THE UNIVERSITY OF WESTERN AUSTRALIA
Achieve International Excellence

Faculty of Science

A literature based research investigation of household cleaning: comparisons between the use of conventional domestic chemical cleaning agents and fiber/ microfiber-based cleaning methods.

Shannan J. Maisey
Sandra M. Saunders
Atmospheric and Environmental Chemistry Research Group
School of Chemistry and Biochemistry

May 2013

TABLE OF CONTENTS

1 Overview in Dot-Point Summary

1.1 Domestic Use of Cleaning Products

- Women with young families are the highest users of cleaning products in the US.
- Users perceive cleaning products as necessary for household hygiene but are aware that they contain chemicals that may be toxic.
- There is a disconnect between the point above and users realising that it means cleaning products pollute the indoor environment.
- The vinegar and bicarbonate of soda (V/B) cleaning substitute does remove some surface dirt and vinegar can kill some bacteria however it is not considered effective by governing bodies.
- The V/B system takes a great deal more effort to achieve a clean surface, with the potential that the method may damage the cleaned surface through corrosion or abrasion.

1.2 How Green is Green When it Comes to Cleaning Products?

- The market for 'green' cleaning products has increased tenfold in 5 years in the US.
- These products are marketed as being environmentally safe, but there is no guarantee that human toxicity has been considered beyond the broad government guidelines.
- The terms, 'eco' and 'green' are not regulated and therefore products so labeled have been found to contain chemicals that are toxic and even carcinogenic.
- There is no requirement in the US for manufacturers to place ingredients list on cleaning products.
- Many 'green' products claim to contain natural products (biogenic chemicals), but this is misleading in terms of human toxicity. Partly

because many natural products readily react under normal household conditions to form harmful secondary pollutants.

- Using 'low VOC' products does not mean less indoor air pollution. The delivery of cleaning products is often through spray packs, which aerosolize non-volatile components thus making them breathable and available to react and spread throughout the home.

1.3 Clean vs. Disinfected

- Cleaning removes surface dirt and dust whereas disinfection removes surface microbial activity (i.e. single cell organisms like germs, bacteria, molds)
- Not 'all dirt is good for us', some bacteria such as E. *coli* need to be removed from surfaces to prevent illness. Therefore some level of disinfection is required.
- Over use of disinfection products can be harmful to our health and impact on our abilities to fight more serious infections.
- Surfaces need to be cleaned before they are disinfected and often the action of drying removes a large percentage of microbial activity.
- Use of chemical disinfectants to kill bacteria requires care to apply and often time (10-15 minutes) to work before being re-wiped.
- The effect of surface disinfection is not long lasting, most microbial activity returns after 4 hours, though this may be with lower levels of the more harmful species.
- The mechanical removal of microbial activity, through physically removing the cells requires no time element or specific application instruction, thus can be achieved with cleaning using microfiber and fiber cloths.
- Beyond a few high risk areas of the home there is no evidence that total disinfection is required or overly effective in normal, healthy households.

- Disinfection of surfaces does not reduce the incidence of viruses in normal households.
- One of the most popular disinfectant and antibacterial agents used in consumer products is triclosan and there are serious concerns about its suitability for general use.
- The microbe kill mechanism for triclosan is the same action as an antibiotic and has been shown to encourage antibiotic resistance (i.e. the creation of super-bugs).
- For this reason and because there is no strong evidence that triclosan is beneficial in most of its applications the American Medical Association has requested that the US Food and Drug Administration review its use in all consumer products.
- Triclosan is suspected to be an endocrine system interrupter, including suppressing the thyroid hormone.
- Triclosan is a persistent environmental pollutant (that means it accumulates and does not break down over the short term) and as such has been found in the tissue of dolphins and to be influencing their development and growth.
- The use of hypochlorite solutions (bleach) on hard surface has been shown to be highly effective at removing microbes but not a good cleaner and thus has to be used in conjunction with other products.
- There is significant potential for bleach solutions to react with other cleaning products to produce chlorine gas, chloroamine gases and other harmful gases.
- Bleach is a well known skin and airway irritant, though is considered to be of low toxicity in the concentrations it is traditionally used.
- Bleach accounted for over 37% of childhood injury from cleaning product exposure in the US between 1990 and 2006.
- Ammonia compounds are commonly used to clean and disinfect hard surfaces and have been shown to be efficient for both actions.

- Exposure to ammonia has many known acute symptoms including headache, dizziness and skin irritation and has been shown to cause long term damage to the lungs and throat.
- Ammonia has been shown to induce chemical emissions from soft and hard surfaces as well as increase the production of harmful aerosol products in gas phase chemistry that occurs under normal household conditions.
- Ammonia is a semi-volatile species, which means that its application to hard surfaces ensures prolonged emission after cleaning events.
- Thymol is a new 'green' disinfectant extracted from the thyme plant. It has been shown to be effective in low concentrations with little toxicity or irritation to humans in these doses.
- Thymol is used in 'green' products that are intended for everyday use, however similar to other natural products there is potential for it to react under normal household conditions and produce more harmful pollutants and this has not yet been explored.
- Solid state disinfectants in cleaning cloths, such as silver nano and micro particles, have been shown to prevent bacterial contamination in wet cleaning tools.
- Only when silver is on the outside of the cloth fibers are the disinfectant properties effective and this action is not effective for killing surface bacteria. Bacterial removal continues to rely on the mechanical removal like other microfiber and fiber cloths.
- There is no evidence that this system is any more effective than thorough rinsing of cloths after use.

1.4 Cleaning Products, Exposure and Health

- Regulations for cleaning products do not require full disclosure of the potential for toxicity from extended use.
- There are over 250,000 children treated for chemical exposure as the result of exposure to cleaning products in the home each year in the US (1990-2006).

- The long term effects of chemical exposure from cleaning products are becoming more evident and are far reaching.
- It has been shown that long term exposure has been associated with cardiovascular hazards including heart stress, through exposure to chemical products and air fresheners.
- There have been links made to chemical exposure from cleaning and breast cancer.
- There is strong evidence that chemical sensitivity and allergic asthma are exacerbated by exposure to cleaning products.
- There are certain chemicals included in cleaning products that are highly debated as to their toxicity.
- The water soluble glycol ethers, including 2-butoxyethanol (2-BE), have been removed from the hazardous chemical list in the US without the support of many researchers; it is still known to be toxic.
- 2-BE and other glycol ethers are semi-volatile, meaning that once they are applied to hard surfaces they are likely to continue to emit for long periods of time and that frequent use of products that contain them (such as all purpose and window cleaners) can result in layering on household surfaces.
- It has been shown that typical to high use of all purpose and window cleaners in a confined space, such as a bathroom, can lead to the toxic occupational exposure limit for 2-BE to be exceeded.
- The delivery of chemical compounds through the skin is well proven, for example nicotine patches, and there is potential for surface chemicals from cleaners such as 2-BE to be absorbed as such.
- Buildings with low surface pollution have been shown to have lower incidence of sick building syndrome symptoms.

1.5 Endocrine System Disruption

- Our understanding of the hormonal influences of very low exposure to endocrine interrupting species is limited. Yet it is thought that many health concerns related to the Western world can be linked to hormonal disruption.

- There is a US EPA task force commissioned to explore the potential for endocrine system disruption (ESD) by common chemical species but as of yet it has not applied any restrictions on manufacturers of products containing suspected agents.
- Many suspected ESD compounds are semi-volatile, meaning if they are applied as cleaning products then they are likely to remain on household surfaces with the potential for long term emission and dermal contact and absorption.
- There is evidence of semi-volatile chemical compounds, thought to be ESD's, in household dust that is widely distributed around the home. This shows that exposure of these compounds is not limited to the area in which they are used.

1.6 The Cumulative Effect of Indoor Cleaning Product Usage

- Domestic cleaning products are not generally used in isolation, which means there is a cumulative effect of VOCs in the areas they are used.
- In a typical US home it can be expected that following a normal cleaning session the total VOC concentration in the home can exceed 300-1200 $\mu g/m^3$ for 1-3 hours after the event.
- Concentrations of individual species can be elevated to 1000 times their expected background concentration for several hours after cleaning has taken place.
- Intensive cleaning in a poorly ventilated bathroom can mean that the limits for toxic exposure to some chemical compounds can be reached during the cleaning process. This includes compounds known to be hazardous to health including 2-butoxyethanol.
- There are no indoor guidelines for long term VOC exposure which means that manufacturers do not have to state the expected emissions from typical product use.

1.7 Chemical Reactivity

- Chemicals in the indoor environment can react with each other and other common indoor pollutants to form secondary pollutants.
- Secondary pollutants are commonly oxygenated and therefore are difficult to detect and more harmful to human health.
- Some of the most reactive species in cleaning products are labeled as ‘natural’. These include terpenes such as limonene and pinene, which are used for their fragrance as well as their ability to dissolve oily residue.
- It has been well documented that terpenes and ozone (commonly found in the urban environment) readily react to forms secondary organic aerosols (SOAs).
- SOAs are much like what is delivered from a spray can, ultra fine mists of liquid particles that are easily inhaled. Meaning that a cocktail of unknown secondary reaction products are delivered directly to the lungs of those exposed.
- It has been shown that the presence of ammonia in a room where terpene/ozone reactions are taking place significantly increases the yield of SOAs that are produced.
- This chemical synergism, where the combination of two chemicals has a greater effect than their separate parts, is also observed for reactions between ammonia, bleach and organic acids commonly found in cleaning products. These reactions form gases that have severe health consequences and in some drastic cases, death.
- Little to no warning is given about many of the potential chemical reactions that can occur when chemical cleaners are combined. Perhaps more alarmingly there is evidence that very few consumers read the warning labels/ instructions on chemical cleaning products.
- There is a vast body of literature outlining the potential for chemical pollutants, many of which come from cleaning products, to react under normal conditions in homes to pollute the air.

- The overwhelming conclusion to these studies is that a lower level of indoor VOCs, through reduced emission, significantly reduces the potential for these reactions to affect and influence health. This can be achieved by reducing chemical cleaner use by adopting alternative, very low emitting, methods such as fiber and microfiber cleaning.

