3468. • Levetin et al. Effectiveness of germicidal UV radiation for reducing fungal contamination within Air-Handling units. Applied and Environmental Microbiology 2001; 67: 3712-3715. • Kowalski WJ. Immune building systems technology. McGraw-Hill, New York. 2003.	
	Merit Total:	55 (M)
	Feasibility Total:	30 (M)

A.2.5 In-Duct Filtration Systems– Germicidal UV

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.6 In-Duct Filtration Systems – Anti-microbial coated filters[8]

Description and Review Aspect	Review	Score
Technology Description/ Scope	Filtration devices in ducts used to reduce bioaerosols concentrations via anti-microbial coated filters	
Target Contaminant (s)	1. Airborne Bacteria 2. Airborne Fungi 3. Virus 4. Particulate matter (outdoor combustion) 4. Particulate matter (ETS)	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms • Asthma, allergies and respiratory symptoms • Respiratory infections • premature mortality • Carcinogen, Asthma, allergies and respiratory symptoms	10
Application (Comm'l/Resid'l)	Commercial and residential applications	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies	8
Potential negative impacts (eg. harmful by-products?)	• Dislodgement of coating agents from filter surfaces and getting into the airstream to be distributed into the indoor space (e.g. nanoparticle coating). • Anti-microbial coatings can contain chemicals that are terpene based (e.g. tea tree oil, essential oils). These can react with outdoor ozone coming into the HVAC systems and form harmful by-products. • The human health impacts of nano-silver are still largely unknown, but some studies and cases indicate that the nanomaterial has the potential to increase antibiotic resistance and potentially cause kidney and other internal problems	8
Technology: Maturity / Development Stage (current market demand / potential)	Multiple products in market with claimed benefit in reducing indoor levels of bacteria, fungi, virus and alleviating health problems. Used commonly in hospital and health-care settings	8
Commercial examples (potential candidates for testing with new protocol)	• ***VariCel V ULTRA: MERV 15 Double Header with Antimicrobial.*** AmericanAirFilter , AAF. (http://www.aafintl.com/Products/Replacement%20HVAC%20Filtration/High%20Efficiency%20Supported%20Pleated%20Filters/VariCel%20V/VariCel%20V.aspx)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• Current standards deal with mechanical filtration per se and not representative of protocol evaluation for anti-microbial filters. e.g. • Challenge aerosols are inanimate (e.g. DOP is used instead of bioaerosol). • Lack of standardized testing protocols for anti-microbial filters.	10
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chambers • M24D • Hut3	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system • Particle monitoring: Grimm system • TSI aerosol generator	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • Disinfection measures of facilities	4
New Facilities/equipment	• Particle monitoring: TSI APS system (same as 3.1)	8

[8] Most anti-microbial coatings can leach over time. Silver nano-particle is also used as an anti-microbial coating.

Description and Review Aspect	Review	Score
required: b) ***analytical***	• Andersen 6-stage viable samplers (same as 3.1)	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Foarde & Hanley. Determine the efficacy of antimicrobial treatments of fibrous air filter. ASHARE Transactions 2001; 107: 156-170. • Pyankov et al. Removal of biological aerosols by oil coated filters. CLEAN 2008; 36: 609-614.	
	Merit Total:	58 (M)
	Feasibility Total:	26 (M)

A.2.6 In-Duct Filtration Systems – Anti-microbial coated filters

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*III*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.7 In-Duct Filtration Systems – Gas phase (sorption) [9]

Description and Review Aspect	Review	Score
Technology Description/ Scope	Office level removal of gaseous pollutant contamination via in duct air cleaning device using physical as well as chemi-sorption.	
Target Contaminant (s)	1. VOCs, formaldehyde 2. Ozone 3. Nitrogen dioxide	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms, carcinogenic and toxic for different VOCs • Premature mortality and morbidity (e.g. asthma, allergies, respiratory and diseases) • Asthma, allergies and respiratory symptoms	10
Application (Comm'l/Resid'l)	Commercial and residential application	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies	10
Potential negative impacts (eg. harmful by-products?)	• Microorganisms prefer to adhere to solid supports made of carbon materials,, thus, carbon filters have high biocompatibility (i.e. microorganism may multiply on carbon based filters become a source of bioaerosols. • Breakthrough or desorption of captured gaseous contaminants may increase indoor concentrations	9
Technology: Maturity / Development Stage (current market demand / potential)	• Multiple products and established in market	6
Commercial examples (potential candidates for testing with new protocol)	• ***Trion OEM Charcoal Pre-Filter*** (http://www.filtersusa.com/results.cfm?categoryid=17) • ***OEM Carbon Filter*** Electro-Air (http://www.filtersusa.com/results.cfm?categoryid=13) • ***Charcoal / Carbon Vapor Air Filters*** Good Filter company (http://www.goodfiltercompany.com/charcoal.html)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 145.1** Laboratory test method for assessing the performance of gas-phase air cleaning systems: loss granular media • **ASHRAE SPC 145.2P** Laboratory Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Air Cleaning Devices (proposed) • **ASHRAE SPC 145.3P** Field Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Installed Systems (proposed)	
Protocol Gaps (Gaps or weaknesses)	• Single VOCs challenge versus multiple VOCs challenge. • Breakthrough (via environmental impacts) and regeneration tests in protocols not established. • Soiling of carbon filters	10
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations (for adsorption principle)	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Porosimitry analyzer? • Ozone monitor (same as 3.3) • GC-MS (same as 3.3) • HPLC (same as 3.3) • Particle monitoring: TSI SMPS, DustTrak and Grimm system (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4

[9] Adsorption (e.g activated carbon, charcoal etc) or chemisoprtion (e.g. impregnated with $KmnO_4$)

New Facilities/equipment required: b) ***analytical***	• ozone monitor (same as 3.3) • ozone calibrator (same as 3.3) • NO/NO2 monitor (same as 3.3) • NO/NO2 calibrator (same as 3.3) • Particle monitoring: TSI APS system(same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Howard-Reed etal – Characterizing gaseous air cleaner performance in the field. Building and Environment. 2008; 43, 3: 368-377 • Axley JW. Tools for the analysis of gas phase air cleaning systems in building. ASHRAE Transactions 1994; 100: 1130-1146. • Weschler et al. Ozone removal efficiencies of activated carbon filters after more than three years of continued service. ASHARE Transactions 1994; 100: 1121-1129. • Yoon et al. Antimicrobial effect of silver particles on bacterial contamination of activated carbon fibers. Environmental Science & Technology 2008; 42: 1251-1255.	
	Merit Total:	59 (M)
	Feasibility Total:	26 (M)

A.2.7 In-Duct Filtration Systems – Gas phase (sorption)

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.8 In-Duct Filtration Systems – Gas phase (photocatalytic oxidation)

Description and Review Aspect	Review	Score
Technology Description/ Scope	Office level removal of gaseous pollutant contamination via in duct air cleaning device using catalytic principles.	
Target Contaminant (s)	1. VOCs including those from ETS 2. Formaldehyde 3. Ozone 4. Nitrogen dioxide	
Health Impact of target contaminant(s)	• Asthma and respiratory symptoms, carcinogenic and toxic for diff VOCs • Asthma, allergies and respiratory symptoms • Premature mortality and morbidity (e.g. asthma, allergies, respiratory and diseases) • Asthma, allergies and respiratory symptoms	10
Application (Comm'l/Resid'l)	Commercial and residential application	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies	10
Potential negative impacts (eg. harmful by-products?)	• Ozone formation and subsequently its by-products of reactions with unsaturated organics: assessment protocol should screen for formation of ozone, irritants, etc. • Water vapor can compete in TiO_2 sites to reduce filtration efficiency.	10
Technology: Maturity / Development Stage (current market demand / potential)	• It is still a new technology that is strongly marketed by vendors	4
Commercial examples (potential candidates for testing with new protocol)	• ***Air Oasis ACT InDuct Air Purifier*** My Air Purifier (http://www.my-air-purifier.com/site/678219/product/AO-ACT) • ***AirGorilla™*** (http://www.filtrationmanufacturing.com/AirGorilla.htm)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols found – the closest applicable protocol deals with gaseous pollutant removal using loose granulated media • Single VOCs challenge versus multiple VOCs challenge (cross-interferences).	10
Labeling support	• Has the potential to label products for energy saving potential and fulfill min requirements of new protocol regulations (for adsorption principle)	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room(s) for particle level monitoring) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Ozone monitor (same as 3.3) • GC-MS (same as 3.2) • HPLC (same as 3.2) • Particle monitoring: TSI SMPS, DustTrak and Grimm system (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard Model). • ETS generator fabrication • Disinfection measures of facilities	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (same as 3.3) • ozone calibrator (same as 3.3) • NO/NO2 monitor (same as 3.3) • NO/NO2 calibrator (same as 3.3) • Particle monitoring: TSI APS system(same as 3.1)	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		8
Cost to complete evaluation:		10

Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Chen WH, Zhang JS. UV-PCO device for indoor VOCs removal: Investigation on multiple compounds effect. Building and Environment 2008; 43: 246-252. • Hodgson et al. Performance of ultraviolet photocatalytic oxidation for indoor air cleaning applications. Indoor Air 2007; 17: 305-316 • Mo et al. Photocatalytic purification of volatile organic compounds in indoor air: A literature review. Atmospheric Environment 2009. 43, 14: 2229-2246.	
	Merit Total:	56 (M)
	Feasibility Total:	26 (M)

A.2.8 In-Duct Filtration Systems – Gas phase (photocatalytic oxidation)				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.9 Desiccant Wheel-Dry

