Housing Conditions and Children's Respiratory Health

by

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ABSTRACT

Understanding how respiratory health risks are associated with poor housing is essential to designing effective strategies to improve children's quality of life. The objective of this thesis is to determine the relationship between the respiratory health of children and the condition of the homes in which they reside – using both building science and health data.

A survey designed to assess the relationship between respiratory health and housing conditions was completed by 3,424 parents of grades 3 and 4 children in Winnipeg, Manitoba, Canada. Air samples were then taken in the homes of a subset of 715 parents – one in the child's bedroom and another in the basement – with an exterior neighborhood air sample as a control measure. Finally, an engineering audit of the 715 homes was conducted – including measurements of relative humidity, temperature, and moisture content of walls.

The first part of this thesis analyzes the association of selected home conditions as reported in the parent survey and the respiratory health of the child (asthma, frequent colds, asthma in combination with frequent colds, or neither condition). The second part of the thesis examines the association between self-reported mould in the home, results of the detailed engineering inspections, and the respiratory health of the child. The engineering inspections consisted of a detailed review of the structural, building envelope, and mechanical systems of the home, supplemented with field measurements of air-borne mould concentrations within the home and the outdoors of each neighborhood.

Major findings include the following: (1) Self-reported visible mould in the home is clearly associated with the presence of air-borne mould; (2) there are fewer healthy children when mould is present in the home; (3) cladosporium levels (CFU/m^3) in the house were associated with children's asthma in combination with persistent colds; and (4) measures taken by homeowners to increase the air-tightness of their homes increased the likelihood of having higher levels of moisture and air-borne mould levels.

One of the main recommendations emerging from this study is the potential harmful effect on air quality by tightening the building envelope and a maximum limit for air-borne levels of Cladosporium in homes that sustain health and well-being of children occupants. This study is unique in its multi-disciplinary approach by incorporating the expertise of both engineering and health research fields. The study contributes to both the medical and engineering research community by enabling researches, designers, and Building Code officials to focus on cost-effective target areas for improving indoor air quality.

ACKNOWLEDGEMENTS

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I am indebted to my friend and advisor, Dr. Dimos Polyzois, who has an insatiable desire to pursue areas of research atypical to structural engineering professors but recognizes the significance such work has on the impact for the health and safety of the public.

The assistance provided by my co-supervisor, Professor Eleoussa Polyzoi of the University of Winnipeg in guiding the statistical analysis of the data is greatly appreciated. The valuable suggestions and recommendations provided by the examining committee members, Dr. Dagmar Svecova, Professor of Civil Engineering and Dr. Kris Dick, Associate Professor of Biosystems Engineering at the University of Manitoba, as well as Professor Tang Lee, Professor of Architecture, Faculty of Environmental Design, University of Calgary are gratefully acknowledged.

Gratitude is extended to the research assistants who participated and assisted with the home inspections and air sampling. I would also like to acknowledge Dr. Theo Koulis of the

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Finally and most significantly, this research project is dedicated to my wife, Tamara Wells and two sons, Joshua and Matthew who’s continual and unwavering support enabled pursuit of a long-time dream.

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1.0 INTRODUCTION

Considerable research has been conducted, over the last 20 years, on the effect of the interior environment on the respiratory health of children (Alberta Health and Wellness, 1999; Decker C., 1991; Health Canada, 1995; Institute of Medicine, 2004). Research, however, has been dominated by the medical field and environmental health specialists who focus on the role that specific genus types of mould have on the respiratory health of children. Engineering considerations relating to the structural, mechanical, and building envelope components of a home and their impact on environmental health have received limited attention. A bridge is, thus, required to link the health effects, as evaluated by the medical practitioners, to the conditions of a home, since the conditions within the home can have a pronounced effect on the health of the occupants (Gunnbjornsdottir, et al. 2003; Haas D., et al., 2006). Attention also needs to be paid to the choice of building materials at the design stage of a home and an understanding of the collective impact such materials may have on the indoor air quality of the home when exposed to moisture.

In 2005, Dr. Dimos Polyzois[1], P. Eng, Dr. Eleoussa Polyzoi[2], Dr. Anita Kozyrskyj[3], and Dr. Kimberly Thompson[4], received funding from the Canadian Institute of Health Research Institute of Population and Public Health (CIHR-IPPH), the Manitoba Health Research Council and the Canadian Institute of Public Health-Regional Partnership Program to: (1) examine the relationship between housing, respiratory health/asthma exacerbation, and school absenteeism among a nine-year-old children in Winnipeg; and,

(2) design a Composite Healthy Housing Index (CHHI) which can be used to evaluate indoor environmental risk associated with upper respiratory problems.

Drawing on the expertise of engineering, health, and education researchers, from the Universities of Manitoba, Winnipeg, and Harvard, Polyzois et al. designed a study to assist health officials make more informed decisions when dealing with children who have respiratory health problems. Understanding how health risks are associated with housing is essential to designing effective strategies to improve children's quality of life. The study by Polyzois et al. (2005) is unique in that it proposes a process whereby specific measures of risk to public health are evaluated and integrated into a database management system, which potentially can become a powerful tool for decision-making.

The work reported for the current dissertation addresses part of this investigation in more detail. More specifically, it investigates the relationship between specific housing conditions and the respiratory health of nine-and ten-year-old children in Winnipeg, including exposure to indoor mould.

The growth of mould within homes requires the presence of oxygen, spores, moisture, moderate temperatures, and an appropriate food source (Trechsel, H.R. et al., 2001), all present within a typical North American home. Building Codes and Housing Standards are designed to control the heat, air, and moisture content within a home and to reduce interior moisture levels to manageable levels. Failure to control any of these parameters can lead to damaging levels of moisture and, thus, possible biological growth within the residence. A major source of moisture penetration in homes is usually attributable to a failure or deficiency in the building envelope which separates the home from the external environment and, thus, comprises the environmental separation, such as the exterior walls, fenestration, and roof systems. Moisture in homes can be due to several sources, including condensation, precipitation penetration, and groundwater penetration. However, the question arises as to whether the presence of such moisture, either from condensation or precipitation penetration, in combination with prolonged contact automatically leads to damaging levels of air-borne mould which may affect the respiratory health of the occupants. A review of the relevant literature (IOM, 2004), suggests that research is required to establish the absence/presence of an associative relationship between mould spores and other related biological contamination within the interior environment and their possible influence on occupant health. Furthermore, research is also required to evaluate the impact that various changes in the building envelope, in combination with mechanical heating/cooling systems, have on reducing interior moisture levels and thus, interior air-borne biological media. In addition, caution may also be required when increasing the air-tightness of homes due to the reduction in passive air changes (CMHC, 2004).

Part 1 of the investigation conducted by Polyzois et al. (2005) consisted of a survey sent to the parents of over 13,000 nine-year-old children in grades 3 and 4 in six school divisions in Winnipeg. The survey included questions on the interior conditions of the home and the respiratory health of their child. This part of the investigation was carried out prior to this candidate's involvement in the research study, but is included here since it represents an integral part of the dissertation study.

Part 2 of the investigation, which forms the bulk of this candidate's dissertation, deals with an analysis of the absence/presence of visible mould, the respiratory health of the child, and associated building conditions within the home as obtained through an engineering audit. This investigation was supplemented by on-site field measurements of the air-borne mould concentrations and evaluations of in-situ environmental conditions within the home, including temperature, relative humidity, and moisture content of the building materials. Air quality was limited to biological testing; no assessment of other indoor air contaminants was completed, including VOC, carbon dioxide, etc.

Detailed building engineering audits of 715 homes were analyzed to explore both associations between specific building systems and conditions, (e.g. structural, mechanical, building envelope), and presence of air-borne mould concentrations as well as the impact that such concentrations may have on the respiratory health of the occupants.

The results of this investigation program are intended to fill a void in the current knowledge base in the building science design and assessment community for the evaluation of the conditions within the homes which may affect the respiratory health of children. Ultimately, results from this program will provide the initial step to developing a Composite Healthy Housing Index which can be utilized to assess the existing housing stock and the impact that the individual building components have, including material type, design, and operating conditions, on the control of heat, air, and moisture in the home, and their influence on indoor air quality.

This thesis consists of six chapters. Chapter 1, Introduction, discusses the reasoning as to why research into causal relationships between housing conditions and respiratory health is required. Chapter 2, Literature Review discusses the problem background, including housing conditions that influence mould growth, mould species in North American houses, and a discussion on the research conducted to date on building science conditions and the impact of mould on respiratory health. Chapter 3, Objectives of Research Investigation discusses the research program methodology, the definitions used, and the materials used in the building condition audits. Results and Discussion comprise Chapter 4 in which the results of the statistical analysis between the survey data, air sampling data, housing conditions, and respiratory health are presented. Chapter 5, Analysis and Discussion of Results detail the implications revealed from the research program relating to the survey results, biological air sampling, housing conditions and the statistically significant associations with environmental conditions, air-borne mould levels, and ultimately, respiratory health. Finally, Conclusions, and Recommendations for Further Research are presented in Chapter 6.

2.0 LITERATURE REVIEW

2.1 Housing Conditions that Influence the Growth of Mould

Mould is part of the natural environment (EPA, 2009; Health Canada, 2007). However, when referred to in relation to buildings, mould is a fungi that may grow on the building materials within an interior conditioned environment. Although mould is present in the natural environment, in order for the fungi to grow in the interior of our buildings, three specific requirements are required (Health Canada, 2007): a source of food, moisture, and temperature.

2.1.1 Food

The first and most significant requirement is the presence of a nutrient, usually cellulose based, a substance which is common in a North American home. Typical sources of cellulose material include the paper backing on gypsum wall board and the wood framing used in the structural framing system (Trechsel, 2001).

Figure 2.1 shows the typical cross-section for a wall of a North American house and the components that define the environmental separation or building envelope.

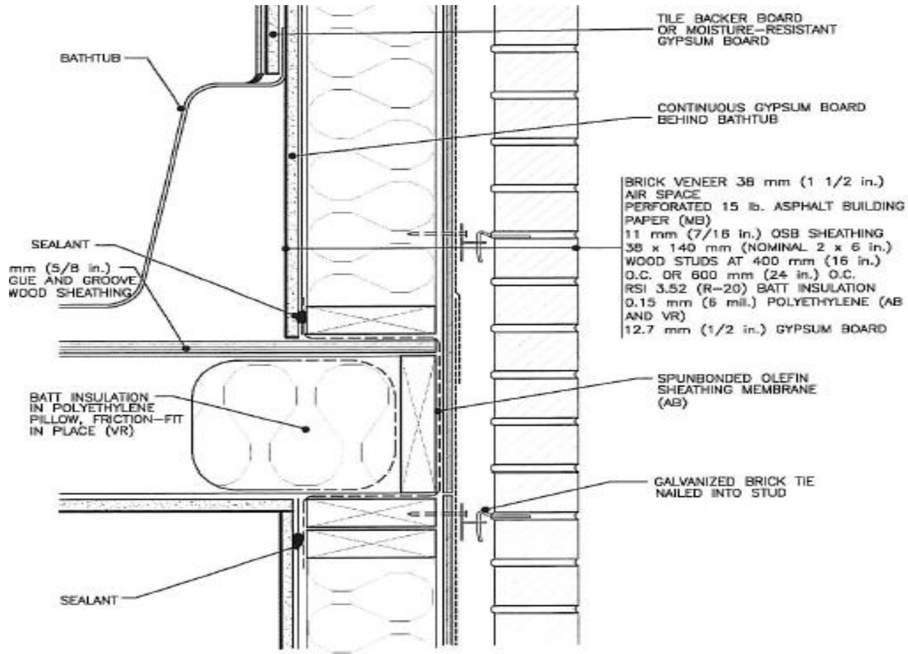


Figure 2.1. Typical Exterior Wall Section of North American Home (Source: CMHC, 2004)

In the wall system shown in Figure 2.1, an exterior cladding, typically brick masonry, stucco or siding, is anchored to the structural backup, wood sheathing. A wood stud wall assembly provides the structural system for the exterior walls while wood joists provide the floor structural system. Protection against precipitation is generally provided by the cladding and the water sheathing membrane, typically building paper applied to the exterior sheathing. The presence of building paper as a water sheathing membrane is a National Building Code requirement (NBC, 2010). Thermal resistance is primarily provided by fiberglass batt insulation, stuffed into the stud cavities. Vapour diffusion resistance is provided by the continuous polyethylene sheeting, applied to the interior face of the studs. Air leakage control is primarily provided by the drywall/polyethylene wall system composite. The aforementioned components comprise the building envelope for a typical North American house. Thus, cellulose products are typically present in all North American houses. The drywall, wood framing, and exterior sheathing all comprise potential food sources for fungi.

2.1.2 Moisture

Moisture is also a critical requirement for mould growth. Sources of moisture may be direct (e.g., precipitation penetration, flood, and groundwater penetration) or indirect (condensation related to indoor relative humidity). The optimum relative humidity for mould growth largely depends on the mould species. Studies indicate that a minimum relative humidity of the material food source is 75% (J.A. Clarke, 1999). Growth rates generally increase with increasing relative humidity, maximizing between 95% to 98% relative humidity (Straube, 2006).

Identifying the source(s) of moisture within homes, precipitation penetration, groundwater and/or condensation can potentially be problematic. Some sources are catastrophic. Many parts of Manitoba, being present on a flood plain, are periodically faced with overland flooding, see Figure 2.2.

Source: John Wells

Figure 2.2. Aerial View of Assiniboine River Valley at Brandon, Manitoba during 2011 Flood

Following conditions of flooding, many residential houses are faced with basement water penetration which saturates the interior building materials (see Figure 2.3).

Source: John Wells

Figure 2.3. Water Penetration at Foundation Wall/Floor Slab Interface

However, less obvious moisture penetration involves concealed moisture build-up. Uncontrolled air leakage can lead to large accumulations of moisture within attic spaces during the winter heating season (see Figure 2.4). Humidification and/or high residual moisture content in the building materials can significantly add to the moisture build-up in roofs and walls.

Source: John Wells

Figure 2.4. Significant Ice Build-up in Residential Attic within Winnipeg due to Uncontrolled Air Leakage

Manitoba does not experience the levels of precipitation experienced by the coastal provinces. However, the national climate indexes, published by the National Building Code of Canada, confirm that under thunderstorm conditions, a very high volume of moisture is experienced over the 15-minute rain index schedule (NBC 2010). Thus, poorly designed precipitation management systems for residential buildings can lead to considerable levels of moisture penetration within the wall systems.

Figure 2.5 shows a residential building complex which was reported by the Owner to experience periodic rain penetration.

Source: John Wells

Figure 2.5. Residential Building 15 Years of Age in Manitoba

Along the interior of this residence, there was no visible indication of any moisture-related damage, such as drywall damage or water stains. However, invasive inspection recesses made into the exterior stucco cladding confirmed major structural damage, as shown in Figure 2.6.

Source: John Wells

Figure 2.6. Extensive Deterioration of the Sheathing of the Building in Figure 5 due to Uncontrolled Moisture Penetration from Precipitation

The uncontrolled moisture penetration had clearly induced considerable structural damage; however, the question arises as to the possible impact on indoor air quality from the extensive decay of the wood framing.

Condensation from uncontrolled air leakage into roof and wall systems can also induce both extensive biological growth and structural damage. Figure 2.7 shows the extensive damage from uncontrolled air leakage in a residential house with an indoor swimming pool.