1.8 Assessing the Fiber/Microfiber Alternative

- Fiber and microfiber cloths work by forcing the sharp edge of the fibers against surface debris to effectively shave contaminants off. The contaminants are then trapped within the fibers until rinsing occurs.
- Scientific evaluations of fiber and microfiber cloths show that they are effective at cleaning surfaces with water alone.
- There is evidence that the cleaning mechanism of fiber and microfiber cloths is not at all improved by the presence of cleaning agents.
- There have been a number of studies investigating the ability of fiber and microfiber cloths to remove surface microbial activity, which are shown to have superior microbial removal rates compared to traditional cloths.
- The type of cloth and quality of fiber has been shown to significantly influence cleaning efficacy and microbe removal.
- Using Zabada cloth cleaners, it has been shown that there is no higher risk of contamination from residual microbes on the cloths surface, after rinsing with hot water, than with other cleaning methods, including cloths soaked with bleach.
- Fiber cloths have been determined to be suitable for maintaining kitchen hygiene standards comparable with methods that use bleach.
- For the cleaning of hard floors, microfiber mops (used with water alone) were compared to traditional mopping systems with cleaning

agents and were found to be superior at removing oil, protein residues and soils.

- Professional cleaning staff has expressed a strong preference for fiber and microfiber cleaning compared to traditional methods that use chemical cleaners. A large part of this preference is because of the relative ease of fiber and microfiber cleaning to achieve similar results.
- It has been estimated that use of microfiber cloths for cleaning has the potential to reduce water consumption by a factor of 20, energy use by a factor of 30, and solid waste (consumption of cloths) by a factor of 50.

2 Literature Review

2.1 Introduction

It is often quoted that the average US household spends 20-30 minutes per day cleaning (Wiley *et al.*, 1991). Yet what is meant by the terms *clean* and *cleaning?* Can we argue that the use of chemical cleaning products just shifts the contamination of the surface from something we can see to something we cannot (chemical residue and air pollution)? What do the cleaning products we use in our homes leave behind on household surfaces or in the air and what does this mean for the health and well being of our families?

It is well understood and documented that the use of some cleaning products in the home can adversely affect the quality of the air indoors, influencing not only respiratory health but having further reaching (and largely un-determined) adverse health outcomes. It has long been perceived that the trade off for this polluting of the indoor environment (and the acute discomfort for the cleaner) is the eradication of dirt, germs and bacteria which are 'dangerous' to inhabitants in the longer term (Altman *et al.*, 2008). The purpose of this literature investigation is to explore what is currently known about the efficacy of household cleaning methods and the influence they have on the indoor environment. This includes evaluating the popular use of cleaning products as well as assessing the cleaning alternatives now available. In particular we are concerned with;

- The efficacy of chemical cleaners compared to more benign processes, including fiber cloths, to clean and disinfect.
- The primary and secondary effects of gas phase pollutants on the indoor environment
- The residual effects of cleaning contaminants on surfaces and how this affects the people who come in contact with them.

- The health effects of short and long-term contact with domestic cleaning products.

This is a comprehensive review, which summarizes published papers on domestic cleaning in English in peer-reviewed journals as well as government policy and consumer advocacy associations, with a specific focus on the last decade and "Westernized" countries.

2.2 Domestic Use of Cleaning Products

Commercial cleaning products, intended for domestic use, are typically composed of 70-95% water mixed with one or more active ingredients, usually a type of surfactant (soap) and/or organic solvent, acid or disinfecting agent. Preservatives, fragrances and dyes are also commonly added (Prud'homme de Lodder *et al*., 2006). In California, as of 2012, there is a 0.5% limit on the Volatile Organic Compound (VOC) content of these cleaners (CARB, 2009). In other States however, the VOC concentration can be higher than 6.5% (Steinemann *et al.*, 2011).

Household product use is a significant pathway for personal exposure to toxic chemical compounds. Understanding usage patterns, beyond sales figures, is important to assess the consumer habits associated with these products. There is currently limited information about what is considered to be 'typical' for consumer behaviour in regards to the thousands of products available for consumption in Western societies. The SUPERB study, conducted in over 500 Californian households, assessed short to long term usage of consumer products, including household cleaning products (Hertz-Picciotto *et al.*, 2010). Data from this study showed that in general, women with small children (under 5 years) were the highest usage category of chemical cleaning products. Consequently, households with young children were more likely to do their own cleaning rather than hiring a professional (Moran *et al.,* 2012). Cultural or ethnic identity has also been shown to have a significant impact on the frequency and quantity of cleaning products used. Women of Caucasian decent living in Western societies have some of the lowest usage, with women of Latino and Middle Eastern decent among the highest (Habib *et al.,* 2006; Moran *et al.,* 2012). From the 8 different cleaning product type categories surveyed, 6 were in use in over 50% of households. Of these, all purpose and glass cleaners were the most highly and frequently used products, for all participants, with 85 % and 89% (respectively) of respondents admitting to using them regularly (Moran *et al.*, 2012).

In a study linking household exposure of chemicals to participant perception and knowledge of chemical sources, there was a significant disconnect between knowing that cleaning products contained potentially harmful chemical compounds and that these chemicals could therefore be detected in the air and dust of the home as well as the urine of inhabitants (Altman *et al.*, 2008). Furthermore, the use of chemical cleaning products was found to be so ingrained in the habits of participants that it was considered to be unremarkable and therefore difficult to accurately recollect typical daily usage. For this reason it was common for product use to be underestimated by survey respondents (Altman *et al.*, 2008). This lack of awareness and conscious thought in cleaning product use is also demonstrated in how products are used. For example, in a study of typical use of household cleaning products, many respondents admitted to rarely reading the label for manufactures warnings and usage instructions, instead smell was often used to choose and assess appropriate usage of cleaning products (Kovacs *et al.*, 1997). Finally, those women whose main occupation was as the homemaker were more likely to take preventative measures against exposure, i.e. by wearing rubber gloves. They were found to have the highest usage of chemical cleaning products in the population and therefore also the highest exposure to toxic compounds (Kovacs *et al.*, 1997, Moran *et al.*, 2012).

Recently, there has been a degree of popular advocacy of the vinegar and bicarbonate of soda (V/B) method for cleaning as an alternative to traditional cleaning products. The combination of these chemicals produces a neutral salt, water and CO_2 gas; these compounds in small concentrations are not hazardous to humans or the environment (Fong *et al.*, 2011). The production of the gas coupled with the mild acid (acetic acid from vinegar) is thought to remove surface contaminants along with the abrasive action of the bicarbonate solids (Olson *et al.*, 1994). Choice, the consumer advocacy group, included the mixture of V/B (often considered to be a 'safe' alternative cleaning agent) in a review of the top 8 commercial bathroom cleaning products. Results from this comparative study showed that none of the products rated above average in the removal of soap scum and molds and the 'natural' alternative of V/B was considered to require considerably more effort than other products. All trial participants found the majority of the cleaners tested to be irritating to the skin and to have an offensive smell, including the V/B option (Choice, 2008). Furthermore, an assessment of the suitability of the V/B method as a disinfectant found that is was limited in its ability to remove harmful microbial species such E. *coli* through cidal reaction (i.e. to kill cells rather than dislodge and promote removal). It was found to be potentially damaging to surfaces through corrosion and abrasion as well as having a pungent and pervasive odour (Olson *et al.*, 1994; Fong *et al.*, 2011).

2.3 How Green is Green When it Comes to Cleaning Products?

Product type has been shown to be a significant determinant of chemical exposure from cleaning products (Bello *et al.*, 2013). Indeed, many studies have identified the type of product as an important factor into the extent of chemical exposure during cleaning (Zhu *et al.*, 2001; Zock *et al.*, 2007). Consequently, there has been strong development of 'green' cleaners. Eco-friendly cleaning products have gained a huge market share in the US, growing from 3% in 2008 to an expected 30% in 2013 (Mintel

Marketing, 2012). Nevertheless, eco and Earth friendly is not always synonymous with a healthy indoor environment. These 'green' products are commonly marketed as being safe for the environment, with implications that they are therefore safe for the consumer's health. Nevertheless there is no unified standard for what is considered to be 'green' and thus the issue of human toxicity is not necessarily even considered in the product development (Bello *et al.*, 2013). The labeling terms "natural," "non toxic," and "green" are not regulated by any government body and do not require manufacturers to list ingredients (Dodson *et al.*, 2012). In fact, some products labelled as 'green', 'organic' or 'non toxic' have been found to contain known carcinogens and VOCs classified as toxic or hazardous with no significant difference in composition from other products on the market (Steinemann *et al.*, 2011). Also of concern is that some of the 'natural products' used in cleaning products have been shown to readily react under normal household conditions to form harmful secondary pollutants (discussed in the chemical reactivity section 2.8).

Finally, focusing solely on the chemical composition of the products does not explore the manner in which these products are used and distributed throughout the home. For example, the use of low VOC products can be negated by trigger spray applications that aerosolize non-volatile ingredients, thus increasing the chance of inhalation and spreading non-volatile and semi-volatile compounds across a wider area of household surfaces (Bello *et al.*, 2013). Reduction of exposure is therefore not limited to the products used but also the *way* in which they are used and the frequency of use (Bello *et al.*, 2013).

2.4 Clean vs Disinfected

In recent years there has been a blurring of the distinction between cleaning for dirt removal and the disinfection of surfaces to remove germs. Cleaning by detergent is defined as the removal of visible soil, blood, food and protein substances and other debris from surfaces and equipment by a manual or mechanical process (Exner *et al.*, 2004). Cleaning in the domestic setting is traditionally an action of mechanical force paired with a cleaning agent and device (i.e. mop, cloth or other tools). This is different to disinfection, which is the application of substances to surfaces to kill and/or remove microorganisms. The mechanism of disinfection can be through killing (cidal disinfection) or by dislodging and physically removing the microorganisms on the surface (Exner *et al.*, 2004).

There is no doubt that some degree of cleaning is required in the home for both health and aesthetic reasons. However, the definition of what is clean is a highly variable and subjective measure. Traditionally cleaning tasks in the home have consisted of;

- Removal of dust and settled particulates, hair and dirt from indoor surfaces.
- Bathroom cleaning to remove soap, grease, dirt, scale and bacteria.
- Kitchen cleaning as a result of food preparation, including surface cleaning, dishwashing and mitigation of food spillage
- Mitigation and reaction to accidental/unforeseen mess i.e. spilt food and dirty foot prints.

More recently, since the 1970's, the action of disinfection has become a routine component of household cleaning (Exner *et al.*, 2004).