Description and Review Aspect	Review	Score
Technology Description/ Scope	Heat recovery /Energy recovery	
Target Contaminant (s)	1. Moisture levels 2. VOCs	
Health Impact of target contaminant(s)	• Asthma, allergies and respiratory diseases via moisture associated problems • some VOCs are carcinogenic	9
Application (Comm'l/Resid'l)	Commercial application	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after measurements	10
Potential negative impacts (eg. harmful by-products?)	• Leakage of contaminants from exhaust stream to supply stream • Cross-contamination via transfer of adsorbed VOCs into the supply air stream. • Potential for over-drying of indoor air • Associated with poor acoustical performance. • Energy costs associated with realistic operation • Cleanliness of components • Regeneration of desiccant materials	8
Technology: Maturity / Development Stage	Products available in market	8
Commercial examples (potential candidates for testing with new protocol)	•	
Existing assessment protocols (scope/coverage)	• **ASHRAE Standard 139** Method of testing for rating desiccant dehumidifiers utilizing heat for the regeneration process.	
Protocol Gaps (Gaps or weaknesses)	• Climatic zones for appropriate use • Cleanliness protocols of installed and used device are not available.	8
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• M24D	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system, APS, DustTrak • Ozone monitor • Humidity Sensors • CO_2 and VOC monitoring • Allergen/biocontaminant testing if benefit claimed	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts. • Large opening for placement of wheel	4
New Facilities/equipment required: b) ***analytical***	• Same as 3.1 • Same as 3.3	8
New Facilities/equipment required: c) technology	Purchase of selected wheel units	
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities		4
Related Scientific Literature / review information	• Fang, et al, A. Desiccant wheels as gas-phase absorption (GPA) air cleaners: evaluation by PTR-MS and sensory assessment: Indoor Air: 18,: 5: 375-385, 2008. • Popescu M, Ghosh TK. 1999. Dehumidification and simultaneous removal of selected pollutants from indoor air by a desiccant wheel using a 1M type desiccant, Journal of Solar Energy Engineering. 121: 1–13.,	
	Merit Total:	**51 (M)**

Description and Review Aspect	Review	Score
	Feasibility Total:	26 (M)

A.2.9 Desiccant Wheel-Dry				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.10 Desiccant Wheel-Wet

Description and Review Aspect	Review	Score
Technology Description/ Scope	Heat recovery /Energy recovery	
Target Contaminant (s)	1. Moisture levels 2. VOCs	
Health Impact of target contaminant(s)	• Asthma, allergies and respiratory diseases via moisture associated problems • some VOCs are carcinogenic	9
Application (Comm'l/Resid'l)	Commercial	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after measurements	10
Potential negative impacts (eg. harmful by-products?)	• Leakage of contaminants from exhaust stream to supply stream • Potential for over-drying of indoor air • Associated with poor acoustical performance. • Energy costs associated with realistic operation • Cleanliness of components	8
Technology: Maturity / Development Stage	Products available in market	8
Commercial examples (potential candidates for testing with new protocol)	•	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available.	8
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	4
IRC Research Facilities: a) ***mechanical*** (availability, status)	• M24D	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system, APS, DustTrak • Ozone monitor • Humidity Sensors • CO_2 and VOC monitoring • Allergen/biocontaminant testing if benefit claimed	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts. • Large opening for placement of wheel	4
New Facilities/equipment required: b) ***analytical***	• Same as 3.1 • Same as 3.3	8
New Facilities/equipment required: c) technology	Purchase of selected wheel units	
Time to complete evaluation:		4
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Chung et al. Removal of selected pollutants from air during dehumidification by lithium chloride and triethylene glycol solutions. ASHRAE transactions. 1993. Part 1: 834-841.	
	Merit Total:	51 (M)
	Feasibility Total:	26 (M)

A.2.10 Dssiccant Wheel-Wet				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.11 HRV & ERV

Description and Review Aspect	Review	Score
Technology Description/ Scope	Heat recovery ventilator/Energy recovery ventilator for commercial buildings. These are normally bigger than residential units.	
Target Contaminant (s)	1. All airborne contaminants via dilution 2. Moisture levels (esp w ERV systems) 3. PM levels (w optional HEPA filters) 4. Biocontaminants (w optional UV lamps …) 5. Radon (promoted use of HRVs by EPA)	
Health Impact of target contaminant(s)	• Premature mortality and morbidity via PM (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases via moisture associated problems • Asthma, allergies and respiratory symptoms via biocontaminants • Cancer via Radon exposure • Asthma, allergies, respiratory and SBS symptoms via dilution of indoor contaminants	10
Application (Comm'l/Resid'l)	Commercial application	
Measurable (positive) impact (ie. basis for technol. labeling)	• Removal efficiencies • Contaminant transfer ratio	10
Potential negative impacts (eg. harmful by-products?)	• Leakage of contaminants from exhaust stream to supply stream (possibly greater risk for ERV) • Off gassing of device into supply stream (from core materials or from PVC ductwork if used) • Potential for over-drying of indoor air • With ERV – pollutant transfer across membrane reduces ventilation effectiveness • Use of HRV/ERV is associated with poor acoustical performance. • Energy costs associated with realistic (seasonal) operation (vs. standardized test conditions) • Cleanliness of components • Poor air distribution	8
Technology: Maturity / Development Stage	Multiple products in market	8
Commercial examples (potential candidates for testing with new protocol)	• Broan • Imperial Air • Lennox • Nu-Air • Nutech • Venmar	
Existing assessment protocols (scope/coverage)	• **AHRI 1060-2005** Performance *Rating of Air-To-Air Exchangers for Energy Recovery Ventilation* • **ASHRAE 84-1991** Method of Testing Air-to-Air Heat Exchangers • **CSA C439-09** *Standard Laboratory Methods of Test for Rating the Performance of Heat/Energy-Recovery Ventilators (R2005)* • **CSA C22.2 No. 113-08** *Fans and Ventilators*	
Protocol Gaps (Gaps or weaknesses)	• Climatic zones for appropriate use of HRV,ERV (Aluminium core in HRV for maximum "sensible" recovery; Energy recovery core for enhanced "latent" recovery – ERV is not recommended for climates where temp drops below 25^0C) • Current protocols are designed for "off the shelf" testing of HRV. There are no HRV protocols in place to determine effectiveness of optional IAQ sensors; indoor humidity and pollutants levels indoors (especially PM, radon); control features: adjustable flows/pressure and flow balancing systems; certified air change; ventilation effectiveness and distribution efficiency of installed system. • Cleanliness protocols of installed and used HRV are not available.	8
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D • Ventilation and Walls Research house	

Description and Review Aspect	Review	Score
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system, APS, DustTrak • Ozone monitor • Humidity Sensors • CO_2 and VOC monitoring • Allergen/biocontaminant testing if benefit claimed	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard Model). • Installations of supply and return ducts.	10
New Facilities/equipment required: b) ***analytical***	• Same as 3.1 • Same as 3.3	8
New Facilities/equipment required: c) technology	Purchase of selected HRV/ERV units	
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	Canadian manufacturers may be interested in product development opportunities (and marketing of "approved" devices)	10
Related Scientific Literature / review information	• Ouazia et al. Assessment of the enthalpy performance of houses using the nergy recovery technology. ASHRAE Transactions 2007; 112:1-11. • Zhou et al. Performance of energy recovery ventilator with various weathers and temperature set-points. Energy and Buildings 2007: 39: 1202-1210 • Marsik T, Johnson R. Use of Simulink to evaluate the air-quality and energy performance of HRV-equipped residences in Fairbanks, Alaska. Energy and Buildings 2008; 40: 1605-1613	
	Merit Total:	64 (H)
	Feasibility Total:	38 (H)

A.2.11 HRV & ERV

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.12 Professional Cleaning – Carpet and Upholstery Cleaning

Description and Review Aspect	Review	Score
Technology Description/ Scope	Professional procedures for appearance retention and soil remove of carpet and upholstery, and environmental quality indoors.	
Target Contaminant (s)	1. VOCs 2. Formaldehyde 3. Odors 4. Debris	
Health Impact of target contaminant(s)	• Asthma, allergies and respiratory diseases via debris associated exposures • Asthma and respiratory symptoms via VOCs exposures • Asthma, allergies and respiratory symptoms via formaldehyde exposures • Poor perceived air quality	9
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality • Before and after evaluation of dust deposits on carpet/upholstery surfaces	10
Potential negative impacts (eg. harmful by-products?)	• Carpet and upholstery care emissions amount to about 1.07 tonnes of VOC per day (32 tonnes per day per person) • Chemicals used maybe harmful to human health • IAQ problems associated with incomplete drying after cleaning problems	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology/Process is available with claimed benefits of improved IAQ, productivity and health outcomes	6
Commercial examples (potential candidates for testing with new protocol)	• VProcare (http://www.vprocare.com/index.asp) • Peters carpet cleaning (http://www.peterscarpetcleaning.com/index.html) • Dryex (http://www.dryex.com/index.html)	
Existing assessment protocols (scope/coverage)	• ***IICRC S100*** Standard Reference Guide for Professional Carpet Cleaninq - 2002 • ***IICRC S300*** Standard and Reference Guide for Professional Upholstery Cleaning - 2000	
Protocol Gaps (Gaps or weaknesses)	• Current protocols focus on techniques, remediation, and preventative maintenance (qualitative in nature) only and do not relate to the improvement of IAQ after cleaning activities.	8
Labeling support	• Has the potential to label products/services for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)		
IRC Research Facilities: b) ***analytical*** (availability, status)	• Ozone monitor (same as 3.3) • GC-MS (same as 3.3) • HPLC (same as 3.3) • Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Disinfection measures of facilities • Standardized contaminant dosing device	8
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8

New Facilities/equipment required: c) technology		
Time to complete evaluation:		6
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		6
Related Scientific Literature / review information	• Vojta et al. Effects of physical interventions on house dust mite allergen levels in carpet, bed, and upholstery dust in low-income, urban homes. Environmental Health Perspectives 2001; 109: 815-819. • Roberts et al. A pilot study of the measurement and control of deep dust, surface dust, and lead in 10 old carpets using the 3-spot test while vacuuming. Archives of Environmental Contamination and Toxicology 2005; 48: 16-23. • Franke et al. Cleaning for Improved Indoor Air Quality: an Initial Assessment of Effectiveness. Indoor Air 1997. 7, 1: 41-54.	
	Merit Total:	58 (M)
	Feasibility Total:	34 (M)

A.2.12 Professional Cleaning – Carpet and Upholstery Cleaning

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.13 Professional Cleaning – Water Damage Restoration and Mold Remediation