Source: John Wells

Figure 2.7. Extensive Structural Damage to Framing from Condensation in Walls

The relationship between moisture and mould growth is well established (Clark, 1995; Oreszczyn 2006). Basements, which experience periodic moisture penetration, tend to exhibit biological growth in the absence of intervention, an example of which is shown in Figure 2.8.

Source: John Wells

Figure 2.8. Black Staining on Base of Drywall Indicative of Biological Growth

The presence of moisture is required for the growth of mould. However, research has also shown that retention time, i.e., the period of time that the material retains moisture, also contributes to biological growth (Sedlbauer, 2002).

Source: John Wells

Figure 2.9. Drywall Finish Covered with Vinyl Wallpaper Increased Water Retention Time and thus Enhanced Biological Growth.

A confounding element in the visual assessment of building interiors for biological growth is that mould growth may not always be visible. As shown in Figures 2.8 and 2.9, periodic water penetration in an open and visible area clearly defines the presence of biological growth. However, the presence of interior finishes and furnishings can conceal the presence of biological growth. Figure 2.10 shows biological growth on an interior wall surface behind a recently removed counter within a home.

Source: John Wells

Figure 2.10. Biological Growth Present Behind Kitchen Counters

Similarly, uncontrolled precipitation penetration into a stud cavity of exterior wall systems will generate biological growth on orientated strand board (OSB) sheathing, as shown in Figure 2.11.

Source: John Wells

Figure 2.11. Biological Growth Present Along Interior of OSB Sheathing, Exterior to Polyethylene Vapour Retarder

It is unclear whether or not biological growth in the cavity of wall systems, which is isolated from the interior of a home by the polyethylene vapour retarder and/or drywall air barrier, can still compromise the indoor air quality of the home.

2.1.3 Temperature

In addition to food and moisture, a reasonable temperature is also required for optimum mould growth. Mould species that are common in the North American home tend to go dormant if temperatures reach below +5^{o} C (Clarke, 1999).

2.2 Mould Species Typically Found in Homes

The impact of mould on human health is generally attributable to specific inherent compositional characteristics. Mould growth can influence air quality because spores and mycelia fragments are dispersed into the air and can be inhaled (IOM, Health

Canada). Mould cell walls naturally contain a compound that can induce an inflammatory response. Mould spores and their mycelial fragments contain allergens, but, more significantly, the spores of some mould species contain low molecular weight chemicals that are cytoxic or have other potentially toxic properties that may be deleterious to human health (Health Canada, 2009).

Although there are hundreds of thousands of mould species present on earth, there are specific moulds of interest in relation to interior building conditions and human respiratory health (Burr, 1988; CMHC, 1996; Gent, 2002; Stark, 2003). Moulds of specific interest include the following.

a. **Aspergillus** (Figure 2.12): Individuals with a weakened immune system or pre-existing medical condition may be vulnerable to aspergillosis, a condition in which the aspergillus spores can grow inside a lung or a wound.

Source: http://www.mycology.adelaide.edu.au

Figure 2.12. Microscopic View of Aspergillus

Sources of aspergillus typically involve dead or decomposing animal and plant material.

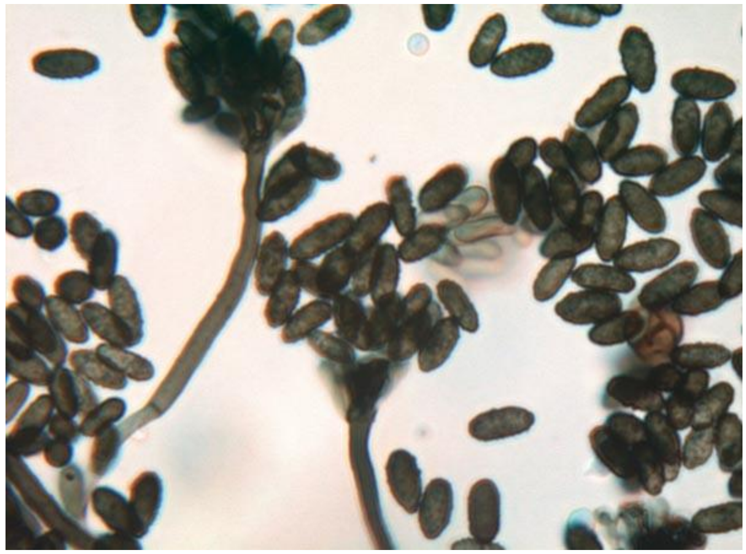
b. **Penicillium** (Figure 2.13): This is a generally opportunistic genus and may cause infection in humans whose immune response is compromised particularly affecting the airways of inhabitants of moisture-damaged buildings (Jussila 2002).

Source**:** http://www.uoguelph.ca

Figure 2.13: Microscopic View of Penicillium

Sources of penicillium include the indoor air from moisture-damaged building materials (Jussila, 2002).

c. **Stachybotrus Chartum** (Figure 2.14): *Stachybotrys* produces mycotoxins which have been reported to affect illness varying from minor to significant, such as rhinitis, reactive airways, and pulmonary fibrosis, respectively (Hossain, 2004).

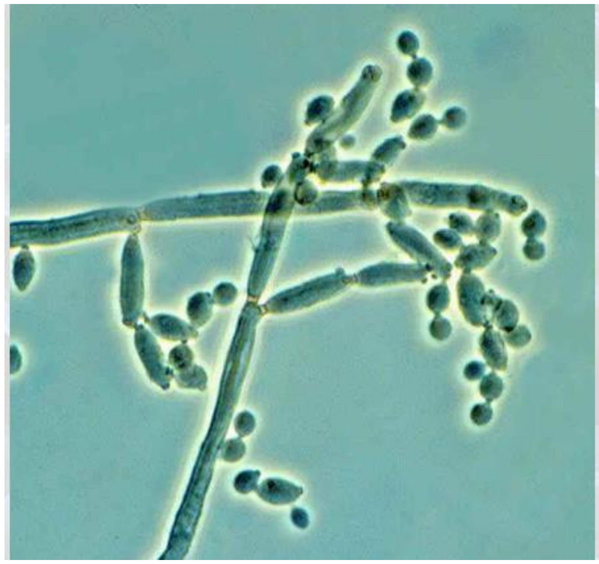


Source: http://www.environmentalhealthscienceinc.com

Figure 2.14. Microscopic View of Stachybotrus Chartum

Stachybotrus moulds tend to grow on material with a high cellulose and low nitrogen content, such as fiberboard, gypsum board, paper, dust, and lint all common within the North American house (www.cdc.gov/mold/stachy).

d. **Cladosporium** (Figure 2.15)**:** *Cladosporium* spp. spores are causative agents, increasing the risk of dermatological conditions such as keratitis and dermatitis as well as respiratory conditions such as sinusitis and pulmonary infections.



Source: http://www.uoguelph.ca

Figure 2.15. Microscopic View of Cladosporium.

Cladosporium is a common outdoor mould as well as a household mould in those areas of the house which generate large volumes of moisture, for example, bathrooms, shower stalls, and kitchens. In addition, cellulose material (e.g. paper backing on drywall, wood framing) exposed to large volumes of moisture will also enhance mould growth. The cellulose requires moisture to initiate and sustain the growth of mould (www.uoguelph.ca).

In the presence of uncontrolled moisture, a plentiful food source, and optimal temperature, consistent with the conditioned environment of a typical North American home, biological growth becomes inevitable. Poor housing, as a neglected site for public health action, has been identified in a number of recent publications (Andriessen, Brunekreef & Roemer, 1998; Bonnefoy et al., 2004; Bornehag et al., 2004; Breysse et al., 2004; Dunn, 2002; Eman, 2002; Haverinen-Shaughnessy et al., 2006; Spengler et al., 2004). Housing however, encompasses a wide range of factors, including biological (e.g. mould, cockroaches, and dust mites,), chemical (e.g. volatile organic compounds (VOC's), tobacco smoke, and paints), and physical (structural, moisture, air, heat, ventilation, and air conditioning (AC)). The large number of variables makes a quantitative evaluation of the impact of these factors on respiratory health difficult. In their "review of evidence on housing and health" presented at the Fourth Ministerial Conference on Environment and Health in Budapest, Hungary (June 2004), Bonnefoy et al. (2004) point out that the existing body of evidence on the relationship between housing and respiratory health remains insufficient to draw definitive conclusions.

Although it is unclear whether indoor dampness causes or only aggravates pre-existing respiratory conditions, such as asthma (Breysse et al., 2004), a recent extensive European Community Respiratory Health Survey (ECRHS), involving 38 study centres, not only found a significant association between self-reported mould exposure and asthma symptoms in adults, but also a higher prevalence of asthma in centres with high self-reported mould exposures (Zock et al., 2002).

The relationship between damp or mouldy indoor environments and respiratory problems has been the focus of a number of recent studies (Curtis et al., 2004; Hwang, & Jaakkola, 2005; Jaakkola, Meklin et al., 2002; NIOSH, 2003; OPSI, 2005; Skorge et al., 2005;) including that conducted by the Institute of Medicine (IOM) in the United States on behalf of the Centres for Disease Control and Prevention, (IOM, 2004). Charged with conducting a comprehensive review of the scientific literature (e.g., Dales, Miller & McMullen, 1997; Dekker et al., 1991; Engvall, Norrby & Norback, 2001;

Gunnbjornsdottir et al., 2003; Jaakkola et al., 2002; Zacharasiewicz et al., 2000; Evans et al., 2000; Kilperlainen et al., 2001; Immonen et al., 2001; Hagerh, Bornehag, & Sundell, 2002; Andriessen, Brunekreef & Roemer, 1998; Williamson, et al., 1997; Douwes & Pearce, 2003; Garrett, et al., 1998; Yang et al., 1997), the study's Committee of Experts confirmed that "sufficient evidence" exists to conclude that mould and damp conditions are associated with asthma symptoms in sensitized persons, and upper respiratory symptoms, cough, wheeze, and hypersensitivity pneumonitis in susceptible persons. Sufficient evidence of an association was defined as "an association between the agent and the outcome … observed in studies in which chance, bias, and confounding could be ruled out with reasonable confidence" (IOM, 2004, p. 23). High levels of moisture generally correlate with higher levels of microbial growth and, thus, elevated levels of air-borne mould (Pekkanen et al., 2007). There appear however, contradictory results which attempt to link specific genus types of mould and their indoor air-borne concentrations to respiratory conditions and/or cold-like symptoms (Grant et al., 1989; Gunnbjornsdottir, et al., 2003; Haas, et al., 2007; Lieberman et al., 2004; Stark, et al., 2003).

In Canada, an extensive 2003 investigation sponsored by the Canadian Institutes of Health Research (CIHR) and conducted by an interdisciplinary team of researchers in partnership with the National Housing Research Committee and the Canadian Housing Renewal Association, addressed the needs, gaps, and opportunities in the area of housing as a socio-economic determinant of health (Dunn et al., 2003). This study concluded that there are clearly well founded concerns about substandard housing and exposure to toxins (e.g., moulds, dust mites, pet allergens) in Canada and identified the lack of research capacity in the area of housing as a socio-economic determinant of health. Based on the recommendation of this report, the National Housing Research Committee established a working group, Population Health and Housing, whose mission was to more fully explore the links between housing conditions and health (Walker, 2003). In 2002, the Institute of Population and Public Health identified health and substandard housing as a strategic research priority.

Understanding how respiratory health risks are associated with housing is essential to designing effective strategies to improve children's quality of life. Although Statistics Canada regularly collects data through its National Population Health Surveys, the data collected contain incomplete information on specific housing conditions in attempts to link it to occupant health and, thus, the surveys have failed to demonstrate statistically significant relationships between housing conditions and respiratory health (Rosenberg & Wilson, 2001). Most jurisdictions in North America have established minimum requirements for healthy homes (e.g., Health Canada, 1995; Alberta Health and Wellness 1999; US-HUD, 1999), but phrasing is often general or vague. For example, in the city of Winnipeg, Clause 3.3.3 of the Maintenance and Occupancy By-Law No. 4903/88 (City of Winnipeg, 2003) states, "No person shall occupy or rent any dwelling which is not clean and sanitary." Thus, it is often left to the discretion of city inspectors to determine what constitutes "clean and sanitary."

In 2001, the U.S. Environmental Protection Agency (EPA) published a report entitled *Healthy Buildings, Healthy People: A Vision for the 21st Century* (US-EPA, 2001) designed to promote discussion and facilitate multi-sectoral collaboration among professionals in public policy, health, building sciences, product manufacturing, and environmental research for the purpose of designing healthy indoor environments. A parallel effort in Canada, *Healthy Indoors Partnership: Achieving Healthy Indoor Environments in Canada*, was launched in 2002 (Healthy Indoors Partnership, 2002) using the EPA as the centerpiece in its stakeholder dialogues.

In 2003, the World Health Organization's (WHO) Regional office for Europe undertook an extensive cross-sectional study to evaluate the relationship between housing and health in seven European cities (Bonnefoy et al., 2003).

At present, there are no Building Codes or International Standards regarding safe levels of mould, both topically visible and/or air-borne within the building environment. Current mould testing procedures are not designed to evaluate whether a home is "safe" or "healthy" (Lstiburek, 2002). There are no numerical standards in which field test results can be reliably compared in order to derive conclusions. Dose-response curves are not available, largely due to the varying responses people experience when exposed to air-borne mould spores. At the present, only guidelines are in place based on interpretation of visual assessment for the absence/presence of mould in combination with quantitative air-borne concentration testing. Mould counts obtained along the interior of a building are typically compared to counts in the exterior or ambient conditions in order to provide an opinion if elevated counts of specific species are present which then only indicate amplification.

Thus, it is clear that the effort to understand the relationship between housing and health is international in scale and that government attention and resources have accordingly been assigned. Further research is strongly warranted in order to determine the presence of a causal relationship between the respiratory health of the occupants and biological growth in combination with deleterious levels of moisture within the building materials used related to the construction and condition of the home. Research is also warranted in order to establish the housing condition variables which also affect air-borne mould concentrations and the impact on the respiratory health of the house occupants. This is the goal of the current study.

3.0 OBJECTIVES OF THE RESEARCH INVESTIGATION

The objectives of the research investigation are to:

(1) examine the relationship between housing and respiratory health/asthma among grades-3 and -4 children in Winnipeg;

(2) compare the presence of self-reported indoor mould and air samples analyzed for air-borne mould;

(3) develop a housing data base documenting information such as the history of water damage in the child's home, evidence of structural duress, type of mechanical system in the home, relative humidity, wall moisture content, and mould count and genus type based on two indoor air samples taken in the basement and child's bedroom. An exterior or control sample was also taken in each neighborhood when interior air samples were collected;

(4) examine the relationship between mould count and home building materials (e.g., concrete masonry, wooden frame, gypsum board); and

(5) statistically analyze the data to determine what associations exist between housing conditions, moisture levels, and the respiratory health of children.

3.1 METHODOLOGY

The research study was carried out in two parts. Part 1 involved the administration of a one-page Initial Contact Survey and distribution of a letter of consent inviting all parents of nine-year-old children attending school in six school divisions in Winnipeg to participate in this part of the study. Parents who agreed to proceed with Part 2, had air-borne biological testing of their child's bedroom and basement and a detailed engineering audit of their home completed. The current Ph.D. candidate was responsible for the work carried out in Part 2.

The work carried out in Part 1 is included here since it constitutes an integral part of the larger study.