The hygiene hypothesis proposed in the late 1980's, suggested that exposure to microbes; germs and bacteria, during early childhood can reduce the risk of allergic reactions and inflammatory intolerances (Strachan, 1989). This theory has been popularized by a misrepresentation of this research, with a mantra that 'all dirt is good for us'. However, contrary to this popular belief, there is no statistically significant or proven relationship between increased household hygiene (i.e. increased disinfectant use) and the increased incidence of allergy in Western countries (Bloomfield *et al.*, 2006). This is primarily because the types of microbial activity that household disinfection is aimed at eliminating are products of modern living environments and thus are not included in Strachan's hypothesis. Nevertheless, as will be discussed, there is evidence that the ubiquity of disinfecting agents in consumer cleaning products is at best ineffective and unnecessary. However more seriously, disinfectant products can have a detrimental effect on our health and ability to fight more serious infections through antibiotic resistance.

Given this ambiguity and the widespread use of disinfectants (used on surfaces) and antibacterial agents (used in personal products) in the home there are two pertinent questions to be explored;

1. Is a high degree (hospital grade) of sanitation required in the home to prevent illness in healthy people? I.e. do we need widespread use of disinfectants under normal circumstances?
2. Is there potential for unintended consequences/outcomes (health and environmental) from the uses of disinfection products in the home?

The use of antibacterial and disinfectant agents to eliminate microbial activity on a daily basis has, for some people, bought a new meaning to the definition of clean. Advertising efforts for many popular products imply that unless a surface has been disinfected of 99.9% of microbial activity it is not truly clean.

Disinfection of surfaces will not occur if the products are not used as manufacturers direct. This can require considerably more care than spraying a product onto a surface. For example, surfaces need to be cleaned before they are disinfected and time is required for the active agents to work before being wiped dry. Nevertheless, when instructions are followed common household wipes and sprays have been shown to be effective in removing E. *coli* and S. *aureus* from a number of kitchen surfaces within 2 hours of use (DeVere and Purchase, 2007). Independent research has shown that Zabada fiber cloths used with hot water alone disinfected common kitchen surfaces of E. *coli* and S. *aureus* with equal or greater efficacy than traditional cleaning cloths soaked with disinfectants (Lalla and Dingle, 2004). For fiber, the wiping action used to achieve a clean surface also disinfects by removing microbes and thus differentiates fiber from chemical cleaning, as there is no time element required to allow for disinfection to occur. Other studies of fiber and microfiber clothes show that cleaning and disinfection can be achieved with water alone (Nilsen *et al.*, 2002; Pesonen-Leinonen *et al.*, 2003) (discussed further in the fiber and microfiber alternative section 2.9). This eliminates the need for chemical products, which as will be discussed below, can have serious health and environmental issues.

There is growing evidence that a high level of microbial elimination is not necessary or even overly effective in normal, healthy households (Scott *et al.*, 1984; Bloomfield and Scott, 1997; Larson *et al.*, 2004). Indeed though some disinfection products, when used properly, do substantially lower surface bacteria, it has been shown that this effect is brief (3-6 hours) before up to 70% of microbes return to surfaces (Scott *et al.*, 1984). Evaluation of disinfection products used *in situ* in household kitchens show that targeted use of disinfection products on small areas of primary contamination (i.e. chopping boards and surfaces where spills occurred) is more effective and less likely to result in wide spread contamination, than blanket use of disinfection products across all surfaces (Josephson *et al.*, 1997). Indeed, surface contamination can be mitigated to some extent by simply ensuring that surfaces are dry (Hirai, 1991). In a randomized double blind control study in over 200 US households it was shown that the widespread use of cleaning agents containing antibacterial/disinfecting agents did not reduce the risk of contracting viral disease in the homes of healthy people (Larson *et al.*, 2004).

There are a number of popular disinfectant agents used in domestic cleaning products that use cidal mechanisms to kill microbes. The most popular of these include triclosan, ammonia complexes and hypochlorite as well as some newer alternative agents including thymol and solid metal agents.

Triclosan (2, 4, 4'-trichloro-2'-hydroxyphenyl ether) is a common antibacterial used in surface cleaners, soaps and toothpastes. It was first patented as a herbicide (weed killer) though it has been used in consumer products since the 1960s (Bhargava and Leonard, 1996). In low concentrations it is not toxic, however it has been the subject of several investigations for waterway contamination (Canosa *et al.*, 2005), endocrine interruption through oral and dermal delivery (Calafat, 2008) including suppressing the thyroid hormone (Paul *et al.*, 2010) and antibiotic resistance (Aiello and Larson, 2003; Suller and Russell, 2000). It has also been found to be a persistent environmental pollutant, for example triclosan has been found in the tissue of dolphins as a result of contamination of waterways (Fair *et al.*, 2009).

The use of triclosan in domestic consumer products is not supported by the American medical association (AMA) due to the antibiotic mechanism style of killing microorganisms. The AMA has previously expressed concerns to the US Food and Drug Administration (FDA) that evidence of antibiotic resistance through the use of triclosan means it should be avoided in consumer products (AMA, 2000). Indeed, the US FDA has found that the inclusion of triclosan does not benefit consumer health in the majority of its applications and is no more effective than traditional soap and water at removing germs in that context (US FDA, 2011).

Dilute hypochlorite solutions, often referred to as bleach, are some of the most commonly used disinfectants in the domestic context (Racioppi *et al.,* 1994). The use of bleach on hard surfaces has been shown to have high efficacy at the removal of important microbial activity (*E. coli and S. aureus*) but has limited ability to remove dirt (Parnes, 1997; Olson *et al.,* 1994). This means that bleach must be used in conjunction with other cleaning products. It has been well established that bleach is a respiratory irritant, with associations between bleach use and prolonged exacerbation of asthma symptoms (Deschamps *et al.*, 1994, Mapp *et al.*, 2000, Gorguner *et al.*, 2004). Though it is considered to be of low toxicity and irritation in typical household concentrations (4-15% hypochlorite), bleach is known to react with other common household cleaners to produce a number of significantly more harmful chemical compounds which have been known to cause serious harm and in some cases death (discussed in chemical reaction section 2.8). Finally, household bleach accounted for 37% of injuries to children by household cleaning agents requiring medical attention between 1990 and 2006 (McKenzie *et al.*, 2010).

Ammonia and quaternary ammonium compounds are common in hard surface cleaners, in particular floor and bathroom cleaners. Ammonia compounds have been shown to have an efficient cleaning capacity as well as disinfection properties (Olson *et al.*, 1994). Nevertheless, exposure to ammonia is known to cause headaches, skin irritation, including burns as well as long term damage to the lungs and throat (Bai *et al.,* 2006; Tomoto *et al*., 2009). Ammonia has also been shown to draw pollutants, such as nicotine, which have been adsorbed to indoor surfaces (i.e. carpets and upholstery), back into the gas phase, effectively increasing the indoor concentration of these pollutants perhaps years after they were emitted (Webb *et al*., 2002). The application of ammonia based cleaners has also been shown to increase emissions from some flooring materials (Wolkoff *et al.*, 1995). Finally, ammonia is a semi-volatile species, meaning that its application to a surface ensures prolonged emission. There are many studies that show that the presence of ammonia influences the indoor chemistry of other chemical pollutants, including other cleaning products, to create more harmful secondary pollutants. These reactions are discussed in further detail in the chemical reactivity section 2.8.

A new 'green' disinfectant that has been shown to kill 99.99% of microbes has recently been introduced to the market. It is a botanical extract from thyme plants referred to as thymol (5-methyl-2-isopropyl-1-phenol). It is marketed as a safe, botanical alternative to ammonium compounds, sodium hypochlorite and triclosan (common chemical agents in household disinfectants). Thymol has been shown to be an effective antimicrobial agent, even against more resistant strains (Edris, 2007; Xu *et al.*, 2008 and others) and, importantly, has not been found to promote antibacterial resistance (Bondi, 2011). Indeed, Bondi (2011) provides a comprehensive outline of research undertaken for the effectiveness and human sensitivity (low when in concentrations below 5%) to the thymol compound and concluded that no areas of uncertainty regarding potentially negative attributes were identified. This review of thymol in the context of traditional disinfectants has been commission by Seventh Generation, (manufacturer safe/eco friends cleaning products) with the intention to approach a best practice for product development. Nevertheless, thymol (5-methyl-2-isopropyl-1-phenol) is a monterpene (details of which are explained in the chemical reactivity section 2.8) and there is potential for it to react under normal household conditions, which have not yet been explored. Though the concentration of thymol in surface sprays may be considered low (0.05%, Bondi, 2011) these products are intended for regular/daily use and longitudinal studies for long term exposure and health outcomes have not yet been performed.

Solid state antibacterial agent adhered to the surface of microfiber cloths have been introduced to the market by brands including Norwex®, e-cloth® and a number of generic cloth brands. Often, these are silver metal micro particles. Silver metal has been shown to significantly reduce microbial activity in microfiber floor mops compared to non treated microfiber mops, as well as cotton cloths and fabrics (De Lorenzi *et al.*, 2011, Hebeish *et al.*, 2011). The silver particles are incorporated to the surface spun fibers and are chemically treated to ensure there is no substantial loss of particles from the cloth. Silver particles on the surface of the fibers are effective, however, fibers with silver just in the core are not effectively antibacterial (Yeo *et al.*, 2003). It is important to note that the inclusion of silver in microfiber does not improve the disinfecting action of the cloth during cleaning. Rather, it acts to kill single celled organisms that have adhered to the cloth surface after mechanical removal, which is achieved by most fiber and microfiber cloths. Thus the purpose of the silver is to inhibit microbial growth on the cloths and prevent spreading the contaminants. Nevertheless, there is evidence to suggest a degree of toxicity of nano particle sized silver, but this has not been fully explored (Asharani *et al.,* 2008). On the other hand, it has been shown that rinsing untreated fiber and microfiber cloths in hot water after use has a similar effect on microbe activity within the cloth (Lalla *et al*., 2005). This suggests the inclusion of silver as an antibacterial in fiber and microfiber cloth may have limited benefit.

2.5 Cleaning Products, Exposure and Health

There are few studies on the efficacy of cleaning techniques or the beneficial attributes of cleaning products beyond their antimicrobial properties. However, there is significant research into the indoor pollutant effects of cleaning methods and their health consequences. Dozens of research papers, to be discussed here, give evidence that the routine use of cleaning products can have negative consequences on consumer health. Indeed, though cleaning products contribute to only a fraction of VOC emissions, the health consequences as a result of their use appear to be disproportionately large (Nazaroff and Weschler, 2004). For this reason, it is of interest to evaluate the cost to health from exposure to chemical cleaners given that there are alternative cleaning methods (i.e. fiber and microfiber), which have been shown to be effective without necessitating this level of chemical exposure.