Description and Review Aspect	Review	Score
Technology Description/ Scope	Professional procedures for water damage restoration and mold remediation for improved environmental quality indoors.	
Target Contaminant (s)	1. Mold 2. Bacteria 3. VOCs (mVOCs) 4. Odors 5. Airborne particulate matter /debris	
Health Impact of target contaminant(s)	• The highest risk posed by associated contaminant is molds that are associated with toxic outcomes.	7
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality • Before and after evaluation of biological contaminations on surfaces	8
Potential negative impacts (eg. harmful by-products?)	• Although source removal is the primary means of remediation, indiscriminate use of cleaning chemicals/biocides/anti-microbial coatings of unknown health effects are regularly used. • IAQ problems associated with incomplete drying/removal (secondary problems) after restoration/remediation.	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology/Process is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• VProcare (http://www.vprocare.com/index.asp) • Peters carpet cleaning (http://www.peterscarpetcleaning.com/index.html) • Dryex (http://www.dryex.com/index.html)	
Existing assessment protocols (scope/coverage)	• ***IICRC S500*** Standard and reference guide for professional water damage restoration • ***IICRC S520*** Standard and reference guide for professional mold remediation	
Protocol Gaps (Gaps or weaknesses)	• Current protocols focus on techniques, remediation, and preventative maintenance (qualitative in nature) only and do not relate to the improvement of IAQ after cleaning activities. • Abrasive cleaning methods could aerosolize settled dust, leading to high concentrations of mold (and bacterial) spores in indoor environments. • Expectations of a remediation maybe deemed successful if it fulfilled the technical criteria but unsuccessful if level of discomfort and/or health symptoms may not have been reduced. • There is no consensus of the target contaminants reduction levels set to evaluate success of remediation.	6
Labeling support	• Has the potential to label products/services for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)		
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS (same as 3.3) • HPLC (same as 3.3) • Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Room size test • Disinfection measures of facilities • Standardized duct dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3)	8

	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		6
Cost to complete evaluation:		4
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		8
Related Scientific Literature / review information	• Haverinen-Shaughnessy et al. Monitoring success of remediation: Seven case studies of moisture and mold damaged buildings. Science of The Total Environment 2008; 399: 19-27. • Huttunen et al. Indoor air particles and bioaerosols before and after renovation of moisture-damaged buildings: The effect on biological activity and microbial flora. Environmental Research 2008; 107: 291-298. • Barnes et al. Comparison of indoor fungal spore levels before and after professional home remediation. Annals of Allergy Asthma Immunology 2007; 98(3): 262-268.	
	Merit Total:	58 (M)
	Feasibility Total:	22 (L)

A.2.13 Professional Cleaning – Water Damage Restoration and Mold Remediation

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.14 Professional Cleaning – General Duct Cleaning

Description and Review Aspect	Review	Score
Technology Description/ Scope	General duct cleaning technology is the mechanical removal of dirt, debris and other materials found in the ductwork and HVAC components.	
Target Contaminant (s)	1. Airborne particulate matter 2. Debris 3. VOCs 4. Formaldehyde 5. Odors	
Health Impact of target contaminant(s)	• Premature mortality and morbidity via PM (e.g. asthma, allergies, respiratory and cardiovascular diseases) • Asthma, allergies and respiratory diseases via debris associated exposures • Asthma and respiratory symptoms via VOCs exposures • Asthma, allergies and respiratory symptoms via formaldehyde exposures • Poor perceived air quality	10
Application (Comm'l/Resid'l)	Commercial and residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality • Before and after evaluation of dust deposits in ductwork	10
Potential negative impacts (eg. harmful by-products?)	• Aggregated dust and debris on the ductwork by the mechanical cleaning may be aerosolized into finer particles that can remain airborne over long periods. • Mechanical cleaning may damage ductwork	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology is widely available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• Power Vac G.T.A., Ltd. (www.powervac.ca) Toronto • Enviro Plus Duct Cleaning Ltd. (www.enviroplusductcleaning.com) Brockville • Francis H.V.A.C. Services Ltd (gillesallaire@francishvac.ca) Ottawa • AWS Remediation Technologies Inc. (www.awstech.com) Ottawa	
Existing assessment protocols (scope/coverage)	• ***NADCA ACR- 2006***. Assessment, cleaning and restoration of HVAC systems. NADCA National air duct cleaners association. Washington, D.C • ***HVCA TR/17*** – Guide to good practice cleanliness of ventilation systems. HVCA Publication TR/17. • ***NAIMA***-Cleaning Fibrous Glass Insulated Air Duct Systems, Recommended Practice 1993.	
Protocol Gaps (Gaps or weaknesses)	Protocols did not include indoor air quality evaluations.	8
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	•	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Ozone monitor (same as 3.2) • GC-MS (same as 3.2) • HPLC (same as 3.2) • Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard model) • Disinfection measures of facilities • Standardized duct dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3)	8

	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		8
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	IRSST	8
Related Scientific Literature / review information	• Luoma et al. Duct cleaning – a literature survey. Air Infiltration Review 1993; 14: 1-5. • Brosseau et al. Methods and criteria for cleaning contaminated ducts and air-handling equipment. ASHRAE Transactions 2000a; 106: 188-199 • Zuraimi MS. 2010. Is ventilation duct cleaning useful? A review of the scientific evidence. Indoor Air. 20: 443-529.	
	Merit Total:	65 (H)
	Feasibility Total:	30 (M)

A.2.14 Professional Cleaning – General Duct Cleaning

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.15 Professional Cleaning – General Duct Cleaning with Biodecontamination

Description and Review Aspect	Review	Score
Technology Description/ Scope	General duct cleaning technology which includes removal of dirt, debris and other materials found in the ductwork and HVAC components followed by disinfection procedures.	
Target Contaminant (s)	1. Airborne Particulate Matter and Debris 2. Airborne bacteria 3. Airborne mould 4. Dustborne bacteria 5. Dustborne mould 6. Allergens	
Health Impact of target contaminant(s)	• Mortality outcomes, asthma, allergies and respiratory diseases via PM and debris exposures	10
Application (Comm'l/Resid'l)	Commercial and residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality • Before and after evaluation of dust deposits in ductwork	10
Potential negative impacts (eg. harmful by-products?)	• Aggregated dust and debris on the ductwork by the mechanical cleaning may be aerosolized into finer particles that can remain airborne over long periods. • Mechanical cleaning may damage ductwork • Some biocides used may be harmful to health, can participate in surface chemistry to generate formaldehyde and harmful by-products (essential oils) • Duct cleaning could r a stir-up settled dust, including mould spores, leading to peak concentrations of mould (and bacterial) spores in indoor environments, directly after the cleaning procedure	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology is widely available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• Superior Air Duct Cleaning (http://www.superioradc.com/) Missisauga • Francis H.V.A.C. Services Ltd (gillesallaire@francishvac.ca) Ottawa • AWS Remediation Technologies Inc. (www.awstech.com) Ottawa	
Existing assessment protocols (scope/coverage)	• ***NADCA ACR- 2006***. Assessment, cleaning and restoration of HVAC systems. NADCA National air duct cleaners association. Washington, D.C • ***HVCA TR/17*** – Guide to good practice cleanliness of ventilation systems. HVCA Publication TR/17. • ***NAIMA***-Cleaning Fibrous Glass Insulated Air Duct Systems, Recommended Practice 1993.	
Protocol Gaps (Gaps or weaknesses)	• Evaluation of biocide application • Protocols did not include indoor air quality evaluations.	10
Labeling support	• Has the potential to label products for special needs, green product, energy saving potential and fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	•	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1)	
New Facilities/equipment required: a) ***mechanical***	• Commercial size ventilation duct test manifold • Sampling manifold (fabrication of Harvard model) • Disinfection measures of facilities • Standardized duct dust dosing device • Standardized duct microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3)	8

	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen)	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		8
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)	IRSST	8
Related Scientific Literature / review information	• Foarde et al. Investigation of contact vacuuming for remediation of fungally contaminated ducted surfaces. Environment International 1997b; 23: 751-762. • Foarde and Maniterez. Evaluating the potential efficacy of three antifungal sealants of duct liners and galvanized steel used in HVAC systems. Journal of Industrial Microbiology and Biotechnology 2002; 29: 38-43. • Zuraimi MS. 2010. Is ventilation duct cleaning useful? A review of the scientific evidence. Indoor Air. 20: 443-529.	
	Merit Total:	67 (H)
	Feasibility Total:	30 (M)

A.2.15 Professional Cleaning– General Duct Cleaning with Biodecontamination

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.16 Building Disinfection via Chemical Cleaning- Ozone

Description and Review Aspect	Review	Score
Technology Description/ Scope	Ozone vapors that intentionally produced indoors to reduce concentrations of gaseous and biological contaminants.	
Target Contaminant (s)	• Ozone • Volatile organic compounds • Formaldehyde • Airborne mould • Airborne bacteria	
Health Impact of target contaminant(s)	• The highest risk posed by ozone itself - it is associated with premature mortality and many respiratory problems.	10
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in concentration of contaminants. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Ozone is a toxic gas with vastly different chemical and toxicological properties from oxygen. Several agencies have established health standards or recommendations to limit human exposure to ozone. • for many of the chemicals with which ozone readily react, the reaction can form a variety of harmful or irritating by-products.	10
Technology: Maturity / Development Stage (current market demand / potential)	Technology is widely available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• ***Ionic Zone 3600 mg/h Ozone Generator / 10h Timer*** Ionic Zone (http://www.ioniczone.com/ozone-generator-timer-p/iz-3600mgt.htm) • ***Empire Maintenance Industries*** (http://www.emo3.ca/) • ***BiOzone Corporation*** (http://www.biozone.com/ozone_air_purification.html)	
Existing assessment protocols (scope/coverage)	• **UL Standard 867** for *Electrostatic Air Cleaners*, Fourth Edition (Dec.21, 2007)	
Protocol Gaps (Gaps or weaknesses)	• UL 867 only addressed electrostatic air cleaners	8
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	2
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• Particle monitoring: TSI SMPS system (same as 3.1) • Particle monitoring: Grimm system (same as 3.1) • Particle monitoring: TSI DustTrak (same as 3.1) • GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Commercial size ventilation duct test manifold • Restoration (of oxidized materials) measures of facilities • Standardized dust dosing device • Standardized microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1)	8