3.1.1 Part 1

The first phase of the research study was initiated in July 2005. The Investigation Team applied and obtained ethics approval for the study from the University of Manitoba Education/Nursing Research Ethics Board, the University of Winnipeg Ethics Board, the Manitoba Health Information Privacy Committee, the Superintendents of all six major Winnipeg school divisions, and the principals of all grades-3 and -4 students attending elementary schools in the six major Winnipeg school divisions: Louis Riel, Pembina Trails, River East Transcona, Seven Oaks, St. James Assiniboine, and Winnipeg School Division. One Independent School Division was also included. All researchers involved in the study received training related to the use of human subjects in research in accordance with the requirements of their institutions. Table 3.1 summarizes the tasks completed under Part 1 while a detailed description of each component within Part 1 follows.

Table 3.1. Summary of Research Tasks for Part 1

Part 1	1.1	A brief Initial Contact Survey was distributed to parents of all grade-3 and-4 students in six Winnipeg school divisions.
		↓
	1.2	All Initial Contact Survey data were entered into an electronic data base and four groups of children were selected from each of four categories: Children with Asthma and Frequent Respiratory Infections* (Group 1); Children with Asthma and No Respiratory Infections (Group 2); Children with No Asthma and with Frequent Respiratory Infections (Group 3); Children with No Asthmas and No/Few Respiratory Infections (Group 4).
		↓
	1.3	Permission was requested from parents of selected children to conduct an on-site home assessment and access school absenteeism records.
		↓
	1.4	Permission was requested from parents to link the housing data with the participants' medical and prescription records in the Manitoba health care database.

*"Frequent" was defined as having four or more colds within the past year.

In September 2005, survey packages were prepared for 13,727 grades-3 and -4 children in the City of Winnipeg, and distributed to the targeted schools. Figure 3.1 below shows the geographic location of each school subdivision with the City of Winnipeg while Table 3.2 shows the response rate for each division.

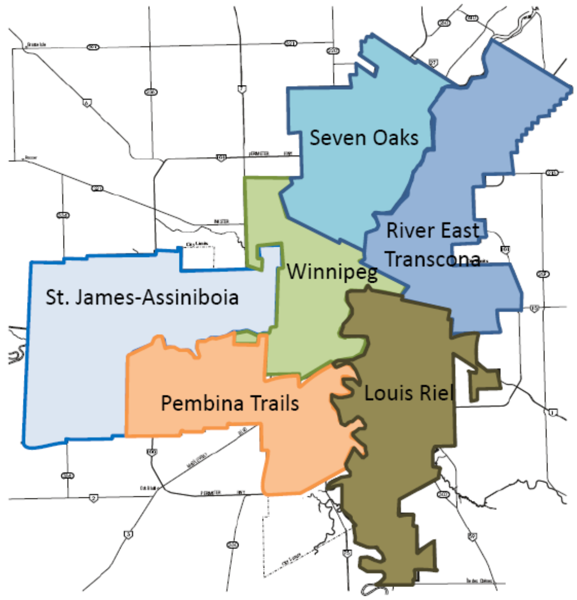


Figure 3.1. School Divisions within Winnipeg in which the Survey was Distributed

The survey packages included letters to parents and the Initial Contact Survey requesting information on incidents of respiratory infections/asthma exacerbation over the past year, as well as permission to contact parents to participate in the study. Specifically, the Initial Contact Survey, provided in Appendix A, was designed to obtain parental information on the following:

1. the child's respiratory health including incidents of respiratory infections/asthma over the past academic year (2004-05) and trips to the doctor and/or hospital,

2. the child's home environment including age of home, presence of mould, location where mould is visible, absence/presence of carpets, number of

smokers in the home, presence of cats or dogs, and whether parents/siblings or other relatives have asthma, and

3. number of school days missed in 2004-05 by the child due to respiratory tract infections and/or asthma.

The average response rate for the Initial Contact Survey in Phase 1 was 25% (3,424). Of these, 2,079 (61%) agreed to participate in Part 2 of the study, which included the detailed housing inspection. A breakdown of the response rate across the six divisions is summarized in Table 3.2.

Table 3.2: Response Rate for Part 1 and Agreement to be Contacted for Part 2

School Division	# of Schools	# of Grades 3 and 4 Children	Response Rates: Yes to Part 1 (Initial Contact Survey)	Response Rates: Yes to be Contacted for Part 2
1	15	1322	363 (27%)	186 (51%)
2	15	1283	358 (28%)	219 (61%)
3	22	1829	663 (36%)	431 (65%)
4	58	4619	569 (12%)	332 (58%)
5	27	2354	774 (33%)	448 (58%)
6	31	2188	648 (30%)	425 (66%)
7	1	134	49 (37%)	38 (78%)
Total		13729	3424 (25%)	2079 (61%)

The number of males in the study was only slightly greater than the number of females, (see Table 3.3).

Table 3.3. Gender of Children in the Study

	N.	%
Female	1675	49
Male	1714	51

Missing: 34 observations

A breakdown of the children's grade they attended is summarized in Table 3.4.

Table 3.4. Grade of Children in the Study

	N.	%
Grade 3	1777	52
Grade 4	1623	48

Missing: 24 observations

The age of the children in the study ranged from 6.5 years to 10.3 years, with a mean age of 8 years, 5 months (min.=6 years, 6 months; max.=10 years, 4 months; S.D. 7.27 years).

Once the responses from the Initial Contact Surveys were received and documented, the respondents were categorized into four groups: Asthma and Frequent Respiratory Infections (Group 1); Asthma and No/Few Respiratory Infections (Group 2); No Asthma and with Frequent Respiratory Infections (Group 3); and No Asthma and No/Few Respiratory Infections (Group 4). Frequent respiratory infections was defined as having four or more colds in the past year. Actual response rate by group are shown in Table 3.5.

Table 3.5. Response Rates for Part I by Group

	No Asthma	Asthma	TOTAL
No/Few Colds	1956 (57%)	171 (5%)	2127 (62%)
Persistent Colds	841 (25%)	456 (13 %)	1297 (38 %)
Total	2797 (82%)	627 (18.0%)	3424 (100%)

3.1.2 Part 2

Following the Initial Contact Survey, a Consent Form for a follow-up survey and a housing inspection was sent by mail to a stratified random sample of 1100 participants drawn from the original sample. Table 3.6 summarizes the tasks associated with Part 2 of this research study.

Table 3.6. Summary of Research Tasks for Part 2

Part 2	2.1	An in-depth housing survey was conducted along with tests to determine the indoor air quality sampling of all the homes where permission was granted.
		↓
	2.2	All data collected in Part 2.1 were entered into an electronic data base.
		↓
	2.3	A thorough inspection of all homes where permission was granted was carried out.
		↓
	2.4	All data from the housing inspections were entered into the housing data base.
		↓
	2.5	Stastical analyses were carried out on all the data.
		↓
FUTURE WORK Part 3	3.0	• Access school records and develop school absenteeism data base. • Cross-link Manitoba health care databases with the housing and school absenteeism data bases. • Conduct statistical analyses. • Develop a Composite Healthy Housing Index identifying the dose-response relationship between dampness/mould in homes and upper respiratory problems/asthma exacerbation among children.

Based on the IOM (2000) study, a prevalence of mould and/or dampness of 25% in the homes was initially assumed (as confirmed through a Winnipeg survey completed in late 2002/early 2003 by Dr. Kozyrskyj, personal communication, September 3, 2004). Thus, we expected to have an 80% power of detecting a relative risk of 1.51 for asthma exacerbation or upper respiratory illnesses if we had an n = 207 per group. If the prevalence was actually 15%, we would have the same power (80%) to detect a higher relative risk of 1.75 for asthma exacerbation or upper respiratory illnesses if our n = 202 per group. We, therefore, set as a target sample size for each group of 210, as shown in Table 3.7.

Table 3.7. Case and Control Groups: Set Target Sample Size

Asthma[2]	Respiratory Infections[1]	
	YES	NO
YES	210	210
NO	210	210

[1] Defined as having 4 or more respiratory infections/cold in the past year
[2] Defined as having received a formal diagnosis of asthma from a physician

After processing the Initial Contact Survey, a Consent Form for a follow-up housing inspection (including the collection of indoor air samples) was mailed to a stratified random sample of 840 participants drawn from the original Part 1 sample of participants who were willing to be contacted for Part 2. A total of 715/840 consent forms were returned (see Table 3.8), giving a response rate of 85.1 percent for Part 2. Part 2 participants by group are summarized in Table 3.8.

Table 3.8. Part 2 Participants by Group

	No Asthma	Asthma	TOTAL
No/Few Colds	201 (28%)	72 (10%)	273 (38%)
Persistent Colds	225 (31%)	217 (30%)	442 (62%)
TOTAL	426 (60%)	289 (40%)	715 (100%)

While obtaining the desired number of subjects was possible for three groups, the pool of children with asthma and no/few persistent colds was not sufficiently large to make the random selection of 210 participants. Nevertheless, we were assured by the project's statistician that we would still expect to have similar or greater power than 80% to detect response rate of 1.60 even for our smaller asthma groups of at least 72 with a conservative asthma prevalence of 30%. Thus, for this group, all the children whose parents expressed an interest to participate were selected. The participants for the remaining groups were randomly selected.

Parental permission to link housing data with their child's Manitoba Medical and Prescription Records was requested. A consent form was mailed to all participating Part-2 parents asking them for their children's Personal Health Identification Number (PHIN) and permission to access their child's health-care database for respiratory illness/asthma-related conditions only. Completed forms were mailed directly back to us by the parents in a self-addressed envelope provided by the research team to ensure privacy.

All Part 2 parents were contacted by phone and a time for housing inspection was arranged. The program attempted to complete the air sampling within the late winter/early spring of 2006 before windows were routinely opened during the day, which would potentially mask the differences between indoor and outdoor moulds. Thus, in the interest of completing the air sampling component as quickly as possible, the detailed engineering audit was moved to and completed later in the summer of 2006. In addition, parents were advised to maintain their normal routine and not to implement any atypical cleaning measures prior to our assessment.

A minimum of two air samples per home using agar strips was also collected and sent to a commercial laboratory for analysis (CFU/m^3 and genus type of top three moulds). An outdoor sample was also completed in each neighborhood of each day of testing. Due to budgetary restraints, genus identification was only completed if the colony forming unit count exceeded 100.

For Part 2, a one-page Housing Survey was developed where the home's history of water and moisture damage, history of home renovations, and reports of any visible mould were obtained from the participants. Appendix B shows a copy of the survey form completed at the time of each home visit. The form was filled in by one of the team members while air sampling was completed.

At the same time, measurements were recorded of relative air humidity, interior air temperatures, surface temperatures, and wall moisture contents for each home in order to gauge how they may be linked to mould growth. These were completed while air sampling was in operation.

Existing housing audit procedural references (HUD, NRC, CMHC, etc.) reference the requirement for obtaining temperature data in the residences under review. A Delmhorst Temperature/Rh digital meter was used to measure room temperature and relative humidity conditions within the rooms throughout the home. Section 3.5 of this thesis provides information on the equipment utilized in the assessment of the homes. Appendix C provides a copy of the form utilized while on-site.

Part 2 of the program consisted of an eight-page Engineering Audit (checklist) of each home being completed documenting, for example, evidence of water damage, structural duress, the type of mechanical system in the home, age and condition of the components comprising the environmental separation for the home. The protocol was developed based on recognized housing condition audit methodologies (HUD, CMHC, NRC, etc.) and the author's 20 years of experience in the assessment of existing buildings. The form allowed an engineering research team to rate the condition of the home's building envelope, structural and mechanical components in addition to their present condition. Prior to full implementation, the author used three homes for training the inspection teams and for determining any redundant variables in the inspection protocol. Appendix C contains a copy of this eight page check-list utilized in the follow-up home inspections. Although all variables are listed in the appendix, only those variables that were confirmed to be statistically significant are reported in this thesis.

The relationship between the various housing conditions and children's respiratory health are summarized in Table 3.9, based on the literature. Questions that the current study may help elucidate are also included.

Table 3.9. Housing Variables and Impact on Respiratory Health

Item	Significance
1. Age and size of house	Older homes tend to experience a greater volume of air leakage compared to newer, more air-tight homes. Infiltration of cold exterior air can have a significant impact on reducing humidity. CMHC studies have suggested that older homes with significant air leakage do not necessarily have better air quality (CMHC Technical Series 2003-111). Moisture is the most important factor controlling fungal growth on substrates (Trechsel, Bomberg, 2009; ASTM Moisture Control in Buildings). The number of occupants within the home in relation to the size of the home can have a pronounced impact on the moisture generation within the home. Christian, again from ASTM Moisture Control in Buildings (Trechsel, Bomberg, 2009) has cited a study where a family of four can generate up to 5 litres of moisture per day. The current study will help establish if these older homes, which retain their original or older windows with corresponding high degrees of air leakage, have lower relative humidity, and therefore, lower incidences of condensation and corresponding lower incidence of mould.
2. Location of house	The location variable will be used to establish if there is a geographic component within the city and surrounding areas where houses, particularly in areas with older combined sewer systems, have higher incidences of basement water penetration and resulting mould growth.
3. Type of construction of the house	Older multi-wythe brick homes tend to have a higher moisture storage capacity compared to newer wood framed houses. Does this higher storage capacity reduce the impact of concealed water damage and consequent condensation and mould growth potential?
4. Roof construction	Cathedral-type ceilings in wood frame houses have a poor performance record with respect to condensation problems. Are ice dams more pronounced in houses with cathedral ceilings, or are they more related to the age of the house? Do houses with cathedral-type ceilings; therefore, produce a higher frequency of respiratory problems in children?
5. Window type and age	Prior to implementation of air-to-air heat exchangers, discreet air leakage through window components and rough openings provided a degree of fresh air infiltration and, thus, reduced relative humidity within the residence. We have observed that replacement of windows which significantly increase air-tightness in homes has resulted in significant increases in condensation problems within homes. Thus, does the higher incidence/increase in condensation levels, because of new windows in older homes, adversely affect air quality and, therefore impact the

	respiratory health of children?
6. Absence/presence of crawlspace	Unprotected earth floor crawlspaces can have a significant impact on condensation within homes due to groundwater evaporation. Crawlspaces can generate 40 to 50 litres per day of moisture into conditioned space (Trechsel, Bomberg, 2009; ASTM Moisture Control in Buildings). Moulds will also be present within the soil of the crawlspace. Does the higher level of condensation from unprotected crawlspaces adversely affect air quality by promoting mould growth in homes?
7. Insulation and finish type within the house, particularly the basement: drywall, wood paneling, plaster, etc.	Drywall contains a significant cellulose component which provides a more adaptable food source to fungi compared to paneling or plywood. In addition, fiberglass batt insulation can trap and hold moisture compared to an extruded closed-cell polystyrene insulation. The study may clarify what finishing and insulation types contribute to or aggravate fungal growth.
8. Evidence of any structural duress to the house	Cracks in the foundation and superstructure aggravate groundwater and precipitation penetration, respectively. The study will be used to help establish if the presence of observed structural duress in the form of cracking and displacement contribute to higher incidences of water penetration and resulting mould growth.
9. Any significant changes/ modifications and/or repairs to residence	This study will allow us to evaluate if additional insulation to exterior walls and/or attic, upgraded windows, and weather stripping and caulking to decrease air leakage and/or precipitation penetration have the affected the interior relative humidity and air quality (CMHC Technical Series 2003-111).
10. General condition of the building materials used in the house, including the condition of the exterior finish	This study will be used to help establish if visible signs of damage to the exterior, (e.g., peeling paint, blistering, efflorescence and/or spalling which indicate the presence of concealed moisture related damage) are correlated with indoor air quality and, thus, mould growth.
11. History of any basement water penetration/sewer backup	Large areas of the city still rely on combined sewer systems and are more prone to backups and flooding during periods of significant precipitation. Groundwater and/or sewer backup can have a significant impact on inducing water damage and, thus, promote mould growth, affecting air quality within the homes. Which is more significant with respect to affecting air quality: condensation or periodic precipitation and/or groundwater penetration into the living space?
12. Absence/presence of previous water damage to roof of the house	This study will help establish if multiple occurrences of water penetration versus a single incident through a deteriorated roof and/or roof assembly such as flashing terminations are required to negatively affect mould growth and, thus, air quality.
13. Evidence of water damage from condensation on walls	High relative humidity within homes promotes condensation on poorly performing windows and potentially walls, particularly at ceiling/wall interfaces, called thermal bridges. Condensation can be concealed within the walls and/or on the surface leading to hidden and visible mould growth.

