ABSTRACT

PHILLIPS, LORI ANN. Indoor Air Quality Risk Perception Study and Modeling Analysis of Factors that Affect Indoor Occupant Exposure. (Under the direction of Chris Frey.)

People spend the majority of their time in indoor environments where pollutant concentrations can be 70 to 100 times greater than those found outdoors. Elevated indoor concentrations pose serious health risks to the occupants of buildings. This research included designing, distributing, and analyzing the results of an indoor air quality risk perception survey to assess the state of knowledge on indoor air risks of residents in North Carolina. This research also included a modeling application that assessed some of the factors that affect indoor occupant exposure including occupancy cycles, particle removal efficiency of air cleaners, air exchange rate of air cleaners, and building characteristics. The RISK software developed by the EPA Indoor Environmental Management Branch was utilized for the modeling application.

Results from the survey indicated that respondents were more knowledgeable of specific risks than others. Respondents cited mold (99%), inadequate ventilation (92%), and cigarette smoke (91%) as the greatest contributors to poor indoor air quality. Many respondents (71%) were willing-to-pay up to $30/month for indoor air quality treatment. Respondents showed uncertainty towards the topic of air cleaners that use ozone and over 50% of respondents agreed that the risks involving poor indoor air quality can be more effectively communicated. Information obtained from write-in questions determined that 16 respondents sought more information on how to select an air cleaner for their home. Overall, respondents expressed their concern for indoor air quality risks and it was determined that the specific topic of how to select an appropriate air cleaner for a residence can be more effectively communicated to the public by environmental professionals.

Results from the modeling analysis of factors affecting occupant exposure showed that differing the air cleaner air exchange rate from 1 to 6.75 resulted in exposure reductions that had an average change of -36.4%. Varying particle removal efficiency by 50 percentage points resulted in exposure reductions that had an average change of -9%. Thus, air exchange rate was found to be the more sensitive variable. Occupancy cycles and building

characteristics were shown to affect occupant exposure as well. Occupants who were simulated to spend longer time periods in the same room as the cleaner tended to receive slightly higher overall exposure reductions. Thus, placement of an air cleaner in a room that all occupants visit during the day may maximize total occupant exposure reductions. The size of the sink area in a particular room relative to the volume of the room affects exposure. The model results imply that small rooms with small sink areas resulted in higher occupant exposures than larger rooms having larger sink areas.

The survey and modeling results were utilized to draft a list of indoor air quality risk communication priorities and recommendations for effective communication. Key recommendations include establishing a set of safe levels or guidelines for potential indoor contaminants and increased communication between environmental professionals and the media in an effort to raise awareness and educate the public on all aspects of indoor air quality issues.

INDOOR AIR QUALITY RISK PERCEPTION STUDY AND MODELING ANALYSIS OF FACTORS THAT AFFECT INDOOR OCCUPANT EXPOSURE

by
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Chair of Advisory Committee

DEDICATION

I would like to dedicate the thesis to my parents, Paul and Marianne Phillips, who have never ceased to offer their support for everything I have ever done. Their constant love and encouragement will be remembered always.

I would also like to dedicate this thesis to my pseudo-sister/dog, Chelsea, whom I miss dearly. She was the best little sister an only-child could have.

BIOGRAPHY

Lori Ann Phillips was born and raised in Hanover Township, PA. She is the only-child of Paul and Marianne Phillips of Hanover Township, PA. After graduating from Hanover Area Jr./Sr. High School in 2000, Lori Ann attended Wilkes University in Wilkes-Barre, PA, where she earned her Bachelors of Science degree in Environmental Engineering. Upon relocating to Raleigh, North Carolina in May 2004, Lori Ann became a graduate student at North Carolina State University in the Civil Engineering Department. Lori Ann has many interests including travel, photography, art, and playing the guitar. She has visited places such as Kenya and Hawaii. While her interests are varied, Lori Ann's true passion will always be music.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 BACKGROUND INFORMATION

1.1 Problem Definition

People spend the majority of the day in indoor environments and thus are exposed to indoor air pollutants. Research has been pointing to previously unrealized pollutants in residences and businesses. There are numerous health risks to building occupants associated with elevated indoor pollutant concentrations (EPA, 2006). Someone who is knowledgeable about indoor pollutants has an advantage for choosing to protect himself over someone who is uninformed. The accuracy and availability of knowledge can directly affect the actions taken by the public for dealing with indoor pollutants. Public perception of risks can be influenced by the manner in which the risks are communicated (Pidgeon *et al*., 2003). Therefore, how the public perceives the risks associated with indoor air quality can yield information for improving risk communication strategies. As information and technology for indoor air health and cleaning becomes available, the public is exposed to new ideas regarding the risks associated with indoor environments, thus enabling change in risk perception (Sloan *et al*., 2003). Changes in risk perception may indicate the effectiveness or ineffectiveness of communication techniques related to indoor air quality. Therefore, the first problem addressed here is to assess the public's current level of knowledge on the topic of indoor air quality in an effort to determine whether improved risk communication strategies are needed.

Air cleaning devices have been on the market for over 25 years. Current indoor air cleaners feature ionization, ozone generation, and electrostatic technologies (EPA, 2006). How effective are these devices at improving indoor air quality? How much do these cleaners actually decrease the risk of adverse health effects to building occupants? And at what cost to the consumer? If a consumer chooses to purchase an indoor air cleaner, the facts surrounding air cleaner efficiency, cost, and reduction of risk should be readily available for the purpose of comparison shopping. Therefore, the second problem addressed here is to evaluate the sensitivity of human exposure to a selected indoor pollutant with respect to activity patterns and characteristics of residential air cleaning technologies.

1.1.1 Objectives

To deal with the problems posed in the preceding section, the objectives of this thesis are:

(1) to determine the current status of public risk perception and knowledge relating to indoor air quality in residences;
(2) to identify areas of improvement for risk communication on indoor environmental risks; and
(3) to assess the effectiveness and exposure reduction capabilities of household room air cleaning units.

The objectives for this master's thesis were met by completing the following tasks:

- Task 1 addresses objectives (1) and (2): conduct a literature review on indoor air quality, risk perception and communication;
- Task 2 addresses objectives (1) and (2): research survey design, construct and distribute a survey on indoor air quality, and statistically analyze the results of the survey;
- Task 3 addresses objective (2): develop recommendations for effective risk communication based on survey results;
- Task 4 addresses objective (3): model and evaluate current indoor air cleaning technologies in residences; and
- Task 5 addresses objective (3): develop recommendations for selecting efficient indoor air cleaning based on model results.

1.1.2 Introduction

The purpose of Chapter 1 is to clearly present the topics and ideas that are covered in this research. Section 1.2.1 describes some of the most common indoor air pollutants and their health effects to people. How these pollutants can come in contact with people and move throughout the indoor environment is explained in Section 1.2.2 and Section 1.2.3, respectively. Section 1.2.4 describes some of the current indoor air treatment technologies available to consumers. Finally, Section 1.3 discusses the risks of indoor pollutants and related topics such as risk communication and risk perception.

1.2 Indoor Air Quality

People spend over 90% of the day in indoor environments, particularly in residences, and are often exposed to potentially harmful indoor air quality (IAQ) (Godish, 2001). If people are in environments where dangerous pollutant concentrations are present, exposures can potentially be quite high. Exposure results from a person coming in contact with a pollutant, either through inhalation, ingestion, or dermal contact (Spengler *et al.*, 2001). The list of indoor air pollutants has grown as more has been discovered about the items and substances used and found in many residences. Mold, particulate matter, radon, ozone, VOCs, pesticides, and inorganic compounds can be harmful to indoor health. Combustion sources such as cigarettes, candles, and ovens also emit harmful compounds into the air. Improper or inadequate ventilation can increase exposure risks to these hazards. Therefore, many sources are present in the indoor environment that pose health risks to the occupants. The possibility of adverse effects is increased with the knowledge that people spend such a significant part of the day indoors (Godish, 2001).

The following sections offer descriptions of some of the more common indoor air contaminants, information regarding health effects and risks, examples of transport mechanisms, and an overview of the treatment technology utilized to control indoor air pollutant levels.

1.2.1 Pollutant Descriptions, Sources, and Health Effects

A variety of substances have been identified as indoor air pollutants and they come from many sources. Table 1-1 lists examples of indoor air pollutants and their sources.

1.2.1.1 Volatile organic compounds

Volatile organic compounds (VOCs) include substances with widely varying physico-chemical properties and are nearly everywhere in the indoor environment. The number of VOCs detected indoors is often higher than outdoors, as they are released by almost all materials, consumer products, furnishings, pesticides, and fuels. Common household items

Table 1-1. Examples of Indoor Air Pollutants and Their Sources (Hines *et al.*, 1993).

Pollutant	**Sources**
Volatile Organic Compounds (VOCs)	Paints, thinners, perfumes, hair sprays, furniture polish, cleaning solvents, carpet dyes, glues, dry cleaned clothing, air fresheners, candles, soaps, bath oils, molds, tobacco smoke, particle board, plywood, veneers, insulation, fuel combustion
Inorganic Compounds (CO, CO_2, NO_x)	Gas-fired stoves and ovens, candles, fireplaces, woodstoves, kerosene space heaters, tobacco smoke
Ozone	Copy machines, indoor air cleaners, UV lighting
Particles	Fireplaces, woodstoves, candles, tobacco smoke
Radon	Release from underlying soil, release from water use
Biological contaminants	Pets, house plants, insects, molds, humans, pillows, bedding, wet or moist materials, HVAC systems, humidifiers

such as cleaners, waxes, paints, adhesives, cosmetics, furnishings, and combustion appliances release VOCs (Maroni *et al.*, 1995). VOCs can enter the indoor environment from outdoor air, from human and biological origin (animal feces, pets, indoor plants), and through the volatilization of VOCs during showering, bathing, and other uses of potable water (Howard and Corsi, 1998).

As of 1989, over 900 different VOCs had been detected in the indoor environment (U.S. EPA, 1989). More recently, Spengler *et al.* (2001) reported that over 1000 different VOCs had been found and identified indoors. Exposure to VOCs can result in both acute and chronic health effects. Many VOCs found indoors have been determined to be human carcinogens and/or they affect the central nervous system, but they can also cause irritation in the eyes and respiratory tract. At high concentrations, many VOCs have been shown to result in kidney and liver damage (Maroni *et al.*, 1995).

A specific VOC that can be found in indoor air is formaldehyde. At normal room temperature, formaldehyde is a colorless gas with a pungent odor that has a strong irritation potential. The major sources of formaldehyde indoors include cigarette smoke, other combustion sources, and urea-formaldehyde resins used as glues in products such as particle board and plywood. Typical concentrations for formaldehyde are <10 ppbv for ambient air and 0.02-0.3 ppm for residential indoor air (Godish, 2001; Cooper and Alley, 2002). The most common human health effect of formaldehyde exposure is eye irritation, which occurs at concentrations of 0.01 to 2.0 ppm (Cooper and Alley, 2002). Other health effects include asthmatic and respiratory reactions, headache, and fatigue. Based on available evidence, the

U.S. EPA, Occupational Safety and Health Administration (OSHA), and International Agency for Research on Cancer (IARC) have listed formaldehyde as a Class 2A (suspected human) carcinogen (Godish, 2001).

1.2.1.2 Inorganic compounds

A number of inorganic compounds can adversely affect indoor air quality and include carbon dioxide, carbon monoxide, nitrogen dioxide, sulfur dioxide, and ozone. Carbon dioxide (CO_2) is a colorless, odorless gas that is the main combustion product of natural gas domestic energy use for cooking and heating purposes. CO_2 is a good indicator of human bioeffluents in the indoor environment. CO_2 concentrations above 1.5% affect respiration and breathing becomes faster and more difficult. Higher levels of CO_2 can result in headaches, dizziness, nausea, and even death (Maroni *et al.*, 1995).

Carbon monoxide (CO) is also a colorless, odorless gas and is the product of incomplete combustion of carbon-containing materials. Common indoor sources of CO include unvented combustion appliances and environmental tobacco smoke (ETS) (Maroni *et al.*, 1995). Overexposure to CO is dangerous since CO reacts with hemoglobin in the blood to form carboxyhemoglobin (COHb). Elevated levels of COHb result in decreased visual perception, manual dexterity, and mental activity. CO exposures exceeding several thousand ppm can result in death from CO poisoning (Cooper and Alley, 2002).

Nitrogen dioxide (NO_2) is the most widely considered of the nitrogen dioxides (NO_x) for indoor air studies. NO_2 is a water soluble red to brown gas with a pungent, acrid odor that is produced during high temperature combustion from the combination of nitrogen and oxygen from air. NO_2 is an oxidizer and can be highly irritating to mucous membranes. Indoor sources of NO_2 include ETS, gas appliances, kerosene heaters, and fireplaces (Maroni *et al.*, 1995). Health effects of NO_2 exposure include respiratory symptoms, increased susceptibility to respiratory infections, and some impairment of lung function (Spengler *et al.*, 2001). Concentrations as low as 0.5 ppm have been shown to cause effects in people with asthma (Cooper and Alley, 2002).

Sulfur dioxide (SO_2) is a colorless gas with a pungent smell resulting from the combustion of fossil fuels. It is often emitted to the indoor environment by oil and coal heaters and is related to the sulfur content of the fuel (Spengler *et al.*, 2001). SO_2 can be detected by the human nose at approximately 0.5 ppm. Health effects from exposure to SO_2 include sensitivities of the respiratory tract for short-term exposure to increased risk of chronic bronchitis with long-term exposure (Maroni *et al.*, 1995).

Ozone (O_3) is a photo-chemical product and there are no significant anthropogenic emissions of ozone into the atmosphere. Ambient levels of O_3 are typically because of in situ photo-chemical reactions. However, ozone can also be formed indoors from the reaction of VOCs, NO_x, and light. Indoor sources of O_3 include air cleaners, UV lighting, photocopying machines, and laser printers. O_3 can also enter the indoor air from outdoors. Health effects resulting from exposures to O_3 include: respiratory and pulmonary impairment in the form of eye, nose, and throat irritation; chest discomfort; coughs; and headaches (Maroni *et al.*, 1995).

1.2.1.3 Physical pollutants

There are some physical pollutants that are present in indoor air, including particulate matter (respirable particles), radon, and lead. Table 1-2 lists the size ranges for some of the common indoor particles. The chemical composition of respirable particles includes polycyclic aromatic hydrocarbons (PAHs), metals, nitrates, and sulfates. PAHs are of particular concern because of their carcinogenic potential. In terms of physical properties, PM consist of fine and coarse mode particles. Fine particles include pollens, biological contaminants, and those generated by combustion sources, cleaning sprays, and cooking aerosols. Coarse particles largely consist of materials carried in from outdoors such as dusts. The production of ETS from smoking injects the indoor environment with a significant amount of particulate matter. Fine particles are especially able to penetrate into the respiratory system. Health effects associated with exposure to fine PM include impairments of the respiratory system. Increased risks for various cancers have been linked to exposure to elevated PM levels (Maroni *et al.*, 1995).

Asbestos refers to a class of fibrous, hydrated silicates. These fibers are chemically inert, heat resistant, and flexible, making them excellent thermal, electrical, and acoustical insulators. In addition to being used as an insulation material, asbestos is widely used in floor coverings and fireproofing (Godish, 2001). Because of past widespread use in building materials, asbestos exposures can potentially occur often. The tiny fibers are inhaled and penetrate the lung tissue leading to a variety health effects and diseases. In addition to lung cancer, Asbestosis can occur from prolonged asbestos exposure. Asbestosis is a reduction of the lung's capacity to exchange air because fibers and scar tissue resulting from embedded asbestos fibers take up valuable space in the lungs (Spengler *et al.*, 2001).

Radon is a naturally occurring gas-phase element found in the earth. It is a noble gas and does not react with other substances. However, radon is produced through the radioactive decay of uranium-226, which is found in many different types of minerals and rocks. Therefore, the primary sources of radon and radon decay products (RDPs) in buildings include the soil, domestic water supply, and building materials. Radon enters buildings through cracks in foundations and substructure vents. The major health concern associated with radon and RDP inhalation exposure is the potential for lung cancer (Godish, 2001).

Lead is a heavy metal that occurs naturally in soil and water. Lead has a variety of uses such as as a pigment in paints. Lead exposures can result from inhalation when aged paint flakes become airborne, inhalation of vapors during paint removal, and ingestion of paint chips by children. Lead is a toxic substance and it inhibits the body's production of vitamin D. Acute exposures resulting in blood lead levels (BLLs) > 60 μg/dL (micrograms/deciliter) may produce colic, shock, severe anemia, nervousness, kidney damage, irreversible brain damage, and even death. Lead has been named as a potential carcinogen (Godish, 2001).

Table 1-2. Size Ranges of Common Indoor Particles (Spengler *et al.*, 2001).

Particle	**Diameter, μm**	**Particle**	**Diameter, μm**
Skin flakes	1 – 40	Asbestos	0.25 – 1
Visible dust and lint	> 25	Resuspended dust	5 – 25
Dust mite	50	Tobacco smoke	0.1 – 0.8
Mite allergen	5 – 10	Diesel soot	0.01 – 1
Mold and pollen spores	2 – 200	Outdoor fine particles (sulfates, metals)	0.1 – 2.5
Cat dander	1 – 3	Fresh combustion particles	< 0.1
Bacteria	0.05 – 0.7	Ozone aerosols	< 0.1

1.2.1.4 Biological contaminants

Biological contaminants arise from many sources including pets, humans, house plants, molds, insects, HVAC systems, and humidifiers. For a building to become contaminated with biological organisms, there needs to be a reservoir for the organisms to colonize and conditions that are favorable for their replication. Moist areas generally serve as superb locations for biological contaminant growth. Examples of areas suitable for biological activity include humidifiers, air conditioning systems, cooling towers, and areas of water damage. These contaminants can cause health effects including allergies, asthma, nausea, symptoms of Sick Building Syndrome (SBS), Legionnaire's disease, humidifier fever, colds, and other infections (Samet and Spengler, 1991). SBS is the term used when an increased number of building occupants complain of a typical group of general, unspecific and irritative symptoms, including headache, dry eyes, lethargy, congested nose, and sore throat. The SBS symptoms usually disappear after the person has left the indoor environment. SBS symptoms are those for which no exact cause is identified (EPA, 1991). Legionnaire's disease can result from inhalation of the *Legionella pneumophila* bacteria that is commonly found in potable water supplies such as cooling towers and humidifiers. Occurrences of Legionnaire's disease are often misdiagnosed, however symptoms are similar to those of pneumonia and can be treated (EPA, 1999).

1.2.2 Sinks and Receptors

There are many sources of contaminants in the indoor environment. Upon emission from a source, the contaminant is transported through the air and is intercepted by a sink or receptor. A sink is a place to which pollutants disappear from the air, while a receptor is something which is adversely affected by polluted air. Examples of indoor sinks include plants, air cleaners, and textiles. Examples of indoor receptors include primarily humans and animals, though plants and materials such as paper, leather, cloth, and paint can also be affected (Boubel *et al.*, 1994). The amount of change in concentration from source emission to sink reception depends on a variety of factors including building construction materials and design, occupant activity, and ventilation (Godish, 2001). The effects of air transport mechanisms, both natural and mechanical, are explained in the following section.

The main receptors of indoor air pollution are humans and animals. Humans and animals are generally exposed to indoor pollutants via inhalation, though other routes are possible. The receptor need not be located in the same room as the source for exposure to occur, since pollutants are transported as air circulates throughout a residence. The most common effects include health reactions due to overexposure to a particular contaminant. In extreme cases, death or serious illness can result (Spengler *et al.*, 2001).

In addition to humans and animals, other possible sinks for indoor contaminants include textiles and furnishings. Carpets, couches, draperies, flooring, ceiling tiles, and clothing are a few examples of sinks for indoor contaminants. Contaminants can be adsorbed onto one of these surfaces. Adsorption involves the transfer of a material from one phase to a surface where it is bound by intermolecular forces. Desorption, the opposition of adsorption, and re-release of contaminants into the air can occur under warmer temperatures or due to changes in pressure or relative humidity (Hines *et al.*, 1993).

Air cleaning devices are another sink for indoor air contaminants. These devices and machines are constructed to remove or reduce contaminant concentrations through a variety of different methods. Air cleaners and their technology are described in Section 1.2.4.

1.2.3 Indoor Air Transport

Indoor air contaminants move from pollutant sources to receptors via different mechanisms of transport (Boubel *et al.*, 1994). Research efforts have been made to characterize types of indoor transport to better understand human exposure routes to indoor pollutants. Indoor air transport can be quite complicated as it is influenced by many factors. The design of a building, location of ducts, furnishings, infiltration of outdoor air, and ventilation system can affect indoor air transport and movement. The following sections elaborate on these topics.

1.2.3.1 Building characteristics

Residential buildings vary enormously in their construction characteristics, including size, design, building materials, insulation, quality of construction, site conditions, and substructure. Sizes can vary from single- to multi-family dwellings. Design can vary from rectangular boxes to more architecturally-complex homes. The addition of an attached garage to a home can significantly affect indoor air transport and contaminant levels (Spengler *et al.*, 2001). In many parts of the world, seasonal temperature differences require some form of heating or cooling appliance or system be used to maintain building occupant comfort. These systems comprise part of the mechanical ventilation system of a residence. The set-up, layout, and maintenance of a home's ventilation system directly impacts transport of indoor air (Godish, 2001).

1.2.3.2 Transport mechanisms

The movement of air through indoor spaces is a physical process called ventilation. Ventilation is the result of two primary transport mechanisms that govern indoor air flows. The two transport mechanisms responsible for the majority of indoor air flow are diffusion and convection. Diffusion is the movement of air from areas of high pressure to areas of lower pressure. Convection is defined as the movement of air due to the rising of warm air and the falling of cooler air. Warm air is less dense and rises above denser, cooler air. Together, diffusion and convection are the mechanisms responsible for the movement of air in indoor environments (Maroni *et al.*, 1995).

When air flows into a space, it mixes, is diluted, and undergoes partial replacement. Ventilation naturally occurs due to differences in pressures between different areas of a house and the outside environment. However, pressure differences are often too variable or inadequate so mechanical forms of ventilation are utilized to maintain general comfort and air quality in buildings. Ventilation is utilized to dilute and remove contaminants, enhance thermal comfort, and remove excess moisture from the air. The transport and interactions of air directly affect the levels of indoor pollution (Spengler *et al.*, 2001). This relationship is illustrated in Figure 1-1.

Natural ventilation occurs in all buildings and results from the following three dependencies:

1. Pressure differences that occur during heating or cooling of a building under closed conditions;
2. Pressure-driven flows when building windows and doors are open; and

3. The continual movement of air through a building as it enters and exits through different openings (vents, cracks, etc.).

Residential buildings in seasonably warm or cold parts of the United States often operate under closed conditions for about nine months each year as a result of the use of heating, ventilation, and air conditioning (HVAC) systems to maintain thermal comfort levels (EPA, 1991). Therefore, natural ventilation in these buildings results from infiltration and exfiltration processes. These processes are affected by pressure differentials associated with temperature differences and wind speed of ambient air. Infiltration and exfiltration displace and replace quantities of air in a building, resulting in the flow of air. In studies conducted in the 1980s, the average residential infiltration/exfiltation rate was found to be less than 1 air change per hour (ACH); lower income housing was found to have rates greater than 1 ACH. This difference can be attributed to newer homes being more energy efficient and "tighter" than older homes, showing that new construction typically allows for less natural ventilation, often decreasing air exchange rates that are vital to comfort (Godish, 2001).

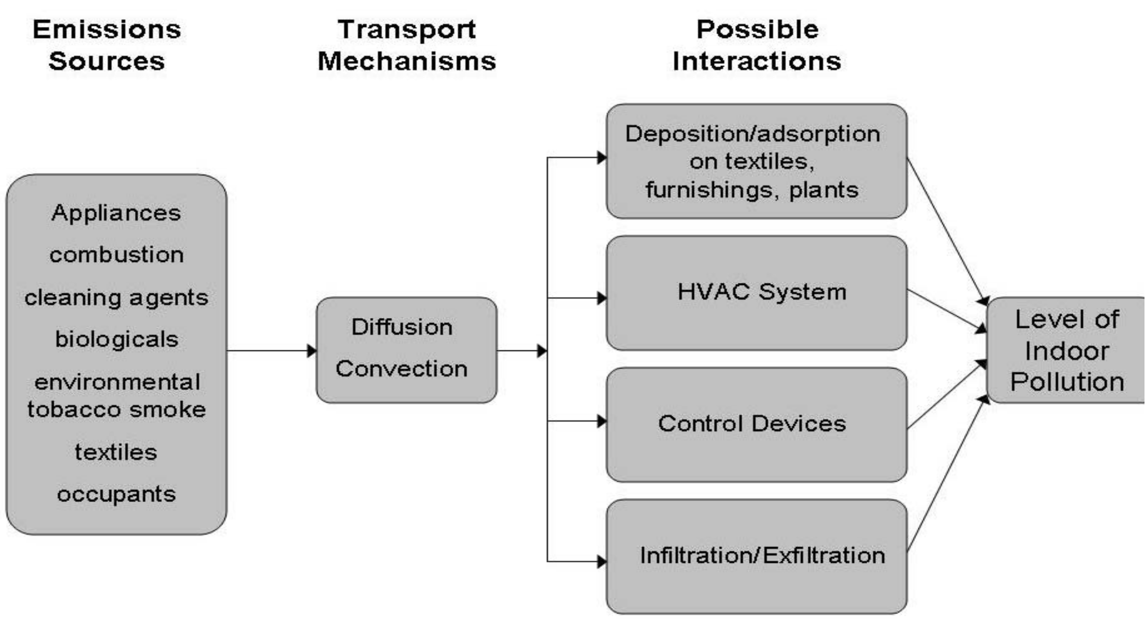

Figure 1-1. Indoor Air Transport and Interactions.

In some climates it is possible for homes to utilize only natural ventilation for ventilation needs. Purely natural ventilation systems consume little energy, require little maintenance, have low first costs, and are environmentally friendly. However, natural ventilation should only be used in areas where outdoor air is suitable for indoor air, such as locations situated away from industry, construction, or other known air pollution sources (Spengler *et al.*, 2001).

Mechanical, or forced, ventilation uses fans or blowers to forcibly exchange the air in a building (Cooper and Alley, 2002). Often, mechanical ventilation is incorporated into a building's heating, ventilation, and air conditioning (HVAC) system (Godish, 2001) Three types of mechanical systems – mixing, displacement, and localized ventilation – exist. Mixing is the most common system utilized in the United States and is comprised of conditioned air being supplied from diffusers at high velocity and at a suitable temperature. Contaminant concentrations are diluted due to mixing ventilation. Figure 1-2 illustrates the ventilation options in a single family home (Spengler *et al.*, 2001).

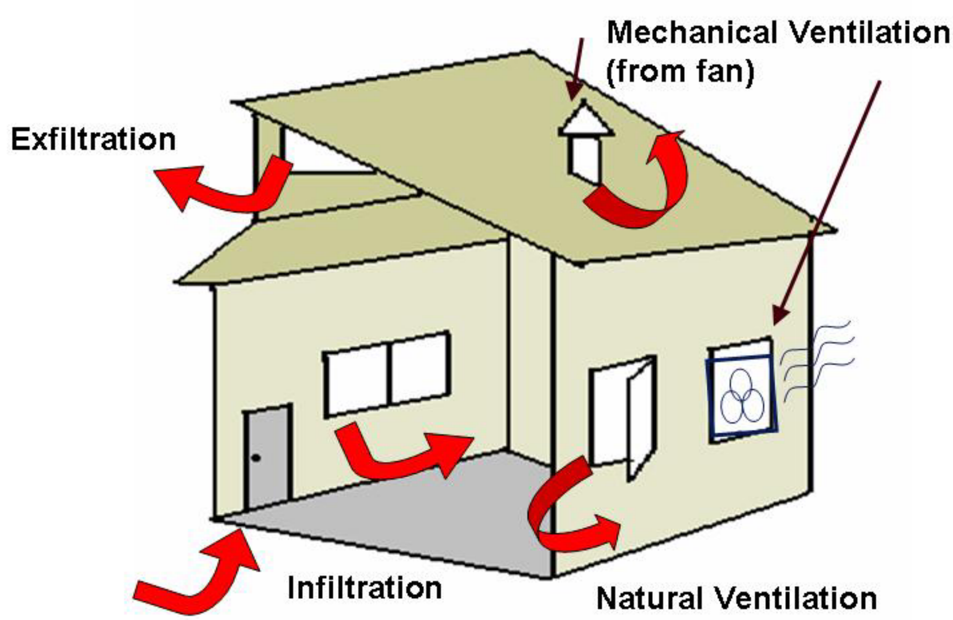

Figure 1-2. Ventilation in a Single-Family House (EPA, 1991).

Displacement ventilation supplies slightly cooler-than-desired, conditioned air from a low sidewall diffuser. Because it is cooler than the room air, the supplied air spreads across the floor and then rises as it is heated. The heat sources (e.g., people) create thermal plumes that can carry away contaminants to exhausts located in the ceiling. While displacement ventilation has been found to be quite effective, thermal comfort issues arise when unwanted cooler air is introduced into a room (Spengler *et al.*, 2001).

Finally, localized ventilation systems supply conditioned air to the areas that are close to building occupants. This ventilation system is similar to the zoned ventilation systems currently utilized in high-end vehicles. Localized ventilation systems have a higher air supply volume, higher supply velocity, and smaller diffuser than the displacement ventilation system (Spengler *et al.*, 2001).

1.2.3.3 Ventilation standards

It is widely accepted by building designers, owners, research scientists, engineers, and policy makers that large non-residential buildings with high occupant densities should have adequate outdoor ventilation air to maintain a healthy and comfortable indoor environment. Standards and guidelines have been developed to assist in the design of HVAC systems for these buildings. In addition to non-residential buildings, ventilation standards and guidelines have also been developed for residences. Ventilation standards are set by specifying ventilation rates, or volumetric air flows required per building occupant. These ventilation rates are typically expressed as cubic feet per minute (CFM) per person or liters per second (L/s) per person (ASHRAE, 2004). Tables 1-3 and 1-4 illustrate some of the guidelines and standards for ventilation rates in residences and rooms within residences, respectively.

1.2.4 Treatment Technology

In response to research findings showing that numerous indoor air contaminants exist and can be linked to various adverse health effects, a number of air cleaning units have been designed and marketed over the years. These air cleaning units range from small, personal air cleaners to whole-house air cleaning systems. As technology proceeds, older units are

Table 1-3. Ventilation Standards and Guidelines for Residences (Samet *et al.*, 1991).

Region	Standard	Comment
Canada	0.5 ACH	Mechanical ventilation, mobile homes
California	0.7 ACH	Standard for "tight" new residential buildings
Sweden	0.5 ACH	All new structures with mechanical ventilation
France	0.5 ACH	All new structures with mechanical ventilation
South Dakota	0.5 ACH	All under consideration for mechanically and naturally ventilated structures

Table 1-4. Ventilation Standards for Rooms Within Residences (Samet *et al.*, 1991).

	ASHRAE *Standard 62-1973*; Single-Unit Dwellings (cfm/person)	
Area	**Minimum**	**Recommended**
General livings areas and bedrooms	5	7 – 10
Kitchens	20	30 – 50
Toilets, bathrooms	20	30 – 50
Basements, utility rooms	5	5

replaced with new, higher efficiency units. The following sections explain the different types of residential air cleaning technology currently available, how their effectiveness is quantified, and how they recently fared during testing by a notable consumer agency, Consumer Reports.

1.2.4.1 Indoor air cleaning units

Air cleaning is one of three methods utilized for improving indoor air. These three methods, in order of effectiveness, are removal or reduction of the contaminant source, ventilation, and air cleaning. While air cleaning cannot remove all of the harmful indoor contaminants, it has been found to be effective against tobacco smoke, pollen, mold, dust, and animal dander. Generally, the smaller the particle the better chance of it being removed by an air cleaner. This is because larger particles such as pollen and dust often settle on surfaces and do not remain suspended in the air for adequate periods of time to be transported to and collected by an air cleaner (EPA, 1990).

Air cleaning units include both whole-house cleaners and room-sized cleaners. The significant difference between these two types of air cleaners is cost. Whole-house cleaners can cost up to about $700, while room-sized cleaners are typically less expensive and can be purchased for as low as $20. Other factors that can affect the cost of air cleaning systems include energy requirements for operation and periodic maintenance costs arising from filter replacement and cleaning.

There are three major types of processes that residential air cleaners use to remove particles from the air including particle filtration, electrostatic precipitation, and negative ion generation. Table 1-5 provides a summary of the three major air cleaning processes. In addition, hybrid air cleaners exist and may include a combination of the aforementioned processes (Hines *et al.*, 1993).

Table 1-5. Summary of Air Cleaning Processes.

Process	How it works	Advantages	Disadvantages
Filtration	Air is drawn through a fibrous filter material. Airborne particles are collected due to diffusion, interception, and/or inertial impaction.	High efficiency filters remove over 99% of airborne particles on a mass basis	Regular filter replacement costs (increase with increasing filter efficiency)
Electrostatic precipitation	Airborne particles are charged and then attracted to strong oppositely-charged surfaces for collection.	High efficiency removal of small respirable particles Low maintenance	Ozone generation
Negative ion generation	Particles pass through a chamber and become statically charged, allowing for the airborne particles to cling or settle to household surfaces for removal.	Inexpensive systems that require minimal maintenance.	May produce ozone Many systems do not actually collect particles

Filtration air cleaners use filters to capture airborne particles. Common filtration mechanisms include diffusion, interception, and inertial impaction. Fibrous filters are used extensively for air cleaning purposes. These filters have fibers assembled perpendicular to the direction of airflow. As air flows through the cleaner, the collision of a particle with the surface of a fiber removes the particle from the air. Depending on conditions in a residence, a filtration air cleaning system will require periodic cleaning and/or replacement filters (EPA, 2006).

There are four basic types of filter construction and these include flat-panel filters, pleated-panel filters, bag or pocket filters, and moving curtain filters. Different types are utilized under different conditions to attain the desired filtration result. Filter efficiency is often reported by a minimum-efficiency reporting value (MERV). MERV scores provide a simplified index of filter efficiency and range from 0 to 20. The higher the MERV, the higher the filtration efficiency of the filter (Spengler *et al.*, 1995). Top-performing residential filters have a MERV of 11 to 13 (Consumer Reports, 2005b). Filters with a MERV of 16 or greater are considered High-Efficiency Particulate Air (HEPA) filters. HEPA filters are gaining in popularity and are being used in a variety of settings, from hospital clean-rooms to vacuum cleaners. Filter costs increase with increasing efficiency (Spengler *et al.*, 2001).

Another process used to remove particles from indoor air is electrostatic precipitation. This process utilizes the attraction of charged particles to oppositely charged surfaces to collect airborne particulates. During this process, particles are charged by ionizing the air with an electric field. These charged particles are then collected by a stronger electric field generated between oppositely-charged electrodes. Electrostatic precipitation provides greater than 99.9% efficient filtration of respirable particles less than 1μm (Maroni *et al.*, 1995).

Electrostatic precipitators can be installed as part of a home's HVAC system or can be found in portable room sized cleaners. During the particle removal process, small amounts of ozone are produced by air cleaners that use electrostatic precipitation. Ozone is produced as a by-product when high voltage near the charging wires converts oxygen to ozone, which then exits the air cleaner and enters the room air. The ozone amounts vary from model to model but should be considered when selecting an electrostatic precipitation unit for a home, since ozone aggravates asthma and decreases lung function (Maroni *et al.*, 1995).

The last main process used by residential air cleaners is negative ion generation. These cleaners use static charges to remove particles from the indoor air. Particles pass through the negative ion generator and become statically charged. The particles are then attracted to surfaces such as walls, floors, household textiles, and occupants. The main principle of a negative ion generator is to ensure that particles are removed from the air, however, many of these systems do not actually collect the particles themselves. In contrast, they simply charge the particle, allowing it to settle on another surface, enabling removal and cleaning by the occupants of the home (Maroni *et al.*, 1995). This “dirty wall effect” has been eliminated with more advanced negative ion generators that try to draw the charged particles back into the unit for collection (Godish, 2001). As with electrostatic precipitators, negative ion generators may produce small amounts of ozone, either intentionally or as a by-product of use (Maroni *et al.*, 1995).

1.2.4.2 Effectiveness of home air cleaners

Testing agencies use many different criteria for assessing the effectiveness of air cleaners; however, the clean-air delivery rate (CADR) is becoming the widely used practice. CADR was developed by the Association of Home Appliance Manufacturers (AHAM) and is a measure of an air cleaner’s cleaning speed while operating on High. Cleaning speed refers to the volume of air (cfm) that an air cleaner can clean in a specific amount of time. CADR is a function of both the airflow and the particle mass filter efficiency of an air cleaner (AHAM, 2005):

$$\text{CADR} = \text{airflow (cfm)} \times \text{filter efficiency (\%)} \qquad (1)$$

For example, an air cleaner with a flow rate of 100 cfm and an efficiency of 80 percent has a CADR of 80 cfm (Spengler *et al.*, 1995). Many models of air cleaners have CADR certifications. These models come with a seal that lists CADR results and the room size that the model can effectively clean. CADR numbers range from about 10 to 450. Air cleaners with a CADR of 10 or less are considered “barely distinguishable from gravity at removing airborne particles” (Consumer Reports, 2005b).

1.2.4.3 Consumer Reports air cleaner ratings

In 2005, Consumer Reports (CR) reported the results of two studies on residential indoor air cleaners. In May 2005, CR released the ratings of negative ion generating air cleaners and in October 2005, CR released a more comprehensive list of ratings that included both filtration and electrostatic precipitation air cleaners (Consumer Reports, 2005a, 2005b). The October report rated both room air cleaners and whole-house air cleaners. Summaries of CR’s findings for room and whole-house air cleaners can be found in Tables 1-6 and 1-7, respectively. All air cleaners tested by CR were rated based on CADR, price, and annual cost. CR judged CADR values above 350 as excellent and those below 75 as poor.

Table 1-6. Summary of Consumer Reports Ratings for Room Air Cleaners (Consumer Reports 2005b).

Rating	Brand & Model	Price	Type[1]	Annual cost		Particle Removal Efficiency[2]	ACH	Score
				Energy	Filter			
1	Friedrich C-90A	$500	EP, I	$60	$72	99.97	5.7[4]	Very Good
2	Kenmore 83202	350	F	90	220	99.97	4.8[3]	Good
3	Whirlpool AP45030R	250	F, I	69	130	99.97	4.8[4]	Good
4	Honeywell 50250	180	F	124	157	99.97	4.81[4]	Good
5	Vornado AQS35	200	F	133	43	99.97	6[3]	Good
6	Blueair 501	500	F	55	176	99.97	6.75[4]	Fair
7	Hunter QuietFlo 30401	230	F	127	120	99.5	4.84[4]	Fair
8	Holmes HAP750-U	160	F	67	105	99.97	4.84[4]	Fair
9	Bionaire Galileo BAP1250-U	200	F	67	102	99.97	4.81[4]	Fair
10	LakeAir Maxum	340	EP	38	76	NA	NA	Fair
Not Recommended								
27	Oreck XL Professional	370	EP	28	38	95	1[4]	Poor
28	Sharper Image Ionic Breeze Quadra	450	EP, I	7	-	NA	NA	Poor

[1] EP = Electrostatic Precipitator, F = Filter, I = Negative Ion Generator

[2] Particle removal efficiencies are based on total mass of particles and were obtained from product packaging when provided by manufacturer. Not all manufacturers readily report this information, as there is no requirement.

[3] ACH for a single room as quoted by manufacturer

[4] ACH for a single room as estimated by using CADR and room size noted on product packaging

Table 1-7. Summary of Consumer Reports Ratings for Whole-House Air Cleaners. (Consumer Reports, 2005b)

Rating	Brand & Model	Price	Annual cost	Type[1]	Overall score
Professionally Installed – These performed best overall, but cost roughly $200 to install.					
1	Aprilaire 5000	$600	$44	EP/F	Excellent
2	Carrier AIRA	500	30	EP	Excellent
3	Trion SE1400	700	32	EP	Excellent
4	Trane Perfect Fit TFE210A9FR3	600	19	EP	Excellent
5	Honeywell F50	600	21	EP	Very Good
Do-It-Yourself – These replace existing filters; annual cost reflects replacement intervals.					
9	American Air Filter Dirt Demon Ultra High Efficiency	30	120	F	Very Good
10	Filtera MERV 13 Mini Pleat	57	228	F	Very Good
11	3M Filtrete Ultra Allergen Reduction 1250	15	60	F	Very Good
12	3M Filtrete Micro Allergen Reduction 1000	12	48	F	Good
13	3M Filtrete Dust & Pollen Reduction 600	10	40	F	Good

[1] EP = Electrostatic Precipitator, F = Filter

Consumer Reports also listed a number of “Quick Picks” for selecting an indoor air cleaner. For the room models, the Friedrich C-90A and Whirlpool models both covered up to 500 square feet, cleaned effectively, and cost less to run than the Kenmore model (ranked number 2). The Friedrich (1) costs twice as much as the Whirlpool (3) but requires less per year to run. For the whole-house models, the Aprilaire and Carrier models were the top two professionally-installed air cleaning systems. Cheaper whole-house highly ranked options include the do-it-yourself American Air Filter and 3M Filtrete filters.

Information that was loosely based on the air cleaning units described in this section was utilized in developing the inputs for the modeling application in Chapter 4.

1.3 Risk Analysis of Indoor Environments

Little data currently exists that describes the risk levels for indoor pollutant exposures. Some generalized risk information pertaining to indoor pollutants can be found, however. For example, Table 1-8 lists some common indoor contaminant concentrations that have been shown to cause associated health effects among building occupants.

Table 1-8. Indoor Air Concentrations Above Which Health Effects Occur (Godish, 2001).

Contaminant[a]	**Concentration**	**Possible Health Effects**
Formaldehyde, mg/m^3 ppmv	 >0.10 >0.08	Mucous membrane irritation, Sick Building Syndrome (SBS)
VOCs, mg/m3		SBS
Ozone, mg/m^3 ppmv	 >0.10 >0.05	Mucous membrane irritation
Nitrogen dioxide, mg/m^3 ppmv	 >0.5 >0.3	Mucous membrane irritation, asthma
Carbon monoxide, mg/m^3 ppmv	 >10 >9	General symptoms
Mineral fibers, Air, f/m^3 Surfaces, f/m^2	 >1000 >30	Mucous membrane and skin irritation
Bacteria in air, CFU/m^3		Allergy, SBS, respiratory complaints
Fungi in air, CFU/m^3		Allergy, respiratory complaints
Tobacco smoke	>0	Eye irritation, SBS
Dust (air), mg/m^3	>0.3	SBS, mucous membrane irritation
Floor dust, g/m^3	>0.5	SBS
Bacteria in floor dust, CFU/g	<10 x 10^3	SBS
Dust Mites Allergen/g dust Mites/g dust	 >2000 ng >100	Allergy, asthma

[a] f/m^3 – fibers per cubic meter
CFU/g – colony forming units per gram

The following subsections introduce background information on risk analysis, risk communication, and risk perception. These topics are important for understanding consumer reactions to notifications about risks in the indoor environment.

1.3.1 Risks and Risk Analysis

Risk is defined as the probability and severity of a future loss, or the probability of damage, injury, illness, death, or other misfortune associated with a hazard (Byrd & Cothern, 2000; Furedi, 1997). Risk is encountered and dealt with on a daily basis. It is up to the individual to decide and evaluate the amounts of risk worth taking to proceed with daily activities (Byrd & Cothern, 2000).