The chemical profile of cleaning products can be considerably complex, with no government regulations requiring the manufacturers of these products to state the ingredients or potential effects from long term use (Steinemann *et al.*, 2011). Numerous studies of chemical emissions from household products have shown that even those products considered to be 'low VOC', 'eco' and 'green' can contain species that are known carcinogens, respiratory irritants and persistent environmental pollutants (Sack *et al.,* 1992; Kwon *et al*., 2007; Steinemann *et al.*, 2011). Furthermore, there are more than 250,000 reported cases of children being poisoned by cleaning products in the US each year, the majority of these cases being in the home (McKenzie *et al.*, 2010).

The long term consequences of prolonged chemical exposure to household cleaning products are now only just beginning to be to be more fully understood. Beyond acute respiratory reactions (i.e. coughing and feeling ill directly after chemical use) there is emerging evidence that longer-term damage to health can be developed. For example long term usage of household cleaning sprays and scented air fresheners has been associated with increased risk of cardiovascular health hazards in older women, and that people with existing pulmonary conditions are likely to be more susceptible to these effects (Mehta *et al.*, 2012). There are also links to domestic chemical exposure and breast cancer (Zota *et al.*, 2010). The incidence of allergic asthma has been increasing in Westernized countries (Lündback, 1998) and there is strong evidence that indicates a positive association between cleaning activities and the onset of asthma in occupational exposure studies (Nielsen *et al.*, 2007). A large multi-country investigation of adult asthmatic response in the domestic environment showed increased asthma symptoms and adverse reactions with exposure to chemical cleaners (Zock *et al.*, 2007). Both studies however do not have conclusions encompassing a definite causal relationship.

There are certain chemical compounds included in cleaning products with debatable toxicity. For example, many general purpose and glass cleaning sprays include aqueous glycol ethers. There is significant contention in the literature of the most widely used and disputed of these chemicals, 2-butoxyethanol (2-BE), to establish if its inclusion in consumer products is harmful to health. Aqueous glycol ethers like 2-BE are used to dissolve oil such as from fingerprints and foods but are ineffective for dirt and mineral scale. The US-EPA classifies glycol ethers as hazardous air pollutants in the 1990 Clean Air Act Amendments; however 2-butoxyethanol was removed from this list in 2004 though this was not necessarily supported by the full body of indoor air research (Singer *et al.*, 2006). Singer *et al.* (2006) showed 2-BE to be readily adsorbed to surfaces within the home and implications have been made that surface coatings may be slowly released over days (Nazaroff and Weschler, 2004). Nevertheless this is determined by the amount of product used and the air exchange rate in the house. Regardless, these semi-volatile organic compounds (SVOCs) are *known* toxic air contaminants for short term, high exposure events (OEHHA, 2008).

Investigation of the typical emissions of these species showed that under normal to heavy use 2-butoxyethanol concentrations could maintain concentrations of 800 $\mu g/m^3$ for 4 hours after cleaning with a single product (Singer *et al.*, 2006). The authors conclude that, based on the calculated emission factors of these cleaning products, it is possible that the concentration of 2-butoxy-ethanol could approach or reach the 14 mg/m^3 concentration threshold for toxicity exposure as a result of household cleaning with typical cleaning products (Singer *et al.*, 2006). The application of glycol ethers to floors and other hard surfaces through the use of cleaning agents has been shown to elevate the concentration of these species in indoor air (Fromme *et al.*, 2013). The semi-volatile nature of these compounds means they exist as a surface layer that ensures delayed and cumulative emissions (Singer *et al.*, 2006) and are likely to be absorbed through dermal pathways (Weschler and Nazaroff, 2008).

In a study commissioned by the Dow Chemical Company, a manufacturer of 2-BE, it was argued that previous emissions studies assessing 2-BE's toxicity over estimate the potential for exposure (McCready *et al.*, 2013). This study is based on low product usage in California, which also has regulated lower VOC concentrations in cleaning products than others US States (CARB, 2009).

It has been considered that the transport of semi-volatile organic compounds, such as 2-BE from household surfaces could be an important avenue for exposure. Several SVOC pharmaceutical drugs are administered by the dermal pathway (e.g. nicotine patches) thus it has been argued that this is a viable pathway for transfer of surface pollutants (Weschler and Nazaroff, 2012). This is supported by evidence that cleaning which reduces indoor surface pollution reduces sick building syndrome symptoms of the occupants (Raw *et al.*, 1993).

2.6 Endocrine System Disruption

Beyond the more acute and apparent health effects from exposure to chemical cleaning agents there are longer term and more difficult to establish consequences. The potential for very low doses of chemical exposure to interrupt endocrine (hormonal) systems is only just being recognized. It has been proposed that endocrine interruption has contributed to the significant increase in metabolic diseases in the Western world leading to increased rates of secondary diabetes and obesity as well as some cancers (Caliman and Gavrilescu, 2009). The US EPA has initiated the Endocrine Disruptor Screening Program (EDSP, http://www.epa.gov/endo/index.htm) for the screening of chemical compounds for their ability to influence the endocrine system. Nevertheless there are no current guidelines for the exclusion or recommended exposure to chemical compounds on the basis of their ability to influence and mimic hormonal systems.

Many of these endocrine disrupting compounds are semi-volatile. This means that they are likely to exist on surfaces for longer periods of time than other, more volatile, species. Consequently, there is potential for these chemicals to build up as a result of frequent use of products containing these species, thus increasing the daily exposure levels (Weschler and Nazaroff, 2008). Chemicals from consumer products are routinely found in human tissue, urine and breast milk (Centers for Disease Control and Prevention (CDC), 2009). For example 4-nonylphenol and nonylphenol ethoxylates are common surfactants in disinfectants, all-purpose cleaners and spot removers and have been widely observed in dust samples in US homes (Betts, 2003). These compounds are known to mimic female oestrogen hormones.

2.7 The Cumulative Effect of Indoor Cleaning Product Usage

Domestic cleaning products are not usually used in isolation and when a cleaning event is underway it is likely that a number of different cleaning products are in use (Moran *et al.*, 2012). It has been shown that homes with higher frequency use of cleaning products have higher sustained total VOC concentrations than lower use homes (Guo *et al.*, 2009). It is therefore very likely that homes which use very low VOC emitting cleaning methods, such a fiber and microfiber cleaning, will have lower concentrations of these chemical species both during cleaning and long term.

In a typical US home, with mid to low ventilation, it can be expected that immediately after normal use of common cleaning products the concentration of individual VOC species can be elevated to between 300-1200 µg/m^3 for 1-3 hours. This can be over 1000 times the expected background concentration for several hours after use (Sparks *et al.*, 1999; Nazaroff and Weschler, 2004). The surface emission of some less volatile species, such as glycol ethers, have been shown to elevate concentrations of that species for several hours and in some cases days, after cleaning and this can have a cumulative effect if regular cleaning using these products is undertaken (Zhu *et al.*, 2001).

Total VOC (TVOC) concentrations were investigated in small, domestic sized bathrooms for a typical cleaning regime. TVOC values averaged 0.02 - 6.49 ppm with peaks to 11 ppm for up to half an hour during and after cleaning took place. Importantly, specific compounds, such as 2-buthoxyethanol concentrations during this cleaning period approach occupational exposure thresholds (Bello *et al.,* 2010). As there are no long-term domestic guidelines for VOC exposure, occupational exposure thresholds which are determined for 1 or 8 hour exposures are often considered to be in excess of optimal for domestic exposure.

Beyond the immediate peak of VOC concentrations after the use of cleaning products it is well established that the distribution of chemical components of cleaning products is not restricted to their place of use. Chemical compounds from cleaning products can react to form or adhere to household dust and in a high activity period, such as cleaning, this can result in the transport of dust to all areas of the home. There is evidence that the chemical constituents from cleaning products can accumulate in dust throughout the home and this has been observed in several large scale studies (Butte and Heinzow, 2002). This means that although the products are used in one area their effects can be observed in many areas of the home and exposure is therefore more widespread.

2.8 Chemical Reactivity

The use of cleaning products indoors introduces pollutants (VOCs) that are not ordinarily in our homes (Nazaroff and Weschler, 2004). This means that indoor VOC concentrations are likely to be higher when chemical cleaning products are used than when compared to inherently very low emitting methods such as fiber and microfiber cleaning.

Secondary emission species are the products of chemical reactions between compounds that are primarily emitted. For example, a primary pollutant is a certain chemical emitted from the use of a surface cleaning spray. If this chemical then reacts in the environment into which it was introduced, the product of this reaction is the secondary species. The formation of secondary species is of concern because it is difficult to predict the exact reactions that take place. This is because different conditions, such as temperature, local pollution sources, infiltration of sunlight, ventilation and room furnishings can all affect which reactions occur. Because many secondary pollutants are formed through reactions with ozone (a highly reactive but common urban pollutant) secondary species are often oxidized, making them both difficult to detect and more likely to be of concern for human health than their parent species (Weschler, 2011).

In a review of the changing chemical profile indoors, Weschler (2009) described the recent (within last decade) ubiquity and dominance of terpene species, particularly in cleaning products. They are commonly referred to as ‘natural ingredients’ and are used for their fragrance as well as their ability to behave as solvents; dissolving sticky and oily residue. The most common terpene species in cleaning products are pinene and limonene (Stienemann *et al.*, 2011). For example, using cleaning products containing limonene have been shown to elevate room concentrations of this compound from 1000 to 6,000 μg/m^3 (~ 1000 times background concentrations) (Nazaroff *et al.*, 2006). Terpene molecules are highly reactive, particularly with ozone. These reactions have been shown to increase the production of formaldehyde and other oxygenated and organic acid species all of which can be harmful to health (Coleman *et al.*, 2008; Long *et al.*, 2000).

This increase in terpene concentrations in the home is important for reactive gas phase chemistry and how we understand the impact that this has on indoor air quality and occupant health (Moran et al., 2012). Terpenes are perhaps the most extensively studied group of unsaturated hydrocarbons for reactions with ozone indoors, particularly as a gas-phase route for Secondary Organic Aerosol (SOA) production (e.g. Weschler and Shields, 1999; Sarwar *et al.*, 2004; Youseffi and Waring, 2012). Structurally, terpenes are hydrocarbon chains of the base unit, isoprene (C_5H_8), a highly reactive unit with two double bonds that is one of the most abundant biogenic VOCs (BVOC).

SOAs are formed as a result of chemical reactions that occur in the air and on surfaces. Much like what is delivered from aerosol spray cans, SOAs are ultra-fine liquid droplets suspended in the air, so small you often can't see them. They are of particular concern because of the efficient delivery of potentially harmful pollutants to the lungs. This is because of their small size but relatively high concentration in the air. Characterising the chemical composition of SOAs is very difficult because they form as a result of thousands of chemical reactions between many gas and liquid phase compounds and their composition is often complex.