	• Andersen 8-stage non-viable samplers for allergen	
New Facilities/equipment required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Foarde et al. 1997a. Investigation of Gas-Phase Ozone as a Potential Biocide. Applied Occupational Environmental Hygiene. 12(8): 535-542. • Esswein, Eric J.; Boeniger, Mark F. 1994. Effects of an Ozone-Generating Air-Purifying Device on Reducing Concentrations of Formaldehyde in Air. Applied Occupational Environmental Hygiene. 9(2):139-146. • Shaughnessy, R.J.; and Oatman, L. 1991. The Use of Ozone Generators for the Control of Indoor Air Contaminants in an Occupied Environment. Proceedings of the ASHRAE Conference IAQ '91. Healthy Buildings. ASHRAE, Atlanta.	
	Merit Total:	54 (M)
	Feasibility Total:	32 (M)

A.2.16 Building Disinfection via Chemical Cleaning- Ozone

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.17 Building Disinfection via Chemical Cleaning- Hydrogen Peroxide Vapors

Description and Review Aspect	Review	Score
Technology Description/ Scope	Hydrogen peroxide decontamination of indoor air and surfaces using H2O2 vapors to reduce concentrations of gaseous and biological contaminants.	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Hydrogen peroxide is a mild irritant at household levels (3ppm) but may cause pulmonary irritation a more than 10ppm (typically found during disinfection). • Building interiors may contain large surfaces composed of complex materials, material compatibility to how the decontaminant vapors impact building materials within an enclosed building interior space. • The use of h2o2 can produce building disinfection by-products such as lower carbonyls when reacted with common building materials such as vinyl composite tile, vinyl composite tile with polish, concrete, and carpet with PVC backing.	8
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• ***CLEAN AIR SYSTEMS, INC*** (http://www.cleanairsystemsinc.com/products.html) • ***BIOQUELL Inc*** (http://www.bioquell.com/)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	2
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Commercial size ventilation duct test manifold • Restoration (of oxidized materials) measures of facilities • Standardized dust dosing device • Standardized microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment		

required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Klapes and Vasely, Vapor-phase hydrogen peroxide as a surface decontaminant and sterilser, App Env Microbiol, 1990; 56:503-506. • Hubbard HF. 2006. Building disinfection chemistry: heterogeneous consumption of gaseous disinfecting agents and resulting by-product formation. PhD thesis. The University of Texas at Austin	
	Merit Total:	50 (M)
	Feasibility Total:	32 (M)

A.2.17 Building Disinfection via Chemical Cleaning- Hydrogen Peroxide Vapors				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.18 Building Disinfection via Chemical Cleaning- Aerosolized Chlorine Dioxide

Description and Review Aspect	Review	Score
Technology Description/ Scope	Chlorine dioxide is used to disinfect buildings contaminated with airborne biological pollutants and used as mold remediation in residences.	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Building interiors may contain large surfaces composed of complex materials, material compatibility to how the decontaminant vapors impact building materials within an enclosed building interior space is. • The use of ClO2 can corrode metal building materials. • Formation of chloroform and carbon tetrachloride after building disinfection using ClO2. These chemicals are toxic and carcinogenic.	8
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• ***Oxiperm® systems ALLDOS*** Eichler GmbH (http://www.grundfosalldos.com/e/html/09_presse/04_Chlordioxid.php) • ***Sabre Technical Services***, LLC (http://www.sabretechservices.com/)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	2
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Commercial size ventilation duct test manifold • Restoration (of oxidized materials) measures of facilities • Standardized dust dosing device • Standardized microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		10

Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Hubbard HF. 2006. Building disinfection chemistry: heterogeneous consumption of gaseous disinfecting agents and resulting by-product formation. PhD thesis. The University of Texas at Austin	
	Merit Total:	54 (M)
	Feasibility Total:	32 (M)

A.2.18 Building Disinfection via Chemical Cleaning- Aerosolized Chlorine Dioxide

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.19 Building Disinfection via Chemical Cleaning- Aerosolized Methyl Bromiode

Description and Review Aspect	Review	Score
Technology Description/ Scope	Methyl bromide is used to disinfect buildings contaminated with biological pollutants.	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Exposure of some building materials to elevated concentrations of methyl bromide leads to an increase in the off-gassing rate of carbonyls • Methyl bromide was listed as a class I ozone depleter in the 1990 US Clean Air Act	8
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	•	
Existing assessment protocols (scope/coverage)	• Nonr	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	2
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Commercial size ventilation duct test manifold • Restoration (of oxidized materials) measures of facilities • Standardized dust dosing device • Standardized microbial dust dosing device	4
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10

Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Corsi et al., Methyl bromide as a building disinfectant: interaction with indoor materials and resulting byproduct formation. Journal of the Air & Waste Management Association 2007; 57: 576-580.	
	Merit Total:	52 (M)
	Feasibility Total:	32 (M)

A.2.19 Building Disinfection via Chemical Cleaning- Aerosolized Methyl Bromiode

Merit				
	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

A.2.20 Indoor Passive Panels – Activated carbon media on indoor wall

Description and Review Aspect	Review	Score
Technology Description/ Scope	Activated carbon filtration media is installed on existing wall in a room to reduce exposures of VOCs, formaldehyde and ozone via passive reaction of indoor air and media surface.	
Target Contaminant (s)	• VOCs • Formaldehyde • Ozone • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the contaminants is ozone which is associated with premature mortality.	10
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Deposition velocity. • Before and after improvement in perceived air quality	10
Potential negative impacts (eg. harmful by-products?)	• Disentanglement of loosely granulated carbon media may increase exposure to particulate matter to occupants. • Sorbed organic compounds will emit into the indoor space when saturated	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology (activated carbon media) is used mainly for induct and portable air cleaning devices which is widely available. But the application is here is via installation of pre-cut media in the indoor space and passive reaction of pollutants and media on wall.	6
Commercial examples (potential candidates for testing with new protocol)	• Gremarco Industries (http://www.gremarco.com/products.php)	
Existing assessment protocols (scope/coverage)	• **ASHRAE 145.1** Laboratory test method for assessing the performance of gas-phase air cleaning systems: loss granular media • **ISO 16000-23** Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials • **ISO 16000-24** Performance test for evaluating the reduction of volatile organic compound (except formaldehyde) concentrations by sorptive building materials	
Protocol Gaps (Gaps or weaknesses)	• Little assessment of lifetime performance	9
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Restoration (of oxidized materials) measures of facilities • Standardized VOC dosing device	8
New Facilities/equipment required: b) ***analytical***	• ozone monitor (from 3.3) • ozone calibrator (from 3.3) • NO/NO2 monitor (from 3.3) • NO/NO2 calibrator (from 3.3) • Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		

Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Kunkel et al. Passive reduction of human exposure to indoor ozone. Building and Environment 2010. 45, 2: 445-452. • Sekine Y, Nishimura A. 2001. Removal of formaldehyde from indoor air by passive type air-cleaning materials. Atmospheric Environment. 35, 11: 2001-2007.	
	Merit Total:	58 (H)
	Feasibility Total:	36 (H)

A.2.20 Indoor Passive Panels – Activated carbon media on indoor wall				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.21 Indoor Passive Panels – Leaching anti-microbial coating on indoor wall

Description and Review Aspect	Review	Score
Technology Description/ Scope	A biocide coating applied to on existing wall in a room to reduce exposures of bacteria, fungi, viruses and other biological agents via passive reaction of indoor air and media surface. Depending on types, coatings can leach very quickly (e.g. biocidal paints) or slowly (silver nanoparticles)	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • Viruses • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Deposition velocity.	10
Potential negative impacts (eg. harmful by-products?)	• Disentanglement of coatings via mechanical abrasion may render ineffective use of technology. • Particle pollution indoors may render the technology ineffective via surface accumulation over coating device. • Under certain conditions, an exudate can form on the surface of coating (leaching) • Some leachates are toxic chemicals, and washing cycles dilute these so that they are efficient for only a relatively short period. • The human health impacts of nano-silver are still largely unknown, but some studies and cases indicate that the nanomaterial has the potential to increase antibiotic resistance and potentially cause kidney and other internal problems. Silver is known to be toxic to fish, aquatic organisms and microorganisms.	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• General polymers (http://www.generalpolymers.com/products/technotes/4685w.pdf) • Biocote (http://www.biocote.com/default.asp)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Standardized biological dosing device • Standardized microbial dust dosing device	8
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment		

required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	• Dubosc et al. Characterization of biological stains on external concrete walls and influence of concrete as underlying material, Cement and Concrete Research 2001. 31, 11: 1613–1617.	
	Merit Total:	59 (M)
	Feasibility Total:	36 (H)

A.2.21 Indoor Passive Panels – Leaching anti-microbial coating on indoor wall				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.22 Indoor Passive Panels – Non-leaching anti-microbial coating on indoor wall

Description and Review Aspect	Review	Score
Technology Description/ Scope	A patented chemical biocide (3-Trimethoxy silyl propyl dimethyl octadecyl ammonium chloride - one end of this polymer has long molecular chain that acts like a sword and punctures the cell membranes of microbes (bacteria, mold, etc.), killing the microbes) applied to indoor walls, the coating acts like a protective layer of swords. The non-leaching chemical biocide material media is coated on existing wall in a room to reduce exposures of bacteria, fungi, viruses and other biological agents via passive reaction of indoor air and media surface.	
Target Contaminant (s)	• Airborne mould • Airborne bacteria • Viruses • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the biological contaminants that are associated with asthma, allergies and respiratory infections	6
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Deposition velocity.	10
Potential negative impacts (eg. harmful by-products?)	• Disentanglement of coatings via mechanical abrasion may increase exposure to particulate matter to occupants. • Particle pollution indoors may render the technology ineffective via surface accumulation over coating device.	9
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• Aegis Microshield (http://aegismicrobeshield.com/impact/index.php)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	10
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Standardized biological dosing device • Standardized microbial dust dosing device	8
New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10

Research Partnership Opportunities? (agency, expertise, facilities, $ support)		4
Related Scientific Literature / review information	•	
	Merit Total:	59 (M)
	Feasibility Total:	36 (H)

A.2.22 Indoor Passive Panels – Non-leaching anti-microbial coating on indoor wall				
Merit	H	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	M	H
		Feasibility		

A.2.23 Indoor Passive Panels – PCO (photocatalytic oxidation) coating on indoor wall