The process of evaluating the levels of risk associated with different events and objects is called risk analysis (NRC, 1983). Byrd and Cothern identify three methods relevant to dealing with risk: risk assessment, risk management, and risk communication. Risk assessment is the process of determining the nature and extent of risks in the environment. The risk assessment process can be divided into four steps including hazard identification, exposure assessment, dose-response assessment, and risk characterization (NRC, 1983).

Risk management is the process of deciding how to handle and what steps to take in dealing with a particular risk. Risk management often involves tackling questions and balancing concerns regarding economic costs, technical feasibility, public acceptance, legality, political perceptions, regulatory objectives, ethical considerations, and enforceability (Byrd and Cothern, 2000). The risk management framework involves defining the problem, making decisions, taking action(s), and evaluating the action(s) (Spengler *et al.*, 2001). The task of initializing and forming a risk management plan is a critical step in the process of risk analysis.

Finally, an important part of risk analysis is risk communication. In order to properly manage a situation, information regarding a specific risk must be effectively communicated to the public or those people closely associated with the risk. Risk communication can be defined as "any public or private communication that informs individuals about the existence, nature, severity, or acceptability of risks" (Spengler *et al.*, 2001). However, research has shown that people often view risks differently and have different perceptions than the risk assessors and communicators. Therefore, it is important that a risk communicator be selective in deciding whom to inform, when to inform them, and exactly how much information pertaining to a risk should be released (Byrd and Cothern, 2000). Also, a precondition for successful work in risk analysis is that it is important to be aware and considerate of people's existing risk perceptions (Renn and Rorhmann, 2000).

The topics of risk communication and risk perception are discussed in the following two sections.

1.3.2 Risk Communication

Effective risk communication should focus on the information that recipients most need to understand. If critical pieces of information are omitted, then the communication fails. It may leave recipients feeling adequately informed when, in fact, they may be worse off due to an illusion of competence. Once the content has been defined, risk communication developers must ensure that the message is understood as intended. Also, authoritative and trustworthy sources are needed for effective communication (NRC, 1989).

The contents of a risk communication often depend on how the audience intends to use it. For example, some people prefer a trustworthy source to simply tell them what to do, while others want quantitative values to make their own choices, and yet others want help in organizing their thoughts. In addition, some people prefer to not be made aware of the entire truth, while others are interested in every detail. Emotions are easily intertwined in the risk communication process and can make consumers more critical of the communication process, especially for high-stakes risks. What, then, are the methods and approaches utilized to develop and deliver risk communication to the public? The answer lies in a number of similar principles outlined by various risk communication experts (Morgan *et al.*, 2002).

Lundgren and McMakin (2004) divide risk communication into three forms – care, consensus, and crisis – of which each has circumstances requiring different tactics to effectively deliver messages to the audience. Care communication is communication about risks for which the danger and the way to manage it have already been well determined through scientific research that is accepted by most of the audience. Care communication includes topics such as health, industrial risks, and indoor air risks. Consensus communication aims to inform and encourage groups to work together to reach a decision about how the risk will be managed. Examples of consensus communication include public participation and advisory panels. Crisis communication is risk communication in the event of extreme, sudden danger, such as nuclear accidents, earthquakes, hurricane and disasters, and disease outbreaks (Lundgren & McMakin, 2004).

Three different kinds of principles are important for conveying a risk communication message. These principles include process, presentation, and comparing risks. Principles of process include knowing your communication limits and purpose, pretesting your message, communicating early, often, and fully, and remembering that perception is reality. Knowing the regulatory, organizational, and audience requirements affects how you can communicate a risk. When pretesting messages, factors such as reading level, knowledge of subject, and levels of hostility should be evaluated if a risk is to be communicated effectively (Lundgren & McMakin, 2004). Risk communication must be timed to involve the audience throughout the entire process, with repetitive contacts and complete information. Also, audiences perceive risks in different ways that might not be entirely correct; however, risk communication needs to take risk perception into account to be successful (Morgan *et al.*, 2002).

Principles of presentation include knowing your audience, not limiting yourself to one communication method, simplifying language and presentation, dealing with uncertainty, and communicating honestly, clearly, and compassionately. Audiences can differ from one risk issue to the next and proper preparation for a particular audience is essential. Knowledge of relationships between race, gender, age, education, and the risk in question are important determinations that allow for effective communication (Morgan *et al.*, 2002). Complex risk issues should be explained with simplified language but not content. Audiences do not have to understand a risk at the same level as an expert, but they should understand it well enough to make an informed decision. Audiences also feel more at ease when there is a feeling of trust between them and the communicator. Trust can be established by communicating honestly and clearly, and taking time to deal with emotions and concerns that may arise within the audience. Finally, principles of presentation need to deal with uncertainty issues. It is important to never present results as definitive, as no study is ever the final word (Lundgren & McMakin, 2004).

Principles for comparing risks include using analogies, using ranges, and comparing to standards. Simple comparisons can help put risks in perspective for many audiences, though care must be taken to not trivialize the comparison as this can seem too simplistic or even offend the audience. Ranges and standards are often easily comprehensible to audiences and can be quite useful (Lundgren & McMakin 2004).

Once the risk communication principles have been defined, it is useful to analyze the audience. An audience analysis can consist of conducting a survey in which demographic information and knowledge of the particular risk are assessed. The results of the survey can then be utilized to formulate a risk communication plan. For the general public in which there is little or no hostility, the news media is often utilized as the main method of risk communication. Public service announcements and telebriefings can be used to communicate risks. If hostility is present, credible experts or representatives from the source wishing to communicate a risk can be sent to radio and television talk shows, radio call-in shows, and major public forums. The specific risk analysis message conveyed must be tailored to meet the needs of the audience, as determined in the audience analysis (Furedi, 1997). Table 1-9 illustrates methods for altering the risk message based on information gathered from an audience analysis (Lundgren & McMakin, 2004).

The results of the audience analysis (survey) can be utilized to identify the perception characteristics of the audience. The importance of understanding risk perception is described below.

1.3.3 Risk Perception

Renn and Rorhmann (2000) define risk perception as a person's judgments and evaluations of hazards they are or might be exposed to, or simply how people view risks. People often consider something risky if there is a chance for loss or negative outcome. Knowledge concerning risks is learned through information from others, media attention, and in some cases by personal experience (i.e. earthquakes and tornados). Risk perception can vary by gender, age, culture, and other variables. Many studies have shown that risk perception is often viewed as an individual and not a social phenomenon, yet more recent work has strongly linked social factors with risk perception (Douglas, 1985). This means that one's risk information and perceptions can be influenced by the perceptions developed by others.

Table 1-9. Use of Audience Analysis to Tailor Risk Messages (Lundgren & McMakin, 2004).

State of Knowledge of the Audience	How to Tailor the Message
Audience unaware	Use graphic method – high color, compelling visuals and theme.
Audience well informed	Build on past information.
Audience hostile	Acknowledge concerns and feelings. Identify common ground.
Audience highly educated.	Use more sophisticated language and structure.
Audience not highly educated.	Use less sophisticated language and structure. Make structure highly visible, not subtle.
Who makes up the audience	Ensure that the message reaches each member.
How the audience wants to be involved in risks assessment or management	If at all possible given time, funding, and organizational constraints, involve the audience in the way they want to be involved.
Misconceptions of risk or process	Acknowledge misconceptions. Provide facts to fill gaps in knowledge and correct false impressions.
Audience concerns	Acknowledge concerns and provide relevant facts.

Experimental studies have found that people often make judgments in terms of how easily they can recall past examples or how easily they can imagine the occurrence of an event (Pidgeon *et al.*, 2003). For example, while stroke is a common form of death, most people only learn about it when a close relative or friend is afflicted or dies. Studies have also shown that judgments vary greatly between experts and laypersons. For example, while the USEPA experts rate indoor air pollution as a "high" risk, placing it in the top ten of twenty-six ranked risks, the public ranked indoor air pollution as 23rd (Breyer, 1993).

Perception variations between gender and race have been found. For example, when asked to rate the riskiness of a hazards, women have been found to have significantly higher risk ratings than men (Flynn *et al.*, 1994). Women have also been found to have greater confidence that various risks exist (Graham *et al.*, 1999). One hypothesis for the perception differences between genders is that women are more nurturing and are perhaps more vulnerable to certain risks than are men. Other hypotheses are that women may be less knowledgeable than men about scientific and technological issues, or that women may distrust what they perceive to be male-dominated technologies (Flynn *et al.*, 1994). Studies have found that nonwhites have higher perceived risks than do whites. White men tend to have significantly lower perceived risks and lower confidence that risks are actually present than do white women, nonwhite men, and nonwhite women. Hypotheses to explain the differences in race perceptions are governed by levels of education, household income, trust issues, and political orientation. Additionally, actual mortality rates for nonwhites are higher than for whites, indicating that the higher perceived risks by nonwhites are realistic expectations (Flynn *et al.*, 1994; Graham *et al.*, 1999).

The way people perceive risks often dictates how they respond and make choices when faced with these risks. Risks can either be voluntary or involuntary. Voluntary risks are often accepted by the public if there is a benefit associated with taking that risk. For example, a voluntary risk that many people take daily is operating a motor vehicle. While drivers can easily be involved in a wreck that can cause many health implications including death, a large majority of the public voluntary decides to take this risk. An example of an involuntary risk would be when a person standing nearby lights a cigarette (Renn and Rohrmann, 2000).

How risks are perceived depends on how specific risks are communicated. Therefore, adequate risk communication is necessary and important for informing the community about potential risks. While some risks are clearly communicated - or others have made advances in communication, such as terrorism risks – other risks remain unclear or hidden from the public eye. Knowledge of a particular risk allows one to make rational decisions regarding that risk. However, if this knowledge is not clearly presented in terms understandable by everyone, the risk communication has failed (Lundgren & McMakin, 2004). Also, if risks are over-exaggerated then the possibility of the risk communication turning into propaganda exists. A public figure who exaggerates a particular risk for political gain is said to be using political propaganda.

A common avenue for presenting risk information to the public is mass media. As press and television coverage increases, the concerns that the public has regarding a specific risk or technology often increase as well. Extensive media coverage of a controversial technological or environmental project has been found to capture the public's attention and often leads to strong public opposition of the topic. Therefore, mass media directly influences public perceptions on risks. The public often relies on information delivered by mass media and perceptions can change with regard to the way the information is delivered and presented

(Pidgeon *et al.*, 2003). Over the past 5 years, an example of increased media coverage on an indoor air issue is the topic of mold[1].

Risk perception research often involves conducting surveys and questionnaires to obtain information regarding current public perceptions. Results from risk perception research can yield valuable information that may be helpful in improving risk communication and management strategies. One approach for qualitative risk perception studies includes looking at "semantic images." The four semantic images of risk in public perception include pending danger, slow killers, cost-benefit ratio, and avocational thrill. Indoor air quality risks are included in the slow killers image. Slow killers include risks seen as invisible threats to one's health or well-being, with effects that are usually delayed. Also, information regarding slow killers is mostly based on the knowledge gained through others, thus engraving an enormous amount of trust on the institutions that provide information and manage the risks (Renn and Rohrmann, 2000).

1.4 Overview of the Chapters

Chapter 2 covers the methodology that was utilized for the survey and a brief overview of the modeling portion of this thesis. Chapter 3 presents the results of the IAQ risk perception survey study. Numerical tables and statistical analyses results are provided along

[1] (1). Staneill, J., "Teen Crusades to Erase Menace of Mold," News and Observer, October 9, 2005. (2). Bonner L., and M. Eisley, "Old Ally Now Eyes Mold," News and Observer, October 16, 2003. (3). Fishman, M., "Mold, Carbon Dioxide Vex Office," News and Observer, December 7, 2004. (4). Ford, S., "Bright College Years of Mold and Heat," News and Observer, August 31, 2003. (5). ReporterBarash, M., "For These Working Dogs, Mold is Gold," CNN News, April 23, 2004. (6). Moffeit, M., "Mold in the Home: Health Hazard or Hype," CNN News, October 8, 2003. (7). Moffeit, M., "Invisible Invaders: Mold Discoveries and Ailments on Texas Campuses," CNN News, July 10, 2000. (8). Wallwork, W., "Water Hazards at Home," Parade Magazine, October 17, 2004. (9). Hirshey, G., "Make Your Household Healthy," Parade Magazine, April 16, 2006. (10). Spencer, S., "Silent Killers: Toxic Mold," CBS Worldwide News, July 26, 2002. (11) Mitchell, R., "Black Mold: Creeping Destruction," CBS News, June 30, 2001. (12). The Early Show, "Mold: Tips to Prevent and Cope," CBS, June 4, 2004. (13). Axlerod, J., "A Spreading Home Health Hazard," CBS News, May 1, 2002. (14). Axelrod, J., "America Waking Up to a Moldy Reality," CBS News, July 17, 2002. (15). 48 Hours Special, "Invisible Killers – Part 1," March 2, 2000. (16). Moriarty, E., "An Insidious Mold," 48-Hours, September 28, 2000. (17). Wallace, K., "Cumberland Students Return to Class After Mold Discovered at School," WRAL-TV News, January 12, 2004. (18). Wallace, K., "NCCU Needs Emergency Response to Fix Mold Problem," WRAL-TV News, October 3, 2003. (19). Wilkinson, D., "Indoor Mold Growing Concern," WRAL-TV News, August 2, 2003. (20). Buscher, M., "Mold Can Be Costly, Risky to Health," WRAL-TV News, August 12, 2005. (21). Wallace, K., "Rocker Ted Nugent Driven Out of Home by Mold," WRAL-TV.com, July 7, 2003. (22). Browden, C., "Mold Forces Governor to Move Out of Mansion," WRAL-TV News, August 10, 2005. (23). Wallce, K., "Greensboro Family Tries to Inform Public on Risks of Toxic Mold," WRAL-TV News, May 9, 2005. (24). Wallace, K., "Mold Forces Closer of Two Floors in SBI Building," WRAL-TV News, January 6, 2004.

with discussion of key findings. Chapter 4 presents the household air cleaner modeling application inputs and results. Air cleaner performance is evaluated and recommendations are made based on model results. Finally, Chapter 5 concludes this thesis with discussion of all key research findings, conclusions, recommendations for future research, and risk communication priorities.

2.0 METHODOLOGY

To meet the thesis objectives outlined in Section 1.1.2, a risk perception survey was completed. Additionally, modeling and assessment of current indoor air cleaners in a residential environment was conducted to determine their effectiveness with respect to cost. Links between survey responses and modeling results were used to develop recommendations for selecting an indoor air cleaner, as well as for risk communication strategies. This chapter describes the methodologies utilized to complete the survey and modeling aspects of this research. An overview of survey research and acceptable implication techniques is provided, as well as information on the modeling software chosen for this research.

2.1 Survey Research

2.1.1 Overview

A survey is a method for obtaining information from a sample of individuals representing just a fraction of the total population. Surveys are implemented to develop statistical information pertaining to a particular subject. Surveys results can be used to estimate, with considerable precision, the percentage of a population that has a particular attribute by obtaining data from only a small fraction of the total population; this distinguishes surveys from other research methods, such as conducting repeated laboratory tests or carrying out a census of a large population (Dillman, 2000). Surveys can be conducted in a variety of manners, including in-person interviews, self-administration via mail, over the telephone, and over the internet. Care must be taken in choosing a sample size and accounting for sampling variation in order to make acceptable generalizations from survey responses. Sampling groups should be representative of the population one is trying to study (ASA, 2005).

Survey results cannot be reported with certainty since it would be impractical to question the entire population. Therefore, survey results are given with some level of confidence. Carefully planned surveys involve pilot-studies that aim to determine pre-survey confidence levels. When time limitations are present, however, confidence levels must be determined at the end of the survey. Low confidence levels should be accompanied by an explanation and methods for improving future results. A survey can be biased when the experimenter has strong feelings on a subject and misinterprets the results. Biases can also arise from poor survey design and can be reduced by using randomized selection of survey subjects from a population group (ASA, 2005).

The survey, often called the survey instrument, must be carefully designed and implemented in order to obtain the desired results. Desirable results include high response rates, low percentages of missed questions, and low error. Postal mail based surveys are known to have lower response rates than internet surveys. However, the probability that a respondent will miss and/or skip a question has been shown to be higher in an internet survey (Schonlau et al, 2002). Also, internet surveys are biased towards those people with computer access. Though internet surveys are gaining in popularity, the number of surveys conducted by self-administration, and mail in particular, still exceeds the number of interview surveys conducted each year. Therefore, mail-based self-administered surveys are still an accepted and widely used method for conducting surveys (Dillman, 2000).

A key factor in designing a survey includes reducing survey error. Four types of survey error can arise and include sampling error, coverage error, measurement error, and nonresponse error. Sampling error is the result of trying to sample some, but not all, of the people in a survey population. Coverage error occurs when the list from which the sample is drawn does not include all elements of the population, thus making it impossible to give all elements of the population an equal chance of participating in the sample survey. Coverage error leads to lack of representation of the intended population. Measurement error results from poor question wording and poor survey construction. Measurement error leads to inaccurate, imprecise, or uninterpretable answers. The final source of error, nonresponse error, occurs when a significant number of people in the survey do not respond and have different characteristics from those who do respond. It is imperative to design the survey to reduce these four types of error (Dillman, 2000).

Many strategies and methods have been developed to aid in survey generation and distribution. One method lists five types of risk-related variables that are often employed in risk perception surveys. These variables include risk level aspects, qualitative features of hazards, benefit aspects, personal relation to hazard, and acceptability aspects. Developing and using a selection of survey questions designed around these five variables is said to result in data that encompasses all aspects of a particular risk (Renn and Rohrmann, 2000). Another method of survey question selection utilizing "semantic" images was mentioned in Section 1.3.3.

The Total Design Method developed by Don A. Dillman and published in 1978 was, and continues to be, a widely accepted method for designing the survey instrument. However, in 2000, Dillman released an updated version of his survey method, The Tailored Design Method. The Tailored Design Method incorporates over 20 years of survey response analysis and includes the most effective techniques for survey design (Dillman, 2000). Many peer-reviewed papers cite Dillman's methods as part of their research methodology. Topics of papers citing Dillman include the medical profession (Bernstein *et* al., 2004), cognitive psychology (Stettler and Trang, 2004), and ecology (Clendenning *et al*., 2004). Additionally, research on the methods of the Tailored Design Method has supported Dillman's techniques for the survey instrument (Trussell and Lavrakas, 2004; Singer, Thurn, and Miller, 1995; James and Bolstein, 1990; de Leeuw, and Hox, 1988). Many aspects of the Tailored Design Method were utilized in this study and are expanded upon in the following section.

2.1.2 The Tailored Design Method

According to Dillman, the Tailored Design Method incorporates the evolution of survey methodology that currently includes procedures for creating respondent trust and perceptions of increased rewards and reduced costs for being a respondent. The overall goal of the Tailored Design Method is the reduction of survey error. Dillman states that a well-prepared self-administered survey should encourage people to respond, while minimizing inaccurate or inadequate answers. Therefore, designing a quality survey begins with two fundamental assumptions: (1) responding to a self-administered survey involves not only cognition, but also motivation, and (2) multiple attempts at contacting participants are essential to achieving an acceptable response rate (Dillman, 2000).

The Tailored Design Method relies heavily on the ideas surrounding social exchange theory. Social exchange theory asserts that actions of individuals are motivated by the return these actions are expected to bring, and in fact usually do bring, from others. The three elements that are used to predict an action are rewards, costs, and trust. The likelihood of a person responding to the request to complete a self-administered survey is greater when the respondent trusts that the expected rewards of responding will outweigh the anticipated costs. The Tailored Design Method offers numerous techniques to establish trust, increase respondent rewards, and decrease social costs (Dillman, 2000). Table 2-1 summarizes the three main elements of the Tailored Design Method. When utilized together, these three elements have been found to increase response rates for self-administered surveys (Dillman, 2000).

Table 2-1. The Three Elements of the Tailored Design Method (Dillman, 2000).

Element	**Method of Incorporating Element in Survey**
Establish Trust	▪ Provide a token of appreciation in advance ▪ Sponsorship by legitimate authority ▪ Make the task appear important ▪ Invoke other exchange relationships
Increase Rewards	▪ Show positive regard ▪ Say thank you ▪ Ask for advice ▪ Support group values ▪ Give tangible rewards ▪ Make the survey interesting ▪ Give social validation ▪ Communicate scarcity of response opportunities
Reduce Social Costs	▪ Avoid subordinating language ▪ Avoid embarrassment ▪ Avoid inconvenience ▪ Make questionnaire short and easy ▪ Minimize requests to obtain personal information

Trust is critical to forming the belief that benefits of completing a survey will outweigh the costs of doing so. Methods of establishing trust include providing a token of appreciation (incentive) in advance, noting sponsorship by a legitimate authority, making the task appear important, and invoking other exchange relationships. While providing one or two dollars in advance for completing a survey is only a small reward, it does seem to establish and create trust. The researcher shows trust in respondents who can easily pocket the money and not return their survey. Research has shown that people are more likely to comply with a request if it comes from an authoritative source that they are familiar with. The overall task of completing the survey can be made to look important by taking care in designing the "look" of the survey. This can be accomplished by personalizing the cover letter on letterhead stationary. Also, repeated follow-up contacts make the task seem urgent (Dillman, 2000).

Examples of providing rewards include showing positive regard, saying thank you, asking for advice, supporting group values, giving tangible rewards, making the survey interesting, giving social validation, and informing respondents that opportunities to respond are scarce. Positive regard can be shown by providing respondents with reasons for why the survey is being conducted, providing contacts to call or write with questions, and personally addressing correspondence. Saying thank you and showing verbal appreciation in advance has been shown to increase survey response. Tangible incentives, in the form of a dollar, two dollars, or even small material incentives, evoke a sense of reciprocal obligation and are shown to increase response rates. Surveys can be made more interesting to respondents by improving layout and design, ordering questions with the more interesting ones placed at the beginning, and making questions easy to understand and answer. Social validation is important because it shows the respondent that others have acted in a similar way (by returning a completed questionnaire) and this encourages the respondent to follow suit (Dillman, 2000).

Ways of decreasing social costs include avoidance of subordinating language, embarrassment, inconvenience, making surveys appear short and easy, and minimizing requests to obtain personal information. People often go to great lengths to avoid subordinating language and refusing to respond to a survey filled with this type of content is a simple way to do this. Respondent embarrassment often leads to unreturned surveys and can be avoided by keeping directions and questions easily understandable. Inconvenience to the respondent can be avoided by providing a return envelope with a real stamp on it. A real stamp improves response rates as compared to using a business reply envelope. A likely reason is that people often keep stamped envelopes readily available, while a business reply envelope is more likely to be inadvertently thrown away. Surveys can be made to appear short and easy by indicating in the cover letter that the survey should only take a few minutes to complete. Finally, requests for intrusive information, such as annual income, should be minimized and located at the end of the survey (Dillman, 2000).

Other concepts critical to the survey instrument include graphical layout and design, question selection and writing, and knowledge of the survey population. These concepts are explained in the following sections detailing the design and construction of the survey used in this research. In summary, the Tailored Design Method is a "set of procedures for conducting successful self-administered surveys that produce both high quality information and high response rates." (Dillman, 2000)

2.2 The Survey

The following parallel sections describe the process of developing, administering, and analyzing the survey that was used in this research. Section 2.2.1 discusses the background methodology utilized in survey research while Section 2.2.2 discusses specifically how the methodology was incorporated into this research.

2.2.1 Survey Development and Design

The methodologies for developing and designing a survey are a critical part of the survey process. These methodologies must be well-thought and efficiently implemented. The following sections discuss the question selection and writing process, as well as methods for formatting the survey.

2.2.1.1 Question selection criteria

Careful planning goes into developing survey questions. For self-administered surveys, the goal is to develop a question that every potential respondent will interpret in the same way, be able to respond to accurately, and be willing to answer. Considerable evidence has shown that people are more likely to give honest answers to self-administered surveys than interview questionnaires, thus magnifying the importance of creating optimal questions. A number of criteria have been developed for assessing survey questions. These criteria include making sure the question requires an answer, minimizing the extent that people have to recall and report on past behaviors, and providing the respondent with motivation to answer the question (Dillman, 2000).

Survey questions consist of a question stem and an answer selection. The answer scale may or may not be stated as part of the question stem. Often, the answer scale is explicitly stated in the survey question instructions. When this is implemented, both ends of the answer scale should be stated, as this eliminates the possibility of biasing the answers toward one side of the scale. The statement "To what extent do you agree or disagree with each of the following statements," is an example of properly worded survey completion instructions. The answer selection can be presented in a number of ways including multiple-choice and ranked scales (ASA, 2005).

There are three different question structures typically employed in surveys. Open-ended questions provide no answer choice and require the respondent to think hard about the question and write a complete answer. Open-ended questions are used to obtain demographic information such as occupation or they are used to collect opinion responses related to behaviors. Closed-ended questions provide the respondent with answer choices with can either be ordered or unordered. Ordered answer choices require the respondent to visualize a scale and determine where on that scale their answer resides, while unordered answer choices require the respondent to compare discrete categories to each other, a task that is often more difficult. Most effective surveys include a combination of all three question structures, with the most emphasis placed on closed-ended ordered questions (Dillman, 2000).

A number of principles for writing survey questions exist. Nine of these principles are described here.

- <u>Choose simple over specialized words</u>. When a word exceeds seven letters, there is a good chance that a shorter word that will be more readily understood by all respondents can be substituted.

- Use the least number of words as possible in questions. People tend to be inefficient when reading long questions, thus giving unequal attention to each word and increasing the occurrence of skipped words and measurement error.
- Balance the answer choices. For ordered answer questions, equal numbers of positive and negative answer choices should be used since respondents easily interpret the midpoint, or neutral point, from the number of categories.
- Distinguish “undecided” from “neutral”. This is accomplished by placing “undecided” at the end of the answer scale as this keeps respondents from feeling “forced” to provide an actual answer to the question.
- State both sides of the answer scale in the question stem. This provides the entire range of the possible answers and helps to eliminate bias that can occur by only providing the word “agree” or “disagree” in the question stem.
- Make response categories mutually exclusive of one another. This will reduce respondent confusion. A respondent should not have to choose between two answer choices that seemingly include the same response.
- Avoid asking the respondent to say yes in order to mean no. These questions are often referred to as double negatives. It has been found that many people often miss the word “not” in these types of questions, thus leading to inaccurate survey data.
- Place objectionable questions at the conclusion of the survey. This reduces their negative impact. For example, most people have negative reactions to questions regarding income and often do not respond. Therefore, it is best to place income questions at the conclusion of the survey and include broad categories for the answer to encourage response.
- Avoid asking respondents to make unnecessary calculations. These calculations often create a large burden on the respondent and have been shown to greatly decrease question response (Dillman, 2000).

Another important aspect of survey design is the order of the questions. A salient beginning meets the respondent’s expectations and identifies questions that the respondent will find interesting. Thus, a survey should begin with questions that catch and hold the respondent’s attention. The first question is the most important and should apply to everyone, be easy to answer, and be interesting. Objectionable questions or those requiring more thought should be placed near the end of the survey (Dillman, 2000).

Questions should be grouped with others that utilize the same answer scale. Switching between scales every few questions can become bothersome and aggravating to respondents, leading to nonresponse or haphazard answers. Overall, the questions within the survey should flow “like a conversation”, drawing the respondent from one question to the next without jumping subjects (Dillman, 2000).

2.2.1.2 Formatting

Once the questions are selected, it is necessary to format the survey. Surveys should be formatted in a manner that is easily understandable by the respondents. A path should be defined so that the different sections of a survey flow from one to the next in a comprehensible way. Also, navigational guides such as fonts, color usage, and symbols should be carefully chosen (Dillman, 2000).

Good survey formatting requires careful planning. Simple 8.5 x 11 inch paper that is secured by single staple is only allowable when monetary restraints are present. Booklet-form surveys have been found to be successful and easily understandable by survey respondents. This is because booklets are simple to follow and present a straight path for navigating the survey. Booklets can be developed utilizing 8.5 x 14 legal sized paper. If more than one sheet of paper is utilized in the booklet, page numbers must be included in the event that a page detaches from the booklet (Dillman, 2000).

Survey questions can be arranged in tabular form. Questions with similar response scales should be grouped together to reduce confusion and stress on the survey respondent. Demographic questions should be located on the final page of the survey. Income questions often evoke apprehension and sometimes even hostility since a recipient may feel this question is an invasion of privacy. Therefore, the income question should always be placed at the conclusion of the survey (Dillman, 2000).

Other formatting issues that should be addressed include the location of survey instructions, question spacing, and use of color. Survey instructions should be placed at the beginning of each section of the survey where a change in survey structure is noted. For example, new survey instructions should be placed at the location of changing answer scales.

The background of survey instructions can be shaded and the font can be made bold in order to differentiate the instructions from the survey questions. Survey questions should be spaced as evenly as possible, as this provides a uniform look and feeling of “connectedness” to the respondent. Unevenly spaced questions could form a distraction that may increase question or survey nonresponse (Dillman, 2000). Finally, color should be used sparingly in self-administered surveys. This is because excessive use of color can distract the survey respondent and/or create eye strain. The goal is to present the survey in the simplest manner that is understandable to respondents. Therefore, a maximum of two colors should be used, if any, when printing surveys (ASA, 2005).

2.2.1.3 Cover letter

Along with the survey, an accompanying cover letter should be drafted and included in the mailings. An efficient cover letter includes a number of elements. Cover letters should be limited to one page and include essential pieces of information in as few words as possible. The mail-out date should be at the top of the cover letter and represents the first element of personalization. Next, the inside name and address should be printed along with salutations addressed directly to the recipient. The body of the cover letter should describe what the letter is about, why the request is useful and important, that answers are confidential, participation is voluntary, mention the enclosed return envelope, whom to contact with questions, explanation of any identification numbers on surveys, a real signature, and the addition of a postscript. Postscripts are one of the most visible aspects of a letter, often read first, and are an appropriate place to express, “thanks again.” These elements, when used in conjunction with one another, constitute a personalized, informative cover letter. Additionally, the cover letter should be printed on letterhead stationary with only one or two colors as this finishes the personalization (Dillman, 2000).

2.2.2 Actual Survey Development and Design

The survey methodologies mentioned in Section 2.2.1 were considered and implemented in the design and development of the survey mailings for this research. Not all of the previously mentioned techniques could be utilized due to time and monetary constraints. Figure 2.1 presents a flow diagram showing the steps that were taken toward

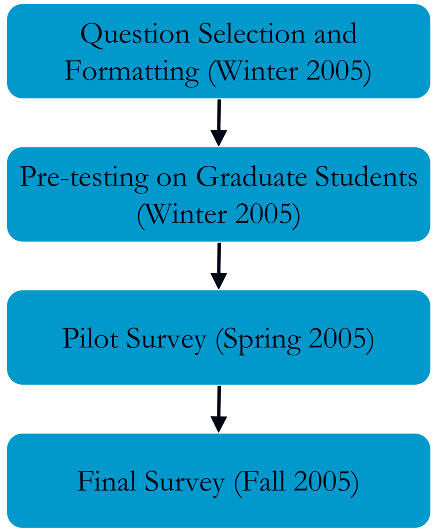

Figure 2.1. Survey Development Flow Diagram/Timeline

development of the final survey instrument. The following section describes and supports the specific methodologies that were utilized in this research survey.

2.2.2.1 Actual survey questions

Taking the question selection principles from Section 2.2.1.1 into account, forty survey questions and 11 demographic questions were created for this research. These questions are illustrated in Figure 2-2, which presents the final survey design utilized for this research. The questions were finalized after many revisions and consultations with resources and experts on survey design. The three types of question structures were utilized, though the majority of the questions are closed-ended ordered response questions.

Survey questions were drafted to obtain information regarding the respondent's knowledge of IAQ, their sources of information, personal relationship to the hazard, and willingness-to-pay for potential protection from poor IAQ. A section of questions that sought to compare the respondents' ranking of potential sources of poor IAQ to current expert opinion was also included.

INDOOR AIR QUALITY SURVEY						
This survey asks questions about your perceptions of indoor air quality. <u>All survey responses will be kept confidential.</u>						
Questions 1 – 18: To what extent do you agree or disagree with each of the following statements about the indoor air quality in your home. Please circle only one number on the rating scale for each question.	**Rating Scale**					
	Definitely Agree	**Somewhat Agree**	**Neutral**	**Somewhat Disagree**	**Definitely Disagree**	**Don't Know**
1. Indoor Air Quality is an important concern in my home.	1	2	3	4	5	6
2. The risks associated with poor Indoor Air Quality are clear to me.	1	2	3	4	5	6
3. Poor Indoor Air Quality is more harmful to children and the elderly.	1	2	3	4	5	6
4. Poor Indoor Air Quality can be fatal.	1	2	3	4	5	6
5. Air pollutant concentrations are often higher indoors than outdoors.	1	2	3	4	5	6
6. I am familiar with how radon can enter a home.	1	2	3	4	5	6
7. I am aware of the risks of radon.	1	2	3	4	5	6
8. Mold growth in a home can be harmful to one's health.	1	2	3	4	5	6
9. Indoor Air Quality will be a concern for future generations.	1	2	3	4	5	6
10. The risks associated with poor Indoor Air Quality are effectively communicated to the public by environmental professionals.	1	2	3	4	5	6
11. Air cleaners and filters (such as HEPA) can keep me safe from poor Indoor Air Quality.	1	2	3	4	5	6
12. Air cleaning systems that use ozone can keep me safe from poor Indoor Air Quality.	1	2	3	4	5	6
13. I am in no danger from the effects of poor Indoor Air Quality.	1	2	3	4	5	6
14. Adverse health effects from poor Indoor Air Quality are unavoidable.	1	2	3	4	5	6
15. If an Indoor Air Quality problem was found in my home, I would take steps to eliminate it.	1	2	3	4	5	6
16. If a home air filter or cleaner was guaranteed to protect me, I would purchase one regardless of cost.	1	2	3	4	5	6
17. I am willing to pay for inexpensive Indoor Air Quality treatment for my home.	1	2	3	4	5	6
18. Most people are not aware of Indoor Air Quality problems in their homes.	1	2	3	4	5	6

Figure 2-2. Final Survey Design – Page 1.

Question	Rating Scale		
	Yes	No	Don't Know
19. I have learned about Indoor Air Quality from TV.	1	2	3
20. I have learned about Indoor Air Quality from newspapers, magazines, or periodicals.	1	2	3
21. I have learned about Indoor Air Quality from friends, family, coworkers, etc. (word of mouth)	1	2	3
22. I own and regularly use a portable home air cleaner.	1	2	3
23. Do you use any other type of home air cleaning device? If Yes, Please List ________________			

Questions 26-38: To the best of your knowledge, please indicate the extent to which the following items contribute to poor Indoor Air Quality in general.	Rating Scale				
	A lot	Some	Not Much	None	Don't Know
24. Cooking	1	2	3	4	5
25. Washing Machines	1	2	3	4	5
26. Vacuuming	1	2	3	4	5
27. Inadequate Ventilation	1	2	3	4	5
28. Cigarette Smoke	1	2	3	4	5
29. Mold	1	2	3	4	5
30. Candles	1	2	3	4	5
31. Fireplaces	1	2	3	4	5
32. Air Fresheners	1	2	3	4	5
33. Cosmetics	1	2	3	4	5
34. Cleaning solvents/sprays	1	2	3	4	5
35. Showers	1	2	3	4	5

Figure 2-2 Cont'd. Final Survey Design – Page 2.

Here, we ask you a few questions regarding your willingness to pay to reduce indoor air pollutants in your home. This is not a sales offer. Please select one answer for each question.

36. Suppose an Indoor Air Quality problem is found in your residence and that there are three treatment options available, each offering a different amount of pollution reduction. Please select the option that you would be willing to pay for.

- ☐ 80% pollution reduction costing $20/month
- ☐ 90% pollution reduction costing $30/month
- ☐ 98% pollution reduction costing $50/month
- ☐ No treatment ($0/month)

37. Suppose an Indoor Air Quality problem is found in your residence. Not considering the amount of pollution reduction, what is the highest amount you would be willing to pay per month to reduce this problem?

- ☐ $ 0/month
- ☐ $10/month
- ☐ $25/month
- ☐ $50/month

38. In your opinion, what is the worst threat to Indoor Air Quality in your current residence? Please select one answer.

- ☐ radon gas entry
- ☐ mold
- ☐ carbon monoxide
- ☐ cigarette smoke
- ☐ inadequate ventilation
- ☐ other....Please list ____________________

39. In your opinion, is poor Indoor Air Quality currently adversely affecting your health?

- ☐ Yes
- ☐ No
- ☐ Unsure

40. Have you taken any steps to improve the Indoor Air Quality in your home? How much money do you estimate that you have spent on this?
Please use the space below to briefly describe these steps, if any.

County Code _________

Figure 2-2 Cont'd. Final Survey Design – Page 3.

Please take one last minute to answer some simple questions about yourself so that we may properly characterize the survey results.

1. Please check one: ☐ Male ☐ Female

2. What is your current age? ________years

3. What is the highest level of education that you have completed?

   ☐ Middle School ☐ High School ☐ College ☐ Graduate School

4. Please indicate your race/ethnicity:

   ☐ Caucasian ☐ African American ☐ Hispanic ☐ Asian ☐ Other

5. In what type of home do you live? Please check one answer.

   ☐ House ☐ Apartment ☐ Townhouse ☐ Condo ☐ Other

6. Do you own or rent your home?

   ☐ Own ☐ Rent

7. Including yourself, how many people currently live in your home? ________ people

8. Please place a checkmark next to the types of pets you have, if any.

   ☐ Dog(s) ☐ Cat(s) ☐ Bird(s) ☐ Rabbit(s) ☐ Rodent(s) ☐ Other

9. Does anyone smoke cigarettes in your home? Check all that apply.

   ☐ Myself ☐ Someone else ☐ No one

10. Do you or does someone else in your home take prescription or over-the-counter medications for allergies or other respiratory illness?

    ☐ Myself ☐ Someone else ☐ No one

    If you or someone else in your home takes prescription allergy or respiratory medications, how frequently are these medications used?

    ☐ Daily ☐ As Needed

11. Which of the following broad categories best describes your household's total income for 2004?

    ☐ $20,000 or less
    ☐ $20,001 to $50,000
    ☐ $50,001 to $100,000
    ☐ $100,001 or more

Figure 2-2 Cont'd. Final Survey Design – Page 4.

A number of hypotheses to be tested were posed during the development of the survey. It was hypothesized that survey respondents would acknowledge the risks associated with poor IAQ and show enough concern to be willing to take action to eliminate potential indoor air risks in their homes. It was hypothesized that respondents would not have sufficient knowledge of the types and severity of particular indoor air risks, disallowing them from appropriately identifying priority risks. It was also hypothesized that respondents would be familiar with the types of indoor air cleaners available to consumers.

Questions 1 through 18 are close-ended ordered response questions that serve to obtain information regarding the respondent's knowledge and views of indoor air related risks. These questions utilize a five-category rating scale with possible answer selections of "Definitely Agree", "Somewhat Agree", "Neutral", "Somewhat Disagree", and "Definitely Disagree". A sixth category, "Don't Know," was included at the end of the scale so that respondents would not feel forced to choose an answer.

Questions 19 through 22 are closed-ended questions that serve to determine respondent's information sources on the topic of indoor air quality and whether the respondent currently uses an indoor air cleaner. These four questions use a "Yes" or "No" rating scale with an additional third category for "Don't Know."

Question 23 is an open-ended question that prompts the respondent to list any other type of home air cleaning device that they use.

Questions 26 through 35 are closed-ended ordered questions that list a variety of household items and tasks that are to be evaluated with respect to their affect on indoor air quality. A four category rating scale including answer choices of "A lot", "Some", "Not much", and "None" was used for these questions. A fifth choice of "Don't Know" was also included.

Questions 36 through 40 asked the respondent about their willingness-to-pay for indoor air treatment options and about steps they have taken to combat indoor air problems in their own homes. Questions 36, 37, 38, and 39 are closed-ended unordered questions, while Question 40 is an open-ended question that allows the respondent to write in the requested answer. Question 39 also includes a response option that allows the respondent to write in a response.

Finally, the 11 demographic questions gather respondent information such as gender, age, education, race, type of home, number of people in home, pets, cigarette smoking, medications for respiratory illness, and household income.

The forty survey questions were developed by making sure that the five risk-related variables from Section 2.11 were incorporated in them. Table 2-2 illustrates the risk variables that were considered when drafting each survey question. Additional risk variables may be substituted or considered for each of the survey questions.

For this research, "Indoor Air Quality is an important concern in my home" was chosen as Question 1. Question 1 most closely relates to the overall subject matter of the survey. Question 1 does not require extensive thought and is easy to answer. Also, the use of the word "concern" in Question 1 catches the respondent's attention and leads them into the following question. The remaining questions were ordered to flow from one to the next. The more difficult open-ended and closed-ended unordered responses were placed toward the end of the survey. Questions utilizing the same rating scales were grouped together to minimize confusion.

2.2.2.2 Actual survey formatting

Upon arranging the finalized questions in tabular form, it was found that they could be formatted to one sheet of legal size paper, measuring 8.5 x 14 inches. The legal paper was folded in half to form a small booklet. The front and middle two pages were comprised of the 40 survey questions and accompanying completion instructions. The survey questions dealing most closely with the title and topic were placed towards the beginning of the first page to capture the respondent's attention. The back page of the booklet included the 11 demographic questions. The demographic questions were placed at the end of the survey so as not to distract the respondent from the main topic being addressed. Also, the question inquiring about household income was placed last on the demographics page.

Questions were spaced as evenly as possible within the page and printing limits of the booklet. The small sections including instructions and the rating scale were shaded with a light gray background to create some contrast from the questions, which had a white background. Also, the instructions and rating scale text were bold. All text on the survey, except for the title instructions for the demographic section was typed using the Verdana font with a size of 8. Studies on font type have shown that the Verdana font is pleasing to the eyes and easily readable (Dillman, 2000). Additionally, a small box was placed on the bottom of the third page. This box contained a county code, manually written in by the researcher, that was used to help track the counties from which completed surveys were returned.

Table 2-2. Risk-related Variables Considered for Survey Questions.

Question	**Risk variable**[1]		**Question**	**Risk variable**[1]
1	p		21	p,r
2	r		22	p
3	q		23	p
4	r		24	q
5	q		25	q
6	p		26	q
7	r		27	q
8	r		28	q
9	q		29	q
10	r		30	q
11	p,b		31	q
12	p,b		32	q
13	r,a		33	q
14	r,a		34	q
15	p,b,a,r		35	q
16	p,b,a,r		36	b,p
17	p,b,a,r		37	b,p
18	q		38	p,r
19	p,r		39	p
20	p,r		40	p,b,a,r,q

[1] p: personal relation to hazard
r: risk level aspects
q: qualitative features of hazards
b: benefit aspects
a: acceptability aspects

2.2.2.3 Actual cover letter

A cover letter was drafted in accordance with the elements listed in section 2.2.1.3. Figure 2-3 presents an example of a cover letter mailed to survey recipients in this research.

2.2.3 Survey Administration

This section describes the methodology for administering the indoor air quality survey to residents of North Carolina. Topics include obtaining the address list, printing methods, and postage methods.

North Carolina State University is a land-grant university and a constituent institution of The University of North Carolina

Department of Civil, Construction, and Environmental Engineering

NC STATE UNIVERSITY

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Campus Box 7908
Raleigh, NC 27695-7908

919.515.2331
919.515.7908 (fax)
www.ce.ncsu.edu

September 30, 2005

John Smith
123 Maple Lane
Your Town, State, Zip

Dear Mr. Smith,

I am writing to ask you to take just a few moments to complete a survey so that we can better understand how North Carolinians feel about the quality of the indoor air in their residences. Results from the survey will be used to offer recommendations to public officials to help them better inform the public and set priorities regarding indoor air quality concerns.