14. Absence/presence of sump-pit	This study will help us examine whether or not the presence of sump-pits reduce frequency of basement water penetration and, thus, keep basements dry and reduces mould growth.
15. Absence/presence of previous water damage to the basement	Groundwater and/or precipitation runoff damage into basements can contribute to higher moisture levels and thus, higher relative humidity and mould counts/air quality.
16. Absence/Presence of Basement.	Does the presence of a basement have an adverse effect on air quality and thus, higher frequency of respiratory problems in children? (CMHC Technical Series 01-105, 1998)
17. Type of heating system: forced air combustion vs. electric baseboard	Combustion devices require significant fresh (outdoor) air for combustion and, generally, result in more air changes, reducing humidity and, thus, condensation potential. Electric baseboard heaters do not promote air changes and, generally, result in higher relative humidity, thereby increasing condensation potential and, thus, possible mould growth.
18. Presence of high efficiency furnace	Installation of a high efficiency furnace in the absence of an air-to-air heat exchanger may result in higher interior relative humidity due to the elimination of a chimney. The increase in moisture levels may promote mould growth and affect interior air quality.
19. Presence and number of exhaust fans within the house	Houses running under negative pressure tend to create infiltration conditions which prevent condensation in the walls. In addition, exhaust fans are effective at reducing interior humidity levels and, thus, condensation. This study will help determine the significance of the number and operation of exhaust fans in reducing condensation and, thus, potential fungal growth.
20. The absence/ presence of the mechanical system to bring in fresh air when in operation, such as an air-to-air heat exchanger or fresh-air intake duct connected to the furnace	Air changes are necessary to reduce the build-up of humidity and, thus, condensation potential within homes. Mechanically assisted ventilation is often used in more air-tight homes to assist in controlling humidity problems and address air quality concerns. This study will help show whether or not mechanical related ventilation is effective at reducing moisture levels within the home and, thus, improve indoor air quality and reduce mould growth.
21. On-site relative humidity	This site measure will help determine whether relative humidity is promoting condensation and, thus, mould growth in residence. Does higher relative humidity within a house directly impact mould growth and, thus, air quality?
22. Drywall moisture content.	This study will help determine whether the presence of damp drywall within homes and specific location observed is associated with condensation and/or water penetration. Does this damp drywall promote mould growth and, therefore, affect air quality?
23. Air leakage through windows and walls	Data examining qualitatively measures of air leakage through window and wall systems in this study. Data gathered will help establish if “leakier” houses have higher humidity and corresponding higher incidences of mould growth (CMHC Technical Series 02-103).

24. Air-borne mould concentrations and genus types	Does the absence/presence of air borne mould affect air quality and, thus, the respiratory health of children? If so, what is the cut-off point where the air-borne concentration significantly affects the child's health? No residential standards currently exist, only workplace recommendations of 150 CFU/m^3. Alternatively, does mould genus type play a larger role than the concentration of mould in the air?

Over 50 independent housing variables, based on the engineering audit, were examined. The specific independent housing variables assessed are listed in Appendix C. Results were analyzed using a series of one-way ANOVAs, separately for the children's bedroom and for the basement. The goal was to determine which **independent** variables, listed in Appendix D, were significantly related to the **dependent** variables (relative humidity or moisture content of the wall within the child's bedroom and within the basement of the residence). The percent value for relative humidity and moisture content were treated as continuous variables. All independent housing condition variables are categorical.

3.2. LOCALE

Winnipeg, Manitoba is located in the central Prairie region of Canada. Its climate is known for considerable swings, with an average summer-time design temperature (2.5%) of approximately $+31^0$ Celsius but with over 5,550 degree heating days per year below +18 degrees Celsius and a winter design temperature of -31^o Celsius (2.5%) and a Moisture Index of 0.58. Winnipeg is also located in the Red River Valley, a flood plain and prone to periodic flooding conditions.

3.3 DEFINITIONS

This following section summarizes the key words used throughout this report and their corresponding definitions.

<u>Asthma</u>: having either received a formal diagnosis of asthma from a physician or, had, over the last 12 months: a) at least one or more asthma attacks, b) gone at least once to emergency due to an asthma attack, c) been hospitalized at least once due to an asthma attack, or d) been prescribed steroids.

Manitoba's health care databases are among the few population-based health care data sources that exist in the world. The Manitoba Health Services Insurance Plan (MHSIP) is a provincial health care insurance program that maintains several electronic databases, which are housed at the Manitoba Centre for Health policy for research purposes. The MHSIP registration file contains a record for every Manitoba resident and provides information on birth date, sex, and geographic locations. Records of physician reimbursement for medical care that is provided are submitted under a fee-for-service arrangement, and contain information on patient diagnose at the 3-digit level of the ICD-9-CM classification system and physician specialty. Discharge abstracts for hospital services include information on up to 16 ICD-9-CM diagnostic codes, with the first diagnosis representing the primary diagnosis responsible for the hospital stay. Prescription records are submitted by retail pharmacies for reimbursement by provincial drug insurance plans and for drug utilization review purposes, and contain data on the prescription dispensing name and identification number, dosage form, and quantity dispensed.

Persistent Colds/Respiratory Infections: According to Williamson et al. (1997), persistent colds are defined as having three or more respiratory infections/colds in the past year. In this research program, persistent colds were defined more stringently as having four or more respiratory infections/colds in the past year.

CFU/m^3: This is the total concentration of culturable microorganisms, incubated by a microbiological laboratory, calculated by dividing the volume of air trapped by the Biotest Hycon RCS Air Sampler into the total number of colonies observed on the culture plate. A colony is a microscopically visible growth of microorganisms on a solid culture medium. Concentrations of culturable bioaerosols are reported as colony forming units (CFU) per unit volume of air.

In the National Building Code of Canada, there are currently no regulatory requirements which dictate specific health limitations on air- borne mould concentrations within residences. Manitoba Workplace Health and Safety (Province of Manitoba, 2005), however, provides the following guidelines on air-borne mould limits within the workplace:

- More than 50 CFU/m^3 of a single species (genus types other than *Cladosporium* or *Alternaria*) may be reason for concern present. Further investigation is necessary.

- Up to 150 CFU/m^3 is acceptable if there is a mixture of species reflective of the outdoor air spores. Higher counts suggest dirty or low efficiency air filters or other problems.
- Up to 500 CFU/m^3 is acceptable in summer if the species present are primarily *Cladosporium* or other tree and leaf fungi. Values higher than this may indicate failure of the filters or contamination in the building.

Lieberman et al. (2004) report that indoor fungal (*indoor fungi generally collected are Cladosporium, Aspergillus and Penicillium*) levels above a range of 150-1000 CFU/m^3 are considered to be sufficient to cause human health problems. The guidelines, however, may not be relevant because of continuing research that attempts to find a link between specific mould genus types, their concentrations, and the health impact on the occupants. Regardless, air-borne mould guidelines for the workplace are unlikely to have relevance for the home when examining the living quarters of a child.

In a report released by the National Institute for Occupational Safety and Health (NIOSH) (2003), which describes the results from a health hazard evaluation of a government facility, the geometric mean value of total indoor culturable airborne fungi was 123 CFU/m^3. Of the 62 participants in the NIOSH study,15% reported asthma and 36% reported chest symptoms (wheezing or shortness of breath).

The European standard for air-borne mould classifications identifies "low" mould levels in the range of 0 to 499 CFU/m^3, "medium" mould levels in the range of at 500 to 999 CFU/m^3, and "high" at mould counts greater than 1,000 CFU/m^3 (CEC, 1994). For purposes of the current study, a value of 100 CFU/m^3 was set as the minimum level of mould count for analysis. Genus identification of the top three mould types was completed for each combined genus sample larger than or equal to 100 CFU/m^3.

Air sampling for mould levels is often used to establish indoor amplification versus exterior, ambient moulds. The American Conference of Government Industrial Hygienists (ACGIH) provided an opinion that indoor mold levels should be less than 1/3 of outdoors levels. Indoor mould levels above this amount indicate amplification and that further investigative work is warranted.

Relative Humidity: This is the ratio, at a specific temperature, of the actual moisture content of an air sample to the moisture content of the air sample if it were at saturation. It is given as a percentage. The Canadian Mortgage and Housing Corporation (CMHC) recommends that the relative humidity within the home be maintained in the range of 30 to 50 percent. However, it must be recognized that, depending on the house type and location within Canada, even a relative humidity of 30 percent during the winter months can lead to damaging high levels of condensation (Trechsel et al., 2001).

Moisture Content (MC) of the Building Material: This is either (a) the mass of moisture per unit volume of any dry building material, (b) the mass of moisture per unit mass of any dense dry building material, or (c) the volume of condensed moisture per unit volume of any light dry material (Trechsel et al., 2001). Moisture content in wood, although the exact percentage for degradation varies per species, is generally assumed to be 19 percent by weight. Typically, moisture contents above 25 percent are necessary to initiate deterioration, and conditions above 20 percent are required to sustain fungal growth and, thus, sustain deterioration (Trechsel, 2001). Regarding gypsum wall board or drywall, moisture contents above 0.50 percent are sufficient to affect paint adhesion while in moisture contents above 2.0 percent, the drywall suffers serious structural damage (CMHC 2007).

Air Temperature: This is the temperature read from a dry bulb thermometer or calibrated digital instrument.

Surface Temperature: This is the temperature of the exposed surface of the object/building surface being measured – usually through a digital contact surface thermometer or infrared device. In combination with relative humidity, lower exterior wall and/or window temperatures from air leakage and/or conductive heat loss (thermal bridges) increases the dew point temperature which can aggravate interior condensation.

The house audit in the current study covered six broad categories. The following section summarizes the variables assessed in the audit of the individual homes. Appendix C lists all specific building components reviewed for each of the homes.

3.3.1 House Condition Information

All house inspections were carried out during the spring and summer of 2006; however, air sampling was primarily completed in April and May of 2006. In the second stage of Part 2, an extensive assessment protocol was developed in order to establish the physical condition of each home (see Appendix C). The focus of residential inspections was on detached dwellings. Specific variables pertaining to the individual house inspected, included the following:

- Size of home: total square footage. Four categories were established for ease of analysis: <1,000 square feet, 1,000-1,500 square feet, 1,500-2,000 square feet, and >2,000 square feet.

- Architectural layout of the home. In total, nine categories were established: bungalow, split level, 2-storey, 3-storey, town-house, semi-detached (side-by-side), row house, multi-storey (apartment/condominium), and "other" if the house reviewed could not be categorized into the above list.

- Age of home, in years. Five categories were established for this variable: 0-5 years; 6-10 years, 11-15 years, 15-20 years, and ≥20 years of age. The audits were completed in 2006 and, thus, is the reference point for establishing the house year of construction.

- Renovations to exterior walls. The resident was questioned about the presence of any modifications to the exterior walls, including, but not limited to, the inclusion of new cladding, possibly in combination with exterior insulation.

- Exterior cleanliness and/or clutter. The inspection protocol required a qualitative assessment of the exterior grounds of the residence, including the general cleanliness and the presence of clutter or debris around the home. Four categories were established: poor, fair, good, and excellent.

- Condensation along the interior of the home. The inspection protocol required examination of the interior wall surfaces for evidence of condensation-related damage. Moisture-related stains are not uncommon at exterior ceiling/wall interfaces due to thermal bridging effects if interior humidity levels are not adequately controlled. Figure 3.2 shows an example of condensation related damage in the ceiling of a house.

	
Condensation and biological growth at ceiling/wall interface due to thermal bridge in framing [1]	Major water damage from condensation in attic assembly

Source: J. A. Wells

[1] This and subsequent photographs were obtained from the author's investigations and are not from the present study.

Figure 3.2. Examples of Condensation Damage in Ceilings of Homes

- Basement. The presence of interior finishes on the basement foundation walls, including but not limited to the absence/presence of insulation, window coverings, and the absence/presence of carpets within the basement were recorded, which can reduce drying potential.

- Home ownership. The occupants were also questioned about whether they owned or rented the home.

3.3.2 Foundation Conditions

Basements can be problematic with respect to water penetration and overall damp conditions. The absence/presence of moisture-related damage in the basement depends on a number of variables. These were assessed on site during the home inspections and included the following.

- Absence/presence of a basement. It is not uncommon for homes to not incorporate a basement or crawlspace. The main floor is constructed of a thickened slab-on-grade where the superimposed live loads and the self-weight of the building are transferred through the concrete slab into the underlying sub-grade.

- Type of foundation wall. The three most common types of foundation systems in Winnipeg include cast-in-place concrete, stone/rubble masonry, and concrete block. Although pressure-treated wood foundations are allowed under the Manitoba Building Code, the number of homes incorporating this type of foundation system is relatively low.

- Condition of foundation wall. Where the foundation wall was visible from the interior, the general condition was assessed by categorizing the walls into four categories: poor, fair, good, and excellent. The presence of cracking or displacement with or without water penetration would generally render a foundation wall as “poor” and “fair” if no efflorescence, displacement, or structural cracks were observed. The following photographs show examples of a foundation wall categorized as “excellent” and “poor”. No invasive recesses were completed to determine the absence/presence of foundation wall waterproofing, damproofing or the condition of the weeping tile.

	
Foundation wall in “excellent” condition. (horizontal line is a pour joint in the concrete, not a crack)	Foundation wall in “poor” condition, (note structural crack and water penetration).

Source: J. A. Wells

Figure 3.3. Foundation Wall Condition Examples

- The presence of moisture in the basement remained a separate variable. Classification was simply yes or no for visible evidence of water in the basement.

- The presence of efflorescence on the interior foundation walls was also noted. This can indicate the presence of accumulating moisture along the exterior which may affect moisture and/or humidity levels within the basement. Note also in Figure 18 that efflorescence is clearly evident on the wall identified as “poor”.

- Basement cleanliness was also noted and distinguished under four categories: “poor,” “fair,, “good,” and “excellent,”.

- Several home designs incorporate crawlspaces within the residence. The crawlspace may be provided with a ground cover finish, such as concrete or exposed earth surface. Thus, crawlspace types were noted based on their ground cover, absence/presence of moisture, and overall general condition. Figure 3.4 shows visual examples of the two crawlspace conditions, “excellent” versus “poor.”

Crawlspace in “excellent” condition, (dry, well graded, and polyethylene vapour retarder sealed to grade beam)	Crawlspace in “poor” condition, (note debris and free-standing water)

Source: J. A. Wells

Figure 3.4. Crawlspace Examples Depicting “Excellent” versus “Poor” Condition

3.3.3 Exterior Conditions

The condition of the exterior cladding and joint caulking can have a significant impact on controlling air leakage and precipitation penetration. In addition, the effectiveness of precipitation management components, such as troughs and rain water leaders, serve to direct moisture away from the residence. Specific variables for the inspection included the following.