Description and Review Aspect	Review	Score
Technology Description/ Scope	Titanium Dioxide (Oxide) UV-PCO coatings is applied on existing wall in a room to reduce indoor air exposures of chemical and biological agents via passive reaction of indoor air and media surface. The technology uses existing ultraviolet light in a room to the catalyst to produce primarily hydroxyl radicals (OH). These hydroxyl radicals are extremely reactive and can oxidize or "break down" typical VOC's and the cellular walls of microbes in indoor environments.	
Target Contaminant (s)	• VOCs • Formaldehyde • Airborne mould • Airborne bacteria • Viruses • odors	
Health Impact of target contaminant(s)	• The highest risk posed by the contaminants is associated with VOCs that are carcinogenic, mutagenic or toxic related.	8
Application (Comm'l/Resid'l)	Commercial and Residential	
Measurable (positive) impact (ie. basis for technol. labeling)	• Before and after reduction in airborne concentration of contaminants. • Before and after reduction in surface concentration of biological contaminants. • Deposition velocity.	10
Potential negative impacts (eg. harmful by-products?)	• Disentanglement of coatings via mechanical abrasion may increase exposure to particulate matter to occupants. • Particle pollution indoors may render the technology ineffective via surface accumulation over coating device. • PCO-UV technology can create ozone and its harmful by-products reactions via degradation of volatiles into formaldehyde, other aldehydes and secondary organic aerosols	10
Technology: Maturity / Development Stage (current market demand / potential)	Technology is available with claimed benefits of improved IAQ and health outcomes	10
Commercial examples (potential candidates for testing with new protocol)	• Pureti (http://www.pureti.com/pclr_faq.html) • Enviroclean (http://www.teamenviroclean.com/home)	
Existing assessment protocols (scope/coverage)	• None	
Protocol Gaps (Gaps or weaknesses)	• No protocols available • Measurements of ozone and by-products of its reaction with other VOCs (e.g. formaldehyde, acetaldehyde, secondary organic aerosols) has to be included in the test protocols	10
Labeling support	• Has the potential to label products for fulfill min requirements of new protocol regulations	6
IRC Research Facilities: a) ***mechanical*** (availability, status)	• Full scale chamber • M24D (select individual room) • Ventilation and Walls Research house	
IRC Research Facilities: b) ***analytical*** (availability, status)	• GC-MS • HPLC • Sampling pumps and pump calibrators	
New Facilities/equipment required: a) ***mechanical***	• Sampling manifold (fabrication of Harvard model) • Standardized biological dosing device • Standardized microbial dust dosing device • Installations of supply and return ducts and HEPA and UV filters at both grilles for equipment protection against challenge aerosols. • ETS generator fabrication • Disinfection measures of facilities • VOC generation system	8

New Facilities/equipment required: b) ***analytical***	• Particle monitoring: TSI APS system (same as 3.1) • Collison nebulizer (from 3.1) • Andersen 6-stage viable samplers (from 3.1) • Andersen 8-stage non-viable samplers for allergen	8
New Facilities/equipment required: c) technology		
Time to complete evaluation:		10
Cost to complete evaluation:		10
Research Partnership Opportunities? (agency, expertise, facilities, $ support)		6
Related Scientific Literature / review information	• Taoda et al. VOC Decomposition by Photocatalytic Wall Paper. Materials Science Forum 2006; 510-511: 22-25. • Chen & Poon.. Photocatalytic construction and building materials: From fundamentals to applications. Building and Environment 2009. 44, 9: 1899-1906.	
	Merit Total:	**60 (M)**
	Feasibility Total:	**36 (H)**

A.2.23 Indoor Passive Panels – PCO (photocatalytic oxidation) coating on indoor wall				
Merit	**H**	*III*	*IV*	*V*
	M	*II*	*III*	*IV*
	L	*I*	*II*	*III*
		L	**M**	**H**
		Feasibility		

Appendix B

IAQ Solutions and Technologies Background Information

IAQ Solutions

The definition of an IAQ solution here is any activities, device and materials that are used and/or performed to improve indoor air quality which do not rely on ventilation and/or ventilation strategy. Thus, ventilation systems such as displacement, personalised and other novel strategies of ventilation are not considered here. Broadly, there are six IAQ solutions that are available in the current market. These are portable air cleaners, filtration systems, air-to-air exchangers, professional cleaning, building disinfection and passive panels.

Portable Air Cleaners – Room units (PAC)

Portable air cleaners (PACs) are intended to remove pollutants in a single room or specific areas for residential application. PACs generally contain a fan to circulate the air and use one or more of the air cleaning technologies discussed below. Portable air cleaners may be moved from room to room and used when continuous and localized air cleaning is needed.

Conventionally, PACs are evaluated by their performance in reducing airborne pollutants measured by the clean air delivery rate (CADR) (AHAM, 2006a). The CADR is a measure of a portable air cleaner's delivery of contaminant-free air, expressed in cubic feet per minute. Many of the PACs tested by AHAM have moderate to large CADR ratings for small particles. However, for typical room sizes, most portable air cleaners currently on the market do not have high enough CADR values to effectively remove large particles such as dust mite, and cockroach allergens (Shaughnessy and Sextro, 2006). AHAM has a portable air cleaner certification program, and provides a complete listing of all certified cleaners with their CADR values on its Web site at www.cadr.org.

Portable air cleaners' manufacturers also install different technologies in their devices to reduce gas-phase pollutants such as VOCs, ozone and formaldehyde. These technologies include adsorption, chemisorption, PCO and plasma decomposition methods. There is currently no protocol that can assess the performance of PAC in terms of gas contaminant removal. Furthermore, the AHAM standard uses house dust, environmental tobacco smoke and pollen as a challenge media (AHAM, 2006a). However, it does not include evaluation of ultrafine particles that can be generated by some portable air cleaners themselves. Despite claims by many manufacturers of reduction of allergen levels with air-cleaner use, there is no protocol that assesses performance of air-cleaners to reduce allergen levels from dust mites, cockroaches, cats, dogs and fungi.

Summary of main issues related to PAC:

- Some PACs produce ozone, which when it is exposed to humans can cause health problems. Ozone also can react with other unsaturated organics in the air or surfaces to form harmful by-products such as formaldehyde and secondary organic aerosols (SOAs), especially in the

ultrafine particle size range. No guidelines have included formaldehyde and particles emissions measurements during PAC evaluations.

- There is currently no protocol that assesses the performance of PACs in terms of gas-phase contaminants and ultrafine particles removal.
- Despite claims by many manufacturers of reduction of allergen levels with PAC use, there is no protocol that assesses performance of PAC to reduce allergen levels from dust mites, cockroaches, cats, dogs and fungi.
- Although many manufacturers claim that PACs can reduce health outcomes, standard/guidelines of health-based criteria are not currently available. Effectiveness based on health outcome has to first take into account the agent being removed from the air and its effect on health.

Filtration System – In Duct Units (FS)

In-duct filtration systems (FS) are used in forced-air heating, ventilation, and air conditioning (HVAC) systems in residential as well as commercial buildings. In-duct FS is a device which removes airborne contaminants from the airstreams within the HVAC system. Depending on the types of technologies used, pollutant removal includes particles such as dust, pollen, mold, and bacteria as well as gas phase contaminants such as VOCs, ozone, nitrogen dioxide and formaldehyde. The technologies used in FS include mechanical, electronic filters (e.g. electrostatic precipitators, ionizers, PCO), ultraviolet germicidal irradiation (UVGI) and gas-phase filtration (see below).

Filtration efficiencies experiments are conventionally performed in laboratory settings using challenge aerosols (such as NaCl, KCl, DEHS) and indices measured concentrations of particles of different sizes upstream and downstream of the filters. In the building industry, filtration efficiencies recommended practices and government guidelines contain minimum recommended efficiency ratings for different air filters. For mechanical filters, the US Department of Energy recommends air filters with a Minimum Efficiency Reporting Value (MERV) of 13 as determined by the ASHRAE 5.2.2-1999 test protocol, and LEED advises builders similarly. ASHRAE recommends MERV 6 or higher air filters to control the amounts of pollen, mold, and dust that reach the wet evaporator coils in air conditioning systems. Common standards that are widely used for rating filtration efficiencies include ASHRAE (52.1, 52.2) and ASTM (F1471). Although there are efforts to develop standards for gas phase filtration using a single compound (ASHRAE 145.2P, 145.3P), there is no protocol available for multiple compounds filtration. Since efficiency drops beyond a certain dirt-loading level, filters must be serviced regularly. Higher density filters such as HEPA (high efficiency particulate air) or ULPA (ultra low penetration air) filters remove more particles, but are more restrictive of airflow and become more quickly loaded with dirt.

Wet coils contaminated with high levels of pollen and dust can allow mold and bacteria colonies to grow. The use of ultraviolet germicidal irradiation (UVGI) for the sterilization of microorganisms has been studied for in ducts systems – microorganism presence are found to be lower with UVGI use, although standards and guidelines for UV filtration are currently unavailable.

Summary of main issues related to FS:

- Some technologies (ESP, ionizers, PCO, UVGI) used in FS produce ozone, which when it is exposed to humans can cause health problems. Ozone also can react with other unsaturated organics in the air or surfaces to form harmful by-products such as formaldehyde and secondary organic aerosols (SOAs), especially in the ultrafine particle size range. There is currently no protocol that assesses the performance of FS in terms of reducing ozone emissions associated with using these technologies.
- There is no protocol available for FS gas-phase filtration using multiple compounds.
- No available protocols on UVGI are available.

Professional Cleaning (PCL)

Professional cleaning involves non-routine cleaning of carpets and upholsteries, water damage restoration, mold remediation and ventilation duct cleaning. Soiling of carpet and hostelries over time can accumulate dusts within the fabrics. Subsequent resuspension of accumulated dusts in carpet and upholstery can increase occupant exposure to airborne particulate matter. Presumably, this may cause health effects especially among sensitive occupants. It has been reported that people living in indoor environments with greater fleece characteristics have higher risks of asthma, allergies and sick building syndrome (Wargocki et al., 1999). Professional water damage restoration and mold remediation has been the response by concerns of mold exposures in indoor environments. Many international scientific organizations have conducted reviews on associations of increased prevalence and incidence of asthma, allergies, respiratory symptoms and infections among building occupants with presence of dampness or mold on the interior surface (). For duct cleaning, it refers to the cleaning of various heating and cooling system components of ventilation air systems. The main objectives of duct cleaning are to improve the general indoor air quality, remove mold growths and vermin infestations on the interior of ventilation systems (e.g. ducts), prevent clogging of ducts with excessive amount of dusts and improve the efficiency of the ventilation system (resulting in a longer operating life, as well as some energy and maintenance cost savings).