You have been randomly selected from the current list of registered voters in the state of North Carolina. Your answers are completely confidential and will be released only as summaries in which no individual's answers can be identified. The only identification on the actual survey is a three digit code that tells us from which counties we receive responses. When you return your completed questionnaire, your name will be deleted from the mailing list and never be connected to your answers in any way. Furthermore, the original surveys will be destroyed once the anonymous information has been entered into a database. This survey is voluntary and we are not promoting any products.

If you have any questions, I will be happy to answer them. I can be reached by email at lphilli@ncsu.edu, or via the address on the letterhead.

Thank you for taking a few moments to contribute to this important research.

Sincerely,

Lori Ann Phillips

Lori Ann Phillips
Graduate Research Assistant

Figure 2-3. Design of Cover Letter Utilized in Survey Mailings

2.2.3.1 Selection of sample size

Factors that must be taken into account when determining the survey sample size include how much sampling error can be tolerated, the population size from which the sample is to be drawn, how varied the population is with respect to the characteristic of interest, and the amount of confidence one wishes to have in the estimates made from the sample for the entire population. Equation 2 illustrates the formula utilized to aid in determining sample size for this survey. Equation 2 assumes a yes/no question format but is acceptable practice for surveys employing many different types of questions (Dillman, 2000).

$$Ns = \frac{(Np)(p)(1-p)}{(Np-1)(B/C)^2 + (p)(1-p)} \tag{2}$$

where Ns = completed sample size needed for desired level of precision
Np = size of population
p = proportion of population expected to choose one of the two response categories (yes/no format questions)
B = acceptable amount of sampling error
C = Z statistic associated with the confidence level (1.96 for 95% level)

With a population of over five million, a 50/50 split on response (p=.5), a 5% sampling error, and 95% confidence level, the necessary sample size is 384. Similarly, the necessary sample size when assuming an 80/20 split on response is 246. A 50/50 split is the most conservative value possible and assumes maximum variation meaning that half of the population will answer one way and the other half will answer in another way.

Upon consultation with an expert in survey distribution, the researcher was told to expect anywhere from 10-20% overall survey response (Cobb, 2005). This estimation was based on factors such as survey length, using real stamps on return envelopes, and multiple contacts. Taking this into account, along with the results from Equation 2, it was determined that a survey distribution of 2000 would yield a sample size close to the research goal of 400, as well as fit into the research budget.

2.2.3.2 Address database

In order to distribute a survey to a sample of residents of North Carolina, it was necessary to obtain an address list. An address database was obtained from the North Carolina State Board of Elections in early August, 2005. This database included the names, addresses, and gender of every registered voter in the state of North Carolina as of August 6, 2005. Registered voters were used because this database displayed the greatest coverage of the available databases. This database included 5,369,170 records. A smaller database containing 2000 names and accompanying addresses was created by generating random numbers, without replication, between 1 and 5,369,170 in Microsoft Excel. These numbers were then individually entered into the voter database to return the record of the particular voter associated with that number. The selected record was copied to a new survey database. The process of searching and copying records from the voter database to the survey database was repeated until 2000 names and addressed had been chosen.

2.2.3.3 Printing methods

After formatting the survey, 2000 copies were produced using a photocopy machine. The same amount of copies of the cover letter was also created using a photocopy machine and was copied onto North Carolina State University Civil, Construction, and Environmental Engineering Department letterhead paper. To encourage responses and establish respondent trust, department letterhead was chosen to make the survey and cover letter look as professional as possible. The inside address and greeting were added to the cover letters by hand-feeding them into an ink-jet printer that was mail-merged to the mailing list database. The mailing addresses were printed on #10 white business envelopes that had been printed with the Civil, Construction, and Environmental Engineering Department letterhead. These mailing envelopes were hand-fed into an ink-jet printer to perform this task. Finally, #9 business reply envelopes with “Indoor Air Quality Survey” and the Civil, Construction, and Environmental Engineering Department address on them were designed by the United States Postal Service and printed by the University printing center. Figure 2-4 and Figure 2-5 illustrate the outgoing survey mailing envelopes and business reply envelopes, respectively.

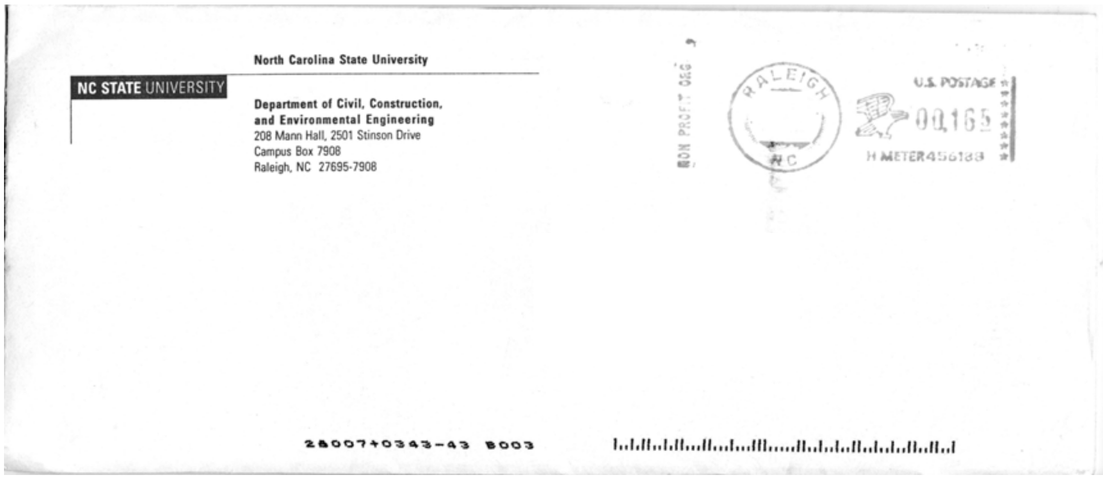

Figure 2-4. Example of an Outgoing Survey Mailing Envelope.

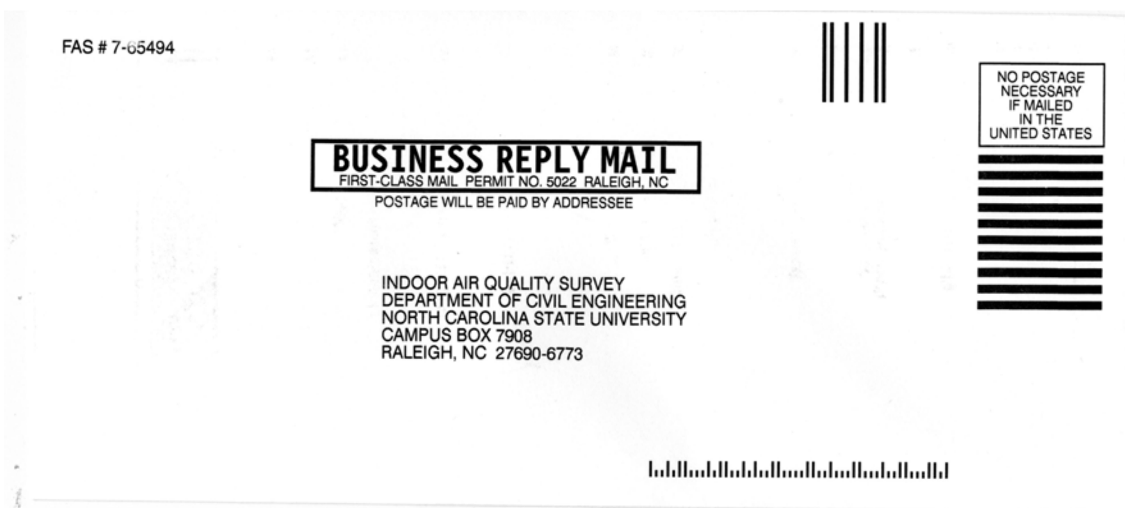

Figure 2-5. Example of a Business Reply Envelope.

When all of the printing was complete, the items (survey, cover letter, and business reply envelope) were folded, assembled, and stuffed into the mailing envelopes in preparation for sending.

2.2.3.4 Postage and delivery methods

The assembled envelopes were transported to University Mail Services to be stamped with outgoing postage. To reduce postage costs, the surveys were sent as non-profit mail, costing 16.5 cents per piece to send. The business reply envelopes contained within the mailing were marked with "no postage necessary," however, each one of these envelopes returned to the researcher cost 42 cents for the service. While it would have been preferable to attach real stamps to the survey reply envelopes as a sign of good faith, this option was not feasible due to monetary constraints. Two thousand real stamps that cost 37 cents apiece would have amounted to an increase of $740 in the project budget.

The first round of 1000 envelopes was mailed on September 23, 2005 and the second round of 1000 envelopes was mailed on September 30, 2005. A week was placed between mailings to reduce the bulk of returned responses that might be received at once.

2.2.3.5 Survey error

As mentioned in Section 2.1.1, the four types of survey error are sampling error, coverage error, measurement error, and nonresponse error. These four types of error were considered during the development and design of the research survey. Sampling error is quantified through means of statistical analysis and is discussed in Chapter 3.

Coverage error can lead to lack of representation of the intended population. For this research, the intended population included all residents of the State of North Carolina. It was not possible to obtain a list of every person in North Carolina, therefore, the list of registered voters was chosen. An attempt to minimize the coverage error created by using this list was completed by using a random number generator to randomly select respondent identification numbers from the list of registered voters. The random number generator function, "RANDBETWEEN (Top, Bottom)" found in the Microsoft Excel workbook was utilized to accomplish this. By specifying an inclusive range of 1 to 5,377,081, the total number of registered voters in North Carolina as of August 28, 2005, Excel randomly chose numbers within the range. These numbers were then matched with the records of registered voters having the same identification numbers. Random survey recipient selection assured that no specific areas of the state were singled out or targeted. Also, census information for the State of North Carolina was compared to the survey's demographic results to assess any possible coverage error.

Measurement error results from poor construction of the survey instrument. Questions that force answers, present inaccurate data, or contain unbalanced answer scales result in measurement error. Measurement error is also due to the correct or incorrect associations that survey respondents may make between related and unrelated questions, respectively. To reduce measurement error in this research, care was taken to assure that all survey questions made logical sense and did not force an unintended answer from the respondent. During survey question development, the survey was tested on a group of individuals who provided feedback on the ease of understanding and general flow of the survey. Any difficult to understand, misleading, or otherwise objectionable questions identified by the test group were revised or omitted from the final version of the survey.

Finally, nonresponse error occurs when members of the intended population do not submit an overall survey response or fail to response to specific survey question. Nonresponse error is addressed by comparing the survey's demographic results to the census information for North Carolina. If there is a large demographic difference between the North Carolina population and survey respondents present, then nonresponse error is indicated.

2.2.4 Survey Analytical methods – Database Design and Entry

Upon receipt of the majority of returned surveys, a database was designed for simple entry of survey responses. Microsoft Excel was chosen for the database because it is both reliable software for calculating summary descriptive statistics and it is easily exportable to a higher software for more complicated statistical analysis. A database was set up in Excel. Questions were placed in numerical order across the top of the spreadsheet, leaving one question per column. Each row of the spreadsheet was designated for a different survey response.

When the returned surveys were opened, it was then easy to press the keyboard "tab" key to toggle across the spreadsheet while entering the question responses. The first 35 questions, which had a rating scale, were entered using the respondent's selected number on the scale. An exception was Question 23, in which the respondent's entire open-ended answer, if any, was recorded in the spreadsheet. Questions 36, 37, 39, and Demographic

Question 11 were entered using the letters 1, 2, 3, and 4. The first answer choice corresponds to 1, the second to 2, and so forth. The respondent's entire open-ended answer, if any, was recorded for Questions 38 and 40. The final questions in the Demographic section were entered by recording a numeric value that represented the selected answer. For example, a respondent indicating that his gender was male would receive a "1" in the appropriate column of the survey response spreadsheet, while a female response would receive a "2". The numeric codes for the demographic questions are included in Appendix A. Demographic Questions 2 and 7 received numeric answers in the spreadsheet.

While the survey recipients were given the option of selecting "don't know" as an answer choice for each survey question, the "don't know" responses were not considered as part of the categorical scales utilized to analyze the survey results. Instead, "don't know" responses were analyzed separately as noted in the following sections.

2.2.5 Survey Analysis Techniques

The analysis of survey results can be simple, complex, or a combination of both. Statistical analyses are the major component of determining survey results. Typically, a wide range of generalizations of regression analysis, such as generalized linear modeling, event history analysis, and multilevel modeling, are frequently applied during analytic survey analysis (Chambers, 2003). Descriptive survey analysis includes estimations of summary measures of a population including means, proportions, and rates (Swan and Sandilands, 1995). The survey response data in this research was analyzed using descriptive statistics, a statistical software package called SAS, and by computing correlation coefficients for pairs of questions. The following sections detail these analyses.

2.2.5.1 Descriptive statistics

Descriptive statistical parameters include values for the mean, median, and mode of question responses. The mean represents the 'average' of all data values and yields a good idea of the value of the population mean, though it can be affected by extreme values. The median represents the middle value when the data are arranged in order and is less affected by extreme values. The mode illustrates the most popular survey response and it is represented by the class with the highest frequency on a histogram (Swan and Sandilands, 1995). By looking at the mean, median, and mode, one can get an idea of the central tendencies in the data. Also, possible relationships between questions can be inferred by examining the descriptive statistics of related questions, leading to further statistical analysis (ASA, 2005).

Descriptive statistics can be performed on survey data quickly and efficiently by utilizing a software program such as Microsoft Excel. More complex statistical calculations require the use of a higher level software program, such as SAS. These programs allow the user to infer generalizations concerning data by analyzing correlations between different survey questions (Swan and Sandilands, 1995).

For this research, the mean, median, and mode of the data were found by using Excel. This is a simple computation and only requires the user to select the individual questions to be analyzed and enter the corresponding cell numbers inside the parentheses of either Mean( ), Median ( ), or Mode( ). Additionally, the 95% confidence interval was constructed on the means for each question by utilizing the following relationship:

$$\text{95\% Confidence Interval} = \pm 1.96 \frac{s}{\sqrt{n}}$$

where,

s = standard deviation of the sample
n = sample size

The 95% confidence interval has a 95 percent frequency of enclosing the true mean.

2.2.5.2 SAS

The statistical analysis software, SAS, was utilized to further assess the data obtained from the survey. Possible relationships between questions were analyzed by calculating the Chi-square probability for specific pairs of questions. The Chi-square probability is useful for determining whether significant differences exist between the results of two or more categorical questions (Swan & Sandilands, 1995). Equation 3 represents the Chi-square probability. An explanation and detailed example of how SAS computes the Chi-square probability is included in Appendix B.

$$\chi^2 = \sum_{j=1}^{k} \frac{(O_j - E_j)^2}{E_j} \tag{3}$$

The SAS analysis was completed by copying the data in Excel and pasting it into the SAS editor. SAS code was then written to compute frequency tables, along with the Chi-square statistics. An example of the SAS code is also included in Appendix B. The frequency tables use bins to summarize the question responses for a given pair of questions. The Chi-square analysis only uses complete data in its computations, or, it does not use data in which one value is missing for a pair of questions. Therefore, the analysis is only calculated on complete sets of survey responses for each question. An incomplete data set can be due to either non-response on the part of the survey respondent or due to an answer response of "don't know" for selected survey questions. "Don't know" answers were not part of the rating scales for the survey responses and were considered as non-response for the Chi-square analysis.

The Chi-square analysis is most accurate for data that has counts of 5 or greater in each of the bins of the frequency table. When bins contain values less than 5, the Chi-square statistic may not be a valid test and care should be taken in reporting the accuracy of the results. To reduce the chance that bins would have counts less than 5, some response categories were combined for specific questions. For instance, the answer responses for the first eighteen survey questions were condensed into three answer categories, or "Agree", "Neutral", and "Disagree". By combining the categories of "Definitely Agree" and "Somewhat Agree" into "Agree", the chance of producing a frequency table with a bin containing a value of less that 5 was lessened.

For this research, the generated Chi-Square results and frequency tables of the survey data were saved as SAS files for later review.

2.2.5.3 Additional statistical analysis

In addition to descriptive statistics and the Chi-Square analysis that was completed using SAS, sample (Pearson) correlation coefficients were calculated between each pair of survey questions. The correlation coefficients are another useful tool for determining possible relationships between question responses. These coefficients range from -1 to 1. The stronger the positive correlation between the pair of questions, the closer to 1 the value of the correlation coefficient will be. The stronger the negative correlation between the pair of questions, the closer to -1 the value of the correlation coefficient will be. Weak correlations have values closer to 0.

Correlation coefficients are useful for identifying trends in data responses and are used in this research to make inferences regarding the survey population. A positive correlation indicates that respondents who agreed strongly with one question also agreed strongly with another; or, that respondents who disagreed strongly with one question also disagreed strongly with another. A negative correlation indicates that respondents who agreed strongly with one question were likely to disagree strongly with the other question in the pair, and vice versa.

Statistically significant correlations are determined by comparing the correlation coefficient with a predetermined level of significance, commonly $\alpha = 0.05$. A critical value, r, with which to compare calculated correlation coefficients for significance is obtained by using Equation 4 (Zar, 1999):

$$r_{\alpha,v} = \sqrt{\frac{t_{\alpha,v}^2}{t_{\alpha,v}^2 + v}} \quad (4)$$

where α = level of significance (0.05)
v = degrees of freedom
t = t distribution statistic

For example, if the critical value of r was determined to be 0.4, a correlation coefficient of 0.5 would be considered significant. Figures 2.7, 2.8, and 2.9 display the scatter plots for correlation coefficients of 0.25, 0.50, and 0.75, representing weak, moderate, and strong relationships, respectively. A correlation of 1.0 or -1.0 would be represented by a straight line on a scatter plot.

Figure 2.6 illustrates a weak rectilinear relationship, indicating that the data from the two axes are weakly related to one another. Figure 2.7 illustrates a moderate rectilinear relationship, indicating that the data from the two axes are moderately related to one another.

Figure 2.8 illustrates a strong rectilinear relationship, indicating that the data from the two axes are strongly related to one another. For the survey data, correlation coefficients were used to determine if a respondent's answers to a specific question were related to her answers to another question.

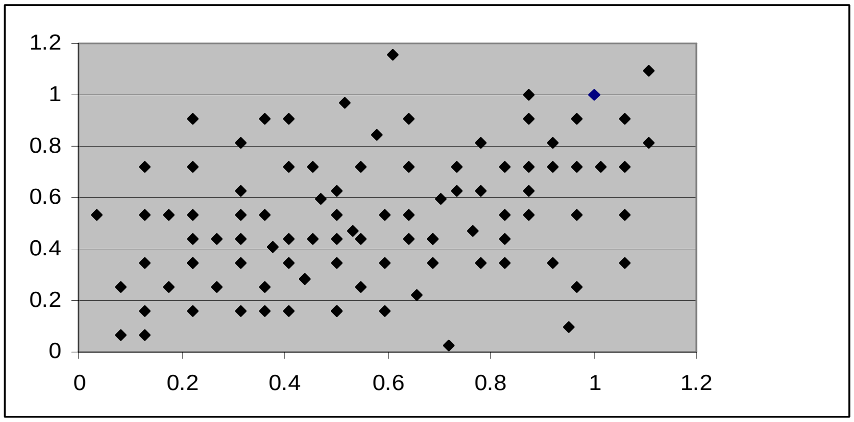

Figure 2.6. Scatter Plot of 0.25 Correlation.

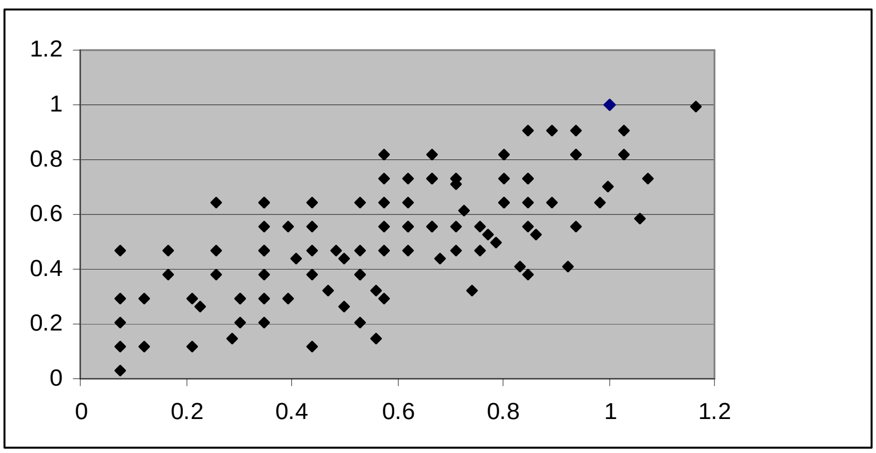

Figure 2.7. Scatter Plot of 0.50 Correlation.

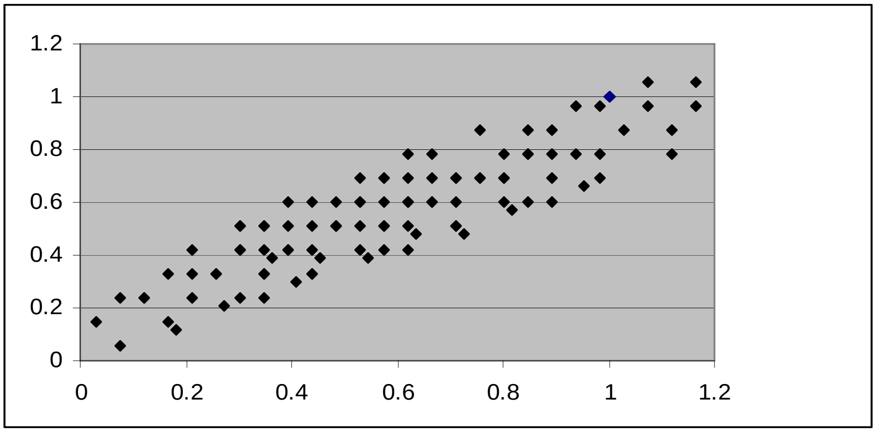

Figure 2.8. Scatter Plot of 0.75 Correlation.

2.3 Indoor Environment Modeling

2.3.1 Indoor Air Models

Indoor environments are complicated systems and thus, are difficult to model. A model used to describe one "well-mixed" room is a simple system to model; however, most residences are comprised of more than one room and are rarely "well-mixed" systems (Spengler et al, 2001). A few computer models exist for modeling a multi-zone indoor environment. Multi-zone models include RISK, CONTAM, and MCCEM. RISK and MCCEM were developed by the Environmental Protection Agency (EPA) while CONTAM was developed by the National Institute of Standards and Technology (NIST). Additional indoor modeling software include the Wall Paint Exposure Model (WPEM) developed by EPA, Indoor Air Quality – Building Education and Assessment Model (I-BEAM) developed by EPA, and MOIST (NIST) which assess transfers of heat and moisture in the indoor environment.

The indoor air model, RISK, was selected for this research because it is one of few models that can simulate the characteristics of indoor air cleaners. This multi-zone modeling program can also be useful in a variety of applications to analyze building airflows, pressure differences and contaminant transport.

2.3.2 RISK - Overview and Uses

EPA's Indoor Environment Management Branch has developed an indoor air quality (IAQ) model, RISK, for analyzing the impact of sources, sinks, ventilation, and air cleaners on indoor air quality. The model incorporates the latest results from EPA research. EPA's research focus thus far has been on indoor air transport phenomena and indoor/outdoor air relationships. The model predictions have been compared with results of research house experiments and the agreement between model predictions and experiments have been very good. RISK is designed to allow calculation of individual, as opposed to population, exposure to indoor air pollutants from sources. The model also provides the capability to calculate risk due to the calculated exposure (EPA, 2005). Risk is calculated using a risk calculation framework developed by Naugle and Pierson (1991).

RISK is based on two assumptions: (1) all rooms in the building are well-mixed; and (2) mass is conserved. Assumption 1 means that the concentration leaving a room through all exits is the same as the concentration in the room. However, this does not mean that the entire building is well-mixed, as each room can contain a different concentration. RISK does not currently allow for calculation of poorly mixed buildings. Assumption 2 means that the amount of air entering a room must equal the amount of air leaving a room. RISK provides a warning if user-inputted mass balances are incorrect. However, RISK will not automatically balance unequal air flows (Sparks, 2005).

The RISK model uses data on source emissions, room-to-room air flows, air exchange with the outdoors, and indoor sinks to predict concentration/time profiles for all rooms in a multi-zone building. The concentration/time profiles are then combined with occupant activity patterns to estimate exposure. The model allows analysis of the effects of air cleaners located in either/or both the central air circulating system or individual rooms on IAQ and exposure. The model allows simulation of a wide range of sources including long-term steady-state sources, on/off sources, and decaying sources. Several sources are allowed in each room. The model also allows for the analysis of the effects of sinks and sink reemissions on IAQ. Recent revisions of RISK now allow for improved analysis of particulate matter and multiple pollutants (EPA, 2005).

The modeling inputs and parameters that were used for this research, along with the results from the indoor air room cleaner modeling application can be found in Chapter 4.

3.0 SURVEYS

This chapter describes the results obtained from conducting an indoor air quality (IAQ) perception survey of registered voters in the state of North Carolina. This chapter begins with a short narrative on the pilot survey that was conducted prior to distributing the main survey for this research. A pilot survey was necessary for determining if any of the survey questions needed further revision or clarification prior to distributing the main survey. The summarized results of the pilot survey are discussed. The majority of Chapter 3 is dedicated to the results of the main survey that was conducted from October through December, 2005. These results are discussed in detail and inferences regarding the survey population are made when appropriate.

3.1 Pilot Survey

A small pilot survey was distributed in the Spring of 2005. A copy of the pilot survey is located in Appendix C. The survey was taken by colleagues within the Civil, Construction, and Environmental and Nuclear Engineering Departments at North Carolina State University. The majority of the respondents were current graduate students at the time of the pilot survey. The objectives of the pilot study were to determine the current status of risk perception relating to indoor environmental quality, identify areas of needed improvement for risk communication on indoor environmental risks, and recommend strategies for improving risk communication tactics.

A total of 53 completed surveys were returned for analysis. Descriptive statistical analysis in an Excel spreadsheet was completed on the total survey response, the male response, and the female response. Results for general demographic information are given in Table 3-1. A summary of the collected survey data can be found in Table 3-2. This table includes data for total response, male response, and female response. The mean, 95% confidence level, and mode of the response were included in Table 3-2 to show the average response, range of possible error, and most repeated response for each question. The questions corresponding to these results can be viewed in Appendix C. The confidence intervals for each question are located in Appendix D. The answer scale for the pilot survey was categorized as follows: a response of “0” indicates “Don’t Know”, “1” represents

"Definitely Disagree", "2" represents "Somewhat Disagree", "3" represents "Neutral", "4" represents "Somewhat Agree", and "5" represents "Definitely Agree".

Generalizations on the survey data were made by examining the statistical results and histograms computed for each question. Values for mean, median, mode, and 95% confidence interval were closely analyzed. The mean represents the 'average' of all data values and yields a good idea of the value of the population mean, though it can be affected by extreme values. The median represents the middle value when the data are arranged in order and is less affected by extreme values. The mode illustrates the most popular survey response and it is represented by the class with the highest frequency on a histogram. The 95% confidence interval represents an interval that has a 95% probability of including the true mean of the data. The confidence interval can be utilized to assess uncertainty (Swan & Sandilands, 1995).

Table 3-1. Demographic Results for Pilot Survey.

	Total	Male	Female
Number of Responses	53	35 (66%)	18 (34%)
Average Age (yrs)	27.4	28.5	25.3
Average # of hours spent indoors each day	19.2	18.6	20.4
Housing Status	**Total**	**Male**	**Female**
Own home	7 (13%)	5	2
Rent	40 (75%)	26	14
Live with Parents	3 (6%)	3	0
Other	2 (4%)	0	2

The most noteworthy findings from the pilot survey include the following generalizations:

- Most respondents (92%) agreed that poor IAQ is an important concern and can have harmful health effects, especially to children and elderly. However, respondents were unsure of details surrounding the severity of health effects and risks.
- Many respondents (43%) were uncertain of the relationship of pollutant concentrations between indoor and outdoor air. More females (63%) than males (36%) incorrectly selected outdoor air as being more polluted than indoor air.
- Most respondents (88%) acknowledged awareness of radon poisoning, yet were unsure if radon poses a current threat to their household.

Table 3-2. Summary Statistical Results for Pilot Survey Responses.

		Total	Male	Female			Total	Male	Female			Total	Male	Female
Q 1	**Mean**	4.49	4.57	4.33	**Q 14**	**Mean**	2.21	2.09	2.44	**Q 27**	**Mean**	4.08	4.06	4.11
	C.I.	0.23	0.18	0.59		**C.I.**	0.30	0.35	0.53		**C.I.**	0.28	0.30	0.61
	Mode	5	5	5		**Mode**	2	2	3		**Mode**	5	5	5
Q 2	**Mean**	4.70	4.69	4.72	**Q 15**	**Mean**	2.96	3.03	2.83	**Q 28**	**Mean**	4.66	4.66	4.67
	C.I.	0.14	0.16	0.27		**C.I.**	0.44	0.49	0.89		**C.I.**	0.14	0.16	0.27
	Mode	5	5	5		**Mode**	4	4	4		**Mode**	5	5	5
Q 3	**Mean**	4.17	4.17	4.17	**Q 16**	**Mean**	4.09	3.97	4.33	**Q 29**	**Mean**	4.38	4.29	4.56
	C.I.	0.37	0.47	0.60		**C.I.**	0.24	0.33	0.32		**C.I.**	0.18	0.22	0.28
	Mode	5	5	5		**Mode**	4	4	5		**Mode**	5	4	5
Q 4	**Mean**	3.43	3.71	2.89	**Q 17**	**Mean**	2.60	2.63	2.56	**Q 30**	**Mean**	0.89	0.83	1.00
	C.I.	0.42	0.42	0.89		**C.I.**	0.49	0.60	0.87		**C.I.**	0.09	0.13	0.00
	Mode	4	4	4		**Mode**	4	0	4		**Mode**	1	1	1
Q 5	**Mean**	2.26	2.17	2.44	**Q 18**	**Mean**	1.79	1.97	1.44	**Q 31**	**Mean**	0.98	0.97	1.00
	C.I.	0.37	0.46	0.60		**C.I.**	0.34	0.43	0.53		**C.I.**	0.04	0.06	0.00
	Mode	1	1	3		**Mode**	1	1	1		**Mode**	1	1	1
Q 6	**Mean**	4.40	4.31	4.56	**Q 19**	**Mean**	3.70	3.94	3.22	**Q 32**	**Mean**	0.52	0.54	0.47
	C.I.	0.23	0.32	0.24		**C.I.**	0.39	0.43	0.77		**C.I.**	0.14	0.17	0.24
	Mode	5	5	5		**Mode**	5	5	5		**Mode**	1	1	0
Q 7	**Mean**	2.58	2.63	2.50	**Q 20**	**Mean**	1.83	2.00	1.50	**Q 33**	**Mean**	0.31	0.26	0.41
	C.I.	0.37	0.46	0.66		**C.I.**	0.41	0.50	0.70		**C.I.**	0.13	0.15	0.23
	Mode	4	4	1		**Mode**	1	1	1		**Mode**	0	0	0
Q 8	**Mean**	2.42	2.11	3.00	**Q 21**	**Mean**	1.77	2.11	1.11	**Q 34**	**Mean**	0.96	0.97	0.94
	C.I.	0.42	0.48	0.78		**C.I.**	0.40	0.51	0.50		**C.I.**	0.05	0.06	0.11
	Mode	2	2	5		**Mode**	1	1	1		**Mode**	1	1	1
Q 9	**Mean**	3.34	3.60	2.83	**Q 22**	**Mean**	1.83	1.97	1.56	**Q 35**	**Mean**	0.20	0.17	0.25
	C.I.	0.41	0.47	0.76		**C.I.**	0.29	0.32	0.60		**C.I.**	0.11	0.13	0.21
	Mode	4	4	4		**Mode**	1	2	1		**Mode**	0	0	0
Q 10	**Mean**	2.09	2.54	1.22	**Q 23**	**Mean**	1.23	1.34	1.00	**Q 36**	**Mean**	0.16	0.15	0.19
	C.I.	0.52	0.64	0.79		**C.I.**	0.27	0.39	0.16		**C.I.**	0.10	0.12	0.19
	Mode	0	0	0		**Mode**	1	1	1		**Mode**	0	0	0
Q 11	**Mean**	4.42	4.46	4.33	**Q 24**	**Mean**	2.02	1.83	2.39	**Q 37**	**Mean**	0.36	0.34	0.39
	C.I.	0.23	0.20	0.55		**C.I.**	0.36	0.43	0.66		**C.I.**	0.13	0.16	0.23
	Mode	5	5	5		**Mode**	2	2	1		**Mode**	0	0	0
Q 12	**Mean**	2.40	2.34	2.50	**Q 25**	**Mean**	4.47	4.49	4.44	**Q 38**	**Mean**	0.98	0.97	1.00
	C.I.	0.32	0.36	0.64		**C.I.**	0.18	0.22	0.33		**C.I.**	0.04	0.06	0.00
	Mode	3	3	4		**Mode**	5	5	5		**Mode**	1	1	1
Q 13	**Mean**	2.62	2.60	2.67	**Q 26**	**Mean**	4.60	4.54	4.72	**Q 39**	**Mean**	0.91	0.91	0.89
	C.I.	0.36	0.42	0.69		**C.I.**	0.14	0.19	0.21		**C.I.**	0.08	0.09	0.15
	Mode	4	2	4		**Mode**	5	5	5		**Mode**	1	1	1

C.I. = 95% confidence interval

- The respondents have gained more knowledge concerning IAQ through newspapers and magazines than through TV commercials and programming.
- The majority of respondents (94%) did not currently own a home air cleaner or other filtration system and it seems that there was some uncertainty regarding increased IAQ safety through the use of these systems.
- The majority of respondents (97%) agreed that IAQ risks can be more effectively communicated to the public. In addition, most believed that they are presently in

danger from poor IAQ effects, though they seemed unsure as whether these effects can be avoided.

- The majority of respondents (91%) admitted they would seek proper treatment if an IAQ problem was detected in their home. Also, most agreed that they would be interested in inexpensive IAQ treatment options. Willingness-to-pay for more expensive options was not assessed in the pilot survey.
- Two-thirds of respondents were males, so there was an uneven distribution of males and females. Also, the majority of respondents (89%) resided in rented residences at the time of the pilot survey. This may mean that many respondents may not have much control over ventilation systems or may leave this type of maintenance to the discretion of their landlord.
- The majority of respondents correctly identified indoor combustion (88%), environmental tobacco smoke (95%), mold (98%), and inadequate ventilation (94%) as contributors to poor IAQ.
- More males than females selected the answer choice of “don’t know”. This trend might be due to the uneven gender distribution of survey respondents.

The majority of the survey respondents had some general knowledge and understanding of the risks associated with poor IAQ. There was some uncertainty among participants regarding the possible sources, health effects, and available treatment technology for IAQ problems. The motivating hypotheses were all supported by the findings of the pilot survey. The data received from the pilot survey did not show any significant misconceptions concerning IAQ among survey respondents. Therefore, problems seemed to lie in lack of information and knowledge on the topic, suggesting that methods of communication needed improvement.

3.2 Indoor Air Survey Results

This section describes the results obtained from the survey that was conducted from October through December, 2005. The methodology utilized for this survey is found in Chapter 2. The motivating hypotheses for the survey are located in Section 2.2.2.1. The following sub-sections present and assess the results for the total survey response, demographics, descriptive statistics, chi-square tests, and correlation coefficient analysis. Additionally, two clear sub-groups that were found to exist among the survey respondents were analyzed separately and their results are also included below. Finally, a summary, including possible interpretations, of the open-ended question responses that were received closes this chapter.

3.2.1 Total Response

Of the 2000 surveys distributed across the state of North Carolina, a total of 163 completed surveys were returned for analysis. This represents a survey response of about 8%. This response is slightly lower than the anticipated total response of 10-20%. The lower response rate can be attributed to a variety of factors. First, response rates could have been affected by not placing a real stamp on the return envelopes. Real stamps have been shown to establish trust with respondents and slightly increase the overall survey response. Real stamps were not placed on the return envelopes for budget reasons. Secondly, the surveys were sent via non-profit mail which means that mail is not automatically forwarded to residents who have changed their addresses. This was evident by the 73 undeliverable surveys returned to the researcher. Additionally, undeliverable surveys were noted to have been returned for reasons of insufficient address. The mailing list was obtained from the North Carolina Board of Elections. It is possible that the mailing list had not been properly updated to reflect changes of address.

Another factor that may have affected the response rate was the failure to include a small incentive in the survey mailing. While incentives have been shown to increase response rates for self-administered surveys, budget limitations did not allow for incentives to be included in this study. Finally, the failure to provide additional contacts with the survey recipients may be a reason for the lower-than-anticipated response rates. Multiple contacts, including advance notification of the survey study, reminder postcards, and additional copies of the survey, have been shown to increase survey response rates. Multiple contacts were not possible in this research due to budget and time constraints.

While the 163 completed responses were less than planned, this amount was still sufficient to make inferences regarding the survey population. By using Equation 2 in

Section 2.2.3.1, it was possible to calculate the sampling error associated with the survey response, which is approximately 7.5%.

3.2.2 Demographic Results

Table 3-3 and Table 3-4 illustrate the demographic results compiled from the returned surveys. For comparison, Table 3-3 also shows some of the statewide demographic statistics compiled from the US Census Bureau.

There were a larger number of female respondents (59%) than male respondents (41%) and the average respondent age was 49. Of the original 2000 surveys distributed across North Carolina, 1074 women and 926 men were randomly selected to receive the mailings. Thus, the survey gender distribution was 54% female and 46% male. The majority of respondents reported themselves as Caucasian homeowners, with almost 50% having attended some college. The majority of respondents do not smoke cigarettes. Many respondents own pets; 62% of respondents own at least one dog and 54% own at least one cat. 71% of respondents own at least one dog or one cat.

A few statistics from the demographic results stand out in this research and may be explained by both coverage and nonresponse error. The average age of survey respondents was 13 years greater than that of residents of North Carolina. This may be explained by the age distribution of the sample population. The mailing list for this survey was developed from a list of registered voters within North Carolina. By omitting residents under the age of 18 (the legal voting age), this is the explanation for the higher average age of survey respondents.

The percentage of survey respondents who attended graduate school is 15% higher than those reported in North Carolina's census. An explanation for this may be that some self-selection occurred among survey respondents. It is possible that recipients of the survey mailing were more likely to respond upon noticing and associating with the institution (North Carolina State University) letterhead.

Also, a high percentage of survey respondents (65%) reported an annual household income of over \$50,000 as compared to the statewide percentage from the census data. This could also indicate the possibility of self-selection among survey respondents. Perhaps the

Table 3-3. Survey Demographic Results[a] – Part 1.

		Total Number of Survey Respondents	Total Percentage (%) of Survey Respondents	North Carolina (US Census)[b]
Gender	Male	66	41	49%
	Female	96	59	51%
Average Age	Total	49	-	36[c]
	Male	52	-	NA
	Female	47	-	NA
Age: 18 years and over	Total	162	100	74%
Education	High School	51	31	28% of all persons
	College	75	46	42% of all persons
	Graduate School	36	22	7% of all persons
Race/Ethnicity	Caucasian	132	82	72%
	African American	20	12	21%
	Hispanic	2	1	4%
	Asian	0	0	1%
	Other	7	4	2%
Own vs. Rent	Own	143	88	69%
	Rent	19	12	31%
Headcount	Average	2.63 persons	-	2.49 persons
Household income	$20,000 or less	15	10	~23%
	$20,001 to $50,000	36	25	~40%
	$50,001 to $100,000	64	44	28%
	$100,001 or more	30	21	9%

[a] Note: Not all values total to 163 due to question nonresponse.
[b] Data source: (United States Census Bureau, 2000)
[c] Average age includes all members of North Carolina population, including persons younger than 18.

Table 3-4. Survey Demographic Results[1] – Part 2.

		Total Number of Survey Respondents	Total Percentage (%) of Survey Respondents
Type of Home	House	137	85
	Apartment	8	5
	Townhouse	5	3
	Condo	0	0
	Other	12	7
Pets	Dogs	62	38
	Cats	54	33
	Birds	5	3
	Rabbits	4	2
	Rodents	3	2
	Others	9	6
Smoke Cigarettes	Yes	19	12
	No	142	88
Respiratory Medications	Yes	96	60
	No	65	40

[1] Note: Not all values total 163 due to question nonresponse.

respondents who felt that they could afford to maintain the indoor air quality in their homes were more likely to respond to the survey mailing.

Almost 64% (104 respondents) of the respondents were from a demographic group of Caucasian, nonsmoking homeowners. This group included 56 females (54%) and 48 males (46%). Since this was viewed as a large percentage of the overall response and may yield significant results, these 104 responses were analyzed separately from the rest of the data. The analysis of the Caucasian, homeowner, non-smokers demographic (Sub-group A) is reported in Section 3.2.6. The respondents who did not fit this demographic, Sub-group B, were also analyzed separately from the total response and these results are reported in Section 3.2.7.

Finally, the distribution of responses that came from different counties across North Carolina was examined. Figure 3-1 illustrates the original distribution of survey mailings. The survey mailing distribution was not stratified by county, as each county would have received about 20 surveys apiece. Stratification of the sample distribution was not incorporated into this research in an effort to retain the demographics that might be associated with more highly and lowly populated counties. However, a stratified sample may be of interest for future research to determine whether survey response differences seem to vary by location.

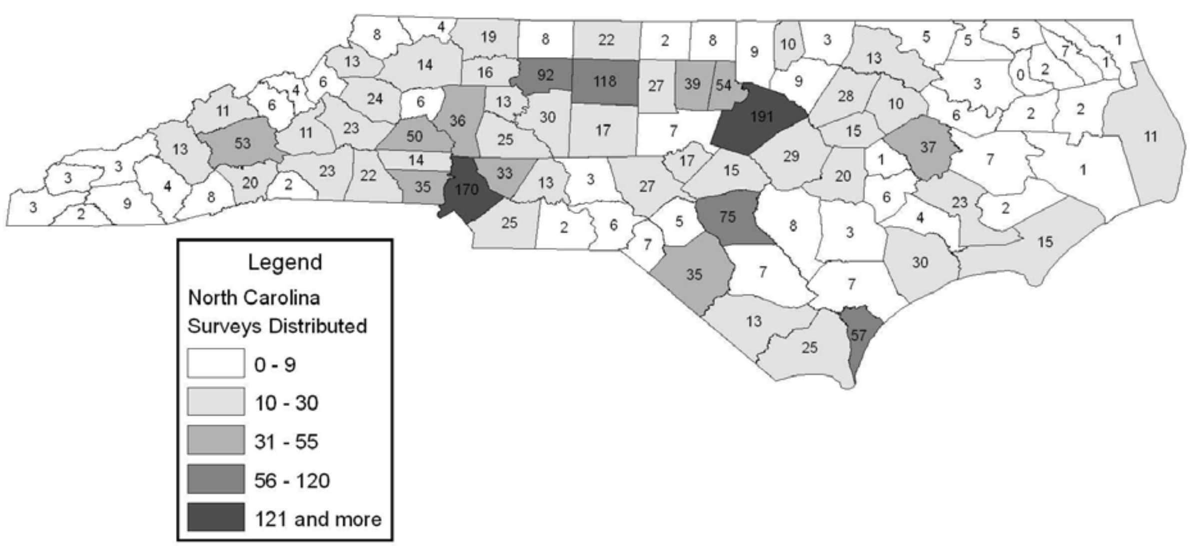

Figure 3-1. Number of Surveys Distributed in North Carolina by County.