Concentrations of SOAs have been shown to increase by more than 7 times following the use of products containing terpenes (e.g. pinene, limonene) indoors (Long *et al.*, 2000). This is because the secondary products produced when limonene reacts with ozone are acids, alcohols, aldehydes and ketones which are less volatile and thus are likely to condense to the liquid phase (Walser *et al.*, 2007). Many of these products are known to be detrimental to health (Wescher, 2011).

Another example of chemical reactivity in the home is the potentially significant and seriously adverse outcomes from reactions involving the combination of cleaning product solutions. There are a number of synergistic consequences from the mixing of common household products with little to no warning given to consumers on product labels. There are many recorded examples of inhalation toxicity as a result of mixing household cleaners. Commonly this is from mixing bleach and ammonia compounds with organic acids and other cleaning constituents. These mixtures often result in the production of chlorine gas, ammonia gas as well as combined chloramines. The combination of bleach and acid to produce the colloquially termed 'mustard gas' is well documented. Table 1 was composed by Nazaroff and Weschler (2004) outlines the known chemical combinations and literature reporting of the health consequences as a result. These consequences range from mild eye and throat irritation to death in some extreme cases.

The combination of common household cleaners has also been shown to increase SOA concentrations indoors. Ammonia (NH_3), commonly used in floor cleaning solutions and as a disinfectant, has been shown to react with common inorganic acids (which are ingredients in many household products) to increase aerosol production under normal conditions (Seinfeld and Pandis, 2003). Recently, it has been shown that the presence of ammonia increases the quantity of SOA production from terpene/ozone reactions (Huang *et al.*, 2012). This provides a more efficient delivery of harmful secondary pollutants via SOA to the lungs of exposed occupants.

Documented inhalation toxicity related to mixing of cleaning products

Nature of study	Products mixed	Toxic gas(es)	Outcomes	Ref[a]
Case reports (2)	NaOCl, vinegar, bleach, and detergent; ammonia and NaOCl	Chlorine, ammonia	Acute illness with recovery in days	a
Case report	Ammonia type and hypochlorite cleaners	Ammonia	Acute illness with recovery in days	b
Case report	Bleach (5.25% NaOCl) and powder containing 80% $NaHSO_4$	Chlorine gas	Acute illness with recovery after several days	c
Case report	Several products applied to clear a clogged drain[b]	Uncertain	Severe obstructive airway disease	d
Case reports (2)	NaOCl (5%) and HCl (10%)	Chlorine gas	Acute illness with recovery in several days	e
Case report	Ammonia with household bleach containing hypochlorite	Chloramines	Acute illness with recovery in days	f
Case reports (3)	Aqueous ammonia (5–10%) with bleach (5.25% NaOCl), plus laundry detergent in 2 cases	Chloramines	Life-threatening toxic pneumonitis requiring prolonged hospitalization and residual symptoms	g
Case reports (5 episodes at 2 state hospitals)	Bleach (NaOCl) and phosphoric acid cleaner	Chlorine	Acute poisoning symptoms that abated within hours to days; a few cases required medical treatment	h
Analysis of 216 cases reported to Regional Poison Information Center	Hypochlorite containing product with (a) ammonia (50%), (b) acid (29%), (c) alkali (21%)	Chlorine/ chloramines	Symptom resolution for 93% of patients within 6 h; 33% received medical care; one patient w/preexisting condition required hospital admission for continued respiratory distress	i
Case report	Sequential application of numerous cleaning products to remove a bathtub stain[c]	Hydrofluoric acid	Hemorrhagic alveolitis and adult respiratory distress syndrome; month-long hospital care; residual pulmonary deficit	j
Case reports (2 cases each w/36 soldiers)	Liquid bleach and ammonia mixed in toilet bowls and buckets	Chloramine gas	Acute symptoms; two patients admitted to hospital, one required several days of intensive care observation	k
Case report	Liquid ammonia (3–10% $NH_3(aq)$) and bleach (5% NaOCl)	Chloramine gas	Upper air compromise and pneumonitis requiring emergency tracheostomy and 7 d of hospital care	l
Case report	Bleach and ammonia	Chloramine gas	Death	m

[a] References: a—Faigel (1964), b—Dunn and Ozere (1966), c—Jones (1972), d—Murphy et al. (1976), e—Gapany-Gapanavicius et al. (1982a), f—Gapany-Gapanavicius et al. (1982b), g—Reisz and Gammon (1986), h—Hattis et al. (1991), i—Mrvos et al. (1993), j—Bennion and Franzblau (1997), k—Pascuzzi and Storrow (1998), l—Tanen et al. (1999), m—Cohle et al. (2001).

[b] Products used (selected active ingredients): Liquid Plum-R (NaOCl, 5%; KOH, 2%); Drano (NaOH, 54%; $NaNO_3$, 30%); Clorox (NaOCl, 5%); Sani Flush ($NaHSO_4$, 75%).

[c] Cleaning products used (active ingredient, if reported): cleanser, mildew stain remover (NaOCl, 25–45%), tub and tile cleaner (H_3PO_4, 18%), ammonia cleaner (NaOH, 2–2.5%), bleach (NaOCl, 5.25%), toilet cleaner (HCl, 14.5%), vinegar (CH_3COOH, 5%), rust remover (H_6F_6, 8%). Application of each product was followed by a cold-water rinse.

Table 1: Extracted from Nazaroff and Weschler 2004, outlining the mixing of common household cleaners and known health effects as a result of exposure to secondary reaction products formed.

Beyond those described here, there are literally thousands of potential chemical reactions that can occur indoors as the result of the emission of chemical constituents from cleaning products. There is a vast body of literature discussing indoor chemical reactivity in the gas phase, encompassing many chemical constituents found in the cleaning products (Weschler, 2004). These studies outline the potential for formation of a number of compounds that are known irritants and in some cases toxic or carcinogenic (Weschler 2011; Carslaw, 2007). The overwhelming conclusion to these studies is that a lower level of indoor VOCs, through reduced emission, significantly reduces the potential for these reactions to occur (Weschler, 2009). As has been discussed, the elevated and often localized emission of VOCs as the result of using cleaning products in the home greatly increases chemical reactivity and the production of secondary pollutants. As an alternative, fiber and microfiber cleaning methods inherently have very low VOC emissions. Low VOC environments greatly reduce the opportunity for the types of chemical reactions and secondary product formation discussed here to occur in homes. This ultimately results in less polluted air with lower potential health risks.

2.9 Assessing the Fiber/Microfiber Alternative

Fiber and microfiber cleaning cloths are made from ultra fine polyester and nylon fibers, the same building blocks as are used to make many of our clothes and soft furnishings. This means that, after a short term period of emitting surface VOCs, these fabrics are inherently very low VOC emitting with low degradation (under normal conditions) (Silas *et al.,* 2007).

The fiber and microfiber cloth cleaning action works by forcing the sharp edge of the fine fibers against surface debris to effectively shave contaminants off. These contaminants are then trapped within the fiber wad through adsorption and static attraction and are released when rinsed with water (Nilsen *et al.*, 2002, Gillespie *et al.*, 2013). Thus, a significant difference between fiber/microfiber cleaning and chemical cleaning is that the mechanical cleaning action does not leave a chemical residue or emit large quantities of VOCs. Furthermore the same product can be used repeatedly.

A scientific evaluation of microfiber and ultra-microfiber cloths investigated the cleaning efficacy of these cloths for typical household contamination of surfaces. It was found that they achieved good cleaning results with water alone, without the need for chemical cleaning agents (Nilsen *et al.*, 2002). Indeed, there is evidence that the cleaning mechanism of fiber and microfiber cloths is not at all improved by the presence of cleaning agents (Pesonen-Leinonen *et al.*, 2003). There is evidence that microfiber and fiber cloths are detrimentally affected in their longevity and efficacy by chorine based chemical mixtures.

Choice, the consumer advocacy group, undertook a comparison of bathroom mitt cleaners whereby their efficacy was assessed compared to traditional chemical cleaners as well as against each other. It was found that a very similar level of perceived clean was achieved with the mitts compared to chemical cleaners. A number of the concerns stated by the trial participants as to whether they would switch related to germ removal and the perceived need to use cleaning products for a 'real' clean (Choice, 2005).

To counter the germ removing efficacy concern, there have been a number of studies investigating the ability of microfiber cloths to remove surface microbes. These have shown superior microbial removal rates compared to traditional cloths, and in some cases complete removal of surface organisms was achieved. However, the type of cloth and quality of fiber has been shown to influence this efficacy (Wren *et al.*, 2008). A study using Zabada fiber cloths has shown very effective removal of surface microbes, greater than traditional cleaning cloths with water alone and impregnated with antibacterial agents, and matching that of cloths soaked with hypochlorite (bleach) solution (Lalla and Dingle, 2004). Further study of Zabada fiber cloth cleaners showed that there was no higher risk of contamination from residual microbes on the cloths surface, after rinsing with hot water, than with other standard cleaning cloths, including those soaked with bleach. Zabada fiber cloths have been determined to be suitable for maintaining kitchen hygiene standards comparable with methods that use bleach (Lalla *et al.*, 2005).

Generic microfiber cloths were compared to sponge, cotton and paper towel wipes for efficacy in removal of surface contaminants (microbial). When used dry, efficacy for all wipes was significantly lower than when wet. When used wet, *new* microfiber cloths outperformed all other cloths for decontamination of the surfaces from S. *aureus* and E.*coli* (Diab-Elschahawi *et al.*, 2010). However this advantage for generic microfiber cloths was lost after 20 process cycles (washing at 90^{o}C) (Diab-Elschahawi *et al.*, 2010). A number of brands of microfiber and fiber cloths were anonymously assessed for cleaning efficiency in terms of removal of surface dirt (i.e. visual) as well as microbes. Though microfiber cloths in general showed superior surface removal compared to paper towels and traditional cloths, the extent of this advantage depended on the type of fiber cloth used (all when wet). The terry toweling textured cloths showed greatest removal efficacy compared to smoother surface cloths, which had reduced capacity to absorb surface dirt. Results also indicated that the quality of the microfiber cloth influenced its performance and this factor should be taken into account when assessing the superiority of microfiber as a cleaning material (Moore and Griffith, 2006).