- Carpet and Upholstery Cleaning

  Generally, professional carpet and upholstery cleaning includes accumulated soil removal using powerful, industrial grade vacuum cleaning equipment. This is normally done after pile preparation achieved through the use of brush, comb, carpet groomer or pile lifter. For ground-in particles or adhered soils that are not removed via dry vacuuming, a process of soil suspension follows. This typically incorporates chemical action using detergents and solvents to suspend, emulsify, peptize or saponify soils of various solubilities at an elevated temperature and mechanical agitation. After a period of ‘dwell time’ (time required for adequate chemical fibre penetration and soil suspension), soil extraction follows by either absorption, wet or dry vacuuming and rinsing methods. To aid evaporation, rotary swirls, wand marks or distortion from the pile is removed. Finally, a six to eight hours drying time is set aside for cleaning to be completed.

- Water Damage Restoration and Mold Remediation

  Buildings are not entirely free from possible occurrence of water damage from floods, broken air conditioners, burst water pipe, and burst sprinkler system. Water damage describes a large number of possible losses caused by water intrusion causing material damage such as rusting of steel, rotting of wood, growth, de-laminating of materials such as plywood and many others. Water damage is typically classified into one of the following three categories:

  Category 1 - Refers to water from a sanitary source that does not pose substantial threat to humans.
  Category 2 - Refers to water that contains a significant contaminant (chemical, biological or physical) and has the potential to cause discomfort or sickness when exposed or even consumed.
  Category 3- Refers to water that is grossly contaminated and contains unsanitary, pathogenic, toxigenic or other harmful agents.

  Correspondingly, different removal methods and measures are used depending on the category of water. The process of water damage restoration begins with inspection and determining category of water. For Category 1, restoration process proceeds without contamination mitigation. Conventionally, pumps, extraction units and air moving equipments are used to remove standing water while weighted devices are used to compress fabric materials to extract water. This is followed by the use of drying pressure equipments for drying wet walls, ceilings and other moisture entrapments. Dehumidification equipments are used to remove moisture in the air either by refrigerant dehumidification or desiccant dehumidification. For Categories 2 and 3, biocides are used in conjunction with the above restoration process. Biocides (and their concentrations) used include alcohols such as ethanol, isopropanol (60-90%), quaternary ammonium compounds (0.4-1.6%), phenolics (0.4-5%), iodophors (75 ppm), glutaraldehyde (2%), hypochlorites (>5000ppm free chlorine mix 1:10) and hydrogen peroxide (3%).

  For mold remediation, the first step in an assessment is to ascertain the conditions of mold infestation. Relative to mold, indoor environments are typically classified into one of the following three categories:

  Condition 1 - An indoor environment with settled spores, fungal fragments or traces of actual growth whose identity, location and quantity are reflective of a normal fungal ecology for a similar indoor environment.
  Condition 2 - An indoor environment contaminated with settled spores that were directly or indirectly contaminated from a Condition 3 area, and which may have traces of actual growth.
  Condition 3 – An indoor environment contaminated with actual mold growth and associated spores. Actual growth includes growth that is active or dormant, visible or hidden.

Mold remediation commences upon confirmation by an independent assessor that mold contamination exists. Physically removing mold contamination is the main method of remediation – Semi-porous materials from the structure, systems and contents are HEPA-vacuumed and either wire brushed or sanded, then damp wiped to return them to Condition 1. Sometimes, methods involving controlled heat application to a structure are applied to kill mold spores and vegetative structures while abrasive cleaning methods such as abrasive blasting to dislodge contamination are applied. The latter can aerosolize particles removed from surfaces and lead to high indoor air exposures to mold. Porous building materials that are Condition 3 are normally discarded. Post remediation evaluation and verification is the last step – remediated contents can be considered clean when contamination, unrestorable contaminated items and debris have been removed, and surfaces are 'visibly' free of dust. Evaluation can also include moisture, surface and air quality measurements.

- Duct Cleaning- General and Biocontamination

  Duct cleaning are employed in both residential and commercial buildings. These include cleaning of the supply and return air ducts and registers, grilles and diffusers, heat exchangers heating and cooling coils, condensate drain pans (drip pans), fan motor and fan housing, and the air-handling unit housing. It can be divided into general duct cleaning (dirt/dust) or general duct cleaning with biocides (dirt/dust and biocontamination).

  Conventional duct cleaning involves the use of open access ports or doors to allow the entire system to be cleaned and inspected. This is followed by the use vacuum equipment that exhausts particles outside of the building or use only high-efficiency particle air (HEPA) vacuuming equipment if the vacuum exhausts inside the building. Vacuum systems include truck/trailer mounted system or portable units (i.e. contact method). Well-controlled brushing of duct surfaces in conjunction with contact vacuum cleaning to dislodge dust and other particles is the normal practice although other techniques include compressed air spray or the use metal "skipper" balls or power washing (water jets). For biocontamination duct cleaning, an additional procedure of coating with biocides is applied. Generally, the biocides are anti-fungal in nature and includes (not limited to) essential oils, polyacrylate copolymer containing zinc oxide and borates, acrylic coating containing decabromodiphenyl oxide and antimony trioxide, acrylic primer containing a phosphated quaternary amine complex and even ozone. Sometimes, manufacturers of products marketed to coat and encapsulate duct surfaces use sealants to prevent dust and dirt particles inside air ducts from being released into the air. As with biocides, a sealant is often applied by spraying it into the operating duct system. Duct cleaning companies conventionally follow NADCA's standards for air duct cleaning and NAIMA's recommended practice for ducts containing fiber glass lining or constructed of fiber glass duct board.

Summary of main issues related to professional cleaning:

- Various cleaning techniques have been reported to dislodge settled fine dusts to make them airborne and increase exposures to particles long after the cleaning has been completed.
- There has been no scientific proof presented on health benefits of professional cleaning.

- The application of biocides may cause some people may react negatively to the biocide, causing adverse health reactions. Chemical biocides are regulated by governmental bodies conventionally under pesticide law.

- Laboratory tests indicate that sealant materials introduced via spraying into operating duct system may not completely coat the duct surface. Application of sealants may also affect the acoustical (noise) and fire retarding characteristics of fiber glass lined or constructed ducts and may invalidate the manufacturer's warranty. Questions about the safety, effectiveness and overall desirability of sealants remain. For example, little is known about the potential toxicity of these products under typical use conditions or in the event they catch fire.
- Ozone used as biocides is a known pollutant with various health outcomes including premature mortality. It also reacts with other saturated organic compounds in the air and surfaces forming harmful by-products such as formaldehyde.

Air-to-Air Exchanger

Air-to-air exchanger is a ventilation device that employs a counter-flow heat exchanger between the inbound and outbound airflow within a residential or commercial ventilation system. Although the system is normally treated as a ventilation device, incorporating filtration technologies or other capabilities (e.g. sorptive) mainly to remove contaminants from the airstream has made this system to be considered as an IAQ solution. Two types of systems are normally discussed when dealing with air-to-air exchanger; 1) HRV provide fresh air and improved climate control, while also saving energy by reducing the heating (or cooling) requirements: and 2) Energy recovery ventilators (ERVs) are closely related, however ERVs also transfer the humidity level of the exhaust air to the intake air. Fixed plates in HRV are used for air/enthalphy exchange. It has no moving parts and consists of alternating layers of plates that are separated and sealed. In ERV, a crosscurrent countercurrent air to air heat exchanger built with a humidity permeable material is used. Increasing number of companies are incorporating filtration devices within the HRV/ERV modules to remove airborne particles and gas-phase contaminants.

If the heat exchange involves rotating wheel composed of a rotating cylinder filled with an air permeable material resulting in a large surface area, we have a dessicant wheel. The surface area is the medium for the sensible energy transfer. As the wheel rotates between the ventilation and exhaust air streams it picks up heat energy and releases it into the colder air stream. The driving force behind the exchange is the difference in temperatures between the opposing air streams which is also called the thermal gradient. Typical media used consists of polymer, aluminum, and synthetic fiber. Researchers have shown the capabilities of rotating wheel to act as a gas phase contaminant removal device (Fang et al., 2008)

The Enthalpy Exchange is accomplished through the use of desiccants. Desiccants transfer moisture through the process of adsorption which is predominately driven by the difference in the partial pressure of vapor within the opposing air-streams. Typical desiccants consist of Silica Gel, and molecular sieves.

- HRV & ERV

  A heat recovery ventilator (HRV) is also called an air-to-air heat exchanger. An HRV is designed to increase ventilation by introducing outdoor air while at same time use the heated or cooled air being exhausted to warm or cool the incoming air. HRVs can be designed to ventilate all or part of the home, although they are more effective in reducing radon levels when used to ventilate only the basement. If properly balanced and maintained, they ensure a constant degree of ventilation throughout the year. There could be significant increase in the heating and cooling costs with an HRV, but not as great as ventilation without heat recovery. A study in Alsaka has shown that home HRV use can reduce heating and cooling costs when compared to natural ventilation although a significant investment is required in the beginning to purchase a unit (Marsik and Johnson, 2008).

  At the core of an HRV is the heat transfer module. Both the exhaust and outdoor air streams pass through the module, and the heat from the exhaust air is used to pre-heat the outdoor air stream. Only the heat is transferred; the two air streams remain physically separate. Typically, an HRV is able to recover 70 to 80 percent of the heat from the exhaust air and transfer it to the incoming air. This dramatically reduces the energy needed to heat outdoor air to a comfortable temperature.

  On the other hand, Energy Recovery Ventilator (ERV) is a device that relies on the process of exchanging the energy contained in normally exhausted building or space air and using it to treat the incoming outdoor ventilation air in residential and commercial HVAC systems. ERVs not only can transfer sensible heat but also latent heat. Since both temperature and moisture is transferred, ERVs can be considered total enthalpic devices.