Figure 3-2 illustrates the distribution of survey responses. Counties receiving many survey mailings were more likely to have a higher number of survey responses. Figure 3-3 illustrates the population distribution across North Carolina. This distribution was obtained from the United States Census Bureau (2000) and is not indicative of the registered voter population across North Carolina; however, for comparative purposes this figure aids in showing that more highly populated counties were more likely to receive higher numbers of survey mailings. One striking caveat exists between these two figures. One of the most highly populated counties, Mecklenburg County, depicted by the black shading in Figure 3.3, only had four survey responses. While this county had 170 surveys distributed to its residents, only four surveys were returned.

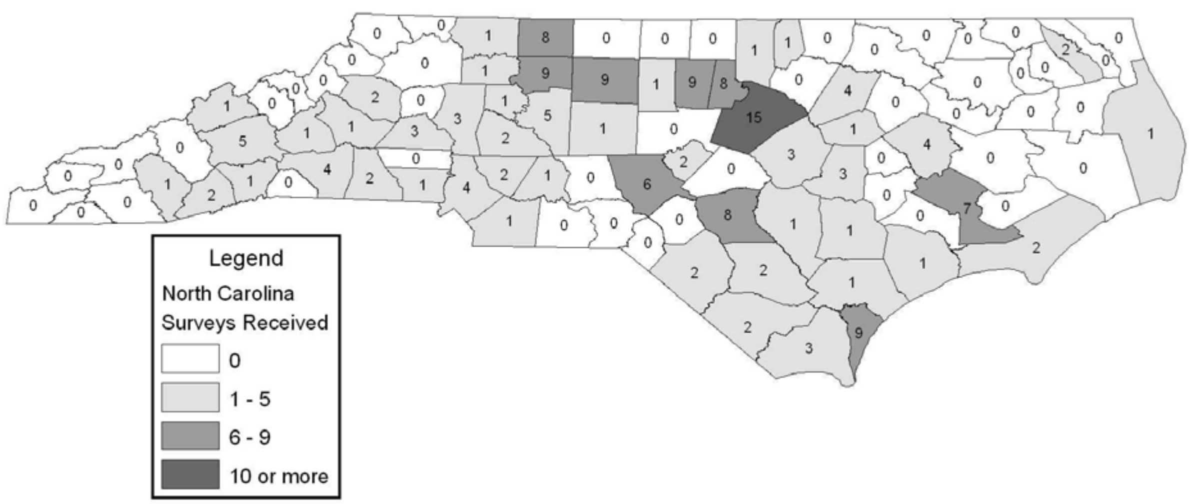

Figure 3-2. Number of Survey Responses Received by North Carolina Counties.

3.2.3 General Inferences Made from Analyzing Descriptive Statistics

The survey questions that were analyzed are located in Figure 2-2. Tables 3-5, 3-6, 3-7, and 3-8 illustrate the means, modes, medians, and number of “don’t know” responses among survey responses, respectively. Additionally, the 95% confidence levels for the means are included in Table 3-5. A table detailing the confidence intervals for each survey question is located in Appendix D. While not statistically complicated, these characteristics of the

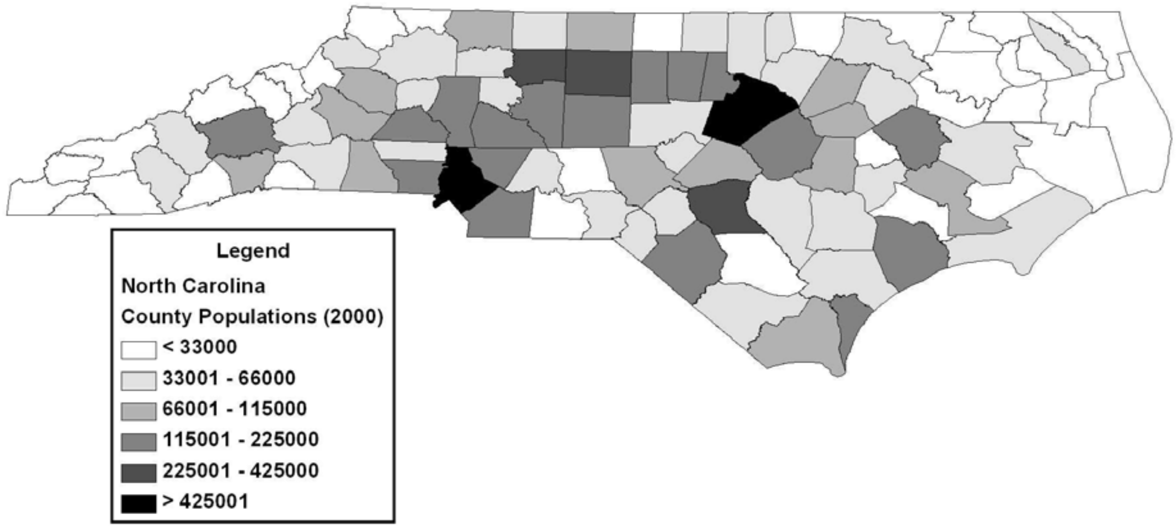

Figure 3-3. North Carolina Population by County (United States Census Bureau, 2000).

survey data can lead to the formation of general inferences regarding the survey population. As shown in Table 3-5, the majority of question response means fall between 1 and 2 on the five-point rating scale, indicating answers of either “definitely agree” or “somewhat agree”. The lowest means, or those with values closest to 1, indicate higher agreement with the survey question. For example, Question 8 and Question 29 have the lowest means and both questions refer to mold found in the indoor environment. Most respondents (99%) feel strongly that mold contributes to poor IAQ and can be harmful to one’s health.

Questions 9, 15, 27, and 28 also have relatively low means. Most respondents believe that IAQ will be a concern for future generations (94%), that respondents would take steps to eliminate an IAQ problem found in their home (98%), and that respondents believe that inadequate ventilation (92%) and cigarette smoke (91%) are large contributors to poor IAQ. These results support the motivating hypotheses located in Section 2.2.2.1.

Question 20 also exhibits a low mean, though this question had only a yes/no rating scale and cannot be compared to the questions mentioned above. When examining Question 19 through 21, though, it can be inferred that respondents have learned the most about IAQ from newspapers, magazines, or other periodicals.

There are a few instances when the total mean for a question is greater than 3, indicating general disagreement with the survey question. Questions 10, 13, and 14 fall into this category. Respondents (74%) believe that risks associated with poor IAQ can be more effectively communicated to the public, that many respondents (77%) believe they are in some danger from the effects of poor IAQ, and that respondents (66%) believe that adverse health effects from poor IAQ can be avoided.

For Questions 24 through 35, respondents were asked to indicate the extent to which the listed items contribute to poor IAQ. The twelve items included cooking, washing machines, vacuuming, inadequate ventilation, cigarette smoke, mold, candles, fireplaces, air fresheners, cosmetics, cleaning solvents, and showers. While a ranking of expert opinion on the severity of these potential indoor pollutants would be optimal, risk data relating each item to one another is unavailable. In Chapter 1, inadequate ventilation, mold, cleaning solvents, and cigarette smoke were mentioned as potential significant contributors to poor IAQ. The survey respondents tended to agree as the mode for survey data for these questions was 1, or that the items contribute "A lot." The other eight items on the list had modes that were determined to be either 2 or 3, indicating "some" and "not much." When risk data relating these items becomes available, more conclusive results can be offered by comparing the respondents' knowledge to expert opinion on these items.

By looking at the differences between the modes of male and female survey respondents, variations in gender response are noticed. For example, in Questions 7 and 8 it appears that more females than males agree that they are knowledgeable of the risks of radon, however, in Question 2 more males strongly agree that IAQ risks are clear to them.

In response to Question 10, females have a higher level of disagreement that IAQ risks are effectively communicated to the public. Based on Question 21, more females agree to have learned about IAQ from friends, family, and coworkers. Finally, for Questions 26, 32, 33, and 34, a greater number of women than men report a belief that cooking, air fresheners, cosmetics, and cleaning solvents/sprays contribute more to poor IAQ. This last comparison might be explained by noticing that women are more likely to be in contact with the possible indoor pollutants mentioned in Questions 26, 32, 33, and 34 and thus, women might be more likely to notice the harmful effects from these items. Also, the women's responses to Questions 26, 32, 33, and 34 agree well with expert opinion found in Section 1.2.1 that cooking, air fresheners, cosmetics, and cleaning products can contribute to poor IAQ.

Table 3-5. Total Survey Results - Means and 95% Confidence Intervals (C.I.)

	Answer Choice					
Question	Total mean	Total C.I.	Male mean	Male C.I.	Female mean	Female C.I.
1	1.45	0.12	1.50	0.15	1.43	0.18
2	1.87	0.17	1.98	0.28	1.79	0.21
3	1.48	0.14	1.50	0.22	1.47	0.19
4	1.44	0.13	1.70	0.22	1.26	0.16
5	1.56	0.14	1.62	0.23	1.51	0.18
6	1.70	0.19	1.67	0.25	1.72	0.27
7	1.76	0.19	1.76	0.23	1.75	0.29
8	1.19	0.07	1.30	0.11	1.12	0.08
9	1.26	0.10	1.35	0.18	1.20	0.11
10	3.30	0.19	3.36	0.27	3.28	0.26
11	2.09	0.14	2.30	0.23	1.96	0.19
12	1.96	0.16	2.03	0.23	1.91	0.22
13	3.56	0.16	3.56	0.27	3.55	0.21
14	3.16	0.19	3.52	0.30	2.93	0.24
15	1.23	0.07	1.24	0.11	1.23	0.09
16	2.12	0.16	2.42	0.25	1.92	0.20
17	1.66	0.15	1.91	0.25	1.46	0.17
18	1.60	0.14	1.74	0.24	1.48	0.16
19	1.38	0.08	1.40	0.12	1.36	0.10
20	1.27	0.14	1.21	0.12	1.30	0.23
21	1.41	0.08	1.50	0.12	1.35	0.10
22	1.75	0.06	1.81	0.09	1.71	0.09
23	-	-	-	-	-	-
24	2.02	0.11	2.00	0.18	2.03	0.14
25	2.17	0.13	2.39	0.18	2.00	0.17
26	1.73	0.14	1.85	0.22	1.64	0.17
27	1.26	0.09	1.41	0.16	1.14	0.10
28	1.23	0.12	1.42	0.24	1.07	0.09
29	1.08	0.07	1.06	0.13	1.06	0.06
30	1.95	0.12	2.11	0.17	1.82	0.15
31	1.65	0.11	1.80	0.14	1.53	0.14
32	1.82	0.13	1.95	0.19	1.72	0.16
33	2.00	0.12	2.00	0.18	1.98	0.16
34	1.45	0.10	1.57	0.17	1.36	0.12
35	2.13	0.14	2.52	0.22	1.84	0.18

Table 3-6. Total Survey Results - Modes

	Answer Choice		
Question	Total mode	Male mode	Female mode
1	1	1	1
2	1	1	2
3	1	1	1
4	1	1	1
5	1	1	1
6	2	2	1
7	2	2	1
8	1	1	1
9	1	1	1
10	4	3	4
11	2	2	2
12	3	3	3
13	5	5	5
14	4	4	4
15	1	1	1
16	2	2	2
17	1	1	1
18	1	1	1
19	2	2	2
20	1	1	1
21	2	2	1
22	2	2	2
23	-	-	-
24	2	2	2
25	3	3	3
26	2	2	1
27	1	1	1
28	1	1	1
29	1	1	1
30	2	2	2
31	2	2	2
32	2	3	2
33	2	3	2
34	1	2	1
35	2	2	2

Table 3-7. Total Survey Results - Medians

	Answer Choice		
Question	Total median	Male median	Female median
1	1	1	1
2	2	2	2
3	1	1	1
4	1	2	1
5	2	2	2
6	2	2	2
7	2	2	2
8	1	1	1
9	1	1	1
10	3	3	4
11	2	2	2
12	3	3	3
13	4	4	4
14	4	4	4
15	1	1	1
16	2	2	2
17	1	2	1
18	2	2	1
19	2	2	2
20	1	1	1
21	2	2	1
22	2	2	2
23	-	-	-
24	2	2	2
25	3	3	3
26	2	2	2
27	1	1	1
28	1	1	1
29	1	1	1
30	2	2	2
31	2	2	2
32	2	3	2
33	2	3	2
34	1	2	1
35	3	3	2

Table 3-8. Total Survey Results - "Don't Know" (DK) responses

	% of Total Responses		
Question	Total DK (%)	Male DK (%)	Female DK (%)
1	1	0	2
2	8	6	9
3	7	8	6
4	17	12	20
5	14	12	15
6	25	15	33
7	22	11	29
8	1	0	2
9	6	6	6
10	2	2	3
11	12	8	16
12	34	28	38
13	12	11	14
14	12	6	16
15	2	2	2
16	4	3	5
17	4	5	4
18	7	5	9
19	10	8	11
20	8	8	7
21	6	6	5
22	1	2	1
23	-	-	-
24	11	11	12
25	24	20	27
26	9	9	9
27	4	2	5
28	2	2	2
29	6	11	2
30	12	8	15
31	7	8	6
32	20	24	18
33	22	26	19
34	6	6	6
35	20	11	27

There is a significant frequency of "don't know" responses for specific questions. Since the "don't know" response was not part of the three- or four-step rating scales used on the survey, it could not be assigned a numerical value and included in determining the descriptive statistics of means, medians, and modes. Therefore, the "don't know" responses were analyzed separately from the rest of the survey data. As given in Table 3-8, many questions received over 20 responses of "don't know". While more females responded to the survey than males, it is clear that females answered "don't know" at a rate of about 2:1 to males, and higher, for some questions. For example, many more females than males responded with "don't know" when asked whether showers contribute to poor IAQ. Many more females than males answered "don't know" to Question 6 and Question 7, which pertain to radon in the indoor environment. As was previously mentioned, the female respondents seemed to be in higher agreement that they were familiar with the risks of radon and how it can enter a home. However, when taking into account the number of females answering "don't know", it seems as though many females are unsure of radon, yet those who do know about it are fairly certain of their knowledge.

The highest occurrence of "don't know" responses, or 54, was found for Question 12. It can be inferred that many respondents are unsure of whether air cleaners using ozone can keep them safe from poor IAQ. Also, many "don't know" responses were noted for Questions 24, 25, 30, 32, 33, and 35. These six questions ask whether the respondent believes that cooking, washing machines, candles, air fresheners, cosmetics, and showers contribute to poor IAQ, respectively. While these six items do contribute to poor IAQ, information regarding them is not widely available and therefore the respondent's answers of "don't know" for these questions seem satisfactory and are expected.

3.2.4 Chi-Square Relationship Results

The Chi-square analysis was performed using SAS to determine any trends in the data. This analysis was used to see if a respondent would be more likely to answer a specific way on a question based on that respondent's answer to another question. As mentioned in Section 2.2.5.2, frequency tables and Chi-square probabilities were computed for different pairs of questions. The Chi-square probabilities were then examined. Probability values of less than 0.05 were noted as significant and recorded in Table 3-9. A Chi-square value of less than 0.05 denotes the existence of a relationship between the pair of questions being examined. It is then up to the researcher to review the frequency table and define the relationship.

Some of the frequency tables had “bins” that contained counts of less than 5. While the Chi-square results from bins containing values less than 5 are not necessarily invalid, the precision of the Chi-square test is much lower under this circumstance and is taken into account. Also, there are a number of data sets missing from each Chi-square analysis. These missing data are the result of non-response on the part of the survey respondent. Non-response for the Chi-square analysis means that the respondent either failed to answer a particular question or answered by selecting the “don’t know” choice. High values for the frequency missing from the analysis may mean that only a small amount of complete data sets were available and therefore the Chi-square probability may not be representative of the entire survey population.

There exist eighteen question pairs for which a Chi-square probability of less than 0.05 was calculated. It was then necessary to look at the frequency tables for these question pairs to try to ascertain the possible relationship between question responses. The following inferences were made by examining the frequency tables associated with the question pairs found in Table 3-9. The pairs of questions are arranged from lowest to highest Chi-Square Probability and are referenced in the text by their comparison number on the table. In some instances, it was not possible to see a clear relationship between questions from the distribution of question responses in the frequency tables.

For comparison 1 between Q36 and Q37, it is clear that the majority of respondents would be willing to pay nearly the same amount for indoor air pollution reduction when both considering and not considering the extent of the pollution reduction. The amount that most respondents were generally willing to pay is \$30 or less per month. The findings from this comparison support the hypothesis that respondents would be willing to take action if an IAQ problem was found in their home.

For comparison 2 between Q31 and D1, women seem more likely to think that fireplaces contribute more to poor IAQ than men.

For comparison 3 between Q10 and D11, those respondents reporting higher household incomes tended to respond that IAQ risks are not effectively communicated to the public by environmental professionals.

For comparison 4 between Q7 and D1, more men than women are aware of the risks associated with radon in the indoor environment.

For comparison 5 between Q13 and D9, more smokers than non-smokers strongly believed that they are in danger from poor IAQ.

For comparison 6 between Q3 and D4, the majority of Caucasian respondents agreed that poor IAQ is harmful to children and the elderly, while non-Caucasian respondents' answers were more varied.

For comparison 7 between Q6 and D1, more male respondents seemed aware of how radon can enter a home than female respondents.

Table 3-9. Results from the Chi-Square Analysis for Pairs of Questions with Probabilities Less Than 0.05.

Comparison Number	Question Pair		Chi-Square Probability	Frequency Missing	Effective Sample Size	Percentage of bins with counts < 5
1	Q36	Q37	0.0001	5	158	38
2	Q31	D1	0.0010	15	148	33
3	Q10	D11	0.0010	21	142	-
4	Q7	D1	0.0015	37	126	-
5	Q13	D9	0.0056	23	140	33
6	Q3	D4	0.0063	13	150	33
7	Q6	D1	0.0092	43	120	-
8	Q13	D11	0.0094	36	127	50
9	Q17	D10	0.0103	12	151	33
10	Q18	D10	0.0117	14	149	33
11	Q28	D1	0.0128	5	158	33
12	Q21	D10	0.0149	8	155	-
13	Q2	Q10	0.0154	15	148	33
14	Q30	D3	0.0276	22	141	44
15	Q17	D1	0.0366	11	152	33
16	Q21	D1	0.0392	12	151	-
17	Q27	D1	0.0479	9	154	33
18	Q20	D4	0.0496	17	146	-

Qi = Survey Question
Di = Demographic Question

For comparison 8 between Q13 and D11, the relationship between income and Question 13 was difficult to determine by simply examining the frequency table. It appeared that most respondents disagreed with Question 13 and believed that they were in some amount of danger from the effects of poor IAQ.

For comparison 9 between Q17 and D10, it was clear that people who took medications for respiratory illness were less likely to be willing to pay for IAQ treatment for their homes. This may be due to income-related issues that many people face when taking potentially expensive medications.

For comparison 10 between Q18 and D10, the relationship between those respondents taking respiratory medications and their feelings regarding Question 18 were difficult to determine from the frequency table. It appeared that the majority of respondents on medication agreed that most people are not aware of IAQ problems in their homes.

For comparison 11 between Q28 and D1, women believe that cigarette smoke contributes more to poor IAQ than men.

For comparison 12 between Q21 and D10, respondents who are not taking respiratory medications have learned more about IAQ issues from family, friends, and coworkers.

For comparison 13 between Q2 and Q10, while many respondents believe that the risks associated with poor IAQ are clear to them, many also disagree or are neutral in believing that information regarding IAQ is effectively communicated to the public by environmental professionals.

For comparison 14 between Q30 and D3, while many respondents agree that candles contribute to poor IAQ at least a little bit, many more high school and college graduates seem to be more concerned with candles that those respondents who attended graduate school.

For comparison 15 between Q17 and D1, more women are willing-to-pay for inexpensive IAQ treatment than men. The male responses for this question predominantly fall in the "neutral" category.

For comparison 16 between Q21 and D1, more women have learned about IAQ issues from coworkers, family, and friends than men.

For comparison 17 between Q27 and D1, men are less concerned with inadequate ventilation as a contributor to poor IAQ than women.

For comparison 18 between Q20 and D4, it seems as though the responses for non-Caucasians are evenly distributed for this question, however a larger number of Caucasians seem to have learned more about IAQ from periodicals.

To conclude this section, a summary of the key findings is offered. It appears from the Chi-square results that women tend to be more concerned about the possible sources of indoor air pollution than men. Women also seem more willing-to-pay for treatment in the event that an indoor air problem is found in their home. On the other hand, men responded more confidently to questions that tried to assess their knowledge of particular indoor hazards. The men's answers agreed well with expert opinion on the harmfulness of radon, as documented in Section 1.2.1.3, and this may mean that the men in the survey population were generally more knowledgeable on this IAQ topic than the women respondents.

It is difficult to make any inferences regarding possible differences in knowledge or perceptions between races since the majority of the respondents were Caucasian. However, it seems as though Caucasians might be slightly more informed than non-Caucasians, as reported by the Chi-square results. The results also indicated that Caucasians are more likely to learn from reading periodicals than non-Caucasians.

One might hypothesize that the amounts respondents are willing-to-pay would increase with increasing household income. However, despite the variances in household income among the respondents, the majority seemed to be willing-to-pay about $30 per month for effective IAQ treatment.

Along the lines of education, the respondents reporting having completed lower levels of education seem to be more concerned with the topic of IAQ than those receiving higher education. Additionally, those respondents reporting higher annual incomes seem to be less aware of the IAQ priority risks established by experts. The three highest priority risks identified by experts include inadequate ventilation, cigarette smoke, and mold (EPA, 1991).

It was hypothesized that if respondents believed that the risks associated with poor IAQ were unclear to them, they would also disagree that information regarding IAQ is effectively communicated to the public by environmental professionals. The results from the Chi-square analysis contradict this hypothesis and show that while many respondents believe that indoor air risks can be more effectively communicated, they also tend to believe that the risks associated with poor IAQ are already clear to them. However, the respondents who provided responses indicating that risks were unclear to them were more likely to disagree that information regarding IAQ is effectively communicated to the public by environmental professionals.

3.2.5 Correlation Coefficient Results

Microsoft Excel was utilized to compute correlation coefficients on the results of each pair of survey questions. Utilizing Equation 4 in Section 2.2.5.3, a critical correlation, r, value was determined to be 0.13 for $v = 161$ and $\alpha = 0.05$. Generally speaking, a correlation coefficient of 0.13 or -0.13 indicates an extremely weak relationship between questions. However, when the coefficients were computed for the survey results, the majority of the coefficients were identified to be less than 0.25 or greater than -0.25, leaving a small number of coefficients that displayed even a weak relationship. Therefore, the values of 0.25 and -0.25 were chosen as the bounds for determining significant question pairs in an effort to examine additional relationships that might not have been present in the Chi-square analysis.

These correlation coefficients may indicate the tendency for respondents to answer one question based on their response for another question. The matrix of correlation coefficients calculated by Excel is located in Appendix E. The following general inferences can be made by examining the correlation coefficients. Approximately 95% of the correlation coefficients were less than 0.25 or greater than -0.25, indicating very low correlations. Significant correlation coefficients were thus assumed to be those coefficients greater than 0.25 or less than -0.25 and are noted in parentheses next to the inference statement to which they refer. The majority of the correlation coefficients obtained from this analysis ranged from 0.25 to 0.40, indicating weak correlations.

Those respondents familiar with how radon can enter a residence tend to be aware of the risks of radon (.87), believe risks are effectively communicated to the public by environmental professionals (0.31), have learned about IAQ from periodicals (0.37), and are younger in age (-0.32).

Those respondents believing that air cleaners and filters can keep them safe from poor IAQ also tend to think that air cleaning systems using ozone can protect them (0.53) and that they are, or have, someone in their household who smokes (-0.27).

Those respondents believing that mold growth in one's home can be harmful to health also tend to agree that IAQ will be a concern for future generations (0.52), and that they have learned about IAQ from both periodicals and family and friends (0.33, 0.29).

Those respondents who would buy an air cleaner if it was guaranteed to protect them are also willing to pay for inexpensive treatment in their homes (0.49) and are willing to pay for more expensive treatment options as well (0.38).

Respondents who own their homes tend to make higher incomes (-0.43).

Younger respondents tend to have more people living in their households (-0.38).

Respondents who think IAQ is an important concern in their homes also tend to agree that the risks associated with poor IAQ are clear (0.36), that they are aware of the risks of radon (0.26), that IAQ will be a concern for future generations (0.33), and they have learned about IAQ from family, friends, and co-workers (0.30). There is also a weak correlation showing that respondents who think that IAQ is an important concern believe they might be in danger from the effects of poor IAQ (-0.27).

Those respondents agreeing that the risks associated with poor IAQ are clear to them also tend to agree that poor IAQ is more harmful to children and the elderly (0.32), that poor IAQ can be fatal (0.26), that they are familiar with and aware of radon risks (0.33, 0.39), that IAQ will be a concern for future generations (0.31), that the risks associated with poor IAQ are effectively communicated to the public by environmental professionals (0.38), that air cleaners using ozone can keep them safe (0.34), and that showers can be a cause of poor IAQ (0.25).

Those respondents agreeing that poor IAQ can be fatal also tend to agree that mold can be harmful to one's health (0.33).

Those respondents agreeing that poor IAQ is more harmful to children and the elderly also tend to believe that air pollutant concentrations are often higher indoors than outdoors (0.29)

Those respondents agreeing that air pollutant concentrations are often higher indoors tend to believe that air fresheners can contribute to poor IAQ (0.30).

Those respondents aware of the risks of radon tend to believe that IAQ risks are effectively communicated by environmental professionals (0.35), would take measures to eliminate an IAQ problem in their home (0.27), have learned about IAQ from periodicals (0.34), believe candles contribute to poor IAQ (0.25), and are younger in age (-0.29).

Those respondents who believe that risks are effectively communicated to the public by environmental professionals also seem to think that air cleaners and filters can keep them safe (0.31), that air cleaners using ozone can keep them safe (0.31), have learned about IAQ from TV (0.26), have lower overall education (0.25), and have lower incomes (0.26).

Those respondents believing they are in no danger from poor IAQ also tend to agree that adverse health effects are unavoidable (0.30), have learned about IAQ from TV (0.29), and do not believe that cooking contributes to IAQ (-0.25).

Those respondents who would eliminate a problem if it were found in their house also tend to think that they would purchase an air cleaner if it were guaranteed to protect them regardless of cost (0.26) and that air fresheners contribute to poor IAQ (0.27).

Those respondents willing to pay for inexpensive IAQ treatment tend to believe that most people are not aware of IAQ problems in their homes (0.27). They also tend to believe that air fresheners and cosmetics contribute to poor IAQ (0.28, 0.31).

Those respondents who have learned about IAQ from friends and family tend to believe that cosmetics and cleaning solvents contribute to poor IAQ (0.28, 0.25).

Those respondents that believe that cigarette smoke contributes to poor IAQ also believe that mold (0.69), candles (0.33), fireplaces (0.36), cosmetics (0.26), and cleaning products (0.30) contribute.

Those respondents that believe that inadequate ventilation contributes to poor IAQ also believe that smoking (0.56), mold (0.43), candles (0.30), fireplaces (0.40), air fresheners (0.26), and cleaning products (0.27) contribute.

Those respondents believing that candles contribute to poor IAQ also believe that fireplaces (0.54), air fresheners (0.43), and cosmetics (0.39) contribute.

Those respondents believing that air fresheners contribute to poor IAQ also believe that cosmetics (0.53), cleaning products (0.38), and showers (0.31) contribute. They are willing to pay more for pollution reduction (-0.25) and more of these respondents are female than male (-0.28).

Those respondents believing that cosmetics contribute to poor IAQ also believe that cleaning products (0.44) and showers (0.39) contribute.

Those respondents believing that fireplaces contribute to poor IAQ also believe that air fresheners (0.40) contribute.

Those respondents believing that cooking contributes to poor IAQ also believe that washing machines contribute (0.28), as well as cosmetics (0.36).

Those respondents believing that washing machines contribute to poor IAQ also believe that vacuuming (0.31), air fresheners (0.28), cosmetics (0.26), cleaning products (0.28), and showers (0.25) contribute.

Those respondents believing that vacuuming contributes to poor IAQ also believe that inadequate ventilation (0.33), fireplaces (0.26), cleaning products (0.32), and showers (0.29) do too.

Those respondents believing that mold contributes to poor IAQ also believe that fireplaces (0.27) and cleaning products (0.32) contribute.

Those people willing to pay less money for pollution reduction tend to have lower household incomes (0.29).

Those respondents receiving less education reported lower household incomes (0.27).

The findings for this section agree well with the major findings from the Chi-square analysis except for one finding which is described and explained in Section 3.2.6. Respondents agreed that many of the items in survey questions Q24 through Q35 contribute to poor IAQ. If a respondent agreed that one of these items contributed, they were more likely to agree that other items from this group of questions contributed to poor IAQ.

The results from this section show that a general concern for the risks associated with poor IAQ is shared by the majority of the survey respondents. This supports the motivating hypothesis that respondents would likely shown concern for IAQ risks. Many respondents agree that the risks associated with poor IAQ are clear to them, that they would be willing-to-pay to rid their homes of poor IAQ problems, and that they believe that indoor air cleaners can protect them from poor IAQ.

3.2.6 Comparison of Chi-square and Correlation Coefficient Results

There was only one instance of contradiction between the Chi-square and correlation coefficient results. This instance occurred between survey questions Q2 and Q10. For the Chi-square analysis, while many respondents believe that the risks associated with poor IAQ are clear to them, many also disagree that information regarding IAQ is effectively communicated to the public by environmental professionals. For the correlation coefficient analysis, those respondents agreeing that the risks associated with poor IAQ are clear to them also tended to agree that IAQ information is effectively communicated by environmental professionals (0.38). This contradiction may be due to the way that these two analyses are used to interpret the data. For example, the Chi-Square analysis pools all of the data into bins in the frequency table prior to calculating the Chi-square statistic. The correlation coefficients are calculated by keeping each specific pair of respondent answers together during the calculation. Additionally, the scale for the Chi-square analysis was condensed into three major categories for SAS computation (to minimize measurement error), while the original five-category scale was utilized for the correlation coefficients. Thus, the correlation coefficient analysis might have identified a trend in the data that was unclear in the Chi-square analysis. The Chi-square analysis for this question pair had a frequency missing of 33%, indicating that the true results may or may not be completely indicative of the data. These are all possible reasons for the contradictions between data analyses.

3.2.7 Sub-group A – Non-Smoking Caucasian Homeowners

While completing the survey results analysis to this point, it became clear that a distinct sub-group of survey respondents existed. This group is referred to as "sub-group A" from this point forward. Sub-group A is made up of 104 of the 163 total respondents, or 64%, and all share three demographic characteristics in common. Sub-group A consists of Caucasian respondents who do not smoke or have any smokers in their residence. Also, these respondents own and live in a home, as opposed to an apartment, condo, trailer, or townhouse. This occurrence could possibly be attributed to self-selection by survey respondents. It was impossible to determine all of the demographics of the survey sample prior to survey distribution. The only known demographic was each respondent's gender. However, the original gender estimate could be inaccurate as it is possible that a respondent could have given the survey to another member of the household to complete.

3.2.7.1 Sub-group A demographic results

Table 3-10 illustrates the demographic results that were computed for Sub-group A. As compared to the overall survey demographics, Sub-group A displays a number of differences. For example, Sub-group A has a higher percentage of males (46%) and slightly lower percentage of females (54%) than the overall survey results. The average age of the respondents of Sub-group A is 51 while the average age of the overall survey respondents is 49. Sub-group A appears to have received higher levels of education than the overall survey population, with 25% attending graduate school. As for household income, it seems as though Sub-group A displays higher household incomes than the overall survey population, with higher percentages of respondents reporting over $50,000 annual household income. Finally, Sub-group A has a similar percentage of respondents reporting the use of respiratory medications in their households.

3.2.7.2 Sub-group A general inferences

The results of the general descriptive statistical analysis are illustrated in Table 3-11, 3-12, and 3-13. A table that includes the full confidence intervals for this data is located in Appendix D.

When compared to the overall survey results, a few distinct differences are easily noticeable. First, the mean age for sub-group A is 51, which is two years older than the overall mean age of 49. By simply comparing the question means between the overall survey results and the sub-group A results reported in Tables 3-9 and 3-10, a trend emerges showing that the sub-group A means are generally higher than the overall means for many of the survey questions. This means that while respondents generally agreed with a survey question, the sub-group's responses tended to be more neutral as compared to the overall response results.

The sub-group A means for Questions 11 through 14 are considerably higher than the overall means. Sub-group A is slightly less likely (34% vs. 55%) to believe that air cleaners, including those that use ozone, can protect them from poor IAQ. Sub-group A tended to believe more strongly that adverse health effects can be avoided (79% vs. 67%).

Table 3-10. Sub-group A – Demographic Results.

		Total Number of Survey Respondents	Total Percentage (%) of Survey Respondents
Gender	Male	48	46
	Female	56	54
Average Age	Total	51	-
	Male	56	-
	Female	46	-
Education	High School	23	22
	College	55	53
	Graduate School	26	25
Race/Ethnicity	Caucasian	104	100
	African American	0	0
	Hispanic	0	0
	Asian	0	0
	Other	0	0
Own vs. Rent	Own	104	100
	Rent	0	0
Headcount	Average	2.73 persons	-
Household income	$20,000 or less	5	6
	$20,001 to $50,000	13	14
	$50,001 to $100,000	49	54
	$100,001 or more	23	26
Type of Home	House	104	100
	Apartment	0	0
	Townhouse	0	0
	Condo	0	0
	Other	0	0
Smoke Cigarettes	Yes	0	0
	No	104	100
Respiratory Medications	Yes	61	59
	No	43	41

Sub-group A also seemed to believe slightly less than the overall survey population that washing machines, air fresheners, cosmetics, and showers contribute to poor IAQ.

A comparison of the modes between the overall survey population and sub-group A does not yield many significant differences. Only for Question 10 does sub-group A display a mode that is noticeably different than the overall survey population. For this question, the sub-group A mode is 2 while the overall mode is 4. More respondents in sub-group A (46% vs. 27%) are in agreement with Question 10, which states that the risks associated with poor IAQ are effectively communicated to the public by environmental professionals.

Table 3-11. Sub-group A Means and 95% Confidence Intervals (C.I.)

Question	Total Mean	Total C.I.
1	1.45	0.14
2	1.97	0.20
3	1.51	0.15
4	1.78	0.17
5	1.74	0.18
6	2.14	0.23
7	2.18	0.24
8	1.23	0.09
9	1.34	0.11
10	3.44	0.23
11	2.55	0.18
12	2.93	0.19
13	4.05	0.22
14	3.64	0.23
15	1.28	0.09
16	2.15	0.18
17	1.66	0.17
18	1.69	0.16
19	1.53	0.10
20	1.26	0.08
21	1.43	0.10
22	1.74	0.08
23	-	-
24	2.30	0.13
25	2.92	0.15
26	1.96	0.17
27	1.29	0.11
28	1.21	0.14
29	1.08	0.05
30	2.20	0.14
31	1.79	0.12
32	2.23	0.17
33	2.52	0.16
34	1.57	0.13
35	2.65	0.17
37	3.02	0.15
D1	1.54	0.10
D2	50.69	2.87
D3	2.03	0.13
D4	1.00	0.00
D5	1.00	0.00
D6	1.00	0.00
D7	2.74	0.22
D9	1.00	0.00
D11	3.00	0.15

Table 3-12. Sub-group A Modes

Question	Total Mode
1	1
2	2
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	2
11	2
12	3
13	5
14	4
15	1
16	2
17	1
18	1
19	2
20	1
21	1
22	2
23	-
24	2
25	3
26	2
27	1
28	1
29	1
30	2
31	2
32	2
33	2
34	1
35	2
37	3
D1	2
D2	44
D3	2
D4	1
D5	1
D6	1
D7	2
D9	1
D11	3

Table 3-13. Sub-group A Medians

Question	Total Median
1	1
2	2
3	1
4	2
5	2
6	2
7	2
8	1
9	1
10	3
11	2
12	3
13	4
14	4
15	1
16	2
17	1
18	2
19	2
20	1
21	1
22	2
23	-
24	2
25	3
26	2
27	1
28	1
29	1
30	2
31	2
32	2
33	2
34	1
35	3
37	3
D1	2
D2	50
D3	2
D4	1
D5	1
D6	1
D7	2
D9	1
D11	3

3.2.7.3 Sub-group A correlation coefficients

Correlation coefficients were computed for Sub-group A. An explanation of the bounds for the correlation coefficients is located in Section 3.2.5. These correlation coefficients may indicate the tendency for respondents to answer one question based on their response for another question. The matrix of correlation coefficients calculated by Excel is located in Appendix E. The following general inferences can be made by examining the correlation coefficients. Correlation coefficients assumed to be high are noted in parentheses next to the inference statement to which they refer.

There was a very strong correlation between respondents who believed that they were familiar with how radon can enter a home and respondents who reported that they were aware of the risks of radon (0.90). There was also a relatively strong correlation showing that respondents who believed that air fresheners contribute to poor IAQ also consider cosmetics to contribute (0.62). Along the same lines, those respondents who believed that inadequate ventilation contributes to poor IAQ also tended to believe that cigarette smoke contributes (0.53). Additionally, those respondents feeling that candles contribute to poor IAQ also seemed to feel that fireplaces contribute (0.50).

Respondents who would purchase an air cleaner, regardless of cost, based on the idea that it would protect them are also willing to pay for inexpensive IAQ treatment options (0.50). Those respondents who tend to believe that air cleaners could keep them safe also felt that air cleaners using ozone could offer protection (0.52). Respondents believing that mold growth in a home can be harmful to one's health also seem to believe that IAQ will be a concern for future generations (0.50).

There were a number of pairs of items from Questions 24 through 35 that had moderate correlations associated with them. These include the following: inadequate ventilation and mold (0.42); cigarette smoke and mold (0.45); cigarette smoke and candles (0.41); candles and cosmetics (0.41); cosmetics and household cleaners (0.43); and cosmetics and showers (0.42).

Another mid-strength correlation exists in that those respondents making higher income seem more willing-to-pay higher amounts to protect their homes from poor IAQ (0.46). Those respondents reporting that IAQ risks are clear to them also reported to be aware of the risks that radon poses (0.448). Finally, those respondents believing that poor IAQ is more harmful to children and the elderly also agree the indoor pollutant concentrations are often higher than outdoor pollutant concentrations (0.40).

A large number of weaker correlation coefficients exist for this data set and are too numerous to receive mention here. These coefficients can be viewed in Appendix E.

3.2.8 Sub-group B – The Others

Sub-group B contains those respondents not included in sub-group A. These respondents are of varied races, own and rent different types of residences, and are made up of both smokers and non-smokers. Sub-group B consists of 59 respondents, or 36% of the total survey response. While the size of sub-group B is a little small for making confident inferences from the data, it is still worthwhile to note the similarities and differences that sub-group B shares with sub-group A and the overall survey results.

3.2.8.1 Sub-group B demographic results

Table 3-14 illustrates the demographic results that were computed for Sub-group B. A table that includes the full confidence intervals for this data is located in Appendix D.

As compared to the overall and Sub-group A survey demographics, Sub-group B displays a number of differences. For example, Sub-group B has a much higher percentage of females (69%) and lower percentage of males (39%) than both the overall and Sub-group A survey results. The average age of the respondents of Sub-group B is 45, which is lower than the averages for the overall (49) and Sub-group A (51) populations. Sub-group B appears to have the highest percentage of respondents reporting to have only received a high school education (48%), as compared to the overall (28%) and Sub-group A (22%) populations. Sub-group B displays lower household incomes than the both the overall and Sub-group A survey populations, with higher percentages of respondents reporting under $50,000 annual household income. Sub-group A has a similar percentage of respondents reporting the use of the respiratory medications in their households. Almost 70% of Sub-group B reported to own their homes.

When looking at the Race/Ethnicity percentages for Sub-group B, almost 50% are Caucasian, 34% are African American, and about 15% reported Hispanic or Other.

Table 3-14. Sub-group B – Demographic Results.

		Total Number of Survey Respondents	Total Percentage (%) of Survey Respondents
Gender	Male	18	31
	Female	40	69
Average Age	Total	45	-
	Male	40	-
	Female	48	-
Education	High School	28	48
	College	20	34
	Graduate School	10	17
Race/Ethnicity	Caucasian	28	48
	African American	20	34
	Hispanic	2	3
	Asian	0	0
	Other	7	12
Own vs. Rent	Own	39	67
	Rent	19	33
Headcount	Average	2.5 persons	-
Household income	$20,000 or less	10	18
	$20,001 to $50,000	23	41
	$50,001 to $100,000	15	27
	$100,001 or more	8	14
Type of Home	House	33	57
	Apartment	8	14
	Townhouse	5	9
	Condo	0	0
	Other	11	19
Smoke Cigarettes	Yes	19	33
	No	39	67
Respiratory Medications	Yes	36	62
	No	22	38

3.2.8.2 Sub-group B general inferences

The results of the general descriptive statistical analysis of sub-group B are illustrated in Tables 3-15, 3-16, and 3-17.

As with sub-group A, sub-group B displays a few differences when compared to the results from sub-group A and the overall results. The mean age of the respondents in sub-group B is 45, which is less than the mean age for the overall survey population (49) and sub-group A (51). While the means of sub-group A were generally larger than those of the overall population, the means of sub-group B cannot be classified this way as they are more varied.

Slightly higher and slightly lower means are apparent between sub-group B and the other data. For Question 5, sub-group B is slightly more neutral in its responses, indicating that sub-group B believes less strongly that indoor air pollutant concentrations are often higher than outdoor concentrations. For Question 6 and Question 7, sub-group B seems to be more neutral about being familiar and aware of radon and its associated risks in the indoor environment. For Question 11, sub-group B seems to have more faith than respondents in sub-group A in the effectiveness of air cleaners for protection from poor IAQ. For Question 32, Question 33, and Question 35, sub-group B appears to be even slightly more neutral in its responses than sub-group A when asked whether air fresheners, cosmetics, and showers contribute to poor IAQ, respectively.

When analyzing the modes calculated for sub-group B, there seemed to be two questions in which sub-group B differed from sub-group A. In Question 6, sub-group B's mode of 3 was higher than sub-group A's mode of 1. It can be inferred from this difference that sub-group B is more neutral and less familiar with how radon can enter a home. Also, for Question 10, sub-group B's mode of 4 was higher than sub-group A's mode of 2. Sub-group B is less satisfied with the communication of IAQ risks by environmental professionals than those respondents in sub-group A.

3.2.8.3 Sub-group B correlation coefficients

Correlation coefficients were computed for Sub-group B. An explanation of the bounds for the correlation coefficients is located in Section 3.2.5. These correlation coefficients may indicate the tendency for respondents to answer one question based on their response for another question. The matrix of correlation coefficients calculated by Excel is located in Appendix E. The following general inferences can be made by examining the correlation coefficients. Correlation coefficients assumed to be high are noted in parentheses next to the inference statement to which they refer.

For sub-group B, quite a few strong to mid-strength correlation coefficients were calculated from the data. Just as with sub-group A, there was a strong correlation between Question 6 and Question 7 indicating that those respondents familiar with how radon can enter a home also believed as though they were aware of the risks of radon (0.81).