- The condition of the exterior joint caulking. Caulking at window and joints within the residence, including window and door rough openings, were closely examined. Caulking condition were categorized as poor, fair, good, or excellent. Caulking exhibiting extensive cohesive or adhesive failures were categorized as "poor" in condition. No attempt was made to determine the type of caulking material, for example acrylic versus silicone or polyurethane. Figure 3.5 provides an example of "excellent" versus "poor" condition caulking.

	
Window/joint caulking in "Excellent" condition	Caulking in "Poor" condition, (note adhesive and cohesive failures)

Source: J. A. Wells

Figure 3.5. Caulking Conditions for "Excellent" on the Left versus "Poor" on the Right

- The exterior cladding systems for homes in Winnipeg typically consist of wood, vinyl, stucco, and brick masonry. As homes typically incorporate more than one type of cladding, the inspection protocol did not identify the specific type of cladding used for each home. Rather, the condition of the cladding was generally categorized as "poor," "fair," "good," or "excellent." Figure 3.6 provides pictorial examples of two cladding classifications.

Cladding (brick) in "excellent" condition, (mortar well bonded to brick and intact)	Cladding in poor condition; coating is trapping moisture with underlying stucco failing

Source: J. A. Wells

Figure 3.6. Pictorial Views Comparing "Excellent" Condition Cladding to "Poor"

- The condition of the rain water management systems in place was also noted, including the presence/absence of troughs and downspouts. The location of the downspout relative to the foundation was also reviewed. Four categories were established: "poor," "fair," "good," and "excellent."

Discontinuous troughs and/or damaged down spouts, where water is directed towards the foundation wall, would be categorized as “poor.” Conversely, gutters and downspouts incorporating extensions to direct water well away from the foundation were categorized as “excellent.”

- The absence/presence of visible structural duress in the homes was also examined. Structural duress was classified as visible differential foundation movement, with or without visible cracks in the foundation walls, when viewed from the exterior.

3.3.4 Fenestration Assessment

Fenestration generally refers to the windows and doors along the exterior building envelope of the home. Both windows and doors were inspected. Specific audit items are summarized below.

- Window type. The three most common window frames were recorded: plastic (polyvinyl chloride or fiberglass), aluminum, and wood.

- Number of panes of glass. The presence of single versus dual versus triple pane units was recorded. Absence or presence of low emissivity coating was not determined.

- Condition of the lites or glazing within the frames as “poor,” “fair,” good,” or “excellent.” “Poor” condition refers to a pumping out of gaskets and/or breakdown in the desiccant in sealed units, and/or excessive wear or missing weather stripping in the tracks of the slider units.

- Age of windows. The window age, when known by the occupants, was recorded in one of four categories: new (< one year old), 1-5 years, 5-10 years, and >10 years old.

- Condition of windows. Window condition was again categorized as “poor,” “fair,” “good,” or “excellent.” Windows in “Poor” condition exhibited deterioration of the frames and/or sash units. Figure 3.7 summarizes the two classifications: “excellent” versus “poor.”

Newer window identified in “excellent” condition	Window identified in “poor” condition

Source: J. A. Wells

Figure 3.7. “Excellent” versus “Poor” Condition for Windows.

- Condensation. Evidence of water damage to the rough opening and/or window frame components were used to identify whether or not visible condensation had occurred in the window units, typically observed during winter conditions in poor quality windows.

Source: J. A. Wells

Figure 3.8. Window Exhibiting Extensive Water Damage and mould growth, (classified as “Poor”)

- Type of door. Typical door types included wood, plastic (PVC or Fiberglass), and metal.
- Condition of door. The condition of the doors inspected was categorized as “poor,” “fair,” “good” or “excellent.”

3.3.5 Roof System Data

The roof system audits included six primary variables, as outlined below.

- Roof construction. The two most common roof systems consist of either an attic-type roof system or a cathedral-type ceiling system. In the first system, the environmental separation is provided by the ceiling in conjunction with a vapour retarder and insulation along the top surface, creating a void space. Although protected from precipitation, this system is permitted to reach ambient temperatures.

  In the cathedral type ceiling, wood joists in a rafter arrangement are used. Environmental separation is again provided by the drywall, polyethylene vapour retarder, and insulation, but no attic space is provided. Frequently, a vented air space is provided between the insulation and the roof sheathing.

- Roof framing type. Homes older than 40 years of age tend to utilize “stick-framing” in which the roof framing utilizes dimensional lumber in the form of rafters and collar ties built on-site. In newer homes, pre-engineered wood trusses, which are fabricated in a plant, delivered and installed on-site are more common.

- Condition of the attic. Attics, where accessible, were inspected for evidence of water damage, as well as for any associated long-term effects of water penetration, such as visible biological growth. The condition of the attics was categorized as “poor,” “fair,” “good,” or “excellent.” Figure 3.9 below visually summarizes an “excellent” attic versus a “poor” condition attic.

	
Attic in "excellent" condition (no visible deterioration to members)	Attic in "poor" condition due to biological growth, moisture and deterioration to sheathing

Source: J. A. Wells

Figure 3.9. Attic in "Excellent" Condition versus "Poor" Condition

- Roofing system material. The most common roofing materials used in Winnipeg houses are: three-tab asphaltic shingles, a membrane type system (such as torch-applied SBS (styrene-butadiene-styrene) modified bitumen or hot applied asphalt with felts protected by gravel ballast), and metal roofs.

- Condition of roof. The condition of the roof systems, where accessible or visible was categorized as "poor," "fair," "good," or "excellent." A roof in "poor" condition would tend to exhibit extensive curling and loss of granules. Flashings at penetrations would also be displaced or disconnected. The figure below summarizes the "excellent" versus "poor" classifications.

	
A three tab shingle roof in "excellent" condition	A three-tab shingle roof in "poor" condition; note loss of granules and curling

Source: J. A. Wells

Figure 3.10. Asphalt Shingle Roof Condition Example of "Excellent" versus "Poor"

- Roof renovations. Houses that have undergone major renovations or modifications within the last 24 months, including new roof systems, were identified in the audit.

3.3.6 Mechanical Systems Summary

Basic mechanical system components within the inspected homes were inspected and recorded. These included:

- Humidity generating devices, such as large aquariums or whirlpool-type hot-tubs. The presence of such devices was recorded.

- Number of exhaust fans. The number of fans within the residence was recorded as 0, 1, 2, and 3 or more.

- Use of exhaust fans. The occupants were asked about the degree of exhaust fan use: often, sometimes, or never.

- Wood burning devices. The absence or presence of an open fireplace or woodstove was noted. Storage of wood indoors can increase the relative humidity and bring moulds into the house.

- HRV. Homes were reviewed for the absence/presence of a heat recovery ventilator (HRV). This was recorded in order to establish whether sufficient mechanically induced air changes to the home were being provided.

- Type of heating system. Any electrical versus gas burning devices were noted.

- Central cooling system. The absence or presence of such a system in the home was recorded because of its effect on interior temperature.

- Air cleaners. The presence of any electric air cleaning devices as noted.

- Furnace filters. Where accessible, these were checked, if present, and their condition was noted.

- Internal drainage. The house basement was examined to determine whether a sump-pit and pump were provided versus a conventional floor drain within the basement floor.

The condition of the pump was not visually verified but the grate was typically lifted on the basement floor drains to establish if water could be seen flowing through the tile.

- Basement insulation. The type and condition of insulation within the basement walls were noted.

3.4 MATERIALS

Surveys and check lists were utilized in order to evaluate the background information on each home and aid in the engineering assessment of the houses under investigation. The survey and audit check sheets are provided in Appendices A, B, and C. Supplementing the visual examination, in-situ measurements of air-borne mould and environmental conditions were also taken, the details of which are summarized in this section.

Air samples were collected in the child's bedroom (Area 1) and in the basement (Area 2) of each home, using a Biotest Hycon RCS Air Sampler device. The RCS Air Sampler works on drawing the ambient air into the device via an impeller. The particles in the air are then impacted by centrifugal force onto an agar medium. The agar strips were then collected and forwarded to an accredited laboratory for incubation and analysis.

The Figure 3.11 shows the RCS Air Sampler device and agar strips that were utilized.

Source: http:/www.Elokarsa.com

Figure 3.11. RCS Air Sampler Device and Agar Strips

A simultaneous control or outdoor air sample, designated Area 3, was taken in each neighborhood so that a comparison of indoor and outdoor mould spore counts could be conducted.

Air sampling was completed by the author and engineering graduate students which assisted in the housing audits, under the direction of the author and academic advisor. The directions employed for the use of the RCS device in the study is summarized below.

1. Wearing vinyl gloves, extract the RCS impeller and housing unit from case. Salvage the existing sterilized foil wrap.

2. Prior to visiting the home, parents were advised in advance of the visit and instructed not to stray from their normal routines, particularly in regard to means and methods of cleaning. At each home, complete two tests, one in the child's bedroom and a second in the basement of the home, preferably in common or play areas.

3. If ambient temperatures are warm and windows are open, close the windows and cycle furnace through one cycle before commencing air quality testing.

4. Install the drum housing onto the unit. Carefully install the propeller onto the shaft within the drum.

5. Peel back the labeled backing from the agar strip casing about 2 to 4 cm, grasp the tab, and carefully remove the strip while avoiding contact with any surface. Stabilize the strip by holding along the sides of the casing. Throughout all handling procedures, prevent contact with any exposed surface to the agar strip.

6. Slide the agar strip into the drum housing with the agar facing <u>INWARDS</u> towards the propeller. Leave the clear end of the tab projecting out about 1 to 2 cm.

7. Set the machine for a FOUR (4) minutes sample duration. Turn machine on and leave undisturbed in the approximate middle of the room for the four minutes.

8. Label the casing.

9. Remove the agar strip from the metal housing avoiding contact with any surface and slide strip back into casing. Tape the edges of the casing shut to seal.

10. Carefully store the agar strip in a portable cooler with an ice pack and move to the next room.

11. Let the unit run for one minute without the agar strip to cleanse the drum and propeller prior to inserting the next agar strip.

12. Carefully dismantle the unit, sterilize with isopropyl alcohol (IPA), and allow it to dry before wrapping the drum and propeller in foil.

13. After testing each house, sterilize the drum and propeller by rinsing with IPA-soaked cotton balls. Allow to dry before re-packaging.

14. Store agar samples in a portable cooler but ship daily to Northwest Labs in Winnipeg for processing and assessment.

Due to budget constraints, only one outdoor (control) air sample was collected in each neighborhood per day since groups of houses were in relatively close proximity. The agar strips were secured in a cooler immediately following testing and transferred within 48 hours to an accredited laboratory where they were incubated and mould colonies counted. In addition to evaluating the volume of mould in each sample in Colony Forming Units (CFU)/m^3, the top three genus types of mould were identified for all agar strips exhibiting a total combined mould count greater than 100 CFU/m^3.

Due to budgetary constraints, we limited the number of air samples to two per home and one exterior. We also limited the identification of the specific mould genus type to the top three in each air sample and only if the total count was higher than 100 CFU/m^3. We based our decision to limit the detailed analysis to mould counts greater than 100 CFU/m^3 which we anticipated to be conservative based on prevailing literature at the time, including Manitoba's Workplace Health and Safety guidelines which stated that "Up to 150 CFU/ m^3 is acceptable if there is a mixture of species reflective of the outdoor air spores."

We tried to carry out the air sampling during the months of April and early May when the weather in Winnipeg is still relatively cold, the ground is still frozen, and the windows are usually closed. We did this in order to reduce the potential for communication from outdoor mould into the houses.

The literature (e.g. Trechsel, et al., 2001) confirms that throughout the heating season, moisture levels in the building materials of the home tend to increase due to vapour diffusion and air leakage, peaking in late winter/early spring. The moisture build-up typically accumulates in the wall and roof system through condensation. In addition, during the spring thaw, residual moisture within the house, in the form of frost or ice, will melt. Melting snow along the exterior of the home, both at grade and on roof and wall surfaces, will also potentially penetrate the building envelope, increasing moisture levels of the building materials.

Testing was, therefore, carried out in the spring of 2006 (April, May, and June) while building material moisture content was anticipated to be higher due to winter related condensation and before windows were routinely opened during the day.

The condensation assumption is valid for homes that are not affected with wind-driven rain penetration or foundation water leakage associated with sustained periods of rain. In a heating-dominated climate, condensation-related concerns play a major role in moisture related-damage to attics and exterior wall systems.

As a result, the team endeavored to complete as much of the field work as possible, particularly the air-sampling, before the late spring/early summer before substrate drying to the exterior was allowed to occur and before windows were routinely opened during the day.

A total of 1911 air samples were taken from 715 homes. Of the air samples where the total combined mould count of CFUs exceeded 100 CFU/m^3, genus identification revealed approximately 25 different types of mould, the most common of which are listed in Table 4.16.

In addition to the air sampling, on the same day that the samples were taken, the following additional data on the home under investigation were collected:

(a) A brief one-page Housing Inspection Protocol was completed in an interview format with the parent/guardian reporting any evidence, over the past year, of water penetration in their home and any specific renovations they undertook to improve water- or moisture-related damage.

(b) Air temperature and relative humidity measurements were taken in all rooms using a Delmhurst Digital Hygrometer/Air Temperature Unit. Figure 3.12 shows the device utilized. Minimum and maximum measurements were recorded throughout the house. Exterior or ambient conditions at each home were also recorded.

Source: http://www.Moisturemeters.com

Figure 3.12. Delmhorst Digital Temperature and Relative Humidity Gauge Used in Study

(c) The surface temperatures of all windows and walls in each room were measured using an infra-red temperature probe. Particular emphasis was given to thermal bridges, such as window perimeters, ceiling/wall and wall/floor interfaces. Figure 3.13 shows the infrared temperature probe device utilized.

Source: http://www.Pridmost.info

Figure 3.13. Rayteck Infrared Temperature Probe Utilized to Measure Surface Temperatures in the Homes

(d) A Delmhurst pin-type penetrating moisture meter was used to measure the moisture content of the building surfaces, specifically the interior walls. A Delmhorst BD-2100 moisture meter was utilized to measure the moisture content of the interior building surfaces. The BD-2100 has three independent scales based on substrate type: wood, plaster/concrete, and gypsum materials. The meter is manually adjusted via a Scale

Button, according to the material type tested. The sensitivity reading range for wood is 6% to 40%, whereas for gypsum the range is significantly more stringent at 0.20% to 50%.

The Delmhorst meter works on electrical resistance in which the metallic pins are inserted into the substrate. The pin penetration depth is only 5/16". The vast majority of the substrates tested were, in fact, gypsum wall board. Wherever wood was encountered, this was either a panel finish or exposed wood framing in a partially finished basement. In such cases, the scale factor on the Delmhorst meter was manually changed to account for the wood substrate.

Our decision to use a DC type device (penetrating pin type) versus a capacitance device (surface mount) was attributable to the fact that a DC resistance based meter is effective at establishing a more accurate estimate of the moisture content of the actual material under examination (Onysko, 2008).

No moisture content correction factors were applied to account for species type of wood or temperature. However, Delmhorst provides a correction factor chart for wood species type and temperature. Based on the relatively low range in recorded surface temperatures, any difference in wood types, such as spruce, pine or fir (SPF) versus the standardized Douglas fir would have little impact on the moisture content readings. Most significantly, based on the shallow pin-penetration depth, only the interior finish material moisture substrate content would have been evaluated which, in the case of this study, was by in large gypsum wall board. Figure 3.14 shows the device utilized.