  HRVs and ERVs can be stand-alone devices that operate independently, or they can be built-in, or added to existing HVAC systems. For a small building in which nearly every room has an exterior wall, then the HRV/ERV device can be small and provide ventilation for a single room. A larger building would require either many small units, or a large central unit. The only requirements for the building are an air supply, either directly from an exterior wall or ducted to one, and an energy supply for air circulation, such as wind energy or electricity for a fan. When used with 'central' HVAC systems, then the system would be of the 'forced-air' type.

- Wet and Dry Desiccant Wheel

  A dry desiccant wheel consists of dry desiccant material formed onto a wheel that has a large surface area. Dry desiccants are adsorbent materials that attract and hold moisture. Examples of dry desiccant materials include silica gel, titanium gel, dry Lithium Chloride, natural zeolites, activated alumina. The air to be dehumidified passes through the desiccant wheel and the moisture is adsorbed. As the desiccant material adsorbs moisture, it becomes saturated and at a certain point will be unable to adsorb any additional moisture.

The wheel is rotated from the building air stream into a natural gas heated air stream or regeneration zone. The heat causes the desiccant to release the moisture, which is then exhausted from the building.

As moisture is adsorbed into the desiccant, it releases energy in the form of heat. In addition, the temperature of the desiccant wheel rises as it passes through the heated regeneration zone. This will cause the temperature of the dehumidified air to rise and may require some post cooling before the air is returned to the conditioned space.

In wet desiccant wheels, air to be dehumidified is passed through a desiccant solution spray. The solution has a lower water vapour pressure than the air and the air is dehumidified. The performance of the liquid desiccant is dependent on its temperature. Because a low temperature results in better performance the liquid is often run through a chiller. Liquid desiccants work on the principle of chemical adsorption of water vapour from the air to be conditioned. These desiccants include Lithium Chloride solution, Lithium Bromide solution, Calcium Chloride solution, Triethylene Glycol and Propylene Glycol. A quick evaluation of the MSDS of these desiccants revealed toxicological effects when inhaled or absorbed on the skin or cause skin and eye irritations.

The water extracted from the air will dilute the concentration of the liquid desiccant and over time, subsequently reduce its effectiveness. To maintain the desiccant at a fixed concentration, it is fed to a regenerator section. At the regenerator the liquid desiccant is heated, which raises the vapour pressure in the air causing moisture to transfer to the desiccant. The heated desiccant is sprayed into an air stream of outdoor air and the moisture is released and exhausted to the outdoors. The regenerated desiccant is then cooled and reused.

One advantage of the liquid desiccant is its ability to supply biologically uncontaminated air. The solutions used kill bacteria on contact. Additionally, there are no wet surfaces, such as those found on cooling coils, to promote bacterial growth. This makes liquid desiccants ideal for use in healthcare facilities and in sensitive industrial applications such as pharmaceuticals.

Summary of main issues related to exchangers:

- Many HRV/ERV devices are incorporating filtration technologies into the body. There is currently no protocol in place to evaluate pollutant removal performance of these technologies in the HRV/ERV under a single pass or recirculation mode.
- Climatic zones for appropriate use of HRV,ERV (Aluminium core in HRV for maximum “sensible” recovery; Energy recovery core for enhanced “latent” recovery – ERV is not recommended for climates where temp drops below 250C)
- Current protocols are designed for “off the shelf” testing of HRV. There is no HRV protocols in place to determine effectiveness of optional IAQ sensors; indoor humidity and pollutants levels indoors (especially PM, radon); control features: adjustable flows/pressure and flow balancing systems; certified air change; ventilation effectiveness and distribution efficiency of installed system.
- Cleanliness protocols of installed and used HRV are not available.

- Liquid desiccants exposures are associated with negative toxicological and irritation outcomes.

Building Disinfection (BD)

Chemical cleaning in building disinfection involves the release of high concentrations of a strong gaseous oxidant or biocide into the indoor environment (typically office buildings) to destroy or inactivate the harmful microorganisms (including biological warfare agent). When a disinfectant is vaporised and released to an indoor environment, it comes into contact with all of the materials indoor, as well as with the biological agents it is meant to destroy. The disinfectants have varying degrees of efficacy and speed of kill, and may also carry drawbacks ranging from the need to mix or a mild odor to staining, extreme toxicity, or loss of efficacy under imperfect conditions. Generally speaking, disinfectants can be placed into categories based on the specific active ingredient (the chemical or combination of chemicals in the product that actually kill the target microorganisms) they contain. Typical gaseous agents for building disinfection include, among others, ozone, chlorine dioxide, methyl bromide and hydrogen peroxide. Others include glutaraldehyde-based products, phenol-based products, Iodophore-based products, quaternary ammonium-based products and alcohol/quaternary-based products.

A special focus has been placed on ozone being used as building disinfectants. Generators introducing high concentration of ozone into the air stream can control and counteract microbial growth and odors from fire and flood damaged buildings. However, ozone is of health concern when considering indoor spaces for human occupancy.

Summary of main issues related to building disinfection:

- Human exposures to these chemicals are associated with negative toxicological and irritation outcomes. Some compounds are known to have adverse environmental impacts.
- Gaseous disinfectants can interact with indoor materials, thus lowering the indoor concentration of the disinfectant and leaving less available to act on the biological contaminant. Thus, the effect of disinfection consumption by indoor materials may compromise the disinfection process.
- Furthermore, the resulting by-products via reaction of disinfectants with indoor materials and other unsaturated gaseous contaminants in indoor air may also be irritating to humans upon reoccupation of the building.
- Both the disinfectant and by-products may prematurely age or otherwise damage materials, such as historical artifacts or electronic equipment.

Indoor Passive Panel (PP)

Indoor passive panels (PP) use commercially available materials to reduce indoor exposures of chemical and biological contaminants via deposition process. Theoretically, by replacing surfaces that have a pollutant low deposition velocity, such as painted walls, with surfaces that have larger deposition velocities, lower indoor air concentrations of pollutants can be achieved. Indoor passive

panels have the ability to improve indoor air quality without much reliance on energy. Technologies that have been incorporated for this solution includes gas phase sorption materials such as activated carbon (VOCs and ozone), photocatalytic oxidation (VOCs, bacteria and fungi), leaching and non-leaching anti-microbial coatings (bacteria and fungi). The use of indoor passive panels has the potential to prevent soiling and mold infestation of indoor surfaces.

Summary of main issues related to indoor passive panel:

- PCO technologies used in PP may produce by-products such as ozone, formaldehyde and carbon monoxide released into the indoor environments. Exposures to these by-products are harmful to human health.
- There is no protocol that evaluates assessment of lifetime performance of PP.
- There is no protocol that evaluates performance of PP using PCO technologies, leaching and non-leaching anti-microbial coatings.
- Leached anti-microbial chemicals from the panels have unknown health and environmental impacts.

IAQ Technologies

Mechanical Filters

Mechanical filters can be used in ducted systems and in portable room units using a fan to force air through the filter for arresting airborne particulate matter (PM). The main mechanism involved in capturing particles using mechanical filters includes impaction of large particles upon the filtration medium. For smaller particles, they are strained out of the air stream by increasingly smaller openings in the filter pack and, for very small submicron-sized particles are captured by diffusion toward the filtration medium surfaces to be subsequently captured via electrostatic interaction.

Mechanical filters includes:

- HEPA
  These units are the best for capturing PM. They utilize a filter media with very high efficiency ratings. A HEPA filter captures PM below 0.3 microns and can be 95%-99% effective at capturing PM below 0.3 microns in size. Combined with high airflow rates, a high performance HEPA air-cleaning system has been shown to capture more sub-micron PM such as viruses, bacteria, allergen and tobacco smoke than any other air cleaning technology.

  HEPA filter media becomes more efficient with use and will trap smaller and more PM as the filter captures more and more PM that fill up the microscopic spaces on the filter fabric. HEPA filtration will not re-release trapped PM back into the air.

- Flat or Panel Filters
  Media filters of various materials are available in a wide range of sizes and thickness. These are low packing density fibrous medium that can be dry or coated with a viscous substance

such as oil to increase particle adhesion. Dry-type filter media may consist of open-cell foams, non-woven textile cloths, paper-like mats of glass or cellulose fibers, wood fill, animal hair or synthetic fibers. They may also consist of slit and expanded aluminum. The typical, low-efficiency furnace filter in many residential HVAC systems is a flat filter that is only efficient in arresting large PM, but not effective in removing smaller PM.

- Pleated Filters
  Here, PM collection efficiency of mechanical filters is enhanced by increasing the filter media density using small denier fibers. Doing this causes smaller media penetrations and increases the screening or straining mesh size at the expense of significant increased resistance to airflow and thus, decreased airflow through the filter. To overcoming this problem, the surface area is extended by pleating the filter medium. This lowers velocity of the airflow through the filter and overall resistance such that pressure drop is reduced. The efficiency of extended-surface (pleated) media filters is much higher than for other dry-type filters.

- Electret Filters
  Electret filters are permanently charged media filter, made from synthetic fibers, to attract airborne PM that are trapped and retained within the fibers in the conventional methods of impingement and diffusion of other dry-type filters. It presents the same problems of conventional media filters such as reduction of airflow as the filter becomes soiled. The filter has relatively low energy cost and have high efficiency when clean.

Summary of main issues related to mechanical filters:

- Electret filters are efficient only in the beginning but their performance degrades over time.
- Deep bed filtration or HEPA filters typically result in high pressure drop (air flow resistance) and thus increase energy consumption. Building owners/managers may resort to reduce the energy consumption by using filters with lower efficiencies. There is no protocol that assesses mechanical filters based on their energy performance.
- Since nanotechnologies are rapidly being marketed and widely used in various sectors, human nanoparticle exposures and its possible health risks is an important concern. There is a need to develop protocol to assess nanoparticle removal using mechanical filters.

Electronic Air Cleaners

These units use an electronic field to help trap particles. There are three types of electronic air cleaners.