Table 3-15. Sub-group B Means and 95% Confidence Intervals (C.I.)

Question	Total Mean	Total C.I.
1	1.51	0.22
2	2.13	0.31
3	1.72	0.29
4	1.63	0.21
5	1.98	0.23
6	2.59	0.31
7	2.39	0.32
8	1.16	0.10
9	1.34	0.19
10	3.29	0.34
11	2.06	0.23
12	3.00	0.29
13	4.06	0.24
14	3.46	0.34
15	1.21	0.10
16	2.33	0.30
17	1.85	0.26
18	1.78	0.26
19	1.54	0.13
20	1.38	0.13
21	1.62	0.13
22	1.84	0.09
23	-	-
24	2.25	0.19
25	2.76	0.23
26	1.83	0.23
27	1.35	0.17
28	1.33	0.21
29	1.25	0.18
30	2.23	0.20
31	1.74	0.20
32	2.34	0.18
33	2.61	0.18
34	1.52	0.16
35	2.73	0.23
37	2.75	0.24
D1	1.69	0.12
D2	45.41	4.39
D3	1.69	0.19
D4	1.91	0.33
D5	2.09	0.40
D6	1.33	0.12
D7	2.50	0.29
D9	1.32	0.12
D11	2.38	0.24

Table 3-16. Sub-group B Modes

Question	Total Mode
1	1
2	1
3	1
4	1
5	2
6	3
7	2
8	1
9	1
10	4
11	2
12	3
13	5
14	4
15	1
16	2
17	1
18	1
19	2
20	1
21	2
22	2
23	-
24	2
25	2
26	1
27	1
28	1
29	1
30	2
31	2
32	2
33	2
34	1
35	2
37	3
D1	2
D2	52
D3	1
D4	1
D5	1
D6	1
D7	2
D9	1
D11	2

Table 3-17. Sub-group B Medians

Question	Total Median
1	1
2	2
3	1
4	1
5	2
6	3
7	2
8	1
9	1
10	4
11	2
12	3
13	4
14	4
15	1
16	2
17	2
18	2
19	2
20	1
21	2
22	2
23	-
24	2
25	3
26	2
27	1
28	1
29	1
30	2
31	2
32	2
33	2
34	1
35	3
37	3
D1	2
D2	42.5
D3	2
D4	2
D5	1
D6	1
D7	2
D9	1
D11	2

Those respondents who believed that mold growth in a home can be harmful to one's health also believed that IAQ will be a concern for future generations (0.61). Also similar to sub-group A, those respondents believing that air cleaners could keep them safe believed that air cleaning utilizing ozone could offer some protection (0.63).

A relatively strong negative correlation existed between Question 16 and Question 37. Thus, those respondents who would be willing to purchase and air cleaner regardless of cost were willing to pay more to reduce a hypothetical IAQ problem in their home (-0.61). Two other mid-strength negative coefficients were calculated for this data. From the first, it can be inferred that respondents who own their homes have higher household incomes (-0.41). From the second, respondents who are older in age have less people currently living in their household than younger respondents (-0.45).

As with sub-group A, there were a number of items from the sub-group B data from Questions 24 through 35 that had mid-strength correlations associated with them. These include the following: vacuuming and inadequate ventilation (0.41); inadequate ventilation and cigarette smoke (0.61); inadequate ventilation and mold (0.46); inadequate ventilation and fireplaces (0.62); cigarette smoke and mold (0.80); cigarette smoke and fireplaces (0.544); mold and cosmetics (0.41); mold and household cleaners (0.49); candles and fireplaces (0.60); candles and air fresheners (0.54); fireplaces and air fresheners (0.49); air fresheners and showers (0.47); and cosmetics and household cleaners (0.46).

A few other correlation coefficients for sub-group B seemed relatively moderate to strong in strength. For example, those respondents who were tentative to believe that the risks associated with poor IAQ are effectively communicated by environmental professionals also seemed more tentative that air cleaners could keep them safe from poor IAQ (0.55). Those respondents believing that the adverse effects from poor IAQ can be avoided tended to have received higher levels of education (0.48). Finally, those respondents who would be willing to purchase an air cleaning system if it were guaranteed to protect them also seem willing to pay for inexpensive IAQ treatment for their homes (0.45).

3.2.9 Write-in Question Results

Question 23, Question 38, and Question 40 were questions in which the respondent had a chance to provide additional information outside of the categorical scale presented for previous survey questions. Question 38 was not a completely open-ended question, however, the final answer choice on the survey was treated as one and is described in this section. Not all respondents elected to provide the information for these write-in questions; however the responses that were obtained were recorded and are summarized below.

Question 23 asked the respondents to list any home air cleaning devices that they use in their residences. Thirty-three survey respondents answered Question 23. Twenty-one respondents listed the use of specialized air filters on the respondents' furnaces and air conditioning units. A few respondents listed the use of a humidifier in this section as well. The remaining responses listed air cleaning devices such as the Ionic Breeze, Oreck Healthmate, EcoQuest, Living Air Classic, and Rainbow Vacuum. Finally, three respondents simply stated that they open the windows of their residence to provide home air cleaning.

Question 38 asked the respondents to choose the worst threat to IAQ in their current residence from a list of five possible threats. A sixth answer choice, in the form of a write-in space, indicating "other…Please list" was also provided. Many respondents incorrectly followed the directions for this question and selected more than one threat from the list. Therefore, the totals for each response category are inaccurate; however they still provide an idea of the respondent's feelings regarding IAQ threats in their current residences. For Question 38, 65 respondents cited mold, 37 cited inadequate ventilation, 20 cited carbon monoxide, 13 cited radon, 12 cited cigarette smoke, 3 cited fumes from outdoors, 3 cited pet related issues, 2 cited cleaning products, 2 cited dust, and 1 cited cooking fumes as the worst threats to IAQ in their residences.

Question 40 asked the respondents if they have taken any steps to improve the IAQ in their homes and how much they estimate that they have spent on these improvements. A total of seventy respondents answered Question 40 but most were reluctant to spend the time to fully answer the question. Therefore, many responses consisted of one-word answers such as "yes" or "none". Eighteen responses for Question 40 cited the use of portable air cleaners, dusting their house, and having their carpets cleaned regularly. Other respondents noted using carbon monoxide detectors and radon test kits to assess the levels of carbon monoxide and radon in their homes, respectively. Another response cited the use of filters in conjunction with an ultraviolet (UV) light system on their air conditioning unit to improve IAQ. Three respondents reported that they have purchased whole-house air cleaning systems that retail for $500-$600, but failed to report the name of the systems. One respondent wrote that he pays almost $200 annually to have his chimney cleaned. Finally, one respondent claimed to have spent nearly $1200 to have a mold problem fixed in their residence.

While the majority of survey respondents (77%) acknowledged that they do not currently own an indoor air cleaner, most also said that they would be willing to purchase inexpensive indoor air quality treatment if it was effective in protecting their households from poor IAQ. The responses gathered from the write-in questions that pertained to the type of indoor air cleaner a respondent uses and whether they have taken any additional steps to improve IAQ showed that there is some consumer uncertainty regarding indoor air cleaners. Out of the 76 respondents that responded to Question 40, 16 respondents showed much interest in air cleaner technology but were unsure how to select and utilize the technology. For Question 40, one respondent wrote, "I do not currently own an air cleaner. However, I feel that my home needs one but I don't know what to look for when purchasing one. Can you give me some more information?" Other respondents wrote similar notes in the answer space for Question 40, stating that they do not currently use anything to improve IAQ in their residences and inquiring whether or not they should be.

This response and others showed that interest in indoor air cleaning technology exists among survey respondents. However, the low percentage of respondents admitting to owning an air cleaner implies that insufficient information relating to the effectiveness and types of available air cleaners is made publicly available or easily accessible to consumers. Therefore, an analysis of the factors surrounding current air cleaning technology was completed to provide consumers with a basis for selecting the ideal air cleaner for their household. The input assumptions and results of the modeling analysis are located in Chapter 4.

3.3 Survey Conclusions

A number of trends among the survey respondents were made clear through the survey analysis. The general consensus among respondents was that IAQ risks are a real issue and will continue to be into the future. The respondents acknowledged IAQ related risks, displayed their willingness to take action in the event of an IAQ threat in their residences, and agreed that better communication of IAQ needs to be implemented. These findings support the motivating hypothesis that respondents would be generally aware of

IAQ risks and willing to take action to protect their homes and families. Respondent's survey answers showed that current risk perceptions of IAQ risks are not typically high. When compared with expert opinion on the severity of IAQ risks, respondent's views fell short, indicating the need for increased risk communication on the topic.

Most respondents correctly identified some of the priority IAQ risks (inadequate ventilation, environmental tobacco smoke, and mold) that experts also identify, as documented in Section 3.2.4, showing that the respondents are somewhat accurately informed. This tends to falsify the hypothesis that respondents would not have sufficient knowledge to be able to correctly identify priority IAQ risks. However, some respondents failed to recognize the lesser known potential IAQ risks, again indicating the need for increased communication of specific topics among the public.

Finally, some uncertainty regarding the use of household air cleaners was identified among the survey respondents, especially concerning air cleaners that use or produce ozone while cleaning. This tends to falsify the motivating hypothesis that respondents would be familiar with air cleaners available to consumers. Results from write-in questions identified some respondents seeking additional information on the characteristics that should be used to select an indoor air cleaner. Better communication of the characteristics and potential benefits of indoor air cleaners would aid in eliminating respondent uncertainty on the topic.

4.0 INDOOR AIR QUALITY MODELING AND ANALYSIS

This chapter contains the case studies, model input assumptions, and results of the indoor air cleaner modeling application. The effect of various generic factors that characterize room air cleaners was evaluated by using the indoor air quality (IAQ) modeling software, RISK. The objectives of this analysis were to determine the effects that particle removal efficiency, air cleaner ACH, and building characteristics have on the PM_{10} exposure reductions of building occupants. Another objective was to conduct a sensitivity analysis to evaluate the importance of the occupant cycle. The impact of generic factors for air cleaners was assessed by inputting the parameters of the EPA research house into RISK, along with indoor and outdoor particulate matter concentrations, and noticing the effects that they had on the simulated indoor concentrations and occupant exposure levels.

4.1 Case Study and Model Input Assumptions

Several case studies were designed to determine the baseline PM_{10} exposures attributable to the infiltration of outdoor air in a simulated house. Indoor sources of PM_{10} were not included due to the inability to locate peer-reviewed emissions values, constants, and mass flows for input into the model. Indoor sinks for PM_{10}, however, were included in this analysis. The major scenarios considered for the case studies included varying occupant's activity cycles and the placement of a generic air cleaner inside the simulated house to determine their effects on occupant PM_{10} exposures. Along with varying occupancy cycles, the characteristics of the generic air cleaner were varied to conduct a sensitivity analysis on these inputs.

A total of five scenarios were evaluated using RISK. Table 4-1 presents a summary of the scenarios. The Base Scenario consisted of no occupants or air cleaners present in the research house for the duration of the simulation. The Base Scenario was executed to determine background PM_{10} concentrations for the research house. Scenario A consisted of the occupants spending the entire duration of the simulation in one room of the research house while no air cleaner was present. Scenario B consisted of the occupants spending the entire duration of the simulation in one room of the research house while an air cleaner was present and assumed to run continuously in the same room. Scenario C consisted of the occupants cycling through daily activities while no air cleaner was present in the research house. Finally, Scenario D consisted of the occupants cycling through daily activities while an air cleaner was present and assumed to run in a specified room of the research house.

Table 4-1. Scenarios Modeled in RISK.

Scenario Name	Occupants Remaining in Same Room for 120 Hours	Occupants Cycling Through Daily Activities	Air Cleaner Used?
Base Scenario			
Scenario A	X		
Scenario B	X		X
Scenario C		X	
Scenario D		X	X

RISK was configured to imitate the IAQ research house that resides on the EPA campus in Research Triangle Park, NC. Figure 4-1 displays a schematic of the research house. The research house is a one-story building that contains nine rooms. Research by EPA has shown that RISK can accurately model and predict indoor particle and volatile organic compound (VOC) concentrations within the research house (Sparks, 2005). Table 4-2 displays the general dimensions of the rooms in the research house. The nine rooms included in this case study are those shown in the figure, with the exceptions being “monitoring room” and “garage”. Additionally, spaces marked “closet” in the figure are assumed to be closed off with no airflow.

Table 4-3 displays a few of the general inputs common to each of the modeling simulations. The average air exchange rate (ACH) was 0.4 air changes/hour, though this was not a constant ACH, as ACH varied at different times of the simulated day. The HVAC system was assumed to run constantly. One size range of particulate matter, PM_{10}, was assumed as the IAQ pollutant over a 120-hour modeling period. Also, a total of three occupants and their daily cycles were simulated.

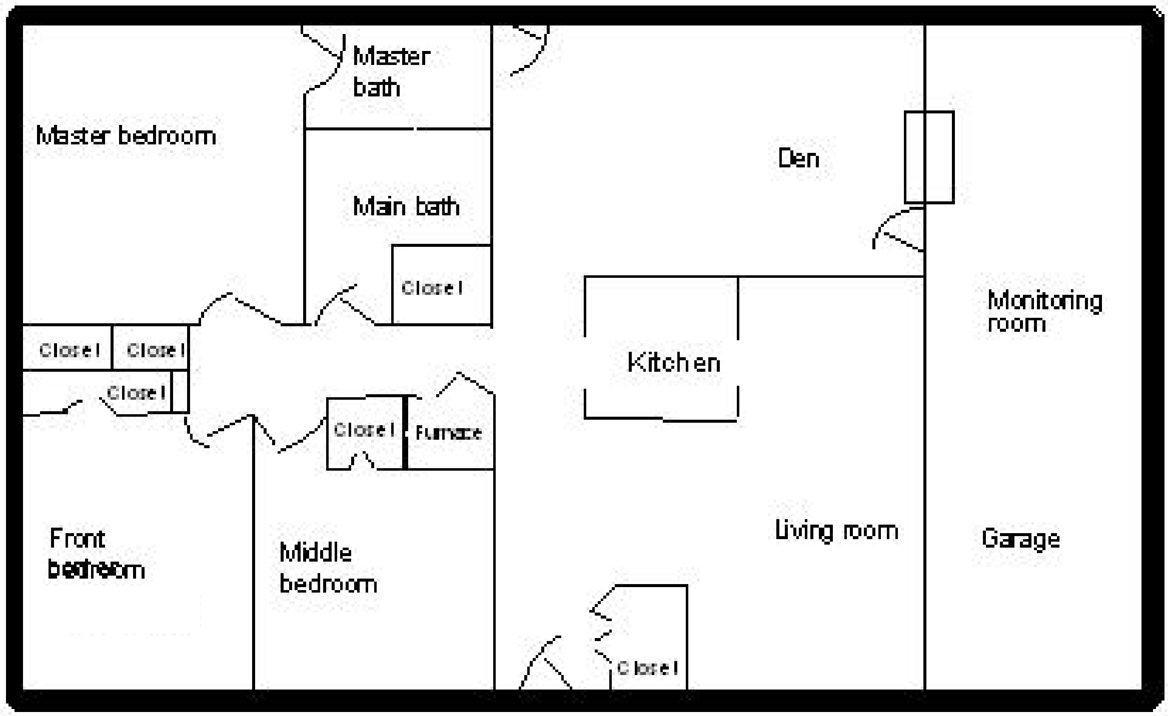

Figure 4-1. Diagram of EPA Research House (Sparks, 2005).

Table 4-2. Research House Dimensions (Sparks, 2005).

Room #	Room Name	Volume (m^3)	Height (m)
1	Den	67	2.44
2	Kitchen	20	2.44
3	Living room	78	2.44
4	Hall	12	2.44
5	Middle bedroom	32	2.44
6	Front bedroom	34	2.44
7	Master bedroom	42	2.44
8	Main bath	12	2.44
9	Master bath	10	2.44

Table 4-3. Research House Inputs.

Overall ACH	0.4
Constant ACH	No
Constant HVAC	Yes
Number of Pollutants	1
Class of Pollutant	Particulate Matter
Pollutant Size	10µm
Hours Simulated	120
Number of Occupants	3

A modeling duration of 120-hours was chosen to ensure that initial indoor PM_{10} concentrations had time to cycle throughout the house and reach a semi- steady state daily cycle towards the conclusion of the simulation. This was evaluated by running a RISK scenario that included constant indoor and outdoor PM_{10} concentrations and noticing the time it took for indoor concentrations to reach steady state was approximately 2.2 days.

General HVAC air flows within the research house move from rooms to the interconnecting hall. Table 4-4 provides the room-to-room HVAC-supplied air flows. Airflow from each room is delivered to the hall, with the exception of the master bathroom, from which airflow is delivered to the master bedroom. There is no airflow into or out of the front bedroom because the vents in the room are closed, thus restricting HVAC flow. However, the door to the front bedroom is open, allowing for natural airflow. Doors to the other rooms of the research house are assumed to be closed.

Table 4-4. Room-to-Room Air Flows Supplied by the House Heating, Ventilation, and Air Conditioning (HVAC) System (Sparks, 2005).

Flow from room	**Flow to room**	**Cubic meters/h**
Den	Hall	334
Kitchen	Hall	118
Living room	Hall	442
Middle bedroom	Hall	213
Front bedroom	Hall	150*
Master bedroom	Hall	493
Master bathroom	Master bedroom	95
Main bathroom	Hall	173

* Note: Natural airflow.

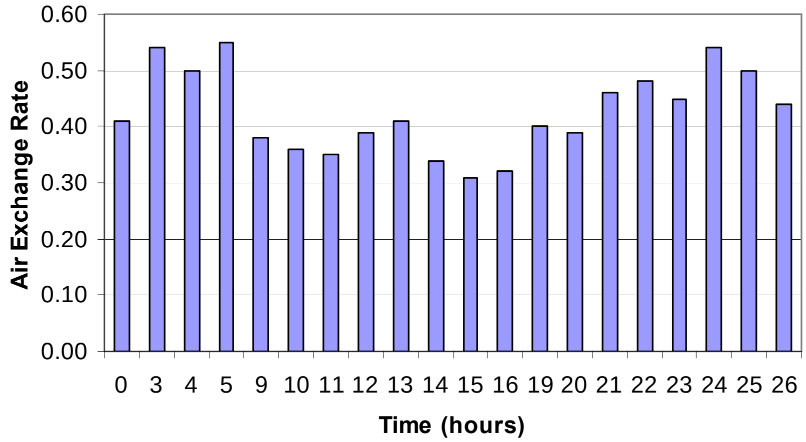

Figure 4-2. Air Exchange Rates (ACH) Rates in Research House (Sparks, 2005).

Figure 4-2 displays the daily (24-hour) fluctuations in ACH that were modeled.

PM_{10} was chosen as the air pollutant to be modeled in RISK. This is because most of the current air cleaning technology is rated to remove a certain percentage of airborne particles. While VOCs might be of interest to evaluate, information regarding VOC removal efficiencies for air cleaners was not readily available. Sparks (2005) has reported the applicability of utilizing RISK to model the conditions in the research house, however, indoor and outdoor PM_{10} concentrations for use with air cleaner analyses are not included in his work and had to be found elsewhere. Figure 4-3 displays the outdoor PM_{10} concentrations used for this analysis. These values were adapted from research conducted by Leaduer *et al.* (1999). Leaduer noticed two peaks in outdoor air PM_{10} concentrations during a 24-hour period. Concentration peaks were associated with the morning and evening rush-hour periods of the day. A daily cycle of PM_{10} concentrations was assembled from Leaduer's research and repeated a total of five times to complete the five day modeling simulation. A more detailed cycle of outdoor concentrations would have been optimal for the modeling application; however, RISK limits the number of outdoor concentration changes to 40 over the entire simulation.

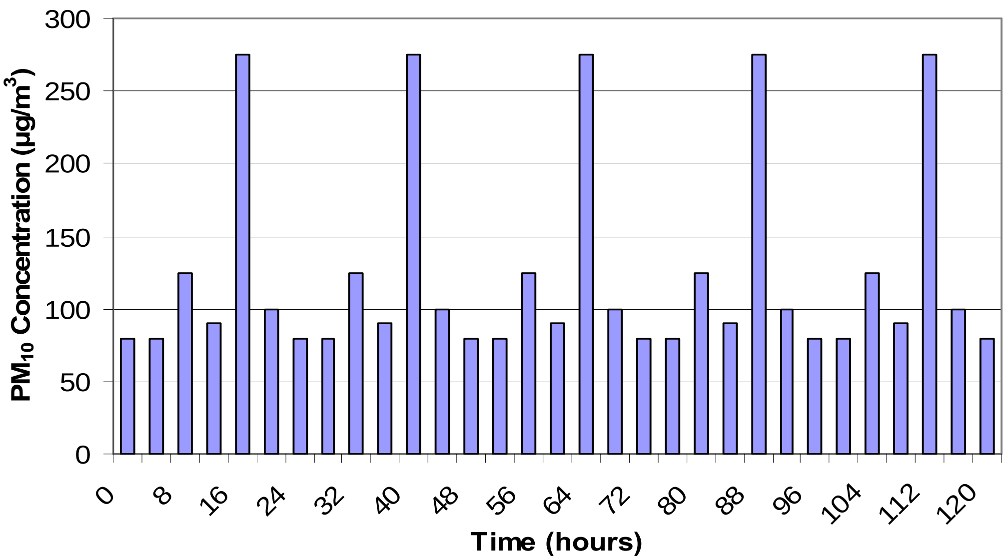

Figure 4-3. Outdoor Particulate Matter Concentrations over Modeling Period (Leaduer *et al.*, 1999).

All rooms of the research house were configured to begin the modeling simulation with an initial concentration of 35µg/m^3 of PM_{10} (Leaduer *et al.*, 1999). There was no indoor source of PM for this modeling application, although the outdoor concentrations directly affect the indoor PM concentrations through the process of building penetration and by the intake of fresh air by the HVAC system. The value used for penetration was 0.65, which was adapted from Wainman *et al.* (2000) and represents the average penetration for a single-story home.

Typical residential houses can have sources of PM, resulting from combustion, cooking, and dusting; however, information regarding the mass flow rates of indoor PM sources was not available so a constant and/or variable indoor source was omitted from this simulation. Therefore, the results from this simulation indicate only the background PM_{10} concentrations that are present in the research house.

Another input that was needed for modeling in RISK was room sink data. Table 4-5 displays this information. This data was obtained from reports evaluating the sinks present in the rooms of EPA's research house. Room sink data is reported as areas that represent all of the possible surfaces to which PM can cling, get trapped, settle on, or otherwise be removed from suspension in the air. The size of a sink area is a function of upholstered furnishings and

Table 4-5. Research House Room Sink Areas (Sparks, 2005).

Room	Sink area (m^2)
Den	104
Kitchen	32
Living Room	120
Hall	19
Middle BR	51
Front BR	54
Master BR	67
Main Bath	10
Master Bath	10

textiles located within a room. RISK does not allow for re-entrainment of PM_{10} once it is removed from the air by a sink.

Building occupancy cycles were evaluated to analyze the PM_{10} exposure levels that occupants may encounter. Three occupants were assumed for this analysis, including a family consisting of an adult female, adult male, and an elementary-school aged child. Tables 4-6, 4-7, and 4-8 display the occupancy cycles for the adult female, adult male, and child, respectively. The occupancy cycle was configured to estimate the exposures considering that the adult male was employed full-time outside of the home, the adult female remained in the home during the day, and the child only left the house to attend school.

Occupant exposure scenarios were also assessed by evaluating the occupants if they remained in the same room of the research house, with and without air cleaners, for the duration of the simulation. A sensitivity analysis to evaluate the importance of the occupant cycle was completed to compare the more extreme case of 100% occupancy in one room to the more realistic case of occupancy cycles.

RISK documentation states that the program uses the following calculation to determine inhalation exposure during model execution:

$$\text{Inhalation Exposure} = C \times BR \times T \tag{5}$$

where,

C = concentration (mg/m^3),
BR = breathing rate (m^3/hr), and
T = the duration of time exposed (hr).

Table 4-9 presents the inputs that were specified in RISK to complete the exposure calculation. When occupant weight is specified in RISK, the program automatically selects a default breathing rate based on the weight. This default value can be overridden; however, the occupant inputs in this case study were modeled to match those utilized by Sparks (2005), and thus the defaults were accepted. This explains the reasoning for having the same breathing rate for the adult male and female even though they have different weights. For the inputs that were utilized, the child's high ratio of breathing rate to bodyweight suggests that if an adult and child were in a room and breathed air having the same concentration, then the child would have much higher exposure to the indoor pollutant. This point is considered in interpreting the results of the modeling analysis.

Only room air cleaners were analyzed for this research. Whole house cleaners were not analyzed because sufficient information regarding efficiencies and air exchange rates could not be located. Also, while room air cleaners are more versatile and can be placed in different room locations and configurations, whole house cleaners need to be configured with the home's HVAC system and information pertaining to these setups was not readily available.

Table 4-6. Adult Female Occupancy Cycle.

Time Enter (hr)	Time Leave (hr)	Location
0	6.5	Master Bedroom
6.5	7	Master Bathroom
7	8	Kitchen
8	12	Living Room
12	12.5	Kitchen
12.5	15	Den
15	17	Living Room
17	19	Kitchen
19	21	Living Room
21	21.5	Middle Bedroom
21.5	24	Master Bedroom

Table 4-7. Adult Male Occupancy Cycle.

Time Enter (hr)	Time Leave (hr)	Location
0	6	Master Bedroom
6	6.5	Master Bathroom
6.5	17	Outdoors
17	18.5	Den
18.5	19	Kitchen
19	22	Living Room
22	24	Master Bedroom

Table 4-8. Child Occupancy Cycle.

Time Enter (hr)	Time Leave (hr)	Location
0	6.5	Middle Bedroom
6.5	7	Main Bathroom
7	7.5	Kitchen
7.5	16	Outdoors
16	18.5	Den
18.5	19	Kitchen
19	21	Living Room
21	24	Middle Bedroom

Table 4-9. Occupant Inhalation Exposure Inputs.

Occupant	Weight (kg)	Breathing Rate (m^3/hr)
Adult Female	60	1.0
Adult Male	80	1.0
Child	25	0.833

Limited information regarding room air cleaner efficiencies and ACHs is available. Room air cleaner ACH refers to the number of times that the air cleaner completely treats the entire volume of a room's air. From Table 1-6 in Section 1.2.4.3, the majority of the air cleaners report removal efficiencies of 99.97% for PM, however, the values for ACH vary from 1 to 6.75. The information included on most air cleaner packaging does not report a specific size range of PM for which the air cleaner is rated to remove 99.97%, therefore, no specific assumption was made. Instead, a sensitivity analysis was conducted to evaluate how much IAQ varies as a function of removal efficiency for PM_{10}.

The indoor air cleaner inputs that were assessed using RISK are located in Table 4-10. Five different generic air cleaners were modeled. Particle removal efficiency was assumed to range from 50% to 99.97%. The upper limit was set at 99.97% because this value is reported by manufacturers of the majority of air cleaners available to consumers, yet the detailed basis of reported removal efficiencies is unknown. A sensitivity analysis on the effects of particle removal efficiency on IAQ factors was assessed in the absence of relevant data for particle removal efficiency and PM sizes.

4.2 Modeling Runs in RISK

A Dell Dimension desktop computer running the Windows XP platform was used to download and install the RISK software from the EPA indoor air modeling website. The

Table 4-10. Room Air Cleaner Inputs Analyzed in RISK.

Air Cleaner	ACH	Efficiencies (%)
1	1.00	50, 70, 85, 90, 95, 99.97
2	4.80	50, 70, 85, 90, 95, 99.97
3	5.70	50, 70, 85, 90, 95, 99.97
4	6.00	50, 70, 85, 90, 95, 99.97
5	6.75	50, 70, 85, 90, 95, 99.97

model was run after specifying all of the inputs mentioned in Section 4.1. A base configuration that included common inputs to each scenario such as room size, air rates, PM_{10} concentrations, and room to room airflows was specified interactively and then saved within RISK to facilitate subsequent input entry. The only inputs not included in the base configuration were those for the generic air cleaners and occupancy, which changed with each of the four scenarios described in Section 4.1.

An initial simulation (Base Scenario) to obtain base concentrations modeled indoor PM_{10} in the absence of occupants and air cleaners in the research house. A sensitivity analysis on the effects of particle removal efficiency on PM_{10} concentrations was then assessed. For every other simulation, one of the four defined scenarios (Scenarios A through D) was specified and the model was allowed to cycle for 120 hours.

Scenario A was simulated a total of nine times, placing the three occupants into a different room of the research house each time. Scenario B was simulated three times, placing the occupants and the air cleaner in the den, kitchen, or living room of the research house. Scenario C was simulated only once, allowing the occupants to cycle through daily activities in the absence of an air cleaner. Finally, Scenario D was simulated three times, allowing the occupants to cycle through daily activities while the air cleaner was located in den, kitchen, or living room of the research house.

A single simulation in RISK took approximately 15 minutes to configure, with model execution taking less than two seconds. All results were accessible from a pull-down menu. The easy user interface of RISK allowed for the quick display of PM_{10} concentrations per room per specified time-step, average 24-hour exposure levels, and cumulative PM_{10} exposure levels for each occupant. However, all of the results had to be copied and pasted into a Microsoft Excel spreadsheet for further analysis. Data was obtained and saved for each of the simulated scenarios.

4.3 Modeling Results

This section presents the results of the analysis of factors influencing occupant exposure levels, which include air cleaners, occupancy cycles, and characteristics of the research house. Reduction in occupant exposure levels, both cumulative and 24-hour average, was assessed and is discussed.

The first modeling results that are presented include the PM_{10} concentrations in the research house when no occupants or air cleaner are specified. The following sections describe and discuss the different scenario results relating to the effects of differing particle removal efficiencies on PM_{10} concentrations, differing occupancy cycles on occupant exposure, the effects of particle removal efficiencies and ACHs of air cleaners on overall occupant exposures, and the effects that different room characteristics have on occupant exposures.

4.3.1 Indoor PM_{10} Concentrations in the Research House

Figure 4-4 shows the indoor PM_{10} concentrations in the den for the duration of the 120-hour modeling simulation in which no air cleaner was present in any of the rooms of the research house. Outdoor PM_{10} concentrations are also included in the plot. Plots of PM_{10} concentrations in the other eight rooms of the research house are similar to the one shown below but are not included in Figure 4-4 to prevent clutter. The purpose of this plot is to illustrate how indoor concentration peaks occur in the time periods directly following the outdoor concentration peaks that are associated with rush-hour traffic cycles. A table of incremental PM_{10} concentrations in every room of the research house during the entire simulation is included in Appendix F for reference.

Figure 4-5 displays the PM_{10} concentrations in each of the 9 rooms of the research house at the conclusion of the 120 hour modeling simulation. The concentrations for seven of the rooms are fairly similar, having an average concentration of approximately 33.0 μg/m^3. The concentrations for the bathrooms are noticeably higher than the other rooms in the research house, due to their smaller volumes, lower air flows, and smaller sink areas. The fairly uniform concentrations in the remainder of the researcher house, however, aids in showing that the house is well-mixed.

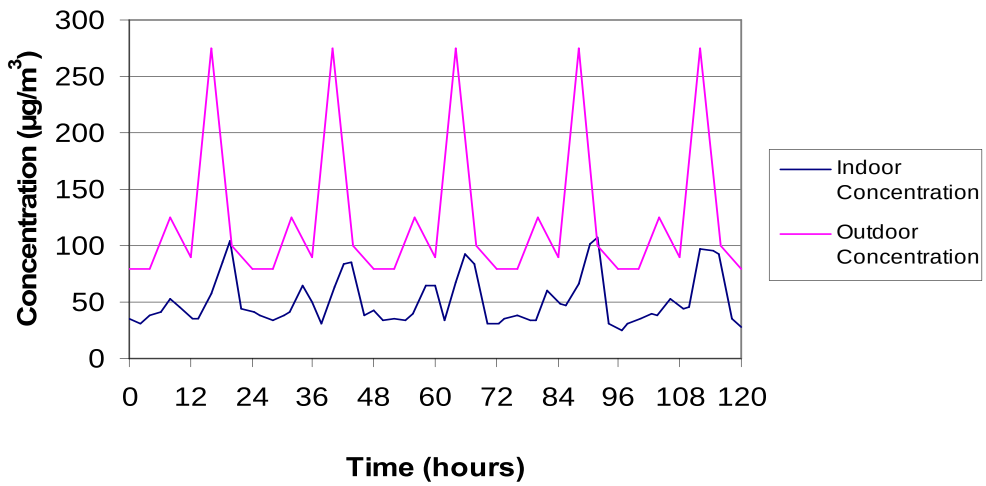

Figure 4-4. Base PM_{10} Concentrations in the Den of the Research House.

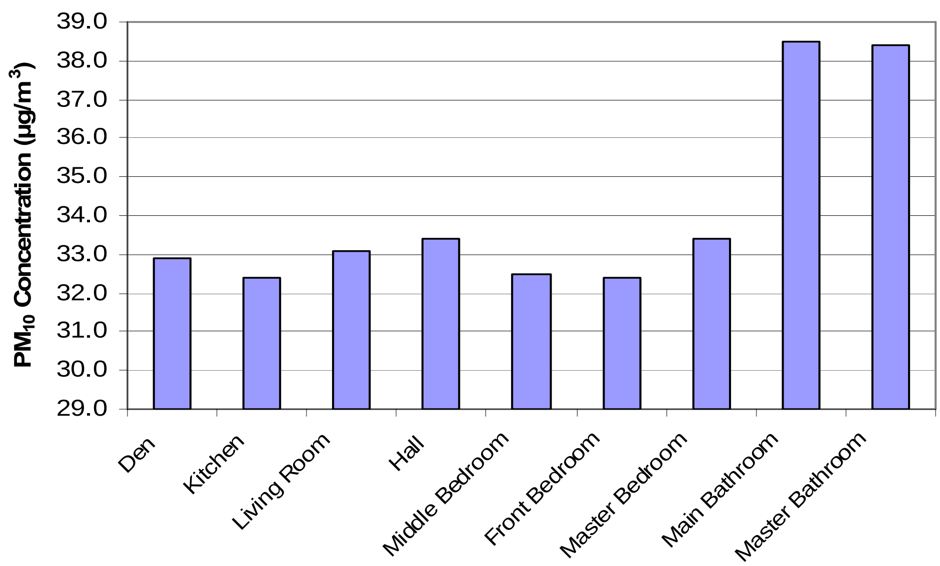

Figure 4-5. PM_{10} Concentrations Present in Research House After 120 Hours.

4.3.2 Occupancy Input Effects on Occupant Exposure

Scenarios A and C assess the occupancy input effects on occupant exposure. The results from these two scenarios were compared to the Base Scenario and to one another. All results are presented below

Scenario A

Table 4-11 displays nine sets results obtained for each room for Scenario A in which all occupants remained in the same room for the duration of the modeling simulation, or 120 hours. No air cleaner was present in any of the simulated rooms. The highest 24-hour average exposures typically occurred during the 4^{th} or 5^{th} day of the simulation. The 24-hour cumulative exposure expresses the total exposure to PM_{10} that each occupant had during day 5 of the simulation. The adult exposure includes the exposures for both the adult female and adult male occupant. The exposure calculation that RISK uses is dependent on pollutant concentrations, the time exposed to the concentration, and breathing rate; these inputs were identical for the male and female adult occupants when they spent the duration of the simulation in the same room.

The exposure values reported by RISK have units of μg-hr/m^3, which is an unconventional unit for exposure. In fact, the units reported in the output of RISK are actually reporting a cumulative concentration and not an exposure. For the purpose of this research, RISK's units are reported in all figures and tables to remain consistent with the model output; however, these units do not match the units obtained from Equation 5 in Section 4.1.

A more commonly used measure of exposure is the potential dose. The exposure output of RISK can easily be converted to a potential dose by multiplying by the ratio of intake rate to body weight and by dividing by an average time of interest, or 24 hours for a daily cycle of exposure. The exposure factors of intake rate, body weight, and averaging time would be approximately the same for a given individual, unless there was some type of variation in activity from one room to the next that caused variation in intake rate. Therefore, if one assumes that these other exposure factors are constant for a given individual, the estimated percentage reductions in exposure based on the cumulative concentration estimates are applicable to potential dose also.

Table 4-11. Simulation of Occupant Exposures when Remaining in Same Room of Research House for 120-hours (Scenario A)[1].

Room	Occupant	(µg-hr/m^3)	Exposure (µg-hr/m^3)
Den	Adult	51.6	1240
	Child	43.0	1033
Kitchen	Adult	50.9	1222
	Child	42.4	1018
Living Room	Adult	51.9	1246
	Child	43.2	1038
Hall	Adult	52.4	1259
	Child	43.6	1048
Middle Bedroom	Adult	51.0	1226
	Child	42.5	1022
Front Bedroom	Adult	50.9	1222
	Child	42.4	1018
Master Bedroom	Adult	52.3	1257
	Child	43.5	1047
Main Bathroom	Adult	60.4	1452
	Child	50.3	1210
Master Bathroom	Adult	60.3	1448
	Child	50.2	1206

[1] 24-hr average and cumulative exposures are based on the final day of the simulation.

The highest occupant exposures occurred in the main and master bathrooms. These rooms represent two of the smallest rooms in the research house. The lowest occupant exposures were reported in the front bedroom and kitchen. The child's exposures were less than adult exposures for each room due to the child's lower breathing rate and bodyweight. However, the child's exposures may be overestimated due to the high ratio of breathing rate to bodyweight that was used for the modeling. Therefore, the child's actual exposure values may be even lower than reported.

As was shown in Figure 4-5, the PM_{10} concentrations were relatively uniform for each of the rooms in the research house, except for the two bathrooms. Therefore, the occupants exposures obtained in Scenario A agree with the baseline PM_{10} concentrations in the simulated well-mixed research house. With the exception of the two bathrooms, occupants can be expected to receive approximately the same PM_{10} exposure in any of the remaining seven rooms of the house.

While no indoor standard exists for PM_{10}, the National Ambient Air Quality Standard for PM_{10} is 150µg/m^3, which is not to be exceeded in a 24-hr period (EPA, 2006). The exposure values obtained from Scenario A are lower than this standard. However, in the event that a PM_{10} source was simulated to be inside the research house, occupant exposures could come closer to exceeding the standard.

Scenario C

Table 4-12 displays the results for Scenario C in which RISK was configured to allow the occupants to cycle according to the occupancy cycle inputs. No air cleaner was present in any of the simulated rooms. The adult male and child occupants had lower exposures due to time spent outside of the research house for work and school, respectively. During the time that the adult male and child were modeled to be outside of the research house, exposure calculations for these occupants ceased and started again once they re-entered the house. Therefore, the adult male and child's exposures were significantly lower than the adult female's exposures due to the amount of time they were simulated as being outside of the research house. Future versions of the RISK software will allow for the continued assessment of occupant exposures outside of the research house.

When Scenario C is compared to the results obtained from Scenario A, similar values for exposure are noted for the adult female. The adult female was simulated to spend 100% of the modeling duration inside the research house for both scenarios. This finding shows that occupant patterns and daily activities may not have a large effect on indoor exposure levels.

The key finding from Scenario C indicates that similar occupant exposures are obtained regardless of whether occupants cycle or remain in the same room for the duration of the simulation. It is assumed that the research house is well-mixed. As documented in Section 2.3.2, RISK only allows for the modeling of well-mixed buildings. The key finding was explored further by determining the effects of spending differing periods of time in contact with the generic air cleaners simulated in Scenarios B and D. Tables 4-11 and 4-12 display the base values to which the room air cleaner results were compared to determine the possible exposure reductions that different air cleaners provide under different occupancy scenarios. The results of the scenarios in which room air cleaners were introduced into the research house are in the following section.

Table 4-12. Simulation of Occupant Exposures when Cycling Through Daily Activities (Scenario C)[1].

Occupant	Highest 24-hr Ave. Exposure (μg-hr/m^3)	24-hr Cumulative Exposure (μg-hr/m^3)
adult female	52.6	1263
adult male	31.4	754
child	30.6	736

[1] 24-hr average and cumulative exposures are based on the final day of the simulation.

4.3.3 Air Cleaner Input Effects on Occupant Exposure

Scenarios B and D assess the air cleaner input effects on occupant exposure. The results from these two scenarios were compared to the Scenarios B, D, and to one another. All results are presented below.

Scenario B

Three different simulations were conducted for Scenario B, which included the assumed placement of one room air cleaner in each of the den, kitchen, and living room of the research house to assess their effectiveness at reducing occupant exposures of PM_{10}. Only one air cleaner was simulated inside the house at a time. The den, kitchen, and living room were chosen since they are the common rooms that all occupants would be expected to spend some amount of time in throughout a regular day, and since room air cleaners should be placed in areas where all occupants can benefit from their cleaning capabilities. A bedroom would be an ideal location for an air cleaner, due to the fact that many occupants often spend approximately 1/3 of the day there; however, since only one air cleaner was simulated in RISK, rooms that were common to all occupants daily activity cycles were chosen for modeling.

Tables 4-13, 4-14, and 4-15 show the occupant exposure results for Scenario B, when the occupants spent the entire modeling simulation in the same room as the air cleaner. Along with exposure values, the percentage reduction for each occupant is shown. The percentage reduction values quantify the amount of reduction in occupant exposure that each specific air cleaner provided in relation to Scenario A.

As expected, the highest exposure reductions resulted from the air cleaner with the highest ACH of 6.75. Percentage exposure reductions decrease with decreasing values of

ACH. The highest exposure reductions when compared to the results from Scenario A are almost 40%, while the lowest exposure reductions are about 7.5%. Figure 4-6 shows a plot of the effects of differences in ACH on the overall percentage of PM_{10} exposure reduction in the living room. From the plot, it appears that the marginal rate of increase in the percentage exposure reduction is diminishing as the ACH increases. This means that a room air cleaner having an ACH of 6 may not offer much less exposure reduction than an air cleaner having an ACH of 7.

Table 4-13. Occupant Exposures when Occupants are in Same Room as Air Cleaners for Duration of Modeling Simulation (Scenario B) – Den[1].

Air Cleaner		Occupant	Highest 24-hr Ave. Exposure (µg-hr/m^3)	24-hr Cumulative Exposure (µg-hr/m^3)	% Reduction from Scenario A
Efficiency	*ACH*				
99.97	1	adult	47.1	1132	8.7
99.97	1	child	39.2	943	8.8
99.97	4.8	adult	35.4	850	31.4
99.97	4.8	child	29.5	708	31.4
99.97	5.7	adult	33.4	803	35.3
99.97	5.7	child	27.8	669	35.3
99.97	6	adult	32.8	788	36.4
99.97	6	child	27.3	656	36.5
99.97	6.75	adult	31.7	760	38.6
99.97	6.75	child	26.4	633	38.6

[1] 24-hr average and cumulative exposures are based on the final day of the simulation.

Table 4-14. Occupant Exposures when Occupants are in Same Room as Air Cleaners for Duration of Modeling Simulation (Scenario B) – Kitchen[1].

Air Cleaner		Occupant	Highest 24-hr Ave. Exposure (µg-hr/m^3)	24-hr Cumulative Exposure (µg-hr/m^3)	% Reduction from Scenario A
Efficiency	*ACH*				
99.97	1	adult	47.1	1131	7.5
99.97	1	child	39.2	942	7.5
99.97	4.8	adult	36.6	880	28.1
99.97	4.8	child	30.5	733	28.1
99.97	5.7	adult	34.8	837	31.6
99.97	5.7	child	29	697	31.6
99.97	6	adult	34.3	823	32.6
99.97	6	child	28.5	685	32.8
99.97	6.75	adult	32.9	791	35.4
99.97	6.75	child	27.4	659	35.4

[1] 24-hr average and cumulative exposures are based on the final day of the simulation.