Source: Moisturemeters.com

Figure 3.14. Delmhorst Penetrating Type Moisture Meter Used to Measure Moisture Content of Building Material Components

(e) Any air leakage through the window and wall systems was assessed using a smoke wand; the wand was also used to establish if the residence was under infiltration or exfiltration. The smoke wands were used to only establish whether or not a house was operating under negative or positive pressure to the exterior. Stack effect and mechanical systems will alter the pressure differential across the building envelope. We also know that wind direction will also affect the direction of smoke travel when held against exterior windows; thus, the Environment Canada weather data was downloaded for each day of the housing inspections with results compared to wind direction. Figure 3.15 shows the device used.

Source: J. A. Wells

Figure 3.15. Smoke Wand Utilized to Detect Air Leakage through Penetrations

4.0 RESULTS AND DISCUSSION

The results section is organized into distinct sections. Part 1 statistical analyses of the survey are first presented. The results of the biological air sampling are then discussed, including a statistical analysis between survey results for visible mould and the air sampling. Respiratory health in relation to biological sampling data is presented followed by a statistical analysis between housing conditions and air-borne mould concentrations within the home.

A series of one-way ANOVAs was completed on continuous data, such as temperature and relative humidity. Discreet variables were analyzed using a chi-square analysis. With the exception of the Part 1 survey, only the statistically significant results are given in this thesis with a probability of $p = 0.05$.

4.1 Results from the Initial Contact Survey

Initial Contact Survey packages were prepared for 13,727 grades-3 and -4 children in the city of Winnipeg and were distributed to all targeted schools within the six school divisions. The average response rate to Part 1 was 25% (3392).

Once we received and entered the responses from the Initial Contact Survey onto an electronic spreadsheet, we categorized the respondents into four groups according to health conditions: Asthma and Frequent Respiratory Infections (Group 1); Asthma and No/Few Respiratory Infections (Group 2); No Asthma and Frequent Respiratory Infections (Group 3); and No Asthma and No/Few Respiratory Infections (Group 4).

The data derived from the Initial Contact Survey were plotted using the Arch-GIS program, identifying the house locations according to the child's respiratory conditions reported in the survey by the parents. The income range of families is also shown in these figures. Figure 4.1 shows the results for children with reported diagnosed asthma and few colds (Group 2).

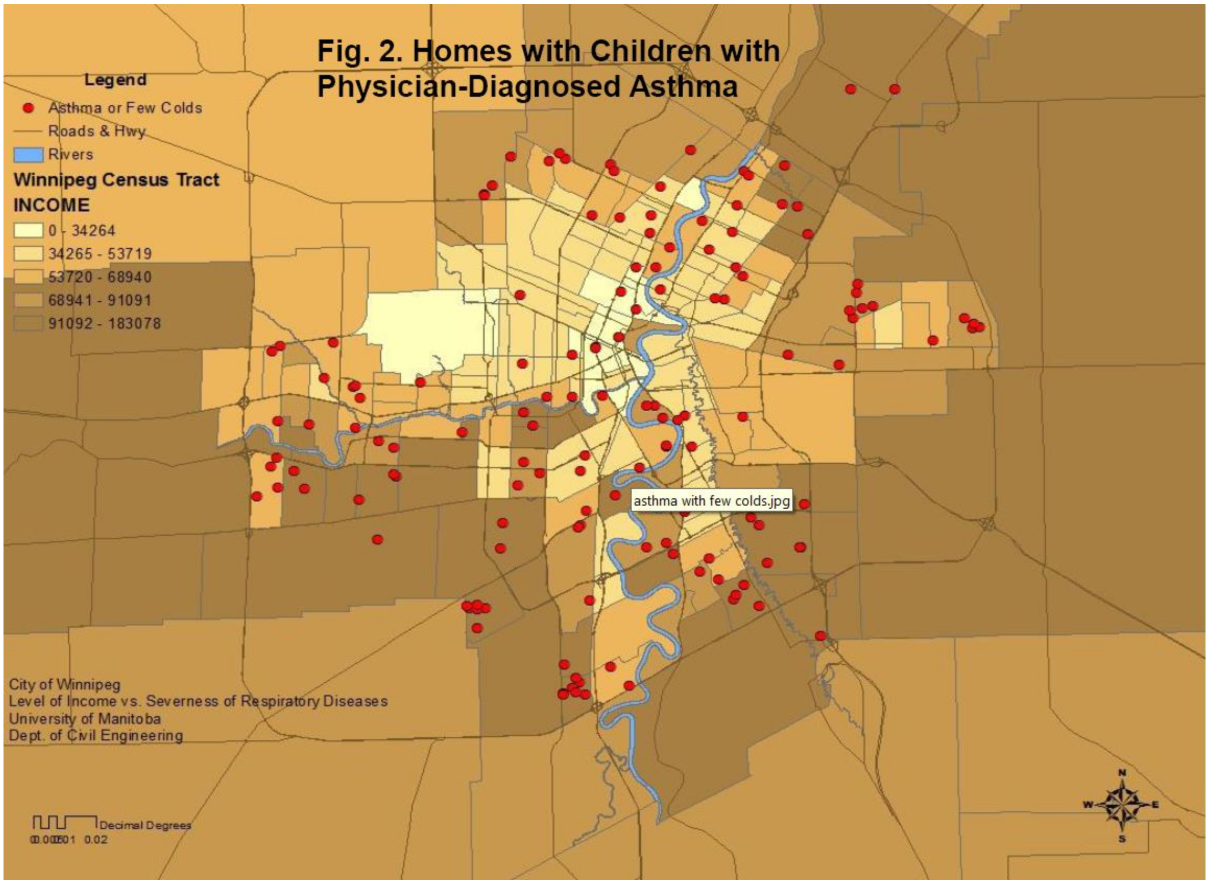


Figure 4.1. Geographic Location of Houses in Winnipeg of Children Diagnosed with Asthma and Few Colds (Group 2).

Figure 4.2 shows the location of homes in Winnipeg where children with no asthma but have persistent colds (Group 3) as well as the location of homes of healthy children (Group 4). It seems that the two groups are evenly distributed throughout the City with the exception of those houses concentrated in the low socio-economic states (SES) areas of Spence, Inkster, Maples, and Garden City (inscribed by white pentagon on figure) where higher concentration of houses with children having persistent colds are reported.

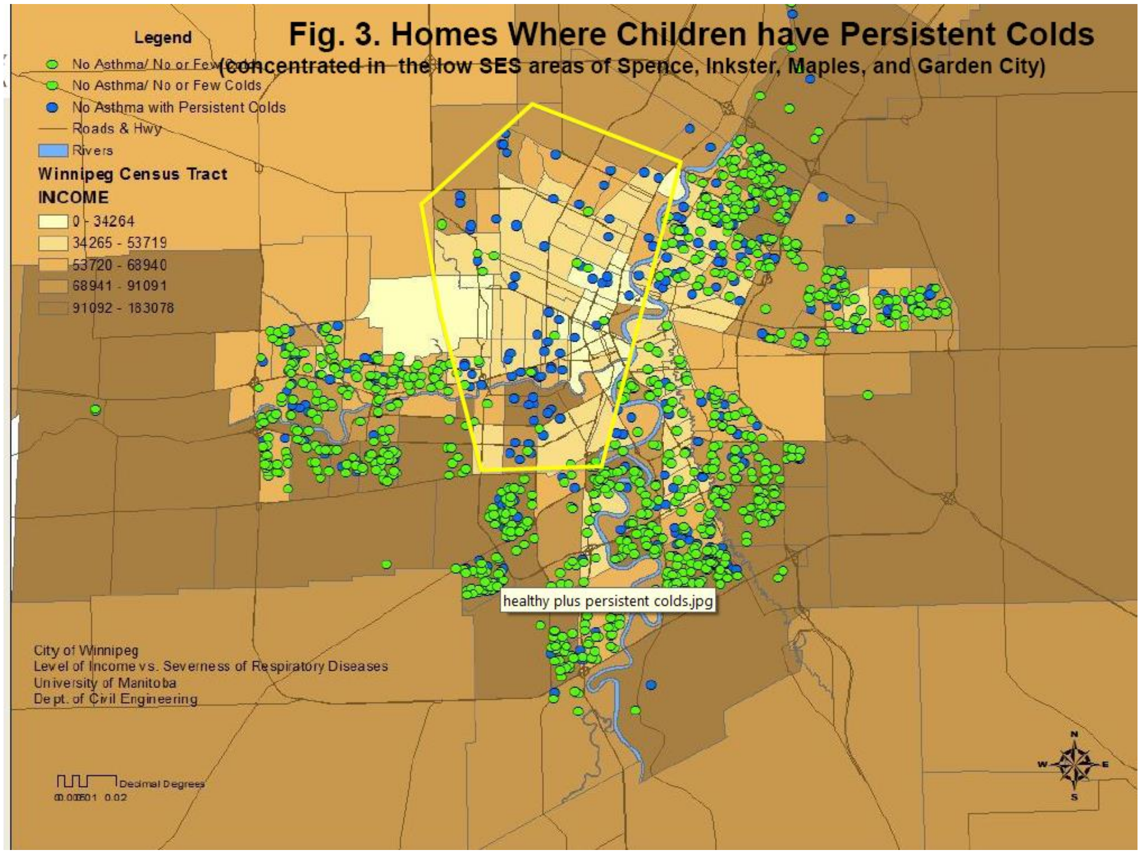


Figure 4.2. Graphic location of houses in Winnipeg of Children with No Asthma and with Persistent Colds (Group 3).

4.1.1 Statistical Analysis of Data from the Initial Contact Survey

Statistical analyses were carried out to examine the relationships between selected aspects of the child’s home environment and his/her respiratory health. The information obtained during the Initial Contact Survey from the parent/guardian of the child included: age of the home in years; years living in the home; whether they own their own home; whether or not visible mould is present anywhere in their home and whether it is in the basement, bathroom, or kitchen; whether children occupants have asthmatic parents, siblings, and/or other relatives; number of rooms in the home that are carpeted;

number of smokers in the home; presence of rodents (mice) in the home; and number of cats or dogs in the home.

The average age of the houses of those parents who responded to this study was 31.6 years. As shown in Table 4.1 below, there was little variation in the age of home or the years living in the home for each of the four categories of children examined. Similarly, the mean for years the occupants were living in the home was 6.6 years.

Table 4.1. Mean Age of Homes and Years Living in Home by respiratory Health Group within Study

Group No.	Respiratory Health Status	Age of Home		Years living in Home	
		n	mean (sd)	n	mean (sd)
4	Few or No Colds/No Asthma	1814	31.2 (23.0)	1890	6.5 (5.1)
3	No Asthma and Frequent Respiratory Infections/Colds Only[1]	767	32.8 (23.1)	816	6.6 (5.9)
2	Asthma and No/Few Respiratory Infections[2]	163	32.6 (23.2)	167	7.1 (5.8)
1	Asthma & Frequent Respiratory Infections[3]	416	31.0 (21.8)	443	6.3 (5.2)
	Total	3160	31.6 (22.9)	3316	6.6 (5.4)

Note: '1' Defined as having four or more respiratory infections/colds in the past year.
'2' Having received a formal diagnosis of asthma from a physician.
'3' Having four or more respiratory infections/colds in combination with physician diagnosed asthma.

The Initial Contact Survey data were analyzed using SAS by the Department of Biostatistics at the University of Manitoba. The results are summarized in Table 4.2.

Individual associations between selected aspects of the child's home environment and his/her respiratory health were examined. Tests of independence (Pearson's chi-squared test) for contingency tables were used to assess the associations. The chi-squared analysis compares percentages of observed versus expected values, specifically, the actual numbers within the various categories versus quantitative methods which compare means. Small values of $\chi 2$ indicate a good agreement between observed and expected values while large values of $\chi 2$ show poor agreement. Thus, expected values are not close to observed values which therefore suggest that the hypothesis in which no statistically significant difference exists between the two groups, expected versus observed values, has a high probability of being wrong and should therefore be rejected.

The use of the $p \leq 0.05$ value was the basic decision or cut-off value which is the generally acceptable limit for statistical significance. Significant observations from the data presented in Table 4.2 are summarized in point form.

Table 4.2. Association Between Selected Aspects of the Child's Home Environment and his/her Respiratory Health

	Group 4 Few or No Colds/No Asthma (%)	Group 3 Respiratory Infections Only (%)	Group 2 Asthma (%)	Group 1 Asthma & Frequent Respiratory Infections (%)	X^2 *(df)* *p*-value
Mould in basement					
Yes (n=612):	47.4	29.9	5.9	16.8	29.11 (3)
No (n=2812):	59.3	23.4	4.8	12.5	<0.0001
Mould in bathroom					
Yes (n=806):	48.3	30.1	6.6	15	35.44 (3)
No (n=2618):	59.9	22.8	4.5	12.8	<0.0001
Mould in kitchen					
Yes (n=90):	30	47.8	4.4	17.8	33.62 (3)
No (n=3334):	57.9	23.9	5.0	13.2	<0.0001
Asthmatic Parents					
Yes (n=629):	38.2	26.1	8.4	27.3	181.28 (3)
No (n=2795):	61.4	24.2	4.2	10.2	<0.0001
Asthmatic Siblings					
Yes (n=539):	41.2	24.7	8.3	25.8	117.57 (3)
No (n=2885):	60.1	24.5	4.4	11.0	<0.0001
Asthmatic Relatives					
Yes (n=1368):	45.5	27.9	6.4	20.2	155.37 (3)
No (n=2056):	64.9	22.3	4.1	8.7	<0.0001
Number of Carpets					
≤3 (n=1535):	56.0	23.6	5.6	14.8	8.0 (3)
≥4 (n=1868):	58.1	25.3	4.5	12.1	0.0460
Smokers living in the home					
Yes (n=888):	50.9	27.8	5.6	15.7	19.03 (3)
No (n=2529):	59.3	23.4	4.8	12.5	0.0003
Rodents in home					
Yes (n=259):	47.9	30.1	3.9	18.1	13.34 (3)
No (n=3165):	57.9	24.1	5.1	12.9	0.0040
Cats or Dogs in home					
Yes (n=1541):	56.8	25.2	4.7	13.2	0.94 (3)
No (n=1879):	57.4	24.1	5.2	13.4	0.8167
Age of home (years)					
0 to 15 (n=851):	60.6	22.4	5.2	11.8	
15 to 27 (n=730):	56.7	23.7	4.3	15.3	11.16 (9)
27 to 45 (n=754):	56.0	26.1	5.0	12.9	0.2647
>45 (n=825):	56.0	25.0	6.1	13.0	
Years in home					
0 to 2 (n=875):	57.4	25.3	4.7	12.7	
2 to 5 (n=819):	55.7	25.4	4.2	14.8	10.17 (9)
5 to 10 (n=764):	56.4	23.7	5.1	14.8	0.3368
>10 (n=858):	58.4	24.0	6.2	11.4	
Own home					
Yes (n=2824):	58.2	23.7	5.3	12.8	13.31 (3)
No (n=600):	52.2	28.5	3.7	15.7	0.004

- The data show that the child's respiratory health is significantly associated with self-reported visible mould in the home. The data revealed that 29.9% of the houses with mould in the basement, 30.1% of the houses with mould in the bathroom, and 47.8% of the houses with mould in the kitchen had children with Frequent Respiratory Infections (Group3), $p<0.0001$.