- Electrostatic Precipitators
  An electronic charge is provided (through a high voltage - also called ionization) as airborne PM pass into the air cleaner. The charged PM are then attracted to a series of flat plates or low efficiency filter media with an opposite electrical charge. Collection can be either a one-stage or a two-stage design. In the former, a charged medium acts to both charge and collect airborne PM. In the latter, the charged airborne PM are drawn between a series of oppositely charged metal plates which attract the charged PM from the air causing them to precipitate onto the metal plates

- Ion Generators

  These devices charge airborne PM, but unlike electrostatic precipitators, these units don't remove them. They only cause them to accumulate and attach themselves to various surfaces around the room. Ionization has the potential to reduce the concentration of airborne microorganisms via ionization of bioaerosols and airborne PM that may carry microorganisms (rafters), causing them to settle out more rapidly. Ionization may enhance agglomeration, creating larger particles out of smaller particles, thereby increasing deposition and gravitational settling. Ionization may also cause attraction between ionized particles and grounded surfaces.

  This device uses either by electron beams or electric discharges (plasma reactors) to decompose volatile organic compounds in indoor air using various with voltage excitation at DC, at low frequency (50–60 Hz) or higher, from kilohertz to megahertz of even microwave range. Various types of discharges have been used which include corona, back-corona, glow discharge, dielectric barrier discharge, and surface discharge. It creates a highly non-equilibrium state where the mean electron energy, or temperature is considerably higher than of the bulk-gas molecules which remains close to ambient temperature. It provides an energetic source of active chemical species such as ozone (O3), oxygen atoms [O(1D) and O(3P)], hydroxyl radicals, and free electrons, which are known to have destructive effect on hazardous gaseous pollutants.

- Charged media filters with ionization source

  These are filters with less dense meshwork of synthetic fibers that have been given an electrostatic charge during manufacture. The electrostatic charge that helps to attract PM is used in combination with another technology like ionization (see above).

Summary of main issues related to electronic air cleaners:

- As the charged plates or filter media collect PM, the electrical attraction diminishes because the surfaces become covered with contaminants.
- Units that capture PM require high maintenance, regular cleaning or short filter replacement periods. Plates need to be constantly cleaned to remove PM build-up to maintain efficiency. Filters need to be constantly replaced to keep the static charge.
- These devices generate ozone -- a known pollutant with various health outcomes including premature mortality. It also reacts with other saturated organic compounds in the air and surfaces forming harmful by-products such as formaldehyde.
- Charged PM that are not captured can re-enter the room where they can build-up and soil the surfaces throughout the room.
- Captured PM on plate type devices can be blown back out into the room because they are not physically held in place (re-entrainment).

Gas-Phase Sorption

Gas phase sorption filtration is designed to remove pollutant gases from the air. There are two types of gas phase filtration mechanisms which include physical adsorption and absorption (also called chemisorption). It is used in PAC, FS and PP.

- Physical adsorption

  This results from the electrostatic interaction between a gas molecule and a surface. Solid adsorbents such as activated charcoal and several other materials such as silica gel, activated alumina, zeolites, porous clay minerals, and molecular sieves are useful as adsorbents due to their large internal surface area, stability, and low cost.

- Chemisorption

  This process occurs when the sorbent attracts gas molecules onto the surface of the sorbent. This involves electron transfer and is essentially a bond-forming chemical reaction between the adsorbing surface and the adsorbed molecule. Chemical reaction can occur when the molecules absorb, or go into solution with elements of the substrate or with other reactive reagents which are manufactured into the sorbate. This way, the sorbent can form chemical bonds with the contaminant molecule which binds it to the sorbent substrate or converts it into more benign chemical compounds. For example, one common chemisorbant employs potassium permanganate as an active oxidating reagent impregnated into an alumina or silica substrate. This chemisorbant will convert formaldehyde, for example, into benign water and carbon dioxide that is desorbed back into the air stream. Once bound, the contaminant is chemically altered and cannot escape back into the air stream (irreversible process).

  Activated charcoal is a widely used adsorbent. The activation process etches the surface of the carbon to produce submicroscopic pores and channels where adsorption can occur. These pores provide the high surface area-to-volume ratio necessary for a good sorbent. Another advantage of charcoal is that it is non-polar, permitting adsorption of organic gases from air with high moisture content.

Summary of main issues associated with gas sorption:

- Although relatively small quantities of activated charcoal have been reported to reduce odors in residences, many pollutants affect health at levels below odor thresholds.
- Activated carbon adsorbs some gaseous indoor air pollutants, especially volatile organic compounds, sulfur dioxide, and ozone, but it **does not** efficiently adsorb volatile, low molecular weight gases such as formaldehyde and ammonia.
- The rate of adsorption (efficiency) decreases with the amount of pollutant captured, gaseous pollutant air cleaners are generally rated in terms of the adsorption capacity (i.e., the total amount of the chemical that can be captured). All adsorbents have limited adsorption capacities and thus require frequent maintenance.
- There is a need to determine the effective residual capacity of activated carbon while it is in use.

- Saturated sorbent filters, may re-emit trapped pollutants becoming a pollution source themselves.

PCO - Photocatalytic Oxidation

PCO is used for the removal of gaseous contaminants via a process of shining ultraviolet light (UV) onto a catalytic surface composed of a metal oxide (e.g. TiO_2) surface coating, to create a chemical reaction that converts gases that pass through the device into less harmful substances. The process is referred to as heterogeneous photocatalysis or, more specifically, photocatalytic oxidation (PCO). The photocatalyst absorbs photons of ultraviolet light to drive oxidation and reduction reactions on the catalyst surface. Highly reactive species hydroxyl radicals and super-oxide ions formed from these reactions oxidize volatile organic compounds (VOCs) to carbon dioxide and water. Reports of studies show the technology is capable of rapidly reducing concentrations of toxic components of tobacco smoke such as formaldehyde, acrolein, and benzene. Claims of odor removal and germicidal properties are also made for this technology.

Summary of main issues associated with PCO:

- Device may produce ozone and carbon monoxide with detrimental effects as discussed above.
- Device may need elevated temperatures to operate efficiently.

Germicidal UV (UVGI)

This technology is commonly used in a variety of healthcare applications where the control of microorganisms is desired. Lately, there has been an increase in the marketing and use of this technology in the commercial office and residential buildings in light of the pandemic flu concern. UV (ultra-violet) disrupts the DNA of microorganisms, including fungi, bacteria, and viruses. It prevents them from reproducing and thus reducing the likelihood of infection. However, the dose of UV needed to affect each group varies where the viruses are the easiest to sterilize, followed by bacteria. Mold and fungi are the hardest to eliminate with UV.

Germicidal UV is delivered by a mercury-vapor lamp that emits UV at the germicidal wavelength. Mercury vapour emits at 254nm. (Many germicidal UV bulbs use special transformers to ensure even electrical flow to the bulbs so the correct wavelength is maintained). Air purification UVGI systems can be standing alone room units with shielded UV lamps that use a fan to force air past the UV light or those placed in the upper room. Other systems are installed in ventilation systems so that the circulation for the premises moves micro-organisms past the lamps. A UV lamp irradiating at the coils and drain pan of cooling system or the filtration system will keep micro-organisms from forming in these naturally damp places.

Summary of main issues associated with UVGI:

- Since germicidal UV has a narrow bandwidth, power fluctuations will render intended irradiating environments ineffective.
- Effectiveness of ultraviolet light at destroying microorganisms depends on the intensity of the light and duration of time the UV light is contacting the microorganism. Air travels at tremendous speed through an air cleaner – thus, there is little contact time of the UV light on bioaerosols.
- Additionally, biological contaminants may be covered with PM in which the UV light will not shine on the microorganism to have an effect.
- Different microorganisms require different light intensities and contact duration to kill them. This is difficult to control in a light chamber where the particles can be at various distances and locations from the UV light source.
- UV light gets weaker over time and requires regular maintenance.
- UV light can degrade the filter media and other components of the air cleaner.

Anti-Microbial Coating

This device includes the use of media filters coated with anti-microbial agents with the objectives of reducing the concentration of airborne microorganisms in the indoor air and potential of the filter media becoming a source for microbial contamination. Anti-microbial coatings include, among others, amine neutralized phosphoric ester, quaternary ammonium compound, iodine, essential oils, active tea tree oil and even silver particles. Sometimes nanotechnologies are introduced to inhibit growth of microorganisms.

Summary of main issues associated with anti-microbial coating:

- Susceptibilities of microorganisms differ- not all microorganisms are killed or suppresse equally using the same antimicrobial agents.
- Some antimicrobial agents are chemicals rich in terpenes and/or terpeneoids (limonene, α-terpinene, 1,8-cineole etc). These volatilize into the air and can react with ozone to form formaldehyde and many secondary reactive compounds that may have health impact.
- Some antimicrobial agents are toxic.
- Anti-microbial coating may leach over time causing reduced effectiveness. Further, leaching of toxic anti-microbial agents may increase risk of harmful exposures to occupants indoors.
- Nanotechnology has a tremendous application but unclear health implication.

Biofiltration

Biofiltration uses naturally occurring microorganisms immobilized in the form of a biofilm on a porous substrate such as soil, compost, peat, bark, synthetic substances or their combination. The substrate provides the microorganisms with both a hospitable environment in terms of oxygen, temperature, moisture, nutrients, pH and a carbon source of energy for their growth and development. As the contaminated air stream passes through the filter bed, contaminants are transferred from the vapor phase to a thin water layer (biofilm) covering the microorganisms held over the surface of the packing particles. The microorganisms utilize these favorable conditions to metabolize carbon based compounds to their primary components - carbon dioxide and water, plus additional biomass and

innocuous metabolic products. The absorption and/or adsorption capacity of the filter media is thus continuously renewed by the biological oxidation of the sorbed contaminants.

Biofiltration has the advantage that the pollutants are not transferred to another phase and therefore, new environmental problems are not created or are only minimal i.e., air pollution problems are not converted to water pollution problems. Moreover the process is said to be cheap and reliable, and does not usually require complex process facilities. Unfortunately, its inexpensiveness has resulted in the cynical perception that "if it's cheaper, it cant be any good", but the low cost of biofiltration is associated to its use of natural rather than synthetic sorbents and microbial rather than thermal or chemical oxidation.

Summary of main issues associated with biofiltration:

- There is a likelihood of microorganisms or other airborne organic compounds released into the indoor environment.
- There is no protocol to evaluate performance of biofiltration and its “effective” lifetime.
- Water vapor released into the environment may caused thermal comfort issues among building occupants.