For the cleaning of hard floors microfiber mops used with water alone, were compared to traditional mopping systems with cleaning agents and were found to be superior at removing oil, protein residues and soils (Pesonen-Leinonen *et al.*, 2003). Microfiber mopping tools were also compared to standard cotton strip mopping for efficacy of microbial removal. The microfiber mopping system was shown to be superior to traditional mopping tools for the removal of microbes (95% removal compared to 68% removal). Importantly, the use of disinfection cleaning products in conjunction with the microfiber system made no improvement to microbe removal (95% removal maintained) (Rutala *et al.*, 2007).

An assessment of replacing a traditional hospital cleaning regime (chemical cleaners and large volumes of water) with microfiber cloth cleaning and steam, showed improvements in the time it took to clean (the visible cleaning results as well as surface contamination). Cleaning staff expressed significant preference for the new regime, which eliminated the need for chemical cleaning products and reduced water consumption during the cleaning process by 90% (Gillespie *et al.*, 2013).

Beyond eliminating the need to purchase and use commercial cleaning agents in most household contexts, it has been estimated that use of microfiber cloths for cleaning has the potential to reduce water consumption by a factor of 20, energy use by a factor of 30, and solid waste (consumption of cloths) by a factor of 50 (Nilsen *et al.*, 2002).

2.10 Conclusion

Cleaning is a necessary task in the domestic environment and a degree of disinfection to maintain low levels of harmful microorganisms is beneficial for occupant health. Nevertheless, there is strong and significant evidence that high and regular use of chemical cleaning agents and wide spread use of disinfectants is not required to achieve a level of cleanliness required for a healthy household.

There is also significant evidence that many of the popular chemical additives in cleaning and disinfection products are detrimental to health through short term acute irritation as well as more serious long term exposure effects. Currently, there are a number of consumer cleaning products that have been designed to minimize the health and environmental impacts of using chemical cleaners. Yet, a lack of regulation of the terms 'green' and 'eco' has made choosing the best products for human exposure difficult, especially when ingredients are not listed on product labels. The mindset of the need for hospital disinfection in all areas of the home is pervasive and not supported by the literature.

Research has shown that the correct use of disinfection products in small areas of the home can reduce potentially harmful bacterial contamination; however widespread usage throughout the home offers no obvious advantage. The disadvantage to widespread usage of disinfectants however has been well documented with the potential for respiratory distress, bio-accumulation, endocrine interruption and general malaise. Furthermore, the mechanical removal of microbial species can be just as effective as cidal mechanisms in removing these bacteria from household surfaces and this can be achieved to a high degree with microfiber and fiber cloths without the need for chemical agents.

A considerable body of knowledge exists exploring the potential for common chemical components of household cleaners to form new and more toxic secondary pollutants by reacting under normal conditions. The chemical synergism that occurs as a result of different products being used concurrently can create short term periods of very high concentrations of secondary products and secondary organic aerosols. This can mean increased and more effective delivery of species known to be harmful to the respiratory system. The mitigation of VOC emission through low usage of chemical cleaning products is considered to be a very effective and desirable measure to reduce chemical reactivity and the formation of harmful secondary reactants. In general, there is evidence that cleaning products are overused and that their efficacy is no greater than wiping surfaces with wet fiber/microfiber cloths for the mitigation of normal household mess and dust.

3 Glossary

Adsorb - The adhesion of molecules/ atoms to surfaces. The result of adsorption is a surface layer or 'skin' of the adsorbed species which does not penetrate the inner material.

Alcohols - Hydrocarbons of variable chain length with an –OH functional group. Alcohols are commonly added to cleaners to assist the dissolution of fats and oily residue in water.

Aldehydes - Hydrocarbons with a carbonyl functional group (double bonded oxygen) at the end of the chain. These species are considered oxygenated and can readily react within the body. Aldehydes are commonly secondary products formed through gas phase reactions between indoor air pollutants.

Ammonia - A weak base comprized of a nitrogen atom with three hydrogen atoms (NH_3). Ammonia is commonly used in cleaning products for its ability to clean and disinfect. It is known to cause skin, throat and lung irritation.

Bio-accumulation - The accumulation of organic or inorganic (e.g. metal) chemical compounds in organisms; including humans. Bio-accumulation is considered for the toxic/ health effect substances. Bio-acumination occurs when the rate of uptake is greater than loss from the organism. Bio-accumulation can account for toxic/ adverse reactions to substances where single exposure episodes are low, yet are frequent and/or long term.

BVOC – Biogenic Volatile Organic Compounds. These are volatile species which are emitted from natural sources. Many BVOCs contain double carbon bonds which mean they have the ability to readily react in typical atmospheric conditions.

Cidal mechanism - The chemical killing mechanism of microorganisms by interfering with the functionality of the cell (to achieve disinfection).

Disinfectant - Chemical substances applied to surfaces to kill or remove microorganisms. The killing mechanisms of disinfectants vary and are non-selective. This means that most beneficial organisms are removed along with more hostile ones. Not all microorganisms are destroyed by disinfectants, thus differentiating this method from sterilisation.

E. *coli* - The abbreviated name for the *Escherichia coli* bacterium. Most strains of E.*coli* are harmless to humans, though a few strains can produce violent symptoms of nausea and vomiting. This is commonly referred to as food poisoning and results from contamination of surfaces and foods with harmful strains of E.*coli* bacteria.

Endocrine System Disruption (ESD) - The endocrine system is responsible for the distribution and regulation of hormones in humans. Some chemical species are known to mimic or mask hormones, thus disrupting the normal function of the endocrine system. It is thought that exposure to very low concentrations of some ESD compounds can have significant effects on normal bodily functions.

Fiber/Microfiber Cloths - Synthetic textiles with very fine individual threads (1/100th width of human hair). Made from polyesters and polyamides, the combination and type of these materials determines the properties of the resultant textile. This means that specific characteristics such as; texture, fiber length and width, water absorption capacity and electrostatic charge capacity, can be determined by the manufacturing process. Cloths designed for cleaning usually have sharp edged fibers which assist in the mechanical removal of dirt and bacteria from surfaces.

Glycol ethers - A chemical group of which 2-butoxyethanol (2-BE) is a member. Commonly used as solvents, these species tend to have higher boiling points than most organic solvents and thus are considered semi-volatile. The toxicity/hazard of exposure to glycol ethers is variable, though some specific species, such as 2-BE are considered toxic at mid to low concentrations.

Hypochlorite - Often used as the colloquially termed bleach. Hypochlorite is the chlorite ion, comprising of chlorine and an oxygen atom. This ion readily decomposes to chlorides and oxygen, thus is a powerful oxidizer to kill microorganisms for surface disinfection.

Hydrocarbon chains – Molecules consisting of chains of carbon atoms with hydrogen atom substrates. Hydrocarbons are also referred to as organic compounds.

Ketones - Hydrocarbons with a carbonyl functional group (double bonded oxygen) at any position along the chain, except the end. Usually highly pungent, the most commonly know ketone is acetone. Some ketones are toxic for humans and the environment.

4-Nonylphenol and Nonylphenol ethoxylates – Chemical precursors to commercial detergents and commonly used as surfactants in cleaning products. These compounds are considered to be potential endocrine interrupters, mimicking oestrogen. These species are also considered environmental pollutants, due to their toxic effect on aquatic organisms.

Organic Acid – A hydrocarbon with weak acidic properties. Organic acids can usually dissolve in organic solvents and are used in many surface cleaners to prevent streaks on smooth surfaces.

Ozone - A highly reactive molecule comprized of three oxygen atoms. Ozone is a common urban pollutant.

S. *Aureus* - The abbreviated name for the *staphylococcus aureus* bacterium which is most commonly found in nasal passages as well as on the skin surface. S.*aureus* bacteria are associated with causing infection in humans. In some case this is severe and S.*aureus* is known to induce toxic shock syndrome, meningitis and skin infections. Some strains of S.*aureus are* known to have considerable antibiotic resistance.

SOA - Secondary Organic Aerosols. Tiny liquid spheres that are suspended in the air <10μm diameter. SOAs are the products of gas phase or liquid-gas chemical reactions. Their production is dependent on conditions as is their compositions, which are complex mixtures of oxygenated, amino and sulfated chemical compounds.

SVOC - Semi Volatile Organic Compounds. These are organic species with higher boiling points than VOCs. This means that at room temperature they exist in both the liquid and gas phase. This property means they likely participate in aerosol formation including the production of SOAs.

Terpenes - Terpenes are a category of BVOCs which are very common in cleaning products. For this reason, they are often referred to as 'natural'. Terpenes are used for their pleasant fragrance (lemon and pine scents being common examples from limonene and pinene respectively) as well as their ability to dissolve sticky and oily residue. Like other BVOCs, the chemical structure of terpenes includes double carbon bonds, meaning that they have the potential to react under normal atmospheric conditions. Commonly these reactions are with ozone, thus resulting in the production of secondary oxygenated products.

Thymol, 5-methyl-2-isopropyl-1-phenol - A biogenic alternative disinfectant agent derived from thyme plants. Thymol has been shown to be a good disinfecting agent with non-antibiotic cidal kill mechanism. Because thymol is a natural product (BVOC) there is likely to be potential for it to react under normal household conditions.

Triclosan, 2, 4, 4'-trichloro-2'-hydroxyphenyl ether - A common pesticide used in consumer products and cleaning agents as a disinfectant. Triclosan has a cidal mechanism akin to antibiotics and for this reason its inclusion in commercial products is questioned by many medical practitioners. There are many known and suspected health and environmental consequences from wide spread use of triclosan.

TVOC - Total Volatile Organic Compounds. This is the cumulative total mass or concentration of VOCs in a defined environment.

Quaternary ammonium compounds - Chemical solutions which contain the quaternary ammonium ion (NH_4^+). These are commonly used in disinfectants as the active antimicrobial agents; however this action is deactivated by the presence of soaps and detergents.

VOC - Volatile Organic Compounds. This class of compounds have low boiling points, which means they are easily transposed to the gas phase at room temperature. There are thousands of VOCs and many are considered to be detrimental to human health and the environment.

4 References

Aiello, A. E., Larson E., 2003. Antibacterial cleaning and hygiene products as an emerging risk factor for antibiotic resistance in the community. *The Lancet Infectious Diseases,* 3, 501-506.

Altman R.G., Morello-Frosch R., Brody J.G., Rude R.A., Brown P., Averick M., 2008. Pollution comes home and gets personal: women's experience of household toxic exposure. *Journal of Health Society and Behaviours*, 4, 417–435.

AMA, 2000. Summaries and Recommendations of Council on Scientific Affairs Reports 2000 AMA Annual Meeting. Use of Antimicrobials in Consumer Products (CSA Rep. 2, A-00). American Medical Association resolution.