- In general, there are fewer healthy children (Group 4, Few or No Colds/No Asthma) when mould is present in the home. For instance, of all children living in homes where mould is present in the basement, 47.4% of them are healthy; for children living in homes where mould is *not* present in the basement, 59.3% are healthy.

- Significant associations were found between respiratory health and carpeting in the home, smokers living in the home, the presence of rodents in the home, and home ownership. For example, 27.8% of the children in homes with smokers in the home had frequent respiratory infections (Group 3) compared to 23.4% of children in homes with no smokers, $p=0.0003$. In homes with rodents, 30.1% of the children had frequent respiratory infections (Group 3) compared to 24.1% of the children in homes with no reported rodents, $p=0.0040$.

- Genetic associations (parents, siblings, or other relatives with asthma) were also observed. The survey revealed that 8.4% of the children with diagnosed asthma (Group 2) had parents with asthma, $p<0.0001$.

- No statistically significant associations were found between respiratory health and the age of the home or the number of years living in the home, p=0.2647 and p=0.3368, respectively.

- Almost all statistically significant associations were in the anticipated direction.

A step-wise multinomial logistic regression was subsequently run to determine independent predictors of Frequent Respiratory Infections (Group 3), Asthma Only (Group 2), and Asthma & Frequent Respiratory Infections (Group 1). The healthy group, Few or No Colds/No Asthma (Group 4), was taken as the reference group. Wald-type chi-squared statistics were used to assess the statistical significance of independent variables. Only significant independent variables were retained in the model. Table 4.3 summarizes the estimated odds ratios (OR) and 95% confidence intervals (95%CI) from this analysis. The odds ratio compares the odds of a child exposed to a specific aspect of his/her home environment having a respiratory health condition (Frequent Respiratory Infections (Group 3), Asthma Only (Group 2), or Asthma & Frequent Colds (Group 1) to the odds of a child having the same respiratory health condition in a group that is not exposed to the same aspect of his/her home environment. For example, there is a probability a child living in a home with mould in the basement is 35% more likely to have frequent respiratory infections/colds than a child that is not living in a home with mould in the basement.

Table 4.3. Independent Predictors of his/her Respiratory Health.

	Group 3 Frequent Colds OR (95% CI)	Group 2 Asthma OR (95% CI)	Group 1 Asthma & Frequent Colds OR (95% CI)
Mould in basement	**1.35 (1.09, 1.68)***	1.26 (0.84, 1.88)	**1.39 (1.06, 1.82)***
Mould in bathroom	**1.33 (1.09, 1.62)***	**1.59 (1.11, 2.27)***	1.19 (0.92, 1.54)
Mould in kitchen	**2.85 (1.70, 4.77)***	1.09 (0.37, 3.27)	1.79 (0.91, 3.53)
Asthmatic Parents	**1.44 (1.15, 1.81)***	**2.37 (1.64, 3.44)***	**2.94 (2.29, 3.77)***
Asthmatic Siblings	1.15 (0.90, 1.46)	**1.93 (1.31, 2.86)***	**2.05 (1.58, 2.67)***
Asthmatic Relatives	**1.59 (1.34, 1.89)***	**1.63 (1.17, 2.27)***	**2.29 (1.83, 2.87)***
Smokers living in the home	**1.33 (1.10, 1.60)***	1.33 (0.94, 1.89)	**1.41 (1.11, 1.79)***

***p<.05**

More specifically,

- Children with reported mould in their home (basement, bathroom, and kitchen) were more likely to have persistent colds compared to those with no reported mould, and the odds ratios ranged from 1.33 (95%CI: 1.09–1.68) to 2.85 (95%CI: 1.70–4.77).

- Children who have asthmatic parents or other relatives have 44% and 59% higher odds of having persistent colds (OR: 1.44, 95%CI: 1.15–1.81; and OR: 1.59, 95%CI: 1.34–1.89, respectively), than children with no asthmatic parents or relatives.

- Children with smokers living in the home were more likely to have persistent colds (OR: 1.33, 95%CI: 1.10–1.60).

- Children with asthmatic parents, relatives, or siblings were more likely to have asthma than children living in homes with no other asthmatic persons. The odds ratios ranged from 1.63 (95%CI: 1.17–2.27) to 2.37 (95%CI: 1.64–3.44).

- There was some evidence to suggest that children with reported mould in the bathroom were more likely to have asthma than those children living in homes with no reported mould in the kitchen (OR: 1.59 (95%CI: 1.11–2.27).

- Children with reported mould in their basement were more likely to have persistent colds in combination with asthma (OR: 1.39, 95%CI: 1.06–1.82).

- Children with asthmatic parents, siblings or other relatives had more than double the odds of having asthma and persistent colds than children with no other asthmatic persons living in the home. In this case, the odds ratios ranged from 2.05 (95%CI: 1.58–2.67) to 2.94 (95%CI: 2.29–3.77).

- Children with smokers living in the home were more likely to have persistent colds in combination with asthma (OR: 1.41, 95%CI: 1.11–1.79) than children living in homes with no smokers.

4.2 Analysis of Air Sampling Data

Air samples were collected from 715 homes utilizing an RCS air sampler. One sample was taken in the child's bedroom, designated as Area 1, and a second sample was obtained in the basement of the child's home, designated as Area 2. In addition, outdoor air samples were collected in the vicinity of these homes each day that air sampling was completed designated as Area 3. The air samples were analyzed by a professional laboratory.

Analysis was initially based on Total CFU's/m^3. One of our research goals was to establish whether or not mould in general, can be statistically associated with the respiratory health of children. The use of Total Mould Counts in CFU/m3 was based on published results of previous researchers (Haas D., Habib J., Galler H., Buzina W., Schlacher R., Marth E., &Reinthaler F.F. (2007); Gent, J., Ren, P., Belanger, K., Triche, E., Bracken, M., Holford, T. (2002); and Godish, Godish, hooper, Hooper, Cole (1996). Research published as late as 2011 are still utilizing Total Mould Counts in establishing the absence/presence of a statistically significant association between total mould and respiratory health For example, Simoni M., et al., in their paper Total viable molds and fungal DNA in classrooms and association with respiratory health and pulmonary function of European schoolchildren, concluded that "...regression models indicated that schoolchildren exposed to elevated levels of viable moulds (>300 CFU/m3) compared with those exposed to low levels (<300 CFU/m3), had almost a threefold higher risk for dry cough at night and rhinitis and almost fourfold higher risk for cough."

The results were grouped into four categories according to their concentration levels: $\geq$ 100 CFU/m^3, $\geq$ 200 CFU/m^3, $\geq$ 300 CFU/m^3, $\geq$ 400 CFU/m^3. These levels reflect the total of all mould genus types. A summary of the results is given in Table 4.4.

Table 4.4. Number of Homes in Each Mould Level (All Genus Types Combined)

Number of Homes by Area Tested	Mould Levels			
	# ≥ 100CFU/m^3 % (95%CI)	**# ≥ 200CFU/m^3** % (95%CI)	**# ≥ 300CFU/m^3** % (95%CI)	**# ≥ 400CFU/m^3** % (95%CI)
Child's Bedroom				
n = 715	455	298	188	135
	63.6 (60.0–67.2)	41.7 (38.0–45.4)	26.3 (23.1–29.7)	18.9 (16.1–21.9)
Basement*				
n = 687	447	296	202	160
	65.1 (61.4–68.6)	43.1 (39.4–46.9)	29.4 (26.0–33.0)	23.3 (20.2–26.6)

*Not all homes had basements.

On the basis of the results presented in Table 4.4, the following observations were drawn:

- A high number of children's bedrooms 63.6% [95%CI: 60.0%–67.2%] were observed to have total air-borne mould counts of at least 100 CFU/ m^3,
- 65.1% [95%CI: 61.4%–68.6%] of basements were found to have total air-borne counts of at least 100CFU/m^3.
- A surprisingly high number of children's bedrooms, 18.9% [95%CI: 16.1%–21.9%] were observed to have total air-borne mould counts of at least 400 CFU/ m^3,
- 23.3% [95%CI: 20.2%–26.6%] of basements were found to have total air-borne mould counts greater than 400CFU/m^3.

The majority of the air sampling was completed in April of 2006. We observed that exterior air-borne mould concentrations increased rapidly with warmer ambient temperatures. Thus, we analyzed the results for April alone, before windows were routinely opened and when ambient conditions were relatively cool. However, when air-borne mould test results were analyzed for April alone, the most common test month in the current study, similar patterns were observed, as shown in Table 4.5.

Table 4.5. Number of Homes in Each Mould Level (all genus types combined) for April Alone.

Number of Homes by Area Tested	Mould Levels			
	# ≥ 100CFU/m³ % (95%CI)	# ≥ 200CFU/m³ % (95%CI)	# ≥ 300CFU/m³ % (95%CI)	# ≥ 400CFU/m³ % (95%CI)
Child's Bedroom	151	73	25	11
n = 288	52.4 (46.5–58.3)	25.4 (20.4–30.8)	8.7 (5.7–12.6)	3.8 (1.9–6.7)
Basement*	151	75	43	27
n = 281	53.7 (47.7–59.7)	26.7 (21.6–32.3)	15.3 (11.3–20.1)	9.6 (6.4–13.7)

*Not all homes had basements.

Based on the total mould levels for April alone, we observed that:

- 52.4% (95%CI: 46.5%–58.3%) of children's bedrooms had air-borne mould counts of at least 100 CFU/ m^3,
- 53.7% (95%CI: 47.7%–59.7%) of basements had air-borne mould counts of at least 100CFU/m^3.
- There were substantially fewer homes with mould counts greater than or equal to 400 CFU/m^3 for April alone, (3.8% (95%CI: 1.9%-6.7%) with mould counts ≥ 400 CFU/ m^3 in the bedroom, and 9.6% (CI: 6.4%-13.7%) in the basement).

For all homes with total mould counts greater than or equal to 100 CFU/m^3, the genus type for the top three moulds was identified and counted separately. The ten most common types of mould identified in all the homes tested are reported in Table 4.6. Cladosporium was the most common mould found in Winnipeg homes with mould counts greater than or equal to 100CFU/m^3 (98% of children bedrooms; 98% of basements), followed by Alternaria (82% of children bedrooms; 77% of basements) and Penicillium (36% of children bedrooms; 49% of basements).

Table 4.6. Ten Most Common Genus Types of Mould Identified in the Target Homes by Area: Children's Bedrooms and Basements

Type of mould		Bedrooms*		Basements**	
		#	% (95%CI)	#	% (95%CI)
1	Cladosporium	447	98.2 (96.6–99.2)	437	97.8 (95.9–98.9)
2	Alternaria	375	82.4 (78.6–85.8)	344	77.0 (72.8–80.8)
3	Penicillium	161	35.4 (31.0–40.0)	218	48.8 (44.0–53.5)
4	Mycelia-Sterilia	126	27.7 (23.6–32.0)	83	18.6 (15.1–22.5)
5	Aspergillus	33	7.3 (5.0–10.0)	90	20.1 (16.5–24.1)
6	Ulocladium	29	6.4 (4.3–9.0)	15	3.4 (1.9–5.5)
7	Mucor	23	5.1 (3.2–7.5)	22	4.9 (3.1–7.4)
8	Epicoccum	19	4.2 (2.5–6.4)	20	4.5 (2.8–6.8)
9	Fusarium	19	4.2 (2.5–6.4)	13	2.9 (1.6–4.9)
10	Pithomyces	18	4.0 (2.4–6.2)	15	3.4 (1.9–5.5)

* based on 455 homes where air sampling total spore count was ≥ 100 CFU/m^3 in the child's bedroom.

** based on the 447 homes where air sampling total count was ≥ 100 CFU/m^3 in the basement.

Given the prevalence of Cladosporium in children's bedrooms and basements, the number of homes with Cladosporium levels of ≥100CFU/m^3; ≥200CFU/m^3; ≥300CFU/m^3, and ≥400CFU/m^3 were examined. We looked into the relevant literature on similar health associations between respiratory health and exposure to cladosporium. Research by Stark P., et al. (2003) concluded that "…total indoor fungal levels (comprised mostly of cladosporium) were associated with an increased risk of asthma in adults." The majority of these homes fell in the level of ≥ 100CFU/m^3. Table 4.7 summarizes the results.

Table 4.7. Number of Homes in Each Cladosporium Level

Number of Homes by Area Tested	Cladosporium Level			
	# ≥ CFU100/m^3 % (95%CI)	# ≥ 200CFU/m^3 % (95%CI)	# ≥ 300CFU/m^3 % (95%CI)	# ≥ 400CFU/m^3 % (95%CI)
Child's Bedroom	316	161	97	62
n = 447	70.7 (66.2–74.9)	36.0 (31.6–40.7)	21.7 (18.0–25.8)	13.9 (10.8–17.4)
Basement*	280	151	108	84
n = 437	64.1 (59.4–68.6)	34.5 (30.1–39.2)	24.7 (20.7–29.0)	19.2 (15.6–23.2)

* Not all homes had basements, based on homes where air sampling total count was ≥ 100 CFU/m^3

Based on the results shown in Table 4.7, we conclude that:

- 70.7% (95%CI: 66.2%-74.9%) of the children's bedrooms had Cladosporium counts greater than or equal to 100 CFU/ m^3 while 64.1% (95%CI: 59.4%-68.6%) of the basements had Cladosporum CFU counts greater than or equal to 100 CFU/ m^3.
- CFU levels decreased rapidly above 400/ m^3; 13.9% (95%CI: 10.8%-17.4%) for the bedrooms and 19.2% (95%CI: 15.6%-23.2%) for the basements of the study homes.

A control air sample was taken in each neighborhood, designated as Area 3, whenever air sampling of the homes was being completed. The ten most common genus types of mould found in Area 3 are summarized in Table 4.8. From the table, cladosporium and alternaria clearly are the most prominent as 82 percent and 71 percent of the samples had mould counts greater than 100 CFU's.

Table 4.8. The Ten Most Common Outdoor Genus Types of Mould Identified in the Neighborhood of the Target Homes: Area 3.

Genus Type of Mould Identified		# of Homes with Specific Genus Type in Area 3*	Percent of Homes in Data
1	Cladosporium	587	82
2	Alternaria	510	71
3	Mycelia-Sterilia	295	41
4	Penicillium	161	23
5	Fusuarium	54	7.6
6	Ulocladium	45	6.3
7	Acremonium	36	5.0
8	Mucor	32	4.4
9	Arthrinium	17	2.4
10	Phoma	14	2.0

*The genus type was identified in air samples with a total mould count ≥100CFU/m^3

The results in Tables 4.6 and 4.8 shows that moulds identified within the home are clearly present in the exterior or outdoor samples with the exception of aspergillus. While aspergillus was the fifth most common genus type inside the homes, it was not amoung the top ten exterior genus types identified in the control or Area 3 air samples.

It should be noted that penicillium was observed to be present in 22% of the children's bedrooms and 24% of the basements of the houses in this study. It was the third most common genus type identified in the homes of the study. Penicillium was found to be prevalent in the outdoor samples.

Cladosporium counts generally increase with seasonally increasing temperatures (Haverinen et al., 2003; Reponen et al., 1994; Stark et al., 2003). We, therefore, reviewed the data obtained for cladosporium for each month. Table 4.9 confirms that as the ambient temperatures increased in June, cladosporium levels, both in the interior and in the exterior of homes increased significantly. Results also show that there is significant communication of air-borne moulds between the exterior and the interior of homes, especially in May, June and July.