Table 4-15. Occupant Exposures when Occupants are in Same Room as Air Cleaners for Duration of Modeling Simulation (Scenario B) – Living Room[1].

Air Cleaner		Occupant	Highest 24-hr Ave. Exposure (µg-hr/m^3)	24-hr Cumulative Exposure (µg-hr/m^3)	% Reduction from Scenario A
Efficiency	*ACH*				
99.97	1	adult	47.4	1138	8.7
99.97	1	child	39.4	948	8.8
99.97	4.8	adult	35.6	855	31.4
99.97	4.8	child	29.6	712	31.5
99.97	5.7	adult	33.6	807	35.3
99.97	5.7	child	28.0	623	35.2
99.97	6	adult	33.0	793	36.4
99.97	6	child	27.5	660	36.3
99.97	6.75	adult	31.6	760	39.1
99.97	6.75	child	26.3	633	39.1

[1] 24-hr average and cumulative exposures are based on the final day of the simulation.

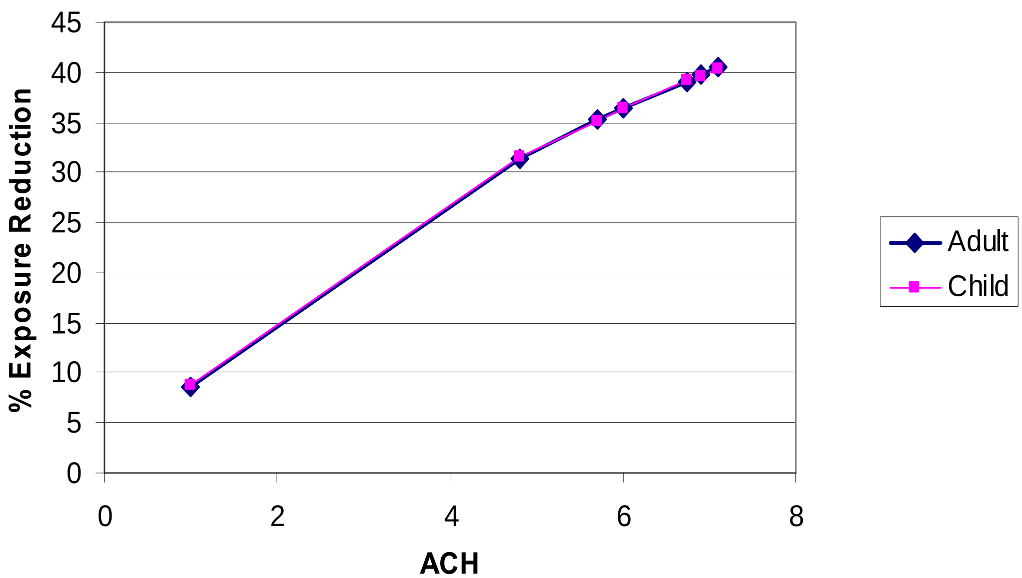

Figure 4-6. Plot of the Effects of ACH on Percentage Exposure Reduction in the Living Room When Occupants Remain in Same Room for Entire Model Simulation.

Higher values of ACH would have been preferable to simulate, however, RISK does not allow for ACHs greater than 7.1. When two additional higher ACHs, 6.9 and 7.1, are included in the analysis, the trend of a marginal rate of increase in the percentage exposure reduction diminishing as ACH increases appears to still hold true. An explanation for this relationship between percentage exposure reduction and high ACHs is that there may exist a dilution effect. A dilution effect can be explained by the gradual decrease in one parameter that follows the gradual increase in another parameter.

The exposure results for Scenario B are essentially the same for the three rooms simulated in RISK. This is due to the well-mixed nature of these rooms as was presented in previous results.

Scenario D

Tables 4-16, 4-17, and 4-18 show the occupant exposure results for Scenario D, when an air cleaner was present in the den, living room, and kitchen of the research house, respectively. For this scenario, the occupants followed the occupancy cycles in Section 4.1. Along with exposure values, the percentage reduction for each occupant is shown. The percentage reduction values quantify the amount of reduction in occupant exposure that each specific air cleaner provided in relation to Scenario B.

Table 4-16. Occupant Exposures when Occupants Cycle Through Daily Activities (Scenario D) – Air Cleaner in Den[1].

Air Cleaner		Occupant	24-hr Ave. Exposure (μg-hr/m^3)	24-hr Cumulative Exposure (μg-hr/m^3)	% Reduction from Scenario B
Efficiency	*ACH*				
99.97	1	adult female	37.6	901	28.5
99.97	1	adult male	21.6	518	31.2
99.97	1	child	21.3	487	30.4
99.97	4.8	adult female	35.5	851	32.5
99.97	4.8	adult male	20.3	486	35.4
99.97	4.8	child	18.9	453	38.2
99.97	5.7	adult female	35.1	843	33.3
99.97	5.7	adult male	20.1	480	36.0
99.97	5.7	child	18.6	447	39.2
99.97	6	adult female	35.0	840	33.5
99.97	6	adult male	20.0	479	36.3
99.97	6	child	18.6	445	39.2
99.97	6.75	adult female	34.8	836	33.8
99.97	6.75	adult male	19.9	476	36.6
99.97	6.75	child	18.5	443	39.5

[1] 24-hr average and cumulative exposures are based on the final day of the simulation.

Table 4-17. Occupant Exposures when Occupants Cycle Through Daily Activities (Scenario D) – Air Cleaner in Kitchen[1].

Air Cleaner		Occupant	24-hr Ave. Exposure ($\mu g\text{-}hr/m^3$)	24-hr Cumulative Exposure ($\mu g\text{-}hr/m^3$)	% Reduction from Scenario B
Efficiency	*ACH*				
99.97	1	adult female	37.8	907	28.1
99.97	1	adult male	22.0	526	29.9
99.97	1	child	20.7	496	32.4
99.97	4.8	adult female	36.2	869	31.2
99.97	4.8	adult male	21.5	515	31.5
99.97	4.8	child	20.2	484	34.0
99.97	5.7	adult female	35.9	863	31.7
99.97	5.7	adult male	21.5	514	31.5
99.97	5.7	child	20.1	482	34.3
99.97	6	adult female	35.8	861	31.9
99.97	6	adult male	21.4	513	31.8
99.97	6	child	20.1	481	34.3
99.97	6.75	adult female	35.6	855	32.3
99.97	6.75	adult male	21.4	510	31.8
99.97	6.75	child	20.0	479	34.6

[1] 24-hr average and cumulative exposures are based on the final day of the simulation.

Table 4-18. Occupant Exposures when Occupants Cycle Through Daily Activities (Scenario D) – Air Cleaner in Living Room[1].

Air Cleaner		Occupant	24-hr Ave. Exposure ($\mu g\text{-}hr/m^3$)	24-hr Cumulative Exposure ($\mu g\text{-}hr/m^3$)	% Reduction from Scenario B
Efficiency	*ACH*				
99.97	1	adult female	36.8	883	30.0
99.97	1	adult male	21.4	511	31.8
99.97	1	child	20.3	486	33.7
99.97	4.8	adult female	32.7	784	37.8
99.97	4.8	adult male	19.3	461	38.5
99.97	4.8	child	18.8	451	38.6
99.97	5.7	adult female	32.0	768	39.2
99.97	5.7	adult male	18.9	453	39.8
99.97	5.7	child	18.6	445	39.2
99.97	6	adult female	31.8	763	39.5
99.97	6	adult male	18.8	450	40.1
99.97	6	child	18.5	443	39.5
99.97	6.75	adult female	31.3	751	40.5
99.97	6.75	adult male	18.6	444	40.8
99.97	6.75	child	18.3	439	40.2

[1] 24-hr average and cumulative exposures are based on the final day of the simulation.

As with Scenario B, the highest exposure reductions for Scenario D resulted from the air cleaner with an ACH of 6.75. Percentage exposure reductions decrease with decreasing values of ACH. The highest exposure reductions when comparing Scenario D to Scenario B are over 40%, while the lowest exposure reductions are about 28%. Figure 4-7 shows a plot of the effects of differences in ACH on the overall percentage of PM_{10} exposure reduction in the living room. Similar to Figure 4-6, from the plot, it appears that the marginal rate of increase in the percentage exposure reduction is diminishing as the ACH increases. One possible explanation is that as ACH continues to increase, a dilution effect on percentage exposure reduction is taking place, as was mentioned for Scenario B.

A key finding from Scenario D indicates that occupancy cycles have an effect on overall exposure reductions. Exposures for the adult male and child were significantly lower than the exposures resulting from Scenario B, however, this can be attributed to their occupancy cycles included periods of time simulated outside of the research house. The adult female's exposure results for Scenario D were also lower than those obtained through Scenario B, indicating that the occupant cycle, coupled with time spent in the vicinity of the one simulated air cleaner, affects overall occupant PM_{10} exposures.

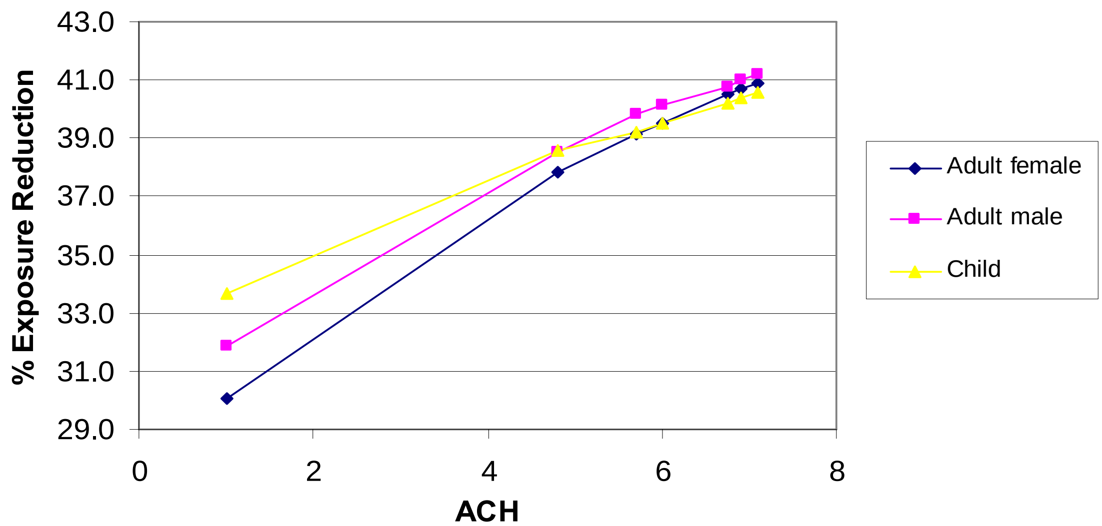

Figure 4-7. Plot of the Effects of ACH on Percentage Exposure Reduction in the Living Room when Occupants Cycle Through Daily Activities.

Tables 4-19, 4-20, and 4-21 identify the cumulative 24-hour exposures and percentages of time spent in each of the rooms of the research house for each of the five generic air cleaners simulated in Scenario D. From these tables, the lowest cumulative 24-hr exposures are reported when the air cleaner is located in the living room, though these values for exposure differ from each other by only a few percent. The living room is the only room of the research house where all three occupants spend at least 8% of the simulated day, followed by the den with at least 6% of the day, and the kitchen with at least 2% of the day.

Figure 4-8 shows the exposures for each occupant when a room air cleaner having an ACH of 6.75 was used in the kitchen. This plot only shows exposures for the last 24-hour period of the 5-day simulation. The periods when the adult male and child are absent from the research house are shown in Figure 4-8. Also, differences in PM_{10} exposures due to differing occupancy cycles are depicted in the figure. For example, at approximately 113 hours, the adult female is located in the kitchen of the research house. The figures displays that the female's exposures are lower than the adult male's and child's exposures at this time. This is due to the female being located in the kitchen, which is the same room in which the air cleaner is located. Thus, spending increased amounts of time in the same room as the air cleaner increases occupant exposure reductions.

Table 4-19. Cumulative 24-hr Exposures and Percentages of Time Spent in Rooms When Air Cleaner is Located in Den (Scenario D).

	Percentage of Time Spent in Each Room (%)		
	Adult Female	Adult Male	Child
Den	10	6	10
Kitchen	14	2	4
Living Room	32	12	8
Hall	0	0	0
Master Bedroom	37	33	0
Master Bath	2	2	0
Middle Bedroom	2	0	39
Main Bath	0	0	2
Front Bedroom	0	0	0
Outdoors	0	45	35
	Cumulative Exposure (µg-hr/m^3)		
	Adult Female	Adult Male	Child
ACH = 1	901	518	487
ACH = 4.8	851	486	453
ACH = 5.7	843	480	447
ACH = 6	840	479	445
ACH = 6.75	836	476	443

Table 4-20. Cumulative 24-hr Exposures and Percentages of Time Spent in Rooms When Air Cleaner is Located in Kitchen (Scenario D).

	Percentage of Time Spent in Each Room (%)		
	Adult Female	Adult Male	Child
Den	10	6	10
Kitchen	14	2	4
Living Room	32	12	8
Hall	0	0	0
Master Bedroom	37	33	0
Master Bath	2	2	0
Middle Bedroom	2	0	39
Main Bath	0	0	2
Front Bedroom	0	0	0
Outdoors	0	45	35
	Cumulative Exposure (µg-hr/m^3)		
	Adult Female	Adult Male	Child
ACH = 1	907	526	496
ACH = 4.8	869	515	484
ACH = 5.7	863	514	482
ACH = 6	861	513	481
ACH = 6.75	855	510	479

Table 4-21. Cumulative 24-hr Exposures and Percentages of Time Spent in Rooms When Air Cleaner is Located in Living Room (Scenario D).

	Percentage of Time Spent in Each Room (%)		
	Adult Female	Adult Male	Child
Den	10	6	10
Kitchen	14	2	4
Living Room	32	12	8
Hall	0	0	0
Master Bedroom	37	33	0
Master Bath	2	2	0
Middle Bedroom	2	0	39
Main Bath	0	0	2
Front Bedroom	0	0	0
Outdoors	0	45	35
	Cumulative Exposure (µg-hr/m^3)		
	Adult Female	Adult Male	Child
ACH = 1	883	511	486
ACH = 4.8	784	461	451
ACH = 5.7	768	453	445
ACH = 6	763	450	443
ACH = 6.75	751	444	439

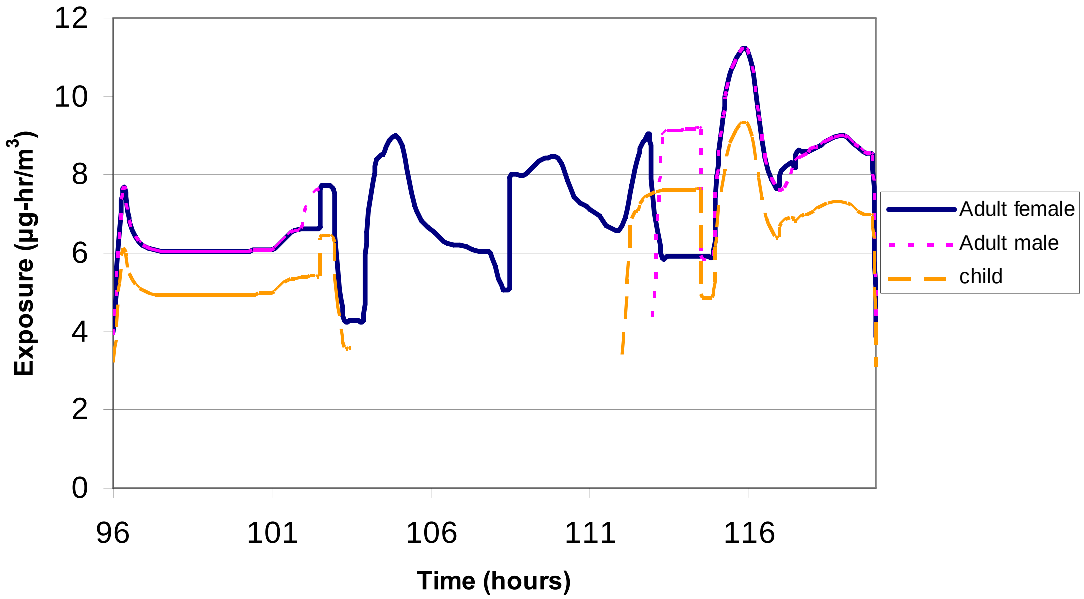

Figure 4-8. Occupant Exposures for Last Day of Simulation when Room Air Cleaner (ACH = 6.75) is Located in the Kitchen of the Research House.

4.3.4 Sensitivity Analysis of Particle Removal Efficiency

In the absence of relevant data for particle removal efficiency, a sensitivity analysis was performed. For the analysis, six different particle removal efficiencies were simulated when an air cleaner located in the den of the research house had an ACH of 6.0. Figure 4-9 illustrates the PM_{10} concentrations resulting from each simulated particle removal efficiency. A table with detailed data from the sensitivity analysis is located in Appendix G. When particle removal efficiency was varied by approximately 50 percentage points, from 50% to 99.97%, the resulting average change in PM_{10} concentration was approximately -17%. Similarly, when particle removal efficiency was varied by approximately 15 percentage points, from 85% to 99.97%, the resulting average change in PM_{10} concentration was approximately -5%.

Table 4-22 provides the effects of particle removal efficiency on percentage exposure reduction when an air cleaner (ACH = 6) was located in the den of the research house and the occupants cycled through daily activities. When particle removal efficiency was varied by 50 percentage points, exposure reductions had an average change of -9%. As mentioned in Section 4.3.3, the results for Scenario D indicated that differing the air cleaner ACH from 1

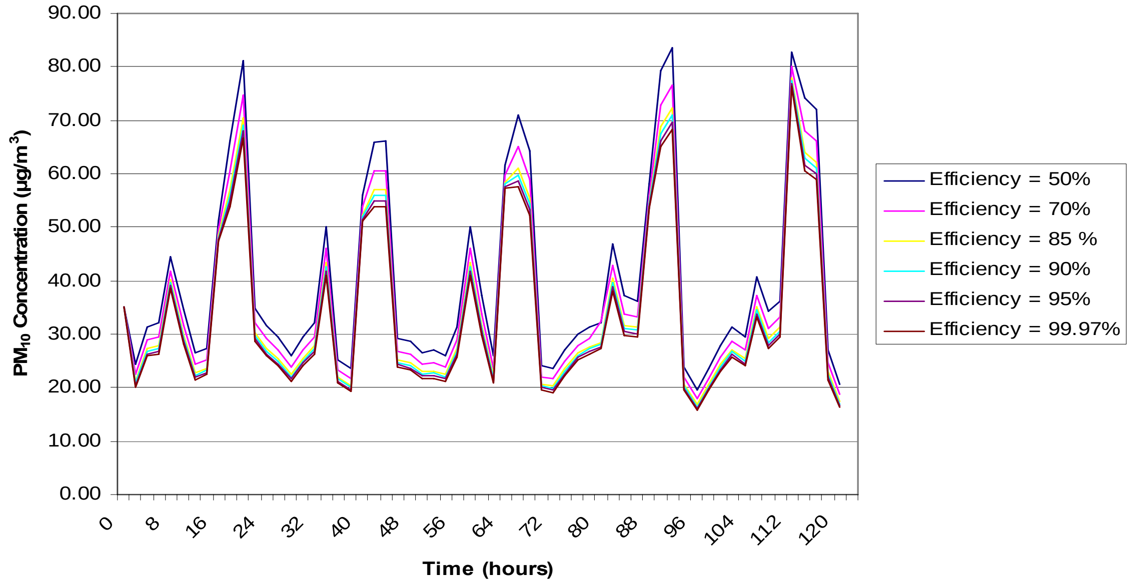

Figure 4-9. Variations in PM_{10} Concentrations in the Den of the Research House Due to Different Particle Removal Efficiencies (Scenario B).

Table 4-22. Effects of Particle Removal Efficiency on Percentage Exposure Reductions in Den of Research House (ACH = 6, Scenario B).

		Particle Removal Efficiency					
		50%	**70%**	**85%**	**90%**	**95%**	**99.97%**
% Exposure Reduction	adult female	36.5	37.1	38.4	38.8	39.1	39.5
	adult male	36.1	36.7	38.9	39.3	39.7	40.1
	child	36.5	37.1	38.4	38.8	39.1	39.5

to 6.75 resulted in exposure reductions that had an average change of -36.4%. These results indicate that changes in particle removal efficiency do not seem to affect IAQ as greatly as changes in air cleaner ACH. However, it is critical that more data relating particle removal efficiency and the PM sizes for which it is rated be made available for further analysis.

4.3.4 Building Characteristics Affecting Occupant Exposure

One of the assumptions of RISK is that the research house is well-mixed, as is documented in Section 2.3.2. The current version of the model does not allow for simulation of houses that are poorly mixed. For the case studies, all rooms were considered to have the same air exchange rate. Therefore, exchange rate was uniform throughout the house, yet, airflows varied by room. RISK does not allow for the simulation of opened and closed windows or outside temperature effects on indoor pollutant concentrations. Indoor parameters would be expected to vary according to outdoor parameter changes or if the HVAC system was not constantly operated, however, these options cannot currently be modeled in RISK.

In Scenario A, the highest occupant exposures occurred in the main and master bathrooms. These rooms represent two of the smallest rooms in the research house. While the hall has an overall volume similar to either bathroom, the hall receives more total airflow than the bathrooms, reducing the occupant exposures by means of dilution.

In Scenario A, the lowest occupant exposures occurred in the front bedroom and the kitchen. The kitchen is much smaller than the front bedroom; however, exposures were similar due to other inputs affecting occupant exposure, including room sink area, room to room airflows, and natural airflows.

An input that greatly affects the exposure levels that occupants encounter in each of the rooms is the sink area. Sink areas varied for each room, as did the total volume of the room. Rooms with larger sink areas in relation to their volume generally had lower overall exposures, while rooms with smaller sink areas in relation to their volume generally had greater overall exposures.

Airflow in the research house typically travels from each of the rooms to the hall. The hall also has one of the smallest sink areas in the house. One might therefore expect the PM_{10} concentrations and exposures to be the greatest in the hall; however, this is not the case. The main HVAC intake for the research house is centrally located in the hall, which keeps airflow constantly circulating throughout the house. Therefore, the flow rate of the HVAC system keeps the hall exposures similar to those of the larger rooms.

The front bedroom had the lowest PM_{10} concentrations reported in Scenario A. This room is not simulated to be receiving air from the HVAC system. Instead, the room's door is left open and the airflow in and out of the front bedroom is due only to natural airflow. While it might be concluded that rooms connected to the HVAC system have higher exposures than rooms having natural airflow, this is typically not true. In the event that a source was located in the front bedroom, this room would be expected to have much higher exposures for longer periods of time due to the lower overall airflows that this room receives. Therefore, it is a result of the specific inputs for the front bedroom in this simulation that the front bedroom has the lowest occupant exposures.

4.4 Discussion of Results

The greatest overall occupant exposure reductions resulted from Scenario D, in which the occupants were allowed to cycle through daily activities and a generic air cleaner was simulated to be operating in one of three rooms of the research house. The adult female was the only occupant assumed to remain in the research house for the entire simulation. Her exposures were lowest from Scenario B, or when she remained in the same room as the air cleaner for the duration of the simulation. The adult female's exposures increased slightly for Scenario D, due to her cycling throughout the various rooms of the research house. These results show that the highest reductions occur when an occupant spends increased time periods in the same room as the air cleaner. In actuality, slightly greater, though probably not significant, exposure reductions occur when the occupant spends greater amounts of time in the same room as the air cleaner. Thus, a central location for a room air cleaner is essential for providing maximum benefits to all building occupants.

Exposure reductions were generally highest for the child occupant when all occupants cycled through daily activities (Scenarios B and D). This is due to the child spending a percentage of the day outside of the research house to attend school. While the adult male also spent a similar amount of time outside of the research house, his simulated exposure reductions are slightly less than the child's. This is due to inputs that would affect individual occupant exposure such a breathing rate and PM_{10} concentrations encountered in different locations in the research house due to the specific occupancy cycles. Realistically, the adult male and child were subjected to PM_{10} concentrations once outside the research house, however, since RISK is not yet configured to handle this kind of detailed analysis, only the adult male and child's exposures inside the house were quantified. Other exposures that are likely to occur outdoors and in other environments (e.g., school, work) are beyond the scope of this analysis.

The exposures reported throughout this chapter do not account for intake rate and body weight. The use of cumulative exposure, or concentration multiplied by time, means that one cannot compare potential dose for the child versus the adult. However, as long as the intake rate, body weight, and averaging time remain the same for the child over the time period of the simulation and when comparing different scenarios, then the estimated percentage reductions are the same from either metric of exposure. It is recommended that EPA include potential dose, in units of μg/kg-day, as well as the concentration multiplied by time metric for exposure, as a model output in the next version of RISK.

4.5 Modeling Conclusions

The results obtained from the simulated scenarios indicate that a variety of factors can influence the PM_{10} exposures that building occupants may encounter. The characteristics of an air cleaner, different occupant activity patterns, and building characteristics affect indoor PM_{10} concentrations and thus, affect occupant exposures. The combination of these factors, as was simulated in this case study, resulted in varying degrees of occupant exposures and is summarized below.

The results of the RISK modeling of room air cleaners show that some air cleaner systems may be more effective at reducing occupant exposures than others. Factors that affect the effectiveness of a room air cleaner are particle removal efficiency and ACH. In the event that particle removal efficiency is 99.97%, higher ACHs lead to higher occupant exposure reductions, as shown by the results obtained from this modeling application.

The results from the sensitivity analysis on particle removal efficiency showed that particle removal efficiency does not seem to greatly affect simulated IAQ factors in the research house. However, more data is needed relating particle removal efficiency and the sizes of PM for which it is rated. This is a critical need for further modeling of air cleaners in the indoor environment.

Additionally, when particle removal efficiency is included on product packaging, there is no mention made of exactly what this relates to. For example, particle removal efficiency could mean the total mass of particles removed from the air. In this case, the use of PM_{10} as the pollutant that was modeled might not be indicative of the actual size of PM that air cleaners remove. $PM_{2.5}$ might be a better choice for future modeling efforts, as $PM_{2.5}$ is known to have higher associated health risks. For the sake of this research, PM_{10} might possibly be an upper bound on the size of PM that an air cleaner can remove from polluted indoor air.

At a constant particle removal efficiency, one might believe that the higher the value of ACH, the higher the exposure reduction. This was generally the case for the results obtained in this case study, however, plots depicting ACH influences on percentage exposure reduction appear to reach a plateau at higher ACHs, indicating that ACHs higher than about 6 might not offer substantially more occupant exposure reductions than lower ACHs. In terms of occupant comfort levels, ACHs that are too high may cause discomfort due to too much airflow within the room. ACHs higher than 6.75 are impractical and were not modeled for this reason.

If room air cleaners are not present in every room, the placement of the air cleaner in a room that all occupants spend significant time in throughout the day may offer the highest exposure reductions. While a room air cleaner placed in one room will affect the pollutant concentrations all throughout the house, greatest reductions will be located in the room in which the air cleaner is located. If the home is well mixed (a situation analyzed here), the location of the air cleaner is not critical. The analysis did not include a poorly mixed home; however, it is hypothesized that in a poorly mixed home, the location of the air cleaner would have a more significant impact on exposure. Thus, placing an air cleaner in a common room ensures that all occupants receive the benefits of the air cleaner.

The results show that the greatest reductions in occupant exposure were present when the occupants remained in the same room as the air cleaner for the duration of the simulation. The scenario, while not realistic, was included as part of the sensitivity analysis to obtain baseline occupant exposures in the event that all occupants remained in the same room for the entire day. Exposures increased for the adult female when occupancy cycles were assumed in the simulation; however, exposures decreased for the adult male and child as a result of their absence from the research house for a portion of the day due to their specific occupancy cycle.

Building characteristics can play an important role in occupant exposure. The size of a room sink relative to the volume of the room seems to cause an increase or decrease in exposure. Airflows between rooms and the HVAC system also seem to contribute to occupant exposure. Natural airflow between rooms might not offer sufficient airflow in the event that a pollutant source is located in one of the rooms. These factors should all be considered when assessing indoor occupant exposure.

In conclusion, the results obtained from this modeling analysis indicate different factors that may be beneficial information for a consumer who is considering purchasing a room air cleaner. In the event that cost is not important, the consumer should try to purchase an air cleaner with the highest air exchange rate and highest possible efficiency as this leads to the greatest reduction of occupant exposures to PM_{10}.

5.0 RESEARCH FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

This chapter compiles and presents the findings, conclusions, and recommendations that were identified through this research. Section 5.1 lists the key findings from the IAQ survey and the RISK modeling analysis of indoor air cleaners, occupancy cycles, and building characteristics. Section 5.2 describes the conclusions drawn from the results of this research. Section 5.3 includes a series of recommendations for improving the survey and modeling methods employed in this research, as well as recommendations for improving communications of IAQ risks.

5.1 Key Findings

The following sections discuss the key findings from the indoor air quality perception survey that was distributed to 2000 residents of North Carolina, as well as the key findings obtained through modeling four different scenarios that included varying occupancy cycles and five generic room air cleaners in RISK.

5.1.1 Survey Findings

Different types of statistical analyses were performed on the survey data compiled from the 163 returned surveys including descriptive statistics, Chi-square analysis, and correlation coefficients. The results from these analyses were all similar with exceptions as noted in Chapter 3. The total response encompassed all 163 survey responses. Sub-group A (64%) was made up of respondents who all shared the same demographics, or Caucasian homeowners who did not smoke. Sub-group B (36%) was made up of the respondents not included in sub-group A, of which over 50% were Caucasian.

Demographic results

The demographics of the survey respondents compared relatively well with the demographics for the State of North Carolina, with a few exceptions. The survey respondents were slightly more educated, more owned homes, and had higher annual household incomes that those reported in the North Carolina Census. Also, the majority of survey respondents were Caucasian (82%) as compared to the Caucasian population of North Carolina (72%). Eighty-eight percent of survey respondents reported that they were non-smokers.

The differences between the respondent demographics and the North Carolina Census information are indicators of potential sources of error in this research. It is also possible that survey respondents participated in self-selection in deciding whether or not to return the survey for analysis. However, the survey distribution list obtained from the North Carolina State Bureau of Elections was the list most representative of the general public that could be obtained at the beginning of this research. Without knowing all of the demographic parameters of the survey sample population prior to mailing the survey, it is impossible to quantify the level of error associated with the response without some level of uncertainty.

Total survey response

A few key hypotheses were posed during the development of the survey. It was hypothesized that survey respondents would acknowledge the risks associated with poor IAQ and show enough concern to be willing to take action to eliminate potential indoor air risks in their homes. It was hypothesized that respondents would not have sufficient knowledge of the types and severity of particular indoor air risks, disallowing them from appropriately identifying priority risks. Also, it was also hypothesized that respondents would be familiar with the types of indoor air cleaners available to consumers.

Upon analyzing the survey results, a key finding was that the majority of the survey respondents seemed to be in agreement with many of the survey questions, indicating that they believe IAQ is an important concern to them and their families. Respondents correctly identified priority IAQ risks of inadequate ventilation, environmental tobacco smoke, and mold, which compared well with expert opinion that was documented in Section 3.2.4. Respondents showed the strongest agreement with questions pertaining to the harmfulness of mold in the indoor environment. Other key findings include many respondents' beliefs that IAQ will be a concern for future generations, that they would take measures to reduce an air quality problem found in their homes, and that poor ventilation and cigarette smoke were the worst contributors to poor IAQ.

In the total response, a few differences between genders were noticed. The male survey respondents seemed more likely to feel as though risks associated with poor IAQ were clear to them, while the female respondents showed that they felt communication of IAQ risks could be improved. Female respondents were more likely to agree that items such as cosmetics, air fresheners, cleaning solvents, and cooking were contributors to poor IAQ than men. However, when looking at the "don't know" responses by gender, almost two females for every one male respondent answered a survey question with "don't know", indicating that females may feel less knowledgeable on the topic overall. The total number of "don't know" responses for both genders was quite high for some questions, possibly indicating that not enough information on the topic is currently available to or known by the survey respondents.

A possible deficiency in knowledge among respondents was recognized. Members of the total survey population all seemed somewhat sure that air cleaners might be able to help protect them; however, they seemed less sure if air cleaners using ozone could protect them. In fact, the highest number of "don't know" responses was obtained for the survey question that pertained to air cleaners using ozone. This finding tends to falsify the motivating hypothesis that respondents would be familiar with the types of air cleaners available to consumers. This finding also indicates that the survey population is not fully aware of the possible harmful effects associated with exposure to ozone, further indicating a need for better communication on this topic.

Sub-group results

When looking at the results for the two sub-groups in the survey population, a few differences were noticed. Sub-group A had stronger agreement that current communications on the risks of IAQ are effective. Sub-group A's responses also led to the belief that this group felt more threatened overall by the possibility of adverse effects from poor IAQ. Sub-group B seemed less informed overall on the topic of IAQ. Sub-group B was also more tentative to believe that air cleaners could help protect them from poor IAQ.

Other findings

The respondent's willingness-to-pay was assessed by including a few questions in the survey that pertained to specific costs associated with operating an indoor air cleaner. A key finding was that most of the respondents agreed they were willing-to-pay for inexpensive indoor air treatment. This finding supported the motivating hypothesis that respondents would be willing to take action to eliminate potential IAQ risks that may be present in their homes. The amount that respondents were willing-to-pay did not increase with increasing household income. Instead, most respondents selected an option of up to \$30/month for treatment of indoor air problems. Even though air cleaners have a higher start-up cost and lower regular maintenance costs, a monthly equivalent was utilized on the survey to make the values seem more attractive overall to the survey respondents.

Finally, the results obtained from the write-in questions on the survey indicated that while some respondents currently owned and operated indoor air cleaners in their homes, others were interested in purchasing an indoor air cleaner but were unsure of which brand, size, or type to buy. This led to the development of a modeling application to examine some of the different room air cleaners currently available to consumers, in an effort to aid the consumer in making this purchase. The key findings from the modeling results are located in the next section.

5.1.2 Findings Based on Modeling Analyses of Indoor Air Quality

A total of five generic room air cleaners were modeled using the indoor environmental quality software, RISK. The modeling analysis examined the effects of air cleaner performance and characteristics, occupant activity patterns, and building characteristics in reducing the PM_{10} exposure of the occupants of the simulated research house. Key findings are presented below.

Air cleaner parameters

Upon conducting the exposure reduction analysis in which all air cleaners had a particle removal efficiency of 99.97%, the room air cleaners with higher ACHs performed the best and greatly reduced occupant exposures to harmful PM_{10}. In fact, air cleaners with an ACH of 6.75 reduced occupant exposures by up to 40% overall. Thus, the greater the capacity of air that an air cleaner can treat, the greater the exposure reduction. However, the marginal rate of increase in the percentage exposure reduction appeared to diminish with increasing ACHs, indicating that air cleaners having an ACH of greater than 6 might not offer much greater exposure reduction capabilities. Also, air cleaners having an ACH of greater than 6 might lead to comfort issues for house occupants, as high ACHs can create a detectable breeze or draft. While the exposure reductions are specific to the simulated research house, similar results could be expected for homes of like size.

The key finding of the sensitivity analysis on particle removal efficiency is that varying particle removal efficiency by 50 percentage points does not affect occupant exposures as much as varying air cleaner ACH from 1 to 6.75. Therefore, air cleaner ACH is the more sensitive variable and important determinant for consumers purchasing an air cleaner for their homes.

A critical need for more data emerged from the results of this analysis. A source of uncertainty exists due to the absence of data indicating the PM sizes for which particle removal efficiencies are rated to remove. Thus, as more data relating particle removal efficiencies to the PM sizes for which they are rated becomes available, the findings of this research can be stated with higher certainty.

Occupancy cycles

The key finding of the analyses on occupancy cycles indicated that the greatest occupant exposure reductions occur when the occupants spend the greatest duration of time in the same room as the air cleaner; however, the differences in occupant exposures resulting from varying the occupancy cycles were not very large. When occupants cycle through daily activities, exposures are slightly higher than if occupants remained in the same room as the air cleaner for the entire day. This result may indicate that air cleaner placement in a home is a important element in order for occupants to receive the greatest exposure reductions and benefits offered by the air cleaner.

Building characteristics

Key findings from analyzing the effects of differing building characteristics in the research house indicated that a variety of factors can influence occupant exposure levels. Rooms with higher overall airflows tended to have lower occupancy exposures. The size of the pollutant sink relative to the size of the room seems to impact exposure levels. For example, small pollutant sinks located in rooms having small volumes can lead to high exposures. The two bathrooms of the research house fell into this category.

The mixing of the air in a home can also affect occupancy exposures. While the research house was assumed to be well-mixed for the presented case studies, occupant exposures would be expected to differ in the event that this assumption was not made. For example, a room that is not particularly well-mixed and contains an indoor pollutant source would be expected to contain higher pollutant concentrations, and thus result in higher occupant exposures, than a room that was well-mixed.

5.2 Conclusions

Both an indoor air perception survey and modeling simulation of room air cleaners and occupant exposures were conducted in this research. Key findings were drawn from the results of both analyses. The following conclusions have been made from the obtained results.

The results from the survey indicate a need for continued and/or improved communication of the risks associated with poor IAQ. A general awareness of IAQ risks was indicated by the survey results, though, some knowledge gaps exist as respondents seemed uncertain of specific aspects pertaining to IAQ. Over 75% of respondents seemed aware of IAQ health risks and even claimed to believe that these risks are effectively communicated, however, the occurrence of unsure (don't know) survey responses accounted for as high as 34% of the total response for specific survey questions. Respondents showed some uncertainty regarding lower priority indoor air risks as well as with specific types of air cleaners available to consumers. The goal of risk communication of IAQ risks should be to assure that all members of the population are adequately informed on all aspects pertaining to the risk.

One major trend in the survey results showed that the majority of respondents were familiar with indoor mold problems. Those respondents familiar with mold also believed that IAQ will continue to be a problem for future generations. Over 90% of respondents consistently identified mold as a major indoor air risk, indicating that the recent and past media attention mold has received, as documented in Section 1.3.3, has been effective. Respondents recognized that IAQ problems cannot be solved overnight and that these problems will continue.

The survey results also led to conclusions concerning air cleaners utilizing ozone and respondent's willingness-to-pay for indoor air treatment. The survey responses indicated a need for better communication on the health risks of ozone. While respondents believed that air cleaners could help protect them from IAQ risks, they seemed unsure of air cleaners that utilized ozone. From the write-in question results, sixteen respondents displayed an interest in obtaining information that would aid them in selecting an air cleaner for their homes. Over half of the respondents also indicated that they would be willing to spend approximately $30/month for indoor air treatment.

The results from the modeling analyses of indoor factors performed in RISK showed that the effectiveness of an air cleaner at reducing occupant PM_{10} exposures is related to the ACH provided by the air cleaner. Air cleaners with higher ACHs resulted in higher occupant PM_{10} exposure reductions. The greatest exposure reductions occur when the occupants spend the longest lengths of time in the same room as the air cleaner. Also, building characteristics such as the volume of the room, sink areas, and airflow can greatly impact occupant exposures.

The occupant exposure levels estimated in the case studies were not significant with respect to the ambient air standard for PM_{10}. No indoor air standard currently exists for PM_{10}. However, occupant exposures may increase and approach the ambient standard of 150 $\mu g/m^3$ in the event that an indoor source is introduced into the modeling scenarios.

Through the modeling analysis, a deficiency in the available data for air cleaners was identified. Little information regarding particle removal efficiency as a function of particle size is available for the air cleaners currently available to the public. This information is critical for accurately predicting indoor pollutant concentrations and exposures when modeling the indoor environment.

While exposure reduction should be a key parameter in selecting an air cleaner, often cost may be the deciding factor for many families. A cost analysis was not performed in this research; however, it is important for the consumer to do his/her research when selecting a room air cleaner. Information on particle removal efficiencies can typically be found on product packaging. Additionally, CADRs are being included on packaging of manufacturers who have their air cleaners tested and certified using the CADR system. Models with a listed CADR are guaranteed to perform at the level indicated. Therefore, it is beneficial for consumers to familiarize themselves with CADRs and select the highest CADR available for the size of the room in which they wish to place an air cleaner.

As more is learned about the possible indoor air pollutants that may be encountered on a daily basis, information should be made publicly available by researchers and other reliable peer-reviewed sources reporting the new findings. In reaction to the continued discovery of indoor air pollutants, consumers may question the risks that these pollutants pose to themselves, their families, and their pets. People may want to know about ways in which they can protect their assets and loved ones. People may also want to learn about contaminant exposure levels to determine how much is too much and how much is safe and/or acceptable. Risk studies that include surveys and modeling seek to answer these questions and provide consumers with exposure and risk-related information.

5.3 Recommendations

This final section offers recommendations for improvements to the research methodology utilized in this research. Also, a list of priorities and recommendations for communicating the hazards and risks of poor IAQ to the public is included.

5.3.1 Survey Improvements

A number of factors affecting the survey response should be improved upon. Higher response rates should be obtained in future surveys by utilizing return envelopes with real stamps affixed to them, instead of business-reply envelopes. Real stamps have been shown to establish feelings of trust with the respondent, thus improving the likelihood of the respondent submitting a survey response. This would also reduce the overall sampling error associated with the survey results.

The inclusion of a small monetary incentive in the survey mailing should be incorporated into the survey methodology and will improve survey response rates. Also, multiple contacts with the survey recipients will provide an increase in overall survey response. For example, pre-survey notification, postcard follow-ups, and additional copies of the survey sent to the recipients on the mailing list will lead to increases survey response rates.

The effectiveness of survey questions should be tested by including duplicate questions that are worded differently, yet seek to obtain the same response. The results from these questions can then be checked to assure that survey measurement error remains at a minimum.

When data explaining the risk levels of potential indoor pollutants is made available, an additional analysis should be conducted that compares the results of respondents' analysis of potential indoor pollutant contributors to those identified and prioritized by risk experts. This analysis should aid in indicating the amount of knowledge that survey respondents have regarding potential pollutant sources and will be helpful for prioritizing future risk communication messages.

Future versions of the survey should include more questions that are designed to better infer the respondent's perceptions regarding poor IAQ. Questions should be concerned with personal relation/experiences to the hazard and feelings of dread and/or fear that respondents may have. The results obtained from these types of questions should provide clearer conclusions regarding the need for future risk communication on IAQ topics.

The survey improvements mentioned in this section should be funded by the US EPA STAR grants program, which currently lists human health risk assessments as one of its main focuses. Adequate resources for a more extensive IAQ survey will lead to more conclusive findings.

5.3.2 Air Cleaner Modeling Improvements

In future research, it would be beneficial to analyze more house configurations to further determine the effectiveness of the model. Actual air quality instrumentation at the research house and additional sites, along with greater efforts at model validation and evaluations would aid in eliminating possible errors.

Differences between PM_{10} exposures and concentrations in the research house were often small between different rooms. Future research should implement a modeling strategy to assess the implications of a house that is not well-mixed, a more realistic case.

The air exchange rates for the generic air cleaners in this research ranged from 1 to 6.75, as indicated by the manufacturers. This represents a large difference between the highest and lowest air exchange capacity of the air cleaners. Actual measurement and validation of these air exchange rates would improve the model results and reduce error. Therefore, another recommendation is that air exchange rates for each air cleaner should be measured by AHAM and reported alongside the CADR found on product packaging.