Asharani P. V., Wu Y.L., Gong., Valiyaveettil S., 2008. Toxicity of silver nanoparticles in zebrafish models, *Nanotechnology*, 19.

Bai, Z.,Dong, Y.,Wang, Z., Zhu, T., 2006. Emission of ammonia from indoor concrete wall and assessment of human exposure. *Environment International,* 32, 303-311.

Bello, A., Quinn M. M., Milton D. K, Perry M. J., 2013. Determinants of exposure to 2-butoxyethanol from cleaning tasks: A Quasi-experimental study. *Annals of Occupational Hygiene*, 57, 125-135.

Bello, A., Quinn M. M., Perry M. J., Milton D. K., 2010. Quantitative assessment of airborne exposures generated during common cleaning tasks: A pilot study. *Environmental Health,* 9, 76–99.

Betts K., 2003. Are U.S. homes a haven for toxins? *Environmental Science & Technology*, 37, 407A–411A.

Bhargava H.N., Leonard P.A., 1996. Triclosan: applications and safety. *American Journal of Infection Control*, 24, 209–218.

Bloomfield S.F., Scott E., 1997. Cross-contamination and infection in the domestic environment and the role of chemical disinfectants, *Journal of Applied Microbiology*, 83, 1-9.

Bloomfield S.F., Stanwell-Smith R., Crevel R.W.R., Pickup J., 2006. Too clean, or not too clean: the Hygiene Hypothesis and home hygiene. *Clinical Exposure and Allergy*, 4, 402-425.

Bondi, C.A.M., 2011. Applying the precautionary principle to consumer household cleaning product development. *Journal of Cleaner Production*, 19, 429-437.

Butte W., Heinzow B., 2002. In house dust as indicators of indoor contamination, *Reviews of Environmental Contamination and Toxicology*, 175, 1–46.

Calafat A.M., Ye X., Wong L.Y., Reidy J.A., Needham L.L., 2008. Urinary Concentrations of Triclosan in the U.S. Population: 2003–2004, *Environmental Health Perspective*, 116,303–307

Caliman F.A., Gavrilescu M., 2009. Pharmaceuticals, Personal Care Products and Endocrine Disrupting Agents in the Environment – A Review, *Clean*, 37, 277–303.

Canosa P., Morales S., Rodríguez I., Rubí E., Cela R., Gómez M., 2005. Aquatic degradation of triclosan and formation of toxic chlorophenols in presence of low concentrations of free chlorine. *Analytical and Bioanalytical Chemistry,* 383, 119-1126.

CARB (California Environmental Protection Agency Air Resources Board). 2009. Regulation for Reducing Emissions from Consumer Products. Available from: http://www.arb.ca.gov/consprod/regs/regs.htm

Carslaw N., 2007. A new detailed chemical model for indoor air pollution. *Atmospheric Environment*, 41, 1164-1179.

CDC (Centers for Disease Control and Prevention). 2009. Fourth National Report on Human Exposure to Environmental Chemicals. Available from: http://www.cdc.gov/ExposureReport/pdf/FourthReport.pdf

CHOICE, 2008. Bathroom cleaner reviews. Available from: http://www.choice.com.au/reviews-and-tests/household/laundry-and-cleaning/floors-and-surfaces/bathroom-cleaners.aspx

CHOICE, 2005, Microfiber cleaning mitts review. Available from: http://www.choice.com.au/reviews-and-tests/household/laundry-and-cleaning/floors-and-surfaces/microfiber-cleaning-mitts.aspx

Coleman B.K., Lunden M.M., Destaillats H., Nazaroff W.W., 2008. Secondary organic aerosol from ozone-initiated reactions with terpene-rich household products, *Atmospheric Environment*, 42, 8234–8245.

De Lorenzi S., Romanini L., Finz G., Salvatorell G., 2011. Biocide activity of microfiber cloths with and without silver after contamination. *The Brazilian Journal of Infectious Diseases*, 15, 20-203.

Deschamps D., Soler P., Rosenberg N., Baud F., Gervais P., 1994. Persistent asthma after Inhalation of a mixture of sodium hypochlorite and hydrochloric acid. *Chest*, 105, 1895-1896.

DeVere E., Purchase D., 2007. Effectiveness of domestic antibacterial products in decontaminating food contact surfaces. *Food Microbiology* 24, 425-430.

Diab-Elschahawi, M., Assadian O., Blacky A., Stadler M., Pernicka E., Berger J., Resch H., Koller W., 2010. Evaluation of the decontamination efficacy of new and reprocessed microfiber cleaning cloth compared with other commonly used cleaning cloths in the hospital. *American Journal of Infection Control,* 38, 289-292.

Dodson R.E., Nishioka M., Standley L.J., Perovich L.J., Brody J.G., Rudel R.A., 2012. Endocrine disruptors and asthma-associated chemicals in consumer products. *Environmental Health Perspectives,* 120, 935-943.

Edris A.E., 2007. Pharmaceutical and therapeutic potentials of essential oils and their individual volatile constituents: a review. *Phytotherapy Research,* 4, 308-323.

Exner M., Vacata V., Hornei B., Dietlein E., Gebel J., 2004. Household cleaning and surface disinfection: new insights and strategies. *Journal of Hospital Infection,* 56, Supplement 2, 70-75.

Fair P.A., Lee H.B., Adams J., Darling C., Pacepavicius G., Alaee M., G. Bossart D., Henry N., Muir D. 2009. Occurrence of triclosan in plasma of wild Atlantic bottlenose dolphins (Tursiops truncatus) and in their environment. *Environmental Pollution*, 157, 2248-2254.

Fong D., Gaulin C., Lê M., Shum M., 2011. Effectiveness of Alternative Antimicrobial Agents for Disinfection of Hard Surfaces, national Collaborating centre for environmental health. Available from: http://www.ncceh.ca/sites/default/files/Alternative_ Antimicrobial_Agents_Sept_2011.pdf

Fromme H., Nitschke L., Boehmer S., Kiranoglu M., Göen T., 2013. Exposure of German residents to ethylene and propylene glycol ethers in general and after cleaning scenarios. *Chemosphere*, 90, 2714-2721.

Gillespie E., Wilson J., Lovegrove A., Scott C., Abernethy M., Kotsanas D., Stuart R.L., 2013. Environment cleaning without chemicals in clinical settings. *American Journal of Infection Control*, 41, 461-463.

Gorguner M., Aslan S., Inandi T., Cakir Z., 2004. Reactive airways dysfunction syndrome in housewives due to a bleach-hydrochloric acid mixture. *Inhalation Toxicology*, 16, 87-91.

Guo H., Kwok N.H., Cheng S.C., Hung W.T., Li Y.S., 2009. Formaldehyde and volatile organic compounds in Hong Kong: concentrations and impact factors*, Indoor Air*, 19, 206-217.

Habib R.R., El-Masri A., Heath R.L., 2006. Women's strategies for handling household detergents. *Environmental Research*, 101, 184-194.

Hebeish A., M. El-Naggar E., Fouda M.M.G., Ramadan M. A., Al-Deyab S. S., El-Rafie M. H. , 2011. Highly effective antibacterial textiles containing green synthesized silver nanoparticles. *Carbohydrate Polymers*, 86, 936-940.

Hertz-Picciotto I., Cassady D., Lee K., Bennett D., Ritz B., Vogt R., 2010. Study of Use of Products and Exposure-Related Behaviors (SUPERB): study design, methods, and demographic characteristics of cohorts. *Environmental Health,* 9, 54.

Hirai Y., 1991. Survival of bacteria under dry conditions; from a viewpoint of nosocomial infection. *Journal of Hospital Infection*, 19, 191–200.

Huang, Y., Lee S. C., Ho K. F., Ho S. S. H., Cao N., Cheng Y., Gao Y. 2012. Effect of ammonia on ozone-initiated formation of indoor secondary products with emissions from cleaning products. *Atmospheric Environment*, 59, 224-231.

Josephson K.L., Rubino J.R., Pepper I.L., 1997. Characterization and quantification of bacterial pathogens and indicator organisms in household kitchens with and without the use of a disinfectant cleaner. *Journal of Applied Microbiology*, 6, 737-50.

Kovacs D.C., Small M.J., Davidson C.I., Fischhoff B., 1997. Behavioral factors affecting exposure potential for household cleaning products. *Journal of Exposure Analysis and Environmental Epidemiology*, 7, 505–520.

Kwon K.D., Jo W.K., Lim H.J., Jeong W.S., 2007. Characterization of emissions composition for selected household products available in Korea. *Journal of Hazardous Materials,* 148, 192-198.

Lalla F., Dingle P., 2004. The efficacy of cleaning products on food industry surfaces. *Journal of Environmental Health*, 67, 17–21.

Lalla F., Dingle P., Cheong C., 2005. The Antibacterial Action of Cloths and Sanitizers and the Use of Environmental Alternatives in Food Industries. *Journal of Environmental Health, 68, 31-35.*

Larson E.L., Lin S.X., Gomez-Pichardo C., Cabilia D.L., 2004. Effect of antibacterial home cleaning and hand washing products on infectious disease symptoms: A randomized, double-blind trial. *Annals of Internal Medicine*, 140, 321–329.

Long C.M., Suh H.H., Koutrakis P., 2000. Characterization of indoor particle sources using continuous mass and size monitors. *Journal of the Air and Waste Management Association,* 50, 1236–1250.

Lündback, B., 1998, Epidemiology of rhinitis and asthma, *Clincal and Experimental Allergy*, 28 (Suppl.2), 3-10.

Mapp C.E., Pozzato V., Pavoni V., Gritti G., 2000. Severe asthma and ARDS triggered by acute short-term exposure to commonly used cleaning detergents. *European Respiratory Journal*, 16, 570-572.

McCready D., Pitt J., Fontaine D.D., Busby M.I., 2013. Potential Sequential Exposures to 2-Butoxyethanol After Use of a Hard-Surface Cleaner, *Human and Ecological Risk Assessment: An International Journal*, 19, 189-214.

McKenzie, L.B., Ahir, N., Stolz, U., Nelson, N.G., 2010. Household Cleaning Product-Related Injuries Treated in US Emergency Departments in 1990-2006. *Pediactrics*, 126, 509-516.

Mehta, A.J., Adam M., Schaffner E., Barthélémy J.C., Carballo D., Gaspoz J.M., Rochat T., Schindler C., Schwartz J.,Zock J.P., Künzli N., Probst-Hensch N., 2012. Heart Rate Variability in Association with Frequent Use of Household Sprays and Scented Products in SAPALDIA. *Environmental Health Perspectives,* 120, 958-964.