When better information relating particle size, particle removal efficiencies, and ACHs becomes available, a cost analysis should be completed to determine whether higher priced air cleaners provide higher levels of exposure reduction to consumers.

For this study, no pollutant source was simulated to be located in the research house. A source or numerous sources should be added in future modeling applications to determine their effects on occupant exposure. For example, sources could be associated with cooking activities, use of the washing machine, showering, and vacuuming.

Finally, it would be interesting to examine the effect of different occupancy cycles in the research house on occupant PM exposure. For example, differing numbers of occupants should be simulated in the research house to determine if this affects the percentage of exposure reduction by the air cleaners. More complex occupancy cycles that closely represent everyday activities, along with varying mixing ratios for different rooms of the house, should be incorporated into the analysis to provide a more realistic modeling application. Also, multiple air cleaners should be introduced into the simulation to determine the effects of their locations on occupant exposure.

5.3.3 Risk Communication Improvements and Priorities

The results from the indoor air perception survey indicate that continued and/or improved communication of the risks associated with poor IAQ is needed. The following improvements to the risk communication process on the topic of indoor air quality should be considered.

The survey results clearly showed that the survey population was aware of the risks of indoor mold. This indicates that the widespread media coverage (see reference in Section 1.3.3) that mold has received has been effective at informing the public of the potential harm when exposed to indoor mold. Similarly, increased media attention is now being given to radon. If similar attention can be given to some of the other lesser known indoor air pollutants, such as cleaning chemicals, air fresheners, candles, and cosmetics, the public will be more informed. A key priority for risk communication should be providing accurate, detailed information in a manner that does not scare the public. Risk communication that causes feelings of panic is ineffective and should be avoided.

The overall goal of risk communication of indoor air pollution should be an increased awareness of the public on the topic. Researchers and agencies such as the EPA should take their findings and create colorful, interesting, and informative television programming, articles, and/or press releases with bold messages. Communication should be designed to catch and hold the public's attention. Risk messages should be relayed in a positive manner, as well. While the possible effects from exposure to indoor air pollutants are negative, communication should be structured to inform the public how to reduce the negative exposures, thus creating positive outcomes.

Clear information on possible adverse health effects should be included in the increased media coverage of indoor air pollutants. Environmental professionals, such as the EPA, should provide detailed methods by which risk information should communicated by the media. Failure of the media to report only the facts should result in strict penalties. By mentioning that effects can be more pronounced and dangerous to children and the elderly, more people might show concern. Adults are protective of children and might be more inclined to take action against poor IAQ knowing that children are more at risk.

Along with increased media coverage of the possible health risks and sources of indoor air pollution, some coverage of indoor air cleaners should be included. Commercials and advertisements currently exist for indoor air cleaners; however, AHAM should create new programming that includes information on CADR and ACH, and explains criteria for selecting an indoor air cleaner. As indicated by the survey results, this would be beneficial and well-received by the public. While AHAM may not be considered the most trustworthy of sources, approximately 80% of air cleaners available to consumers include a CADR rating on their product packaging. AHAM is an industry-funded organization whose mission is to enhance the value of the home appliance industry through leadership, public education and advocacy. Though the potential for AHAM to be acting in self-interest exists, their mission statement instills good faith that they would be the best entity for educating the public on their product, CADR.

Finally, a set of safe levels or guidelines for indoor air pollutant exposures should be identified and then communicated to the public. EPA's Indoor Environmental Management

Branch is currently researching this and would be a trustworthy source for communicating this information to the public. If the public was aware of safe levels, and an inexpensive method for assessing one's home was made available, more people would be willing to consider and address the possibilities of poor IAQ in their homes.

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APPENDIX A
NUMERIC CODES FOR DEMOGRAPHIC QUESTIONS

Numeric Codes for Analyzing Demographic Questions in SAS

1.	Male	1	6.	Own	1
	Female	2		Rent	2
2.	No code		7.	No code	
3.	Middle School	1	8.	Dog	1
	High School	1		Cat	2
	College	2		Other	.
	Graduate School	3		No Pets	0
4.	Caucasian	1	9.	No one	1
	African American	2		Myself	2
	Hispanic	3		Someone else	2
	Asian	3			
	Other	3	10.	No one	1
				Myself	2
5.	House	1		Someone else	2
	Apartment	2			
	Townhouse	3	11.	$20,000 or less	1
	Condo	4		$20,001 to $50,000	2
	Other	5		$50,001 to $100,000	3
				$100,001 or more	4

*** All “don’t know” responses and those questions for which no response was given (blanks) received a “**.**” in SAS. Each “**.**” was considered a “miss” for the analysis.

APPENDIX B
EXPLANATION, SAS CODE, AND OUTPUT EXAMPLE FOR CHI-SQUARE ANALYSIS

Explanation of how SAS computes Chi-square Probabilities:

For the survey analysis, the expected frequencies for computing the Chi-square analysis are not known. When expected frequencies are not known, the default procedure used by SAS to compute Chi-square probability uses the test for equal proportions. The test for equal proportions tests the data to determine if the proportions (probabilities of success) in several groups are the same.

For the frequency tables used in this research, the CHISQ option in the TABLES statement computes a chi-square goodness-of-fit test. Let C denote the number of classes, or levels, in the table. Let f_i denote the frequency of class i (or the number of observations in class i) for $i = 1,2,\ldots,C$. Then PROC FREQ computes the chi-square statistic as:

$$\Phi = \sum_{i=1}^{C} \frac{(f_i - e_i)^2}{e_i}$$

where e_i is the expected frequency for class i under the null hypothesis and is calculated as:

$$e_i = \frac{RTxCT}{N}$$

where RT = Row Total from frequency table
CT = Column Total from frequency table
N = Total Sample Size

The following example details the computation of the Chi-Square probability for Survey Question 10 and Demographic Question 11. Please refer to the frequency table on page 150 for values of row frequencies, column frequencies, and total sample size. The expected frequencies are calculated first:

Row 1/Column 1	(33x18)/141 = 3.51
Row 1/Column 2	(33x35)/141 = 8.19
Row 1/Column 3	(33x61)/141 = 14.28
Row 1/Column 4	(33x30)/141 = 7.02
Row 2/Column 1	(37x15)/141 = 3.94
etc…	

Next, the degrees of freedom are calculated as:

DF = (R-1)(C-1) = (3-1)(4-1) = (2)(3) = 6

where R = total number of rows
C = total number of columns

The following calculation solves for the Chi-Square statistic:

$$\Phi = [(10-3.51)/3.51]^2 + [(5-8.19)/8.19]^2 + [(10-14.28)/14.28]^2 + [(8-7.02)/7.02]^2 + [(4-3.94)/3.94]^2 + [(10-9.18)/9.18]^2 \ldots$$

$$\Phi = 22.44$$

Finally, a Chi-Square table is utilized to determine the Chi-Square probability. With a Chi-Square statistic of 22.44 and 6 degrees of freedom, the resulting probability is 0.0010. This probability is less than 0.05 and is considered significant. The frequency table is then examined to infer the relationship that exists between the two questions. Upon reviewing the frequency table, it can be inferred that those survey respondents with higher incomes were more likely to answer that Indoor Air Quality risks are not effectively communicated by environmental professionals.

SAS Code Example:

This code example is for Survey Questions 1 through 10 as they are compared to Demographic Questions 11.

```
data a;
input x1-x11;
x1c=(x1=1)+(x1=2)+2*(x1=3)+3*(x1=4)+3*(x1=5);
if (x1=.) then x1c=.;
x2c=(x2=1)+(x2=2)+2*(x2=3)+3*(x2=4)+3*(x2=5);
if (x2=.) then x2c=.;
x3c=(x3=1)+(x3=2)+2*(x3=3)+3*(x3=4)+3*(x3=5);
if (x3=.) then x3c=.;
x4c=(x4=1)+(x4=2)+2*(x4=3)+3*(x4=4)+3*(x4=5);
if (x4=.) then x4c=.;
x5c=(x5=1)+(x5=2)+2*(x5=3)+3*(x5=4)+3*(x5=5);
if (x5=.) then x5c=.;
x6c=(x6=1)+(x6=2)+2*(x6=3)+3*(x6=4)+3*(x6=5);
if (x6=.) then x6c=.;
x7c=(x7=1)+(x7=2)+2*(x7=3)+3*(x7=4)+3*(x7=5);
if (x7=.) then x7c=.;
x8c=(x8=1)+(x8=2)+2*(x8=3)+3*(x8=4)+3*(x8=5);
if (x8=.) then x8c=.;
x9c=(x9=1)+(x9=2)+2*(x9=3)+3*(x9=4)+3*(x9=5);
if (x9=.) then x9c=.;
x10c=(x10=1)+(x10=2)+2*(x10=3)+3*(x10=4)+3*(x10=5);
if (x10=.) then x10c=.;
cards;
1      2      1      2      2      1      1      1      1      2      4
3      4      4      1      4      .      .      2      2      5      4
1      1      1      2      1      .      2      1      1      4      .
1      2      1      1      3      2      1      1      1      3      3
1      2      1      .      .      .      .      1      1      4      2
2      4      2      1      1      1      2      1      1      5      3
1      3      1      2      2      4      2      2      3      2      3
1      1      1      1      1      4      3      2      3      5      2
1      2      3      1      2      3      4      1      1      4      3
1      5      .      4      .      .      .      2      .      5      2
1      1      1      1      2      2      2      1      1      4      3
1      1      1      1      2      1      1      1      2      3      3
1      2      1      2      3      3      2      1      1      4      3
1      2      1      1      1      1      1      1      1      4      4
1      1      3      3      2      1      1      1      1      4      3
4      3      1      1      1      4      4      1      1      5      4
1      1      1      1      1      .      .      1      1      5      3
1      2      1      .      1      2      2      1      1      3      4
2      2      2      3      3      2      2      2      2      4      .
2      .      3      .      .      2      3      2      .      3      3
1      1      2      1      2      3      4      1      1      4      3
2      2      1      1      1      1      2      2      1      3      3
2      .      1      .      .      2      1      1      1      5      3
1      4      2      2      2      4      2      1      2      5      3
1      1      1      1      1      3      3      1      1      3      3
1      .      1      .      .      .      .      1      1      .      .
```

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1	3	2	.	2	4	4	1	2	4	2
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1	2	1	1	1	1	1	1	1	4	3
1	.	.	.	.	.	.	.	1	1	1
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2	5	.	.	.	2	3	1	.	5	3
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.	.	.	.	.	.	.	.	.	.	3
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3	.	1	.	.	.	.	1	.	5	2
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1	.	.	.	1	3	3	1	1	5	3
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1	2	1	.	.	.	.	2	1	4	2
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1	5	.	.	.	.	.	1	.	.	2
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1	1	1	1	1	.	.	1	1	1	1
5	2	2	.	2	.	.	1	.	5	4
2	2	3	1	1	4	5	1	2	3	2
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1	1	.	.	5	1	1	1	1	5	.
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2	2	2	3	3	2	2	2	1	4	3
1	2	1	1	1	1	1	1	1	2	3
1	3	2	4	2	2	3	1	2	4	4

2	1	1	2	2	2	1	1	2	4	3
1	5	1	.	.	.	.	1	1	5	2
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2	3	1	.	1	4	4	1	1	4	1
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1	1	2	1	4	1	1	1	1	3	3
1	1	5	1	2	1	1	1	1	3	.
1	2	2	2	1	2	2	1	1	3	3
1	2	2	3	2	2	2	1	1	2	3
1	2	1	1	2	2	2	1	1	2	4
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1	1	1	1	1	1	1	1	1	5	2
1	1	2	1	1	3	3	1	1	1	1
1	2	3	3	1	3	3	1	1	5	3
.	2	3	2	4	.	.	.	.	3	1
1	2	4	1	2	5	5	1	1	5	3
2	1	2	2	.	1	1	1	1	3	4
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2	2	1	2	3	3	3	2	2	2	4
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1	2	1	1	1	4	4	1	1	5	3
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1	2	2	2	2	4	4	1	1	4	3
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5	5	5	1	2	1	.	1	.	1	1
2	1	1	1	1	1	1	1	1	2	2
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2	2	2	.	2	.	.	1	1	4	2
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2	.	1	1	2	.	.	2	5	2	1
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1	4	2	.	.	.	.	1	1	5	2
3	2	1	2	1	.	5	2	3	3	2
1	1	1	1	1	3	1	1	1	1	2
1	3	1	3	2	3	3	2	1	4	4
2	3	2	3	3	.	2	1	2	4	3
1	1	2	1	2	1	1	1	1	3	3
1	.	.	.	1	3	2	1	1	3	4
2	2	2	3	2	2	2	2	1	2	4
1	1	1	1	1	1	2	1	1	5	4
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1	1	1	1	1	1	1	1	1	2	.

```
1       2       2       2       2       4       4       1       1       2       .
1       2       2       3       3       .       .       3       2       3       3
1       1       1       1       1       1       1       1       1       2       .
1       2       1       1       4       .       .       1       1       3       2
2       2       2       3       3       2       2       2       2       3       1
4       5       5       2       .       5       5       1       2       5       2
2       2       5       1               1       1       1       1       4       3
2       4       2       .       2       2       4       2       2       5       3
2       3       2       2       1       4       4       1       1       2       2
1       1       1       1       1       1       1       1       1       2       3
2       1       2       1       1       1       2       1       1       2       .
1       2       1       1       2       3       3       1       1       3       3
2       3       1       3       2       3       1       1       2       4       3
2       3       1       1       .       1       1       1       2       4       4
2       3       1       1       2       .       .       2       2       4       2
1       .       1       1       .       .       .       1       1       5       3
1       4       4       1       2       4       4       1       1       5       4
1       2       1       2       1       1       1       1       1       4       4
1       4       2       2       2       4       4       1       1       5       4
2       .       .       2       .       5       5       1       2       4       3
2       5       2       3       2       5       5       2       2       5       3
3       2       1       2       1       2       2       2       3       3       2
1       1       1       2       .       2       1       .       2       2       .
proc freq data=a;
tables x1c*x11/chisq;
run;
proc freq data=a;
tables x2c*x11/chisq;
run;
proc freq data=a;
tables x3c*x11/chisq;
run;
proc freq data=a;
tables x4c*x11/chisq;
run;
proc freq data=a;
tables x5c*x11/chisq;
run;
proc freq data=a;
tables x6c*x11/chisq;
run;
proc freq data=a;
tables x7c*x11/chisq;
run;
proc freq data=a;
tables x8c*x11/chisq;
run;
proc freq data=a;
tables x9c*x11/chisq;
run;
proc freq data=a;
tables x10c*x11/chisq;
run;

quit;
```

SAS Output Example

This is the result for Survey Question 10 and Demographic Question 11:

Table of x10c by x11

x10c / x11 Frequency Percent Row Pct Col Pct	1	2	3	4	Total
1	10 7.09 30.30 66.67	5 3.55 15.15 14.29	10 7.09 30.30 16.39	8 5.67 24.24 26.67	33 23.40
2	4 2.84 10.81 26.67	10 7.09 27.03 28.57	18 12.77 48.65 29.51	5 3.55 13.51 16.67	37 26.24
3	1 0.71 1.41 6.67	20 14.18 28.17 57.14	33 23.40 46.48 54.10	17 12.06 23.94 56.67	71 50.35
Total	15 10.64	35 24.82	61 43.26	30 21.28	141 100.00

Frequency Missing = 21

Statistics for Table of x10c by x11

Statistic	DF	Value	Prob
Chi-Square	6	22.4391	0.0010
Likelihood Ratio Chi-Square	6	22.2447	0.0011
Mantel-Haenszel Chi-Square	1	5.8971	0.0152
Phi Coefficient		0.3989	
Contingency Coefficient		0.3705	
Cramer's V		0.2821	

Effective Sample Size = 141
Frequency Missing = 21

WARNING: 13% of the data are missing.

APPENDIX C
PILOT SURVEY

Indoor Air Quality Survey:
This short survey is designed to obtain information regarding your perspective of indoor air quality risks and the communication of those risks. All survey responses will be kept anonymous.

Check one: Male_____ Female_____ Age: _____
Estimated number of hours spent indoors each day: ______
Do you… own your home? ☐ rent? ☐ live with parents? ☐ Other? ☐

	Definitely Agree	Somewhat Agree	Neutral	Somewhat Disagree	Definitely Disagree	Don't know
1. Indoor Air Quality (IAQ) is an important concern.	☐	☐	☐	☐	☐	☐
2. Poor IAQ can be harmful to one's health.	☐	☐	☐	☐	☐	☐
3. Poor IAQ is more harmful to children and the elderly.	☐	☐	☐	☐	☐	☐
4. Poor IAQ can be fatal if untreated.	☐	☐	☐	☐	☐	☐
5. IAQ is not a concern to my family.	☐	☐	☐	☐	☐	☐
6. Living with poor IAQ is a risk to one's health.	☐	☐	☐	☐	☐	☐
7. The risks associated with poor IAQ are clear to me.	☐	☐	☐	☐	☐	☐
8. Outdoor air is more polluted than indoor air.	☐	☐	☐	☐	☐	☐
9. I am aware of radon poisoning.	☐	☐	☐	☐	☐	☐
10. Radon poisoning is not currently a threat in my household.	☐	☐	☐	☐	☐	☐
11. Mold found in your home can be harmful to one's health.	☐	☐	☐	☐	☐	☐
12. I have learned about IAQ from TV commercials and programming.	☐	☐	☐	☐	☐	☐
13. I have learned about IAQ from newspapers, magazines, or other periodicals.	☐	☐	☐	☐	☐	☐
14. Media (TV, newspapers, etc) has effectively communicated the dangers of poor IAQ.	☐	☐	☐	☐	☐	☐
15. Air cleaners and filters (such as HEPA) can keep me safe from poor IAQ.	☐	☐	☐	☐	☐	☐
16. The risks associated with poor IAQ can be more effectively communicated to the public.	☐	☐	☐	☐	☐	☐
17. IAQ was less of a concern ten years ago than it is today.	☐	☐	☐	☐	☐	☐
18. Poor IAQ will not be a major problem for future generations.	☐	☐	☐	☐	☐	☐

--

19. I have heard of using special filters to clean indoor air.	❑	❑	❑	❑	❑	❑
20. I own a home air cleaner or other filtration system.	❑	❑	❑	❑	❑	❑
21. I have heard of using ultraviolet radiation to disinfect indoor air.	❑	❑	❑	❑	❑	❑
22. I feel that I am in no danger from the possible effects of IAQ.	❑	❑	❑	❑	❑	❑
-- 23. I often smoke in indoor areas.	❑	❑	❑	❑	❑	❑
24. Harmful health effects from poor IAQ are unavoidable.	❑	❑	❑	❑	❑	❑
25. If an IAQ problem was found in my household, I would take steps to eliminate it.	❑	❑	❑	❑	❑	❑
26. I want to protect myself from the adverse effects of poor IAQ.	❑	❑	❑	❑	❑	❑
27. If a home air filter or cleaner was guaranteed to protect me, I would purchase one.	❑	❑	❑	❑	❑	❑
28. If IAQ improvement for my home was inexpensive, I would be interested.	❑	❑	❑	❑	❑	❑
29. I believe that many people are not aware of poor IAQ problems.	❑	❑	❑	❑	❑	❑

Do these things contribute to poor indoor air quality? Check:	Yes	No
30. Cooking/Oven Emissions	☐	☐
31. Cigarette Smoke	☐	☐
32. Copy Machines	☐	☐
33. Microwaves..	☐	☐
34. Inadequate Ventilation	☐	☐
35. Improper Lighting	☐	☐
36. Excessive Noise	☐	☐
37. Indoor Plants	☐	☐
38. Mold	☐	☐
39. Candles/Fireplaces	☐	☐

APPENDIX D
95% CONFIDENCE INTERVALS ON MEANS

Pilot Survey 95% Confidence Intervals

Question	Total Survey Results			
	Mean	Confidence Level (95%)	Confidence Interval	
			From	To
1	4.49	0.23	4.26	4.72
2	4.70	0.14	4.56	4.83
3	4.17	0.37	3.80	4.54
4	3.43	0.42	3.01	3.85
5	2.26	0.37	1.90	2.63
6	4.40	0.23	4.17	4.62
7	2.58	0.37	2.21	2.96
8	2.42	0.42	1.99	2.84
9	3.34	0.41	2.93	3.75
10	2.09	0.52	1.57	2.62
11	4.42	0.23	4.19	4.64
12	2.40	0.32	2.08	2.71
13	2.62	0.36	2.26	2.98
14	2.21	0.30	1.91	2.50
15	2.96	0.44	2.53	3.40
16	4.09	0.24	3.85	4.34
17	2.60	0.49	2.11	3.09
18	1.79	0.34	1.45	2.13
19	3.70	0.39	3.30	4.09
20	1.83	0.41	1.42	2.24
21	1.77	0.40	1.38	2.17
22	1.83	0.29	1.54	2.12
23	1.23	0.27	0.96	1.49
24	2.02	0.36	1.66	2.38
25	4.47	0.18	4.29	4.65
26	4.60	0.14	4.46	4.75
27	4.08	0.28	3.79	4.36
28	4.66	0.14	4.52	4.80
29	4.38	0.18	4.20	4.55
30	0.89	0.09	0.80	0.97
31	0.98	0.04	0.94	1.02
32	0.51	0.14	0.37	0.65
33	0.30	0.13	0.18	0.43
34	0.96	0.05	0.91	1.01
35	0.19	0.11	0.08	0.30
36	0.15	0.10	0.05	0.25
37	0.36	0.13	0.23	0.49
38	0.98	0.04	0.94	1.02
39	0.91	0.08	0.83	0.99

Pilot Survey 95% Confidence Intervals

Question	Male Survey Results			
	Mean	Confidence Level (95%)	Confidence Interval	
			From	To
1	4.57	0.18	4.39	4.76
2	4.69	0.16	4.53	4.84
3	4.17	0.47	3.70	4.64
4	3.71	0.42	3.29	4.14
5	2.17	0.46	1.71	2.64
6	4.31	0.32	4.00	4.63
7	2.63	0.46	2.17	3.08
8	2.11	0.48	1.63	2.59
9	3.60	0.47	3.13	4.07
10	2.54	0.64	1.90	3.18
11	4.46	0.20	4.25	4.66
12	2.34	0.36	1.98	2.70
13	2.60	0.42	2.18	3.02
14	2.09	0.35	1.73	2.44
15	3.03	0.49	2.54	3.51
16	3.97	0.33	3.65	4.30
17	2.63	0.60	2.03	3.23
18	1.97	0.43	1.54	2.40
19	3.94	0.43	3.51	4.38
20	2.00	0.50	1.50	2.50
21	2.11	0.51	1.60	2.63
22	1.97	0.32	1.66	2.29
23	1.34	0.39	0.95	1.74
24	1.83	0.43	1.40	2.26
25	4.49	0.22	4.27	4.70
26	4.54	0.19	4.36	4.73
27	4.06	0.30	3.76	4.36
28	4.66	0.16	4.50	4.82
29	4.29	0.22	4.06	4.51
30	0.83	0.13	0.70	0.96
31	0.97	0.06	0.92	1.03
32	0.54	0.17	0.38	0.71
33	0.26	0.15	0.11	0.41
34	0.97	0.06	0.92	1.03
35	0.17	0.13	0.04	0.30
36	0.14	0.12	0.02	0.26
37	0.34	0.16	0.18	0.50
38	0.97	0.06	0.92	1.03
39	0.91	0.09	0.82	1.01

Pilot Survey 95% Confidence Intervals

Question	Female Survey Results			
	Mean	Confidence Level (95%)	Confidence Interval	
			From	To
1	4.33	0.59	3.74	4.93
2	4.72	0.27	4.46	4.99
3	4.17	0.60	3.57	4.76
4	2.89	0.89	1.99	3.78
5	2.44	0.60	1.85	3.04
6	4.56	0.24	4.32	4.79
7	2.50	0.66	1.84	3.16
8	3.00	0.78	2.22	3.78
9	2.83	0.76	2.07	3.60
10	1.22	0.79	0.44	2.01
11	4.33	0.55	3.78	4.88
12	2.50	0.64	1.86	3.14
13	2.67	0.69	1.98	3.36
14	2.44	0.53	1.91	2.98
15	2.83	0.89	1.95	3.72
16	4.33	0.32	4.02	4.65
17	2.56	0.87	1.68	3.43
18	1.44	0.53	0.91	1.98
19	3.22	0.77	2.45	3.99
20	1.50	0.70	0.80	2.20
21	1.11	0.50	0.61	1.61
22	1.56	0.60	0.96	2.15
23	1.00	0.16	0.84	1.16
24	2.39	0.66	1.73	3.04
25	4.44	0.33	4.12	4.77
26	4.72	0.21	4.51	4.94
27	4.11	0.61	3.50	4.72
28	4.67	0.27	4.39	4.94
29	4.56	0.28	4.27	4.84
30	1.00	0.00	1.00	1.00
31	1.00	0.00	1.00	1.00
32	0.44	0.24	0.21	0.68
33	0.39	0.23	0.15	0.62
34	0.94	0.11	0.84	1.05
35	0.22	0.21	0.02	0.43
36	0.17	0.19	0.00	0.35
37	0.39	0.23	0.16	0.62
38	1.00	0.00	1.00	1.00
39	0.89	0.15	0.74	1.04

Main Survey Total Response 95% Confidence Intervals

Question	Total Survey Results			
	Mean	Confidence Level (95%)	Confidence Interval	
			From	To
1	1.45	0.12	1.33	1.58
2	1.87	0.17	1.70	2.03
3	1.48	0.14	1.33	1.62
4	1.44	0.13	1.31	1.57
5	1.56	0.14	1.42	1.71
6	1.70	0.19	1.51	1.89
7	1.76	0.19	1.57	1.95
8	1.19	0.07	1.13	1.26
9	1.26	0.10	1.16	1.36
10	3.30	0.19	3.11	3.49
11	2.09	0.14	1.95	2.24
12	1.96	0.16	1.80	2.12
13	3.56	0.16	3.39	3.72
14	3.16	0.19	2.96	3.35
15	1.23	0.07	1.17	1.30
16	2.12	0.16	1.96	2.28
17	1.66	0.15	1.51	1.80
18	1.60	0.14	1.46	1.73
19	1.38	0.08	1.31	1.46
20	1.27	0.14	1.13	1.41
21	1.41	0.08	1.33	1.48
22	1.75	0.06	1.69	1.82
23	-	-	-	-
24	2.02	0.11	1.91	2.14
25	2.17	0.13	2.04	2.30
26	1.73	0.14	1.60	1.87
27	1.26	0.09	1.17	1.35
28	1.23	0.12	1.11	1.35
29	1.08	0.07	1.01	1.15
30	1.95	0.12	1.83	2.07
31	1.65	0.11	1.54	1.76
32	1.82	0.13	1.69	1.95
33	2.00	0.12	1.88	2.12
34	1.45	0.10	1.35	1.55
35	2.13	0.14	1.99	2.27

Main Survey Total Response 95% Confidence Intervals

Question	Male Survey Results			
	Mean	Confidence Level (95%)	Confidence Interval	
			From	To
1	1.50	0.15	1.35	1.65
2	1.98	0.28	1.71	2.26
3	1.50	0.22	1.28	1.72
4	1.70	0.22	1.48	1.91
5	1.62	0.23	1.39	1.85
6	1.67	0.25	1.42	1.91
7	1.76	0.23	1.53	1.99
8	1.30	0.11	1.19	1.41
9	1.35	0.18	1.17	1.53
10	3.36	0.27	3.09	3.64
11	2.30	0.23	2.08	2.53
12	2.03	0.23	1.80	2.26
13	3.56	0.27	3.29	3.83
14	3.52	0.30	3.22	3.82
15	1.24	0.11	1.14	1.35
16	2.42	0.25	2.17	2.67
17	1.91	0.25	1.66	2.16
18	1.74	0.24	1.50	1.98
19	1.40	0.12	1.28	1.52
20	1.21	0.12	1.09	1.32
21	1.50	0.12	1.38	1.62
22	1.81	0.09	1.72	1.90
23	-	-	-	-
24	2.00	0.18	1.82	2.18
25	2.39	0.18	2.21	2.57
26	1.85	0.22	1.63	2.06
27	1.41	0.16	1.24	1.57
28	1.42	0.24	1.18	1.65
29	1.06	0.13	0.93	1.19
30	2.11	0.17	1.94	2.28
31	1.80	0.14	1.66	1.94
32	1.95	0.19	1.76	2.14
33	2.00	0.18	1.82	2.18
34	1.57	0.17	1.40	1.74
35	2.52	0.22	2.30	2.74

Main Survey Total Response 95% Confidence Intervals

Question	Female Survey Results			
	Mean	Confidence Level (95%)	Confidence Interval	
			From	To
1	1.43	0.18	1.25	1.60
2	1.79	0.21	1.58	2.01
3	1.47	0.19	1.27	1.66
4	1.26	0.16	1.10	1.42
5	1.51	0.18	1.32	1.69
6	1.72	0.27	1.45	1.98
7	1.75	0.29	1.46	2.03
8	1.12	0.08	1.04	1.20
9	1.20	0.11	1.09	1.31
10	3.28	0.26	3.03	3.54
11	1.96	0.19	1.77	2.14
12	1.91	0.22	1.68	2.13
13	3.55	0.21	3.34	3.76
14	2.93	0.24	2.68	3.17
15	1.23	0.09	1.14	1.32
16	1.92	0.20	1.72	2.11
17	1.46	0.17	1.30	1.63
18	1.48	0.16	1.32	1.64
19	1.36	0.10	1.26	1.46
20	1.30	0.23	1.08	1.53
21	1.35	0.10	1.25	1.45
22	1.71	0.09	1.62	1.80
23	-	-	-	-
24	2.03	0.14	1.89	2.17
25	2.00	0.17	1.83	2.17
26	1.64	0.17	1.46	1.81
27	1.14	0.10	1.04	1.23
28	1.07	0.09	0.98	1.17
29	1.06	0.06	1.00	1.13
30	1.82	0.15	1.67	1.98
31	1.53	0.14	1.39	1.66
32	1.72	0.16	1.55	1.88
33	1.98	0.16	1.82	2.14
34	1.36	0.12	1.24	1.48
35	1.84	0.18	1.66	2.02

Main Survey Sub-group A 95% Confidence Intervals

Question	Total Survey Results			
	Mean	Confidence Level (95%)	Confidence Interval	
			From	To
1	1.45	0.14	1.31	1.60
2	1.97	0.20	1.77	2.17
3	1.51	0.15	1.36	1.66
4	1.78	0.17	1.61	1.95
5	1.74	0.18	1.57	1.92
6	2.14	0.23	1.91	2.38
7	2.18	0.24	1.94	2.42
8	1.23	0.09	1.15	1.32
9	1.34	0.11	1.23	1.45
10	3.44	0.23	3.21	3.67
11	2.55	0.18	2.38	2.73
12	2.93	0.19	2.74	3.12
13	4.05	0.22	3.83	4.27
14	3.64	0.23	3.41	3.87
15	1.28	0.09	1.19	1.37
16	2.15	0.18	1.97	2.33
17	1.66	0.17	1.49	1.84
18	1.69	0.16	1.53	1.85
19	1.53	0.10	1.44	1.63
20	1.26	0.08	1.18	1.35
21	1.43	0.10	1.34	1.53
22	1.74	0.08	1.66	1.82
23	-	-	-	-
24	2.30	0.13	2.17	2.43
25	2.92	0.15	2.78	3.07
26	1.96	0.17	1.79	2.13
27	1.29	0.11	1.18	1.40
28	1.21	0.14	1.07	1.34
29	1.08	0.05	1.03	1.14
30	2.20	0.14	2.06	2.34
31	1.79	0.12	1.67	1.91
32	2.23	0.17	2.06	2.40
33	2.52	0.16	2.36	2.68
34	1.57	0.13	1.44	1.69
35	2.65	0.17	2.47	2.82

Main Survey Sub-group B 95% Confidence Intervals

Question	Total Survey Results			
	Mean	Confidence Level (95%)	Confidence Interval	
			From	To
1	1.51	0.22	1.29	1.73
2	2.13	0.31	1.82	2.44
3	1.72	0.29	1.43	2.02
4	1.63	0.21	1.41	1.84
5	1.98	0.23	1.74	2.21
6	2.59	0.31	2.29	2.90
7	2.39	0.32	2.08	2.71
8	1.16	0.10	1.07	1.26
9	1.34	0.19	1.15	1.53
10	3.29	0.34	2.95	3.62
11	2.06	0.23	1.84	2.29
12	3.00	0.29	2.71	3.29
13	4.06	0.24	3.82	4.30
14	3.46	0.34	3.12	3.80
15	1.21	0.10	1.11	1.32
16	2.33	0.30	2.04	2.63
17	1.85	0.26	1.59	2.12
18	1.78	0.26	1.53	2.04
19	1.54	0.13	1.41	1.67
20	1.38	0.13	1.26	1.51
21	1.62	0.13	1.49	1.74
22	1.84	0.09	1.75	1.94
23	-	-	-	-
24	2.25	0.19	2.05	2.44
25	2.76	0.23	2.53	2.99
26	1.83	0.23	1.60	2.06
27	1.35	0.17	1.18	1.52
28	1.33	0.21	1.12	1.55
29	1.25	0.18	1.07	1.42
30	2.23	0.20	2.03	2.42
31	1.74	0.20	1.54	1.94
32	2.34	0.18	2.16	2.52
33	2.61	0.18	2.43	2.79
34	1.52	0.16	1.36	1.68
35	2.73	0.23	2.50	2.97

APPENDIX E
CORRELATION COEFFICIENTS

Total Response Correlation Coefficients

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*	*Column 8*	*Column 9*	*Column 10*	*Column 11*	*Column 12*	*Column 13*	*Column 14*	*Column 15*	*Column 16*
Column 1	1.0000															
Column 2	0.3602	1.0000														
Column 3	0.2154	0.3209	1.0000													
Column 4	0.1030	0.2640	0.0595	1.0000												
Column 5	0.0376	0.1675	0.2877	0.1379	1.0000											
Column 6	0.1451	0.3291	0.1136	0.1881	0.1452	1.0000										
Column 7	0.2553	0.3936	0.2441	0.1331	0.0527	0.8736	1.0000									
Column 8	0.1915	0.1300	0.0745	0.3275	0.1828	0.1120	0.1527	1.0000								
Column 9	0.3339	0.3107	0.0588	0.1448	0.1514	0.1739	0.1406	0.5259	1.0000							
Column 10	0.1034	0.3753	0.1744	0.1585	0.1560	0.3145	0.3477	-0.0287	0.0251	1.0000						
Column 11	0.0354	0.0259	0.1291	0.1769	0.1143	-0.0736	-0.0275	0.1547	0.0683	0.3059	1.0000					
Column 12	0.0494	0.3445	0.2100	0.1314	0.2462	0.2255	0.2336	0.1030	0.0148	0.3101	0.5334	1.0000				
Column 13	-0.2739	-0.0049	0.0325	-0.1702	-0.1785	0.0997	0.1083	-0.1681	-0.0937	0.1666	-0.0103	0.0389	1.0000			
Column 14	-0.0575	0.0987	0.0086	-0.0341	0.0206	-0.0532	-0.0493	0.0099	0.0415	0.2085	0.0017	0.1734	0.2963	1.0000		
Column 15	0.1591	0.1415	0.1570	0.1556	0.0841	0.2052	0.2690	0.2043	0.0774	0.1177	0.1601	0.1027	-0.0353	-0.0328	1.0000	
Column 16	0.1381	0.1285	0.1012	0.1432	0.1901	-0.0636	-0.0038	0.1726	0.1901	0.1450	0.0885	0.0564	-0.0150	0.0585	0.2614	1.0000
Column 17	0.0265	-0.0901	0.1061	0.0120	0.2118	-0.1168	-0.0188	0.0970	0.2109	-0.0562	0.0814	-0.0444	-0.1140	-0.0716	0.2322	0.4877
Column 18	-0.0470	-0.0311	0.0766	0.0340	0.1009	-0.0596	-0.0131	0.0175	-0.0150	-0.1414	0.0164	-0.0916	-0.0595	-0.1012	0.2243	0.2434
Column 19	0.0473	0.1908	-0.0044	0.0366	-0.0049	0.0590	-0.0205	-0.1501	-0.0213	0.2596	-0.0127	0.0098	0.2945	0.2276	-0.0757	-0.0203
Column 20	0.0194	0.1185	0.1059	0.1779	0.1493	0.3661	0.3410	0.3340	0.1649	0.1016	-0.1065	-0.0180	0.0249	-0.0110	0.1338	0.1710
Column 21	0.2951	0.1141	0.1971	0.2189	0.1617	0.0911	0.0286	0.2870	0.2334	0.0392	-0.0130	0.0000	-0.0821	-0.1145	0.1517	0.0882
Column 22	0.0652	0.0982	0.0703	0.0782	0.1473	-0.0518	0.0494	-0.0052	0.0204	-0.0564	0.0231	0.0263	0.0954	-0.0887	0.1140	0.1253
Column 23	0.1335	0.0910	-0.1746	0.0477	0.0484	0.1656	0.1307	0.1098	0.1557	0.1410	0.0694	0.0961	-0.2537	-0.0324	0.1455	0.0805
Column 24	0.1778	0.0607	-0.1280	0.1869	0.1302	-0.0950	-0.0292	0.1028	0.0951	-0.0281	0.0346	0.0374	-0.1387	-0.0594	0.0008	0.1359
Column 25	0.1930	0.1197	-0.1103	0.1094	0.1397	-0.0726	-0.1187	0.0537	0.1585	-0.0308	-0.0522	-0.1247	-0.2463	-0.0343	0.0209	0.1490
Column 26	0.0111	-0.0239	0.1082	0.0408	0.2163	0.0906	0.0759	0.1386	0.2066	-0.0741	0.1161	0.1236	-0.1144	-0.1449	0.2150	0.0221
Column 27	-0.0120	-0.0552	0.0405	0.0580	0.1115	0.1879	0.1234	0.1325	0.0559	0.0174	0.1018	0.1106	0.0319	-0.0299	0.0314	0.0016
Column 28	-0.0243	-0.0602	0.0277	-0.0355	0.2273	0.0844	0.0461	0.1318	0.1314	-0.0904	-0.0435	0.0010	-0.0189	-0.0930	0.0184	0.1766
Column 29	0.0969	0.0395	-0.0132	-0.0799	0.1654	0.2422	0.2520	0.1321	0.1736	0.1723	0.0607	0.1348	0.1194	0.0111	0.1574	0.0457
Column 30	0.0474	0.1498	-0.0539	0.0054	0.1684	0.0937	0.0973	0.0126	0.0701	0.0869	-0.0954	0.1025	-0.0071	0.0959	0.1061	0.0529
Column 31	0.2325	0.0748	0.2030	0.0496	0.2961	0.1379	0.2147	0.0881	0.0702	-0.0195	0.0170	0.0643	-0.0283	-0.1063	0.2749	0.2114
Column 32	0.1752	0.0234	-0.0508	0.0462	0.1038	0.1387	0.2075	0.1644	0.2127	0.0065	0.0858	0.0651	-0.0193	-0.1877	0.0945	0.0881
Column 33	0.0953	0.1872	-0.0060	0.1383	0.1069	0.2160	0.2229	0.1804	0.0126	-0.0518	-0.0367	-0.1009	-0.0790	-0.0099	0.0640	0.0585
Column 34	0.2404	0.2531	0.0658	0.2314	0.0939	0.0062	0.0485	0.0448	-0.0873	0.0090	-0.0687	0.1000	-0.2323	-0.0911	0.0791	-0.0243
Column 35	0.0418	-0.0128	0.0063	-0.0256	-0.1065	-0.0768	-0.1160	-0.0381	-0.0391	-0.0296	0.0010	0.0652	-0.0863	0.0193	-0.0864	-0.1590
Column 36	0.0176	0.0543	-0.0355	-0.0931	-0.0525	0.0664	0.0813	-0.0492	-0.0762	0.0163	0.0275	-0.0472	0.1003	0.0126	-0.0398	-0.3754
Column 37	0.1539	0.2043	0.1123	0.0119	0.1120	0.0630	0.0822	0.0585	0.2219	-0.0524	-0.0537	0.0078	-0.1108	0.0335	-0.0120	0.0257
Column 38	-0.0265	-0.0611	-0.0295	-0.2036	-0.0565	0.2374	0.2063	-0.1870	-0.1211	-0.0098	-0.0873	0.1249	0.0584	-0.1133	-0.0070	-0.2306
Column 39	-0.0480	-0.1401	-0.0693	-0.0481	0.1296	-0.3155	-0.2946	-0.0316	-0.1591	-0.1639	0.1463	0.0698	-0.1603	-0.0891	-0.0236	-0.0008
Column 40	-0.0308	0.1276	0.0544	0.0468	0.0254	0.1853	0.1971	0.0109	0.0015	0.2525	0.0777	0.1082	0.1048	0.2189	0.1411	0.1847
Column 41	0.0020	0.1446	0.1608	-0.0991	0.1308	0.1337	0.0675	0.0293	-0.0447	-0.0212	-0.1066	0.1672	0.0318	-0.0377	-0.0386	-0.0132
Column 42	0.1056	-0.0604	-0.0551	-0.1770	0.0118	0.0901	0.0537	-0.0796	0.0285	-0.1759	-0.2062	-0.0667	-0.0806	-0.1230	-0.1047	-0.0191
Column 43	0.0864	0.0685	0.1176	-0.1207	0.1473	0.0394	0.0288	0.0317	0.1679	-0.0743	-0.1797	-0.0478	0.0710	0.0201	-0.0291	0.0862
Column 44	0.0296	0.0199	-0.0894	0.0403	-0.0648	0.1545	0.0647	-0.0735	0.0412	0.0022	0.0028	-0.0808	0.1515	-0.0864	0.0289	-0.0823
Column 45	-0.0138	-0.0996	0.0418	0.0857	-0.0051	0.0784	0.0474	0.1287	0.1351	0.1275	0.0469	-0.0972	0.0695	0.1190	0.0916	0.0689
Column 46	0.1131	-0.0899	-0.1034	0.0089	-0.0856	0.0744	-0.0074	-0.0289	0.1212	-0.1141	-0.2731	-0.0991	-0.1123	-0.0489	-0.0713	0.0510
Column 47	-0.0293	-0.0136	0.0206	0.0035	0.0231	0.1123	0.0818	0.0101	-0.0991	-0.0684	-0.1266	0.0021	-0.0402	-0.1515	-0.0015	-0.0349
Column 48	-0.0828	-0.0308	-0.0282	0.0834	0.0293	0.0059	-0.0264	-0.0687	-0.1317	0.2593	0.1317	0.0000	0.0851	0.0594	0.1722	0.1070

Total Response Correlation Coefficients

17	18	19	20	21	22	24	25	26	27	28	29	30	31	32	33	34
Column 17	*Column 18*	*Column 19*	*Column 20*	*Column 21*	*Column 22*	*Column 23*	*Column 24*	*Column 25*	*Column 26*	*Column 27*	*Column 28*	*Column 29*	*Column 30*	*Column 31*	*Column 32*	*Column 33*
1.0000																
0.2728	1.0000															
-0.1160	-0.0869	1.0000														
0.0135	-0.1981	0.2125	1.0000													
0.0906	-0.0606	0.0000	0.1931	1.0000												
0.2035	-0.0672	0.0396	0.0602	0.1388	1.0000											
0.1302	0.0526	-0.0184	-0.0058	0.0496	0.0270	1.0000										
0.1548	0.1210	0.1244	0.0261	0.0566	0.0493	0.2795	1.0000									
0.1260	0.1479	0.0710	-0.0884	0.1799	0.0350	0.2336	0.3134	1.0000								
0.1716	0.0793	-0.0354	0.1380	0.2357	0.0032	0.1402	0.1377	0.3318	1.0000							
0.0626	0.1859	0.0091	-0.0219	0.1133	-0.0334	0.0372	0.0094	0.2197	0.5589	1.0000						
0.2243	0.1146	0.0594	0.1985	0.1060	0.0007	0.0352	0.0742	0.2108	0.4299	0.6925	1.0000					
0.0683	0.0798	0.0369	0.0276	0.0442	-0.0295	0.1847	0.1456	0.1134	0.3010	0.3314	0.2016	1.0000				
0.0518	0.1272	0.1527	0.1528	0.0935	-0.0192	0.1569	0.1600	0.2601	0.4007	0.3584	0.2709	0.5382	1.0000			
0.2805	0.1503	-0.1883	0.0575	0.1934	0.1597	0.1877	0.2809	0.1511	0.2585	0.2095	0.1685	0.4359	0.3988	1.0000		
0.3057	0.0378	-0.1382	0.0438	0.2844	0.0945	0.3583	0.2647	0.1513	0.1162	0.2580	0.2054	0.3910	0.1520	0.5301	1.0000	
0.0745	0.0368	-0.0354	0.0973	0.2547	0.1483	0.1445	0.2777	0.3188	0.2656	0.3043	0.3154	0.1974	0.2480	0.3762	0.4388	1.0000
0.0270	0.1351	-0.0136	0.0368	0.2468	0.0238	0.1889	0.3525	0.2857	0.1569	0.0146	0.1114	0.0863	0.1615	0.3066	0.3856	0.3694
-0.1626	0.0065	-0.0136	-0.0524	-0.0427	-0.0869	-0.0427	-0.0805	-0.0665	-0.0260	-0.0212	-0.0731	-0.0934	0.0157	-0.2541	0.0314	-0.1262
-0.2383	-0.1422	0.1044	-0.0801	-0.1813	-0.0537	-0.0238	-0.0039	-0.0778	-0.1898	-0.1028	-0.1323	0.0188	-0.1283	-0.0076	-0.0202	-0.0961
0.0379	-0.0203	0.0438	0.0172	0.1052	-0.0414	0.0070	0.0888	0.1126	0.0452	0.1654	0.0883	0.0730	0.0843	0.0724	-0.0446	0.1001
-0.2472	-0.1072	0.0242	0.0501	-0.1678	-0.1295	0.0387	-0.1505	-0.1288	-0.1994	-0.2296	-0.1213	-0.0991	-0.2396	-0.2798	-0.1653	-0.1712
0.0671	0.0639	-0.0730	-0.1041	0.0344	-0.0584	-0.1971	0.0432	0.0656	0.1123	0.0546	0.0355	-0.1107	-0.0015	0.1069	-0.0929	0.0163
-0.0945	0.1116	0.1762	0.0647	-0.0938	-0.1739	0.0470	0.0126	0.0768	-0.1336	-0.0445	0.1380	0.1428	0.0728	0.0284	0.0023	0.0644
0.0601	-0.0188	-0.0439	0.0463	0.1057	0.0513	0.0077	-0.0820	-0.0419	0.1023	0.0772	0.1411	-0.0810	-0.0494	-0.0551	-0.0065	-0.0407
-0.0020	-0.0015	-0.0011	-0.0253	0.0270	0.1081	-0.0261	0.0164	-0.1228	-0.0700	-0.0855	-0.0689	0.0480	-0.1220	0.0123	-0.0396	-0.1825
-0.0511	0.0003	0.0016	0.0120	0.1071	0.1063	0.0189	-0.1133	-0.0591	-0.0253	-0.0604	0.0297	0.1566	-0.0197	0.0966	0.1518	-0.0231
-0.1705	-0.0025	0.1138	0.1778	-0.1243	-0.0162	-0.0182	0.0376	-0.0946	-0.0709	-0.0417	-0.0773	-0.0074	-0.0284	-0.1458	0.0129	0.0109
0.0682	0.0967	-0.0249	0.1087	0.0918	0.1050	0.0937	-0.0722	0.0098	-0.0358	0.0949	-0.0116	0.1524	0.0924	0.1195	0.1909	0.0575
0.0162	-0.0760	0.0446	-0.0209	0.1280	0.0513	-0.0291	0.0582	0.0707	0.0041	0.0939	0.0358	-0.0625	-0.0027	-0.0524	0.0105	-0.0914
-0.2285	0.0719	-0.0411	0.0759	-0.0924	-0.1956	-0.0508	0.0690	-0.0082	0.0261	0.1253	-0.0983	0.0157	0.0120	-0.0013	-0.1166	0.0265
0.0214	0.0695	0.0326	-0.0341	-0.0766	-0.1087	0.0767	0.0812	-0.0244	-0.0930	0.0287	-0.0440	-0.0337	-0.0292	-0.0459	-0.0240	-0.0200

Total Response Correlation Coefficients

				Demographic										
35	36	37	39	1	2	3	4	5	6	7	8	9	10	11
Column 34	*Column 35*	*Column 36*	*Column 37*	*Column 38*	*Column 39*	*Column 40*	*Column 41*	*Column 42*	*Column 43*	*Column 44*	*Column 45*	*Column 46*	*Column 47*	*Column 48*
1.0000														
0.0402	1.0000													
0.0719	0.0638	1.0000												
0.0509	-0.0830	-0.0864	1.0000											
-0.1619	0.0642	-0.0443	-0.0673	1.0000										
0.0689	-0.0248	-0.0095	-0.0721	-0.1448	1.0000									
0.0219	-0.1125	0.1366	0.0034	0.1363	-0.1078	1.0000								
-0.1033	0.1075	-0.1109	0.0285	0.1606	-0.1738	-0.0731	1.0000							
-0.0301	0.1095	-0.0080	-0.0052	0.1943	-0.0347	-0.2947	0.1493	1.0000						
0.0077	0.1057	-0.1083	0.0541	0.1070	-0.2023	-0.1911	0.1291	0.3911	1.0000					
-0.1177	0.0278	0.1864	-0.1440	0.2093	-0.3818	0.1467	-0.0519	-0.0792	-0.1406	1.0000				
-0.1142	-0.0906	-0.0254	-0.0940	-0.1702	-0.2282	0.0738	-0.2079	-0.1557	-0.0313	0.1404	1.0000			
0.0033	0.0000	-0.2025	0.0533	0.0263	-0.0001	-0.2480	0.1784	0.3730	0.0452	-0.0750	-0.0809	1.0000		
-0.0436	-0.0140	0.0327	0.0272	-0.0063	0.0707	-0.1160	0.1192	0.0190	-0.0914	0.0997	-0.0772	0.0656	1.0000	
-0.0091	-0.0886	0.2886	-0.1455	-0.0700	-0.0348	0.2706	-0.0982	-0.3571	-0.4314	0.2046	0.1587	-0.1547	0.0261	1.0000

Sub-Group A Correlation Coefficients

Question

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*	*Column 8*	*Column 9*	*Column 10*	*Column 11*	*Column 12*	*Column 13*	*Column 14*	*Column 15*	*Column 16*
Column 1	1.0000															
Column 2	0.2688	1.0000														
Column 3	0.1206	0.2468	1.0000													
Column 4	0.2298	0.3733	0.2587	1.0000												
Column 5	0.1407	0.2255	0.4013	0.2044	1.0000											
Column 6	0.2969	0.3962	0.0641	0.2583	0.1091	1.0000										
Column 7	0.3130	0.4398	0.1254	0.2575	0.0499	0.9019	1.0000									
Column 8	0.2932	0.1947	0.2691	0.3984	0.2529	0.0877	0.1643	1.0000								
Column 9	0.3604	0.3245	0.1895	0.2156	0.2240	0.0861	0.1378	0.4969	1.0000							
Column 10	0.1586	0.3603	0.1403	0.1215	0.1755	0.3576	0.3605	0.0147	0.1253	1.0000						
Column 11	0.0338	0.0074	0.1567	0.2004	0.2019	-0.0716	-0.0455	0.1098	0.1542	0.2234	1.0000					
Column 12	0.1139	0.3896	0.1313	0.1709	0.1948	0.2719	0.2634	0.0726	0.1666	0.1758	0.5212	1.0000				
Column 13	-0.2532	-0.0216	-0.1455	-0.1246	-0.2076	0.0306	0.0102	-0.1459	-0.0647	0.1838	0.0133	0.0782	1.0000			
Column 14	-0.0574	0.0684	-0.1052	-0.0439	0.0530	-0.0473	-0.1082	0.0184	0.0545	0.1206	-0.1537	0.0890	0.3338	1.0000		
Column 15	0.2037	0.1547	0.3024	0.0840	0.1958	0.2811	0.3346	0.2336	0.1161	-0.0171	0.0311	0.0787	-0.0127	-0.0358	1.0000	
Column 16	0.2318	0.0841	0.2303	0.1687	0.2643	-0.0070	0.0933	0.2352	0.1410	0.0634	0.1987	0.0859	-0.0221	0.0096	0.3196	1.0000
Column 17	0.0022	-0.1364	0.1560	0.0474	0.2771	-0.1232	-0.0313	0.1304	0.1522	-0.0786	0.2002	0.0492	-0.0794	0.0215	0.3402	0.5039
Column 18	-0.0058	0.0205	0.2506	-0.0329	0.0440	-0.0438	0.0187	0.0740	0.0643	-0.2061	0.0200	-0.0249	-0.1300	-0.2186	0.2993	0.2193
Column 19	0.0489	0.2393	-0.0434	0.0050	-0.0131	-0.0421	-0.1068	-0.1115	-0.0243	0.3809	-0.0006	0.0637	0.3193	0.3103	-0.0214	0.1412
Column 20	0.1890	0.2592	0.0788	0.1222	0.0997	0.3520	0.3520	0.0113	0.0587	0.3917	-0.0945	-0.0636	0.1110	0.1414	0.0234	0.0758
Column 21	0.3271	0.0831	0.1737	0.1687	0.1775	0.0445	0.0297	0.3749	0.1230	0.0551	0.0710	-0.0075	-0.0837	0.0503	0.1212	0.0466
Column 22	-0.0170	0.0909	0.1140	0.1675	0.1697	-0.0132	0.1221	0.0804	-0.0530	-0.0308	0.1690	0.1309	0.0538	-0.0181	0.2328	0.2093
Column 23	0.2009	0.0945	-0.0889	-0.0639	-0.0975	0.2735	0.2324	-0.0276	0.0014	0.0382	-0.0341	-0.1431	-0.2530	-0.1267	0.1648	0.1109
Column 24	0.2819	0.3017	0.0162	0.2299	0.1194	0.0042	0.1283	0.1759	0.1126	0.0580	0.1431	0.0873	-0.2120	-0.0999	0.0582	0.1538
Column 25	0.1908	0.1713	-0.0507	0.0420	0.1316	0.0080	-0.0681	0.1158	0.1416	0.0212	0.0158	-0.1298	-0.1771	0.0473	0.0572	0.1152
Column 26	0.0549	-0.0195	0.1355	0.1127	0.1368	0.0755	0.0573	0.2353	0.3129	-0.0088	0.2283	0.0219	-0.1448	-0.1019	0.2955	0.0885
Column 27	0.0134	-0.0727	0.0781	0.1387	0.0592	0.1939	0.1363	0.2548	0.1225	0.0346	0.2029	0.0679	-0.0270	-0.0029	0.1280	0.0254
Column 28	0.0165	-0.1104	0.1023	0.0639	0.3219	-0.0204	-0.0327	0.3920	0.1243	-0.1588	0.1734	0.0289	-0.1207	-0.0355	0.1796	0.2218
Column 29	0.2793	0.1422	0.0932	-0.0608	0.0605	0.2416	0.2990	0.1642	0.2295	0.2892	0.0988	0.0507	0.1060	0.0155	0.2197	0.0902
Column 30	0.1628	0.1980	-0.0159	-0.0108	0.0403	0.0793	0.0858	0.0262	0.0531	0.1379	-0.0887	-0.0090	0.0041	0.1082	0.1362	-0.0033
Column 31	0.2674	0.0927	0.2750	0.1335	0.2514	0.1614	0.2121	0.1059	0.0236	-0.0428	0.0813	0.0348	-0.0196	-0.1492	0.3991	0.1929
Column 32	0.2628	0.1640	0.0222	0.0800	0.0579	0.1869	0.2878	0.1207	0.1242	0.1894	0.2121	0.1755	-0.0411	-0.1642	0.1866	0.0783
Column 33	0.1751	0.2632	0.0253	0.2276	0.1044	0.3583	0.3626	0.2629	-0.0239	0.0398	0.1098	0.0388	-0.1829	-0.0183	0.1463	-0.0524
Column 34	0.2017	0.3313	0.1234	0.2612	0.1604	0.0478	0.0542	0.0789	-0.1596	0.0169	-0.0408	0.1243	-0.2427	-0.1091	0.1322	-0.0777
Column 35	0.0103	0.0941	-0.0850	-0.0326	-0.1947	0.0058	-0.0733	-0.0730	-0.0071	0.0488	-0.0436	-0.0172	-0.0976	-0.1067	-0.1637	-0.3337
Column 36	0.0187	0.1041	-0.0696	-0.0584	-0.0727	-0.0125	-0.0160	-0.1006	-0.0755	0.0452	-0.1363	-0.0289	0.1554	0.0788	-0.1113	-0.1746
Column 37	0.1410	0.1767	0.0369	0.0647	0.0299	-0.1068	0.0192	0.0934	0.1861	-0.1124	-0.0697	0.0950	-0.0919	0.0524	0.0149	0.0322
Column 38	0.0438	-0.0088	-0.1711	-0.2710	-0.1398	0.2625	0.1840	-0.1668	0.0103	-0.0211	-0.1773	0.0406	0.0434	-0.1786	-0.0332	-0.2156
Column 39	-0.1428	-0.0229	0.0350	-0.0182	0.2963	-0.3681	-0.3805	-0.0181	0.0078	-0.2118	0.2230	0.0659	-0.1403	-0.0017	-0.0729	0.0793
Column 40	0.1438	0.1165	0.0368	-0.0255	-0.0125	0.2077	0.1994	-0.0469	0.0726	0.1646	-0.0981	0.0433	0.0657	0.0489	0.1227	0.1592
Column 41	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Column 42	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Column 43	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Column 44	0.2056	0.0273	-0.0797	0.0160	-0.0501	0.2446	0.1305	-0.0923	0.0283	0.0177	-0.0695	0.0443	0.0690	-0.0811	0.0776	-0.0436
Column 45	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Column 46	0.0637	0.0784	0.0769	0.0911	0.0199	0.1558	0.0676	-0.0095	-0.0714	-0.0325	-0.0444	0.0008	-0.0939	-0.1968	0.0802	0.0019
Column 47	0.0724	-0.0418	0.0502	-0.1048	0.0648	-0.0810	-0.0622	-0.1224	-0.1201	0.0362	-0.0258	-0.0931	0.0863	-0.1230	0.0781	0.2708

Sub-Group A Correlation Coefficients

17	18	19	20	21	22	24	25	26	27	28	29	30	31	32	33	34
Column 17	*Column 18*	*Column 19*	*Column 20*	*Column 21*	*Column 22*	*Column 23*	*Column 24*	*Column 25*	*Column 26*	*Column 27*	*Column 28*	*Column 29*	*Column 30*	*Column 31*	*Column 32*	*Column 33*
1.0000																
0.3291	1.0000															
-0.1184	-0.2306	1.0000														
-0.2706	-0.2937	0.2684	1.0000													
-0.0071	-0.1003	0.0240	0.0441	1.0000												
0.2615	-0.1601	-0.0266	0.0109	-0.0025	1.0000											
0.1186	0.1497	-0.0187	0.0141	-0.0546	-0.0350	1.0000										
0.0919	0.1648	0.0480	0.0456	0.0689	0.0524	0.2377	1.0000									
0.0568	0.0522	0.0453	-0.1696	0.1751	-0.0090	0.2930	0.2952	1.0000								
0.1302	0.0447	-0.1502	-0.0281	0.2349	-0.0123	0.1609	0.0604	0.2970	1.0000							
0.1020	0.1537	-0.2018	-0.0547	0.1652	-0.0153	0.0783	0.0082	0.2106	0.5298	1.0000						
0.1116	0.0506	-0.1083	-0.0868	0.0103	0.0130	0.0141	0.1078	0.2690	0.4233	0.4479	1.0000					
0.1501	0.0752	0.0025	0.0438	0.0626	0.0080	0.0993	0.0335	0.1837	0.2338	0.4061	0.1762	1.0000				
0.0239	0.0969	0.0951	0.2195	0.1539	0.0331	0.0734	0.1177	0.2350	0.2317	0.2336	0.1268	0.4957	1.0000			
0.2673	0.2412	-0.1560	0.0648	0.2047	0.1954	0.1697	0.3203	0.1758	0.2174	0.3021	0.1371	0.3872	0.3604	1.0000		
0.2803	0.0660	-0.1694	-0.1019	0.2333	0.0417	0.3920	0.2742	0.1556	0.1312	0.2820	-0.0502	0.4122	0.1436	0.6167	1.0000	
-0.0844	-0.1019	-0.1576	0.0378	0.3154	0.1613	0.2177	0.2530	0.3502	0.2890	0.2933	0.1059	0.2042	0.2126	0.3955	0.4316	1.0000
-0.0633	0.1071	-0.0538	-0.0962	0.2445	0.0118	0.2964	0.3990	0.2789	0.1162	-0.0335	0.0746	-0.0944	0.1077	0.2231	0.4221	0.3583
-0.1919	-0.0337	-0.1151	-0.0846	-0.1252	-0.1654	-0.0080	-0.0859	0.0122	-0.0617	-0.0889	-0.1425	-0.1086	-0.1010	-0.3035	0.0327	-0.1233
-0.1669	-0.1589	0.0950	0.0455	-0.1468	-0.0607	-0.0896	-0.0415	0.0325	-0.1642	-0.0682	-0.1742	0.0122	-0.1033	0.0394	-0.0006	-0.1057
0.0082	0.0837	-0.0072	0.0883	0.0496	-0.0007	0.0218	0.2571	0.0886	-0.0156	0.1072	0.0094	0.0929	0.0637	0.0006	-0.1395	0.0360
-0.2791	-0.1340	0.0600	0.0094	-0.1835	-0.1237	0.1806	-0.0654	-0.0709	-0.2374	-0.2825	-0.1206	-0.1250	-0.3186	-0.3874	-0.1484	-0.0603
0.2733	0.1434	-0.0356	-0.1907	0.1375	0.0765	-0.1723	0.0805	0.0906	0.2284	0.1361	0.1220	-0.1886	0.0772	0.1415	-0.0781	0.0090
-0.0444	0.0481	0.2284	-0.1312	0.0309	-0.1095	0.0724	0.0704	0.1601	-0.1408	-0.1872	-0.0782	0.1137	-0.0604	-0.0284	0.0573	-0.0623
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
-0.2327	-0.0859	0.0396	0.0583	-0.1219	-0.0748	0.0169	0.0319	-0.0799	-0.1228	-0.1465	-0.0699	0.0275	-0.1224	-0.0791	0.0985	0.0711
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
-0.2438	0.0882	-0.0110	0.1163	-0.0104	-0.2273	0.0456	0.0141	-0.0912	0.0727	0.1617	0.0317	0.0580	0.0128	0.0742	-0.1031	0.0575
0.0897	0.0434	0.0470	-0.0649	-0.0438	0.0182	0.0000	-0.0523	-0.0765	-0.1367	-0.0185	-0.0659	0.0238	-0.0598	0.1364	0.1385	-0.0870

Sub-Group A Correlation Coefficients

				Demographic									
35	36	37	39	1	2	3	4	5	6	7	9	10	11
Column 34	*Column 35*	*Column 36*	*Column 37*	*Column 38*	*Column 39*	*Column 40*	*Column 41*	*Column 42*	*Column 43*	*Column 44*	*Column 45*	*Column 46*	*Column 47*
1.0000													
0.2253	1.0000												
0.1374	0.3215	1.0000											
0.0281	-0.0806	-0.1029	1.0000										
-0.1479	-0.0157	-0.0279	-0.0885	1.0000									
0.0389	-0.0215	-0.0932	-0.0718	-0.3249	1.0000								
0.0204	-0.1162	0.1117	-0.0099	0.2639	-0.2381	1.0000							
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1.0000						
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		1.0000					
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		1.0000				
-0.0174	0.1007	0.2045	-0.1489	0.3602	-0.3764	0.2409	#DIV/0!	#DIV/0!	#DIV/0!	1.0000			
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1.0000		
-0.0768	0.0642	-0.0831	0.0886	-0.0331	-0.0213	-0.2494	#DIV/0!	#DIV/0!	#DIV/0!	0.1535	#DIV/0!	1.0000	
0.1021	0.0382	0.4627	-0.2516	-0.0286	-0.0406	0.1009	#DIV/0!	#DIV/0!	#DIV/0!	0.1764	#DIV/0!	0.0285	1.0000

Sub-Group B Correlation Coefficients

	Question 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*	*Column 8*	*Column 9*	*Column 10*	*Column 11*	*Column 12*	*Column 13*	*Column 14*	*Column 15*	*Column 16*
Column 1	1															
Column 2	0.4862	1.0000														
Column 3	0.3141	0.3854	1.0000													
Column 4	-0.0579	0.0872	-0.1566	1.0000												
Column 5	-0.1681	0.0490	0.1051	0.0773	1.0000											
Column 6	-0.1195	0.1836	0.1127	0.0751	0.2553	1.0000										
Column 7	0.1306	0.2922	0.3864	-0.1013	0.0389	0.8126	1.0000									
Column 8	0.0144	0.0342	-0.1948	0.1633	0.0370	0.2056	0.1446	1.0000								
Column 9	0.2983	0.3026	-0.0885	0.0629	0.0361	0.4072	0.1575	0.6137	1.0000							
Column 10	0.0294	0.4028	0.2204	0.2143	0.1519	0.2428	0.3243	-0.1257	-0.1126	1.0000						
Column 11	0.0467	0.1098	0.1707	0.0804	0.0336	0.0556	0.0836	0.2540	-0.0464	0.4037	1.0000					
Column 12	-0.0280	0.2720	0.2884	0.0748	0.3603	0.1257	0.1759	0.1581	-0.1773	0.5522	0.6325	1.0000				
Column 13	-0.3305	0.0275	0.3379	-0.2826	-0.1359	0.2681	0.3919	-0.2298	-0.1547	0.1316	-0.0529	-0.0296	1.0000			
Column 14	-0.0670	0.1602	0.1758	-0.0304	-0.0048	-0.0380	0.0938	-0.0086	0.0296	0.3411	0.2450	0.3211	0.2203	1.0000		
Column 15	0.0947	0.1377	-0.0149	0.2865	-0.1337	0.0683	0.1236	0.1233	0.0169	0.3514	0.3926	0.1624	-0.0929	-0.0391	1.0000	
Column 16	0.0061	0.1763	-0.0559	0.1152	0.0371	-0.1946	-0.2389	0.0827	0.2477	0.2829	-0.0009	0.0156	0.0057	0.1525	0.1929	1.0000
Column 17	0.0456	-0.0419	0.0368	-0.0047	0.0850	-0.1490	-0.0176	0.0569	0.2843	-0.0107	-0.0948	-0.1734	-0.1883	-0.1946	0.0756	0.4544
Column 18	-0.1161	-0.1122	-0.1246	0.1533	0.1871	-0.1308	-0.0964	-0.0764	-0.1165	-0.0408	0.0482	-0.1945	0.0801	0.0783	0.1069	0.2657
Column 19	0.0445	0.1152	0.0441	0.0906	0.0051	0.2519	0.1620	-0.2415	-0.0172	0.0648	-0.0316	-0.0885	0.2365	0.0838	-0.1816	-0.2542
Column 20	0.0176	0.2208	0.2003	0.1459	-0.0042	0.3447	0.3008	0.1137	0.3111	0.0510	-0.0924	0.0520	-0.0131	-0.0604	0.0154	0.0658
Column 21	0.2445	0.1441	0.2027	0.3587	0.0789	0.1083	-0.0211	0.1529	0.4011	0.0424	-0.1037	0.0128	-0.0780	-0.3714	0.2339	0.1106
Column 22	0.2056	0.0918	-0.0165	-0.0856	0.0515	-0.2162	-0.1759	-0.2000	0.1471	-0.0889	-0.2238	-0.1781	0.2145	-0.2123	-0.1270	-0.0407
Column 23	0.0267	0.0970	-0.2653	0.1947	0.2903	0.0063	-0.0405	0.3457	0.3451	0.2870	0.2271	0.4002	-0.2600	0.1086	0.1075	0.0513
Column 24	0.0045	-0.2816	-0.2687	0.1269	0.1826	-0.2491	-0.3231	-0.0329	0.0740	-0.1896	-0.2122	-0.0386	0.0115	0.0020	-0.1465	0.1233
Column 25	0.2023	0.0646	-0.1758	0.2145	0.2184	-0.1798	-0.2007	-0.0876	0.1900	-0.1166	-0.2787	-0.1071	-0.3987	-0.1891	-0.0565	0.2163
Column 26	-0.0764	-0.0376	0.0647	-0.0589	0.3333	0.0924	0.0877	-0.0682	0.0470	-0.1676	-0.1236	0.2505	-0.0641	-0.2234	0.0555	-0.0836
Column 27	-0.0550	-0.0382	-0.0147	-0.0783	0.1993	0.1456	0.0756	-0.1089	-0.0409	-0.0031	-0.0398	0.1693	0.1643	-0.0672	-0.1411	-0.0451
Column 28	-0.0599	-0.0543	-0.0368	-0.0929	0.1798	0.1208	0.0874	-0.0237	0.1453	-0.0513	-0.1358	-0.0302	0.0623	-0.1301	-0.0633	0.1501
Column 29	-0.2102	-0.1053	-0.1416	-0.1092	0.3279	0.2477	0.1605	0.0728	0.0925	-0.0041	-0.0073	0.2584	0.1452	0.0109	0.0414	-0.0247
Column 30	-0.1111	0.1006	-0.0815	0.0192	0.3453	0.1507	0.1325	-0.0340	0.0946	0.0158	-0.1706	0.2463	-0.0256	0.0706	0.0401	0.1352
Column 31	0.1751	0.0425	0.1402	-0.0846	0.3560	0.0756	0.2265	0.0579	0.1598	0.0350	-0.1281	0.1062	-0.0531	-0.0164	0.0000	0.2471
Column 32	0.0056	-0.1896	-0.1726	-0.0039	0.1802	0.0197	0.0070	0.2613	0.3659	-0.2880	-0.1553	-0.1638	0.0296	-0.2236	-0.0868	0.0980
Column 33	-0.0528	0.0595	-0.0351	-0.0361	0.1182	-0.0770	-0.0983	-0.0144	0.0680	-0.2153	-0.3491	-0.2952	0.1815	0.0000	-0.1052	0.2246
Column 34	0.3008	0.1303	-0.0158	0.1878	-0.0295	-0.1058	0.0319	-0.0150	-0.0057	0.0117	-0.1128	0.0585	-0.2084	-0.0495	-0.0053	0.0323
Column 35	0.0797	-0.1544	0.0781	0.0041	0.0020	-0.2431	-0.1995	0.0247	-0.0788	-0.1188	0.1339	0.1683	-0.0700	0.2038	0.0420	0.0322
Column 36	0.0283	0.0103	0.0305	-0.1980	0.0232	0.2857	0.3190	0.0334	-0.0747	-0.0424	0.2283	-0.0464	-0.0024	-0.0989	0.0616	-0.6128
Column 37	0.1689	0.2354	0.1864	-0.0588	0.2373	0.4009	0.2121	0.0037	0.2749	0.0475	0.0014	-0.1390	-0.1563	0.0130	-0.0482	0.0000
Column 38	-0.1624	-0.1932	0.1232	-0.0423	0.0688	0.0974	0.2385	-0.2108	-0.3431	0.0270	0.2267	0.2758	0.0974	0.0234	0.0799	-0.2959
Column 39	0.0956	-0.2792	-0.1497	-0.1213	-0.1381	-0.1473	-0.0872	-0.0909	-0.3983	-0.1149	-0.0674	0.0803	-0.2080	-0.2455	0.0307	-0.0711
Column 40	-0.2674	0.1950	0.1298	0.1215	0.1726	0.2774	0.2655	0.0883	-0.0962	0.3808	0.2816	0.2245	0.2051	0.4811	0.1411	0.2823
Column 41	-0.0814	0.0744	-0.0465	0.1747	-0.0724	0.0336	-0.0079	0.3361	0.0658	0.0309	0.1226	0.1350	-0.0489	0.0661	0.0985	-0.0637
Column 42	0.1780	-0.1520	-0.1675	-0.2566	-0.0577	0.0865	0.0997	-0.0822	0.0634	-0.2374	-0.1296	-0.0859	-0.1901	-0.1236	-0.1276	-0.0893
Column 43	0.1183	0.0548	0.0953	-0.1634	0.1866	-0.0662	-0.0014	0.1451	0.2793	-0.0961	-0.1240	-0.1103	0.1549	0.0831	0.0133	0.0669
Column 44	-0.2559	0.0280	-0.0740	0.0597	-0.0641	-0.0048	-0.0779	-0.0602	0.0645	-0.0414	0.0899	-0.2691	0.3951	-0.1122	-0.1031	-0.1142
Column 45	0.1962	-0.1879	-0.2291	0.0849	-0.2947	-0.0098	-0.0487	0.0122	0.1695	-0.1271	-0.2814	-0.2147	-0.2421	-0.0402	-0.0393	-0.0176
Column 46	-0.1851	-0.1691	-0.0603	-0.1577	0.0300	0.0191	0.1111	0.0582	-0.1475	-0.1294	-0.2473	0.0000	0.1008	-0.0619	-0.1684	-0.1052
Column 47	-0.2924	-0.0133	-0.0139	0.2709	0.0804	0.2115	0.0219	-0.0824	-0.1409	0.4795	0.0914	0.0982	0.0496	0.2415	0.2551	0.0342

Sub-Group B Correlation Coefficients

17	18	19	20	21	22	24	25	26	27	28	29	30	31	32	33	34
Column 17	*Column 18*	*Column 19*	*Column 20*	*Column 21*	*Column 22*	*Column 23*	*Column 24*	*Column 25*	*Column 26*	*Column 27*	*Column 28*	*Column 29*	*Column 30*	*Column 31*	*Column 32*	*Column 33*
1.0000																
0.1886	1.0000															
-0.1099	0.1471	1.0000														
0.2920	-0.0825	0.3244	1.0000													
0.2061	-0.0250	-0.0331	0.3975	1.0000												
0.0807	0.0966	0.1818	0.0558	0.3773	1.0000											
0.1562	-0.0812	-0.0226	-0.0148	0.2397	0.1512	1.0000										
0.2681	0.0661	0.2481	0.0265	0.0757	0.0886	0.3329	1.0000									
0.2619	0.3068	0.1232	0.0813	0.2224	0.1525	0.1395	0.3352	1.0000								
0.2376	0.1364	0.1727	0.2674	0.2367	0.0168	0.1194	0.2779	0.4127	1.0000							
-0.0080	0.2328	0.3477	0.0633	0.0054	-0.0900	-0.0115	0.0368	0.2510	0.6125	1.0000						
0.2962	0.1582	0.1880	0.2569	0.1266	-0.0530	0.0632	0.0922	0.2185	0.4556	0.7970	1.0000					
-0.0642	0.0846	0.1014	0.0068	0.0055	-0.1309	0.3214	0.3247	0.0090	0.3988	0.2247	0.2327	1.0000				
0.1056	0.1796	0.2461	0.3234	0.0384	-0.0949	0.2583	0.1995	0.2874	0.6208	0.5434	0.3854	0.6012	1.0000			
0.3104	-0.0090	-0.2669	0.0220	0.1408	0.0449	0.2340	0.2469	0.1203	0.3410	0.0515	0.2137	0.5380	0.4873	1.0000		
0.3546	-0.0136	-0.0739	0.2446	0.3756	0.1969	0.3205	0.2727	0.1700	0.0882	0.2174	0.4148	0.3527	0.1737	0.3341	1.0000	
0.3657	0.2968	0.1854	0.2036	0.1797	0.1339	0.0103	0.3232	0.2546	0.2366	0.3348	0.4913	0.1862	0.3029	0.3499	0.4614	1.0000
0.1563	0.1775	0.0570	0.2100	0.2222	0.0193	0.0404	0.3020	0.3107	0.2136	0.0867	0.1295	0.3656	0.2406	0.4693	0.3183	0.3941
-0.1410	0.0622	0.1323	0.2199	0.0585	0.0146	-0.0812	-0.0616	-0.1591	0.0191	0.0469	-0.0605	-0.0772	0.1448	-0.2005	0.0196	-0.1248
-0.2892	-0.1062	0.1212	0.0019	-0.1843	0.0126	0.0598	0.0021	-0.2637	-0.2126	-0.1162	-0.0850	0.0424	-0.1640	-0.0464	-0.0263	-0.0949
0.0655	-0.1844	0.1337	0.0679	0.1839	-0.1473	-0.0059	-0.1271	0.1610	0.1309	0.2418	0.1404	0.0407	0.1183	0.1895	0.0980	0.2175
-0.2325	-0.0796	-0.0448	-0.1257	-0.2136	-0.1971	-0.1838	-0.2558	-0.2016	-0.1327	-0.1629	-0.1782	-0.0523	-0.0894	-0.0908	-0.2384	-0.3921
-0.1793	-0.0419	-0.1332	-0.2802	-0.0634	-0.2681	-0.2598	-0.0603	-0.0192	-0.0790	-0.0462	0.0146	-0.0141	-0.1178	0.0772	-0.1100	0.0032
-0.1299	0.2248	0.0969	0.0252	-0.2251	-0.2407	-0.0106	-0.1288	-0.1098	-0.1216	0.2091	0.3757	0.1903	0.2239	0.1582	-0.0745	0.2614
0.2343	0.0432	-0.1388	0.2128	-0.0201	-0.1713	0.2006	0.0917	0.0816	0.0764	0.0777	0.0102	-0.1089	0.0273	-0.1960	0.1134	0.0615
-0.0581	-0.0124	-0.0394	-0.0738	-0.0727	0.0990	0.0550	0.0734	-0.1267	-0.1337	-0.2042	-0.1761	0.1094	-0.1784	-0.0126	-0.0931	-0.2982
-0.1639	-0.0288	0.0051	0.0366	0.0500	0.1082	0.0727	-0.1080	-0.0327	-0.0599	-0.1604	-0.0476	0.3047	0.0241	0.1477	0.2843	0.0112
-0.0442	0.1512	0.2586	0.0710	-0.0876	0.1758	-0.0848	0.0404	-0.1310	0.0391	0.1585	-0.0663	-0.0696	0.1058	-0.2675	-0.1483	-0.1194
-0.0114	-0.1490	0.0788	-0.0840	0.0608	-0.0232	-0.0550	0.1230	0.1326	0.0070	0.1419	-0.0269	-0.1034	0.0950	-0.0700	-0.0526	-0.1053
-0.2099	0.0408	-0.0983	-0.1287	-0.2619	-0.1453	-0.2042	0.1725	0.1581	-0.0652	0.0550	-0.2285	-0.0584	0.0124	-0.1645	-0.1645	-0.0324
0.0047	0.1111	0.0053	-0.1169	0.0551	-0.1946	0.1603	0.1686	0.0104	-0.0308	0.1196	0.0330	-0.1318	-0.0635	-0.2974	-0.2129	-0.0369

Sub-Group B Correlation Coefficients

				Demographic									
35	36	37	39	1	2	3	4	5	6	7	9	10	11
Column 34	*Column 35*	*Column 36*	*Column 37*	*Column 38*	*Column 39*	*Column 40*	*Column 41*	*Column 42*	*Column 43*	*Column 44*	*Column 45*	*Column 46*	
1.0000													
-0.1877	1.0000												
0.0044	-0.2126	1.0000											
0.0748	-0.0967	-0.0476	1.0000										
-0.2212	0.1594	-0.0137	-0.0584	1.0000									
0.1301	-0.0044	0.0308	-0.0500	0.2063	1.0000								
0.0436	-0.0761	0.1081	0.0621	0.0206	-0.0224	1.0000							
-0.0741	0.0430	-0.1292	-0.1230	-0.0171	-0.2424	0.0443	1.0000						
-0.0573	0.0966	0.0796	-0.0124	0.2336	0.0665	-0.3257	-0.2654	1.0000					
-0.0166	0.1148	-0.0586	0.0405	0.0712	-0.2215	-0.1525	-0.3310	0.2244	1.0000				
-0.2664	-0.0531	0.1315	-0.1204	-0.0333	-0.4519	-0.0619	0.1782	-0.1788	-0.1807	1.0000			
0.0248	-0.1390	-0.1514	0.0532	-0.1346	0.2058	-0.2336	-0.1409	0.0544	-0.3203	-0.0388	1.0000		
0.0127	-0.1233	0.2109	-0.0847	0.0345	0.2300	0.1174	0.1585	-0.0151	-0.2039	0.0062	0.0734	1.0000	
-0.1356	-0.1202	-0.0481	0.0067	-0.0259	-0.1738	0.3129	0.3352	-0.2223	-0.4077	0.1471	0.0052	0.0800	1.0000

APPENDIX F
INCREMENTAL INDOOR PM_{10} CONCENTRATIONS FOR DURATION OF SIMULATION

	PM10 Concentrations (µg/m^3)								
Time (hr)	Den	Kitchen	Living Room	Hall	Middle BR	Front BR	Master BR	Main Bath	Master Bath
0	35	35	35	35	35	35	35	35	35
2	31	31	32	32	31	31	32	37	37
4	39	38	39	41	39	38	40	46	46
6	41	41	41	42	41	41	42	48	48
8	54	52	53	43	52	53	51	57	58
10	45	44	45	47	45	44	46	53	53
12	35	34	35	36	34	34	35	41	41
14	35	35	35	36	35	35	36	41	41
16	57	56	57	30	55	58	50	52	57
18	85	84	86	87	84	84	86	100	100
20	104	103	105	105	103	103	105	121	121
22	45	44	45	44	44	44	45	52	52
24	41	40	41	42	40	40	41	48	48
26	38	37	38	39	37	37	38	44	44
28	33	33	34	34	33	33	34	39	39
30	38	37	38	39	38	37	39	45	45
32	41	40	41	41	41	40	42	48	48
34	64	63	65	65	64	63	65	75	75
36	49	49	50	51	49	48	52	61	59
38	30	30	31	31	30	30	31	36	36
40	64	62	63	38	62	64	57	61	65
42	84	83	85	87	83	83	86	99	99
44	85	84	86	87	84	84	86	100	100
46	38	37	38	39	37	37	38	44	44
48	42	42	42	41	42	42	42	49	49
50	34	34	35	35	34	34	35	40	40
52	36	35	36	38	35	35	37	43	42
54	34	33	34	34	33	33	34	39	39
56	40	40	40	40	40	40	41	47	47
58	64	63	65	65	64	63	65	75	75
60	64	63	65	65	64	63	65	75	75
62	34	33	34	35	33	33	34	40	40
64	68	66	67	34	65	69	59	61	67
66	92	91	93	96	92	91	94	110	109
68	83	82	84	85	82	82	85	98	98
70	31	31	31	32	31	31	31	36	36
72	31	30	31	32	31	30	32	37	36
74	35	34	35	35	34	34	35	40	40
76	38	37	38	35	37	37	37	42	43
78	34	34	34	35	34	33	35	40	40
80	34	33	34	34	33	33	34	39	39
82	61	60	61	64	60	60	62	72	72
84	48	48	49	51	48	48	50	58	57
86	46	46	47	47	46	46	47	54	54
88	66	64	65	36	63	66	58	61	66
90	102	100	102	102	100	100	103	118	118
92	108	106	108	109	106	106	109	126	125
94	31	30	31	31	30	30	31	36	36
96	26	25	26	27	25	25	26	30	30
98	30	30	30	30	30	30	31	35	35
100	36	35	36	35	35	35	36	41	41
102	40	39	40	40	39	39	40	46	46
104	38	37	38	39	37	37	38	44	44
106	52	52	53	53	52	52	53	61	61
108	45	44	45	48	44	44	46	54	53
110	46	46	46	47	46	46	47	54	54
112	97	94	96	51	93	98	85	89	96
114	96	95	97	98	95	95	98	113	113
116	93	92	93	95	92	92	94	109	109
118	36	35	36	40	36	35	37	44	43
120	27	27	28	30	27	27	29	33	33

APPENDIX G
SENSITIVITY ANALYSIS OF PARTICLE REMOVAL EFFICIENCY

	PM$_{10}$ Concentrations (µg/m^3) in Den of Research House							
Time (hr)	**50.00**	**70.00**	**85.00**	**90.00**	**95.00**	**99.97**	**% difference between 50% and 99.97%**	**% difference between 85% and 99.97%**
0	35	35	35	35	35	35	0	0
2	24	22	21	21	20	20	18	5
4	31	29	27	27	26	26	18	5
6	32	29	28	27	27	26	18	5
8	44	42	40	40	39	39	13	4
10	34	32	30	29	29	28	19	6
12	27	24	23	22	22	21	19	6
14	27	25	24	23	23	22	18	5
16	51	50	48	48	48	47	8	2
18	66	61	57	56	55	54	18	5
20	81	75	70	69	68	67	18	5
22	35	32	30	30	29	29	18	5
24	32	29	27	27	26	26	18	6
26	29	27	25	25	24	24	18	6
28	26	24	23	22	22	21	18	5
30	30	27	25	25	25	24	18	6
32	32	29	28	27	27	26	18	5
34	50	46	43	43	42	41	18	5
36	25	23	22	22	21	21	17	5
38	24	22	20	20	20	19	18	5
40	56	54	52	52	51	51	9	2
42	66	61	57	56	55	54	18	5
44	66	61	57	56	55	54	18	6
46	29	27	25	25	24	24	18	6
48	29	26	25	24	24	23	19	6
50	27	24	23	23	22	22	18	6
52	27	25	23	23	22	22	20	6
54	26	24	23	22	22	21	18	5
56	31	29	27	27	26	26	18	5
58	50	46	43	43	42	41	18	5
60	37	34	32	31	30	30	20	6
62	26	24	22	22	21	21	19	6
64	62	60	58	58	58	57	7	2
66	71	65	61	60	59	57	19	6
68	64	59	55	54	53	52	19	6
70	24	22	21	20	20	20	18	6
72	24	22	20	20	19	19	19	6
74	27	25	23	23	23	22	18	5
76	30	28	26	26	26	25	16	5
78	31	29	27	27	27	26	16	4
80	32	32	29	28	28	27	15	4
82	47	43	40	40	39	38	19	6
84	37	34	32	31	30	30	20	6
86	36	33	31	31	30	30	18	5
88	58	56	55	54	54	53	8	2
90	79	73	69	67	66	65	18	5
92	84	77	72	71	70	68	18	5
94	24	22	21	20	20	19	18	5
96	20	18	17	16	16	16	19	6
98	24	22	21	20	20	19	18	5
100	28	26	24	24	23	23	18	5
102	31	29	27	27	26	26	17	5
104	29	27	25	25	24	24	18	6
106	41	37	35	35	34	33	18	5
108	34	31	29	29	28	27	20	6
110	36	33	31	31	30	30	18	5
112	83	80	78	77	77	76	8	2
114	74	68	64	63	62	60	19	6
116	72	66	62	61	60	59	18	6
118	27	25	23	22	22	21	21	6
120	21	19	17	17	17	16	21	6
						AVERAGE	**17**	**5**