Mintel Marketing, 2012. Available from http://www.mintel.com/

Moore G., Griffith C., 2006. A laboratory evaluation of the decontamination properties of microfiber cloths. *Journal of Hospital Infection,* 64, 379-385.

Moran R.E., Bennett D.H., Tancredi D.J., Wu X., Ritz B., Hertz-Picciotto I., 2012. Frequency and longitudinal trends of household care product use. *Atmospheric Environment,* 55, 417-424.

Nazaroff W.W., Coleman B.K., Destaillats H., Hodgson A.T., Liu D., Lunden M.M., Singer B.C., Weschler C.J., 2006. Indoor Air Chemistry: Cleaning Agents, Ozone and Toxic Air Contaminants. Report 01-336. Sacramento, CA:California Air Resources Board, 145–156. Available from: http://www.national-toxic-encephalopathy-foundation.org/iac.pdf

Nazaroff W.W., Weschler C.J., 2004. Cleaning products and air fresheners: exposure to primary and secondary air pollutants. *Atmospheric Environment*, 38, 2841-2865.

Nielsen G.D., Larsen S.T., Olsen O., Løvik M., Poulsen L.K., Glue C., Wolkoff, P., 2007. Do indoor chemicals promote development of airway allergy? *Indoor Air*, 17, 236–255.

Nilsen S.K., Dahl I., Jãrgensen O., Schneider T., 2002. Micro-fiber and ultra-micro-fiber cloths, their physical characteristics, cleaning effect, abrasion on surfaces, friction, and wear resistance. *Building and Environment,* 37, 1373-1378.

OEHHA, 2008. Determination of Acute Reference Exposure Levels for Airborne Toxicants. March 1999; Acute toxicity summary for Ethylene Glycol Monobutyl Ether. Available from: http://oehha.ca.gov/air/acute_rels/pdf/111762A.pdf

Olson W., Vesley D., Bode M., Dubbel P., Bauer T., 1994. Hard Surface Cleaning Performance of 6 Alternative Household Cleaners Under Laboratory Conditions. *Journal of Environmental Health*, 56, 27-31.

Parnes C.A., 1997. Efficacy of sodium hypochlorite bleach and ''alternative'' products in preventing transfer of bacteria to and from inanimate surfaces, *Journal of Environmental Health*, 59, 14-20.

Paul K.B., Hedge J.M., DeVito M.J., Crofton K.M., 2010. Short-term exposure to triclosan decreases thyroxine in vivovia up regulation of hepatic catabolism in young Long-Evans rats. *Toxicological Sciences*, 113, 367–379.

Pesonen-Leinonen, Redsven R., Kuisma I., Hautala M., Sjoberg, A.M., 2003. Cleaning efficiencies of mop cloths on floor coverings, *Tenside Surfactant Detergents*, 40, 80-86.

Prud'homme de Lodder L.C.H., Bremmer HJ, and van Engelen JGM. 2006. Food and Consumer Products Safety Authority of The Netherlands, RIVM report 320104003/2006: Cleaning Products Fact Sheet.

Available from: http://www.rivm.nl/dsresource?objectid=rivmp:13094&type=org&disposition=inline&ns_nc=1

Racioppi F., Daskaleros P.A., Besbelli N., Borges A., Deraemaeker C., Magalini S.I., R. Martinez- Arrieta R., Pulce C., Ruggerone M.L, Vlachos P., 1994. Household bleaches based on sodium hypochlorite: review of acute toxicology and poison control center experience. *Food Chemical Toxicology*, 32, 845-861.

Raw G.J., Roys M.S., Whitehead C., 1993. Sick Building Syndrome: Cleanliness is next to Healthiness. *Indoor Air*, 3, 237-245.

Rutala W.A., Gergen M.F., Weber D.J., 2007. Microbiologic evaluation of microfiber mops for surface disinfection. *American Journal of Infection Control,* 39, 569-573.

Sack T.M., Steele D.H., Hammerstrom K., Remmers J., 1992. A survey of household products for volatile organic compounds, *Atmospheric Environment*, 26A, 1063–70.

Sarwar G., Olson D.A., Corsi R.L., Weschler C.J., 2004. Indoor fine particles: the role of terpene emissions from consumer products. *Journal of the Air and Waste Management Association*, 54, 367–377.

Scott E., Bloomfield S.F., Barlow C.G., 1984. Evaluation of disinfectants in the domestic environment under 'in use' conditions. *Journal of Hygiene (London*), 2, 193-203.

Seinfeld J.H., Pandis S.N., 2003. Atmospheric Chemistry and Physics. Wiley, New York

Silas J., Hansen J.H., Lent T., 2007. The future of fabric: Healthcare. Healthy Building Network & Health Care Without Harm's Research Collaborative. Available From: http://www.noharm.org

Singer B.C., Destailaillats H., Hodgson A.T., Nazaroff W.W., 2006. Cleaning products and air fresheners: Emissions and resulting concentrations of glycol ethers and terpenoids. *Indoor Air*, 16, 179-191.

Sparks L.E., Guo Z., Chang J.C., Tichenor B.A., 1999. Volatile organic compound emissions from latex paint—Part 1. Chamber experiments and source model development. *Indoor Air*, 9, 10–17.

Steinemann A.C., Macgregor I.C., Gordon S.M., Gallagher L.G, Davis A.L., Ribeiro D.S., Wallace L.A., 2011. Fragranced consumer products: Chemicals emitted, ingredients unlisted. *Environmental Impact Assessment Review,* 31, 328-333.

Strachan D.P., 1989. Hay fever, hygiene, and household size. *British Medical Journal,* 299, 1259–1260.

Suller M.T, Russell A.D., 2000. Triclosan and antibiotic resistance in Staphylococcus aureus. *Journal of Antimicrobial Chemotherapy*, 46, 11–18.

Tomoto T., Moriyoshi A., Sakai K., Shibata E., Kamijima M., 2009. Identification of the sources of organic compounds that decalcify cement concrete and generate alcohols and ammonia gases. *Building and Environment*, 44, 2000-2005.

US FDA, 2011, Triclosan: What Consumers Should Know, Food and Drug Administration. Available from: http://www.fda.gov/ForConsumers/ConsumerUpdates /ucm205999.htm

Walser M. L., Park J., Gomez A. L., Russell A. R., Nizkorodov S. A., 2007. Photochemical aging of secondary organic aerosol particles generated from the oxidation of d-limonene. *Journal of Physical Chemistry A*, 111, 1907−1913.

Watson W.A., Litovitz T.L., Rodgers Jr. G.C., Klein-Schwartz W., Reid N., Youniss J., Flanagan A., Wruk K.M., 2005. 2004 Annual report of the American Association of Poison Control Centers Toxic Exposure Surveillance System. *American Journal of Emergency Medicine*, 23, 589–666.

Webb A.M., Singer B.C., Nazaroff W.W., 2002. Effect of gaseous ammonia on nicotine sorption. In: Levin, H. (Ed.), Indoor Air 2002: Proceedings of the Ninth International Conference on Indoor Air Quality and Climate, Vol. 3, Santa Cruz, CA, pp. 512–517.

Weschler C.J., 2004. Chemical reactions among indoor pollutants: what we've learnt in the new millennium. *Indoor Air*, 14 (Suppl 7), 184-194.

Weschler C.J., 2009. Changes in indoor pollutants since the 1950s. *Atmospheric Environment,* 43, 153-169.

Weschler C.J., 2011. Chemistry in indoor environments: 20 years of research. *Indoor Air*, 21, 205-218.

Weschler C.J., Nazaroff W.W., 2008. Semivolatile organic compounds in indoor environments. *Atmospheric Environment*, 42, 9018–9040.

Weschler C.J., Nazaroff W.W., 2012. SVOC exposure indoors: fresh look at dermal pathways. *Indoor Air*, 22, 356-377.

Weschler C.J., Shields H.C., 1999. Indoor ozone/terpene reactions as a source of indoor particles, *Atmospheric Environment*, 33, 2301–2312.

Wiley J.A., Robinson J.P., Piazza T., Garrett K., Cirksena K., Cheng Y.T., Martin G., 1991. Activity Patterns of California Residents. Available from:http://www.ntis.gov/search/product.aspx?ABBR=PB94108719.

Wolkoff P., Clausen P.A., Nielsen P.A., 1995. Application of field and laboratory emission cell 'FLEC'—Performance study, intercomparison study, and case study of damaged linoleum. *Indoor Air,* 5, 196–203.

Wren M.W.D., Rollins M.S.M., Jeanes A., Hall T.J. Coen P.G., Gant V.A., 2008. Removing bacteria from hospital surfaces: a laboratory comparison of ultramicrofiber and standard cloths. *Journal of Hospital Infection,* 70, 265-271.

Xu J., Zhou F., Ji B.P., Pei R.S., Xu N., 2008. The antibacterial mechanism of carvacrol and thymol against Escherichia coli. *Letters in Applied Microbiology,* 47, 174-179.

Yeo S.Y., Jeong S.H, 2003. Preparation and characterization of polypropylene/silver nanocomposite fibers. *Polymer International*, 52, 1053–1057.

Youseffi S., Waring M.S., 2012. Predicting secondary organic aerosol formation from terpenoid ozonolysis with varying yields in indoor environments. *Indoor Air*, 22, 415-26.

Zhu J., Cao X.L., Beauchamp R., 2001. Determination of 2-butoxyethanol emissions from selected consumer products and its application in assessment of inhalation exposure associated with cleaning tasks. *Environment International*, 26, 589–597.

Zock J.P., Plana E., Jarvis D., Antó J.M., Kromhout H., Kennedy S.M., Künzli N., Villani S., Olivieri M., Torén K., Radon K., Sunyer J., Dahlman-Hoglund A., Norbäck D., Kogevinas M., 2007. The use of household cleaning sprays and adult asthma: an international longitudinal study. *American Journal of Respiratory and Critical Care Medicine*, 176,735–741.

Zota A., Aschengrau A., Rudel R., Brody J., 2010. Self-reported chemicals exposure, beliefs about disease causation, and risk of breast cancer in the Cape Cod Breast Cancer and Environment Study: a case-control study. *Environmental Health,* 9, 40. Available from:http://www.ehjournal.net/content/9/1/40

THE UNIVERSITY OF WESTERN AUSTRALIA
Achieve International Excellence

Faculty of Science

The University of Western Australia
M310, 35 Stirling Highway, Crawley WA 6009

Tel +61 8 6488 3153
Fax +61 8 6488 1005
Email sandra.saunders@uwa.edu.au
Web www.chembiochem.uwa.edu.au