Table 4.9. Mean Cladosporium Count (CFU/m^3) for each Month

Sample Date	Area 1	Area 2	Area 3
April			
Average	**90.7**	**96.9**	**333.6**
May			
Average	**176.2**	**164.6**	**327.7**
June			
Average	**503.6**	**619.1**	**1567.1**
July			
Average	**343.3**	**472.8**	**1546**

The majority of the air samples, approximately 60% were taken during the month of April. Air samples taken in in May and June confirm that exterior cladosporium counts increased significantly during this month.

4.2.1 Statistical Analysis between Data from the Initial Contact Survey and Air Sampling Data

Based on the data obtained from the air sample analysis, a statistical analysis was completed to determine if an association exists between the self-reported mould in the home by the occupants and the presence of air-borne mould measured in CFU/m^3. Tests of independence (Pearson's chi-squared test) for contingency tables were used to assess the associations between self-reported mould and air-borne mould.

For all months combined, there seems to be no significant association between those parents who reported mould in their home and those who reported no mould in their homes irrespective of the mould levels. For the month of April, however, a statistically significant association was found between occupant-reported visible mould in the house and three air-born levels (≥ 100CFU/m^3, ≥ 200CFU/m^3, ≥ 400CFU/m^3) in the child's bedroom shown in Table 4.10 in bold font.

Table 4.10. The Number of Homes in Each Mould Cut-Off Level Correlated to Reported Presence/Absence of Total Mould (CFU/m^3) in the Children's Bedroom

Self-Reported Indoor Mould	Mould Level			
	≥ 100CFU/m^3 # (%)	**≥200CFU/m^3** # (%)	**≥CFU300/m^3** # (%)	**≥400CFU/m^3** # (%)
All Months Combined				
Yes (n=347):	231 (66.6%)	153 (44.2%)	100 (28.8%)	73 (21.0%)
No (n=368):	224 (60.8%)	145 (39.4%)	88 (23.9%)	62 (16.9%)
For April Only				
Yes (n=143):	**85 (59.4%)***	**46 (32.2%)***	16 (11.2%)	**10 (7.0%)***
No (n=145):	**66 (45.5%)***	**27 (18.6%)***	9 (6.2%)	**1 (0.7%)***

*p<0.05

There was a statistically significant association between self-reported visible mould and air-borne mould levels in the basement for levels ≥ 100CFU/m^3 and ≥ 200CFU/m^3 for all months combined. For April, this association held for mould levels ≥ 100 CFU/m^3 , ≥ 200 CFU/m^3, and ≥ 300 CFU/m^3, as well (see Table 4.11).

Table 4.11. Number of Homes in Each Mould Level that Reported the Presence/Absence of Mould in the Basement.

Self-Reported Indoor Mould	Mould Level			
	≥ 100/m³ # (%)	**≥ 200/m³** # (%)	**≥ 300/m³** # (%)	**≥ 400/m³** # (%)
All Months Combined				
Yes (n=331):	**228 (68.9%)***	**157 (47.4%)***	103 (31.1%)	76 (23.0%)
No (n=356):	**219 (61.5%)***	**139 (39.0%)***	99 (27.8%)	84 (23.6%)
For April Only				
Yes (n=139):	**85 (61.2%)***	**46 (33.1%)***	**28 (20.1%)***	18 (12.9%)
No (n=142):	**66 (46.5%)***	**29 (20.4%)***	**15 (10.6%)***	9 (6.3%)

* $p<0.05$

4.2.2 Association between Air Sample Results and Frequent Colds and/or Asthma

The data were analyzed to determine the absence/presence of a statistical association between the air sample results, based on all mould genus type, CFU's and frequent respiratory infections and/or asthma (Groups 3, 2, and 1) in the child occupants of the home.

As the data does not conform to a normal distribution, that is, no mean or standard deviation, non-parametric methods of statistical analysis were required. The non-parametric technique utilized for the analysis of multiple groups is the Kruskal-Wallis test. It is essentially, the non-parametric equivalent of an ANOVA analysis. A Kruskal-Wallace Non-Parametric Test of the distribution of mould genus types revealed an association only for cladosporium spores by area of the house (child's bedroom or basement). The only association revealed was between cladosporium levels in air samples taken during April and the child's asthma. No association was revealed for any of the other moulds, including penicillium or aspergillus.

Table 4.12. Cladosporium Levels (CFU/m³) during April for the Four Groups of Respiratory Condition of Child.

April CFU Counts for Cladosporium by Area in the Home	Respiratory Condition of Child: Group 4 Few or No Colds/No Asthma	Group 3 Frequent Colds Only	Group 2 Asthma Only	Group 1 Asthma & Frequent Colds	χ^2 *(df)* *p*-value
Bedroom Median (25%ile, 75%ile)	97.0 (63, 125)	91.0 (59,137)	97 (44,190)	125 (91,181)	*9.82 (3)* 0.020
Basement Median (25%ile, 75%ile)	88 (63, 119)	75 (44,125)	112 (69,197)	131 (66,187)	*9.65 (3)* 0.022

***p<.05**

From the table, the analyses shows an association between Cladosporium CFU levels from air samples taken in April and the child's asthma in combination with frequent colds (Group 1), respiratory health condition.

4.2.3 Association between Air Sampling Results and Environmental Conditions within the Children's Home

The following interior environmental data collected during the house audits: air temperature, surface temperatures, relative humidity and building material moisture content. The statistics for these conditions are shown in Table 4.13.

Table 4.13. Relative Humidity, Air Temperature, Wall Surface Temperature and Wall Moisture Content Statistics by Area

	Relative Humidity (%)			Air Temperature (^oC)			Wall Surface Temperature (^oC)		Wall Moisture Content (%)	
Area	1	2	3	1	2	3	1	2	1	2
25%ile	40.2	40.2	32.1	19.3	18.2	13.9	17.6	12.6	0.2	0.3
Median	45.1	44.8	43.6	20.7	19.4	17.7	19.0	14.2	0.2	0.4
75%ile	51.5	50.6	55.3	22.1	20.5	20.5	20.2	15.8	0.3	0.6
Mean	45.9	45.7	44.9	20.7	19.3	17.2	18.9	14.1	1.16	2.26
SD	8.98	7.88	16.1	2.29	1.75	5.33	2.23	2.37	3.66	4.06
Min	21.0	22.5	11.9	12.6	12.9	2.1	9.4	6.6	0.0	0.0
Max	93.8	70.9	93.3	39.7	24.7	57.4	26.0	22.2	36.1	36.1

Note: Area 1: Child's Bedroom, Area 2: Basement, Area 3: Exterior (control)

A non-parametric Spearman rank test was run comparing air-borne mould counts (Total Mould Level (CFU/m^3) all species combined) and the various indoor environmental conditions. The Spearman's correlation coefficient is calculated from ranks rather than from original measurements. Thus, variables to be correlated are each ranked separately from smallest to largest, and then the rankings are correlated with each other. The coefficient takes on a value between +1 and -1 corresponding to direct and/or a reversed relationship between the ranks.

The results from this test revealed an unclear pattern between the total mould count in the home and the indoor environmental conditions. Figure 4.3 and 4.4 show the scatter plots of mould levels as a function of the indoor environmental conditions for Area 1 (Child's Bedroom) and Area 2 (Basement), respectively.

Although a statistical association between mould levels and indoor environmental conditions cannot be necessarily ruled out, the results are highly skewed, as shown in Figures 4.3 and 4.4, thereby masking possible associations. It is important to note that the data obtained in this study represent a snap-shot in time for the conditions in the home, thus, the reason for significant variations in the results. Data logging of the environmental conditions, where multiple measurements are obtained over-time within each home, could lead to statistically significant associations.

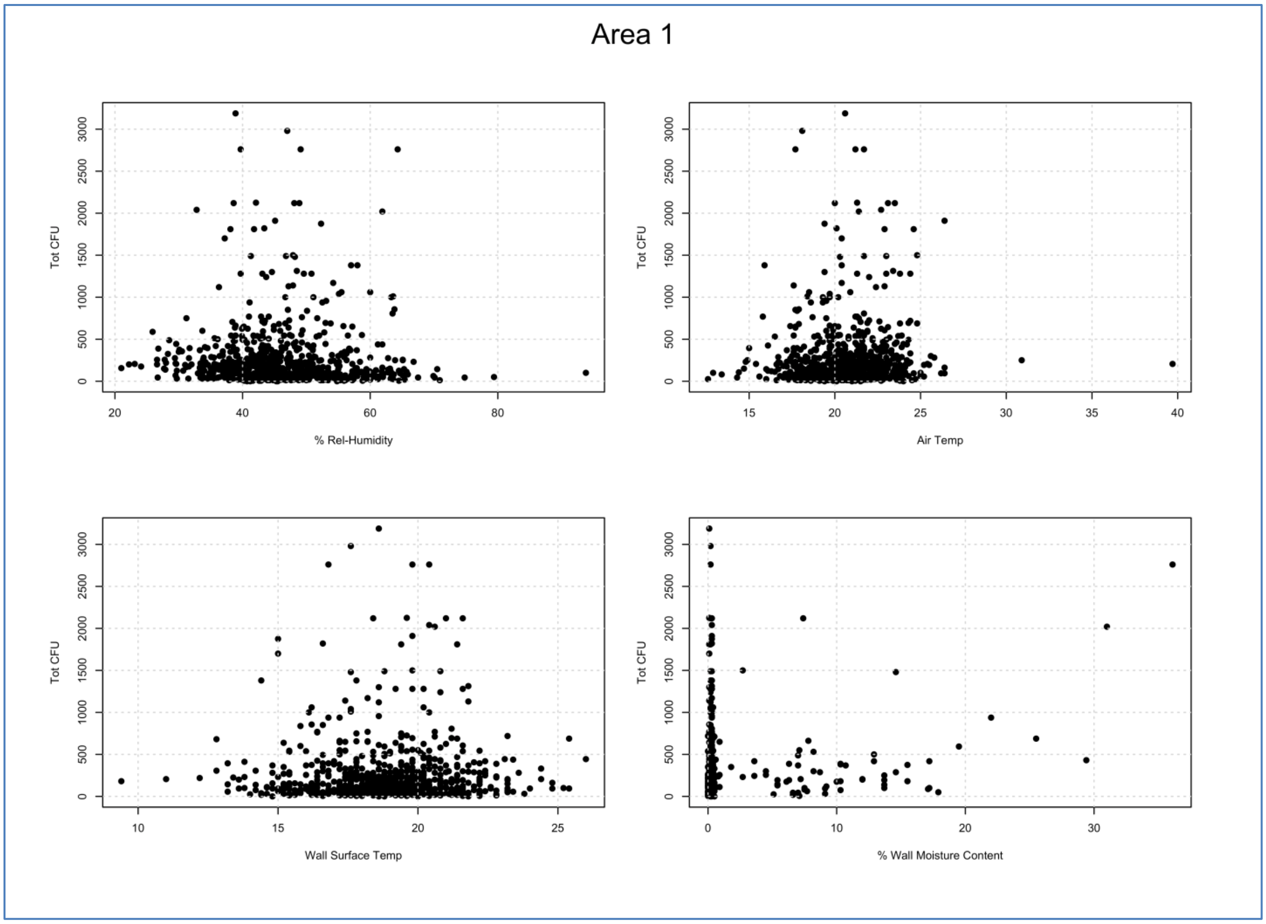


Figure 4.3. Plot of Total CFU/m^3 vs. Room Environmental Conditions

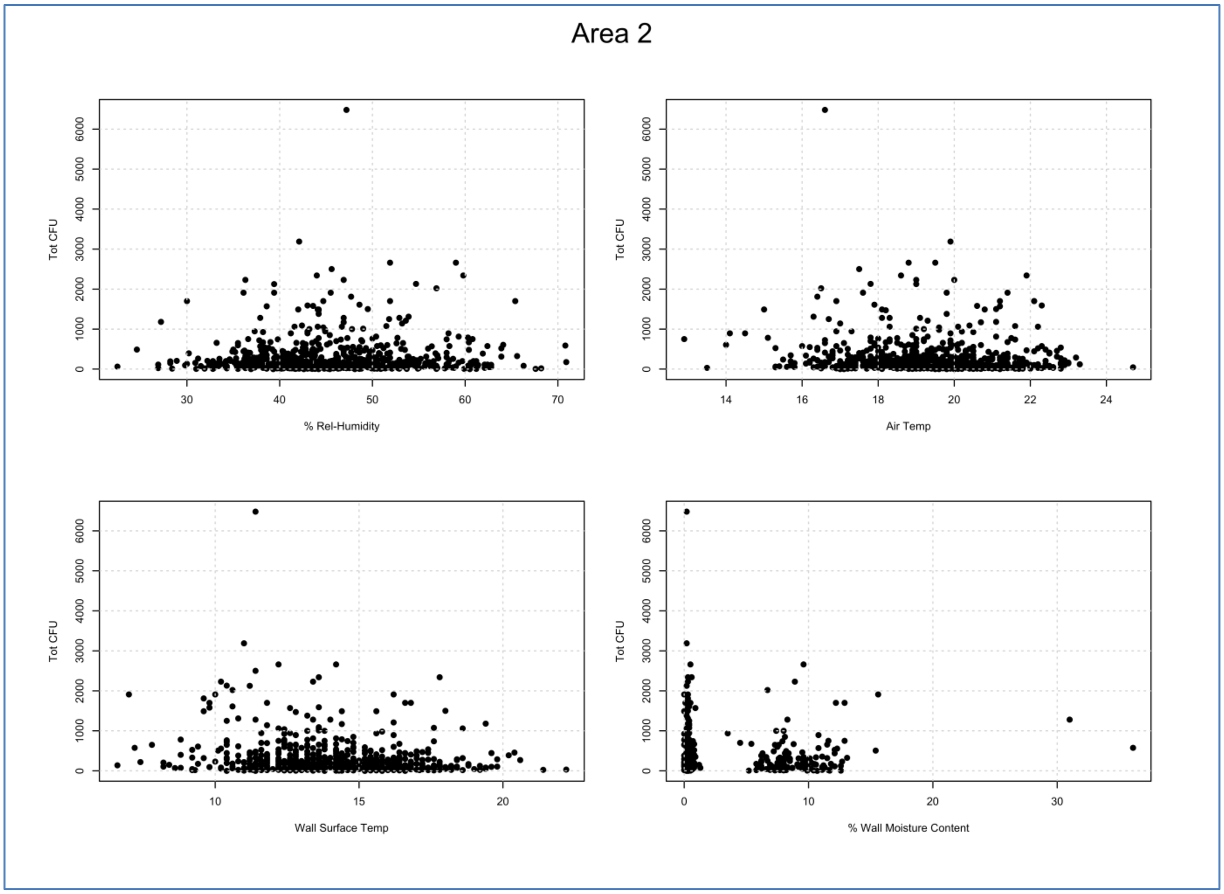


Figure 4.4. Plot of Total CFU/m^3 vs. Room Environmental Conditions

4.3 Housing Conditions Affecting Indoor Environmental Conditions (Temperature, Relative Humidity and Moisture Levels) in Children's Homes

As the data comprising the environmental measurements follows a normal distribution, a series of ANOVAs were completed on the housing condition variables in order to determine the absence/presence of statistically significant associations between the conditions recorded during the housing inspections and the indoor environmental conditions of temperature, moisture and relative humidity recorded during the housing audits.

Initially, the data was analyzed using the rating system: Excellent, Good, Fair, and Poor, that was used in assessing the condition of the various housing components during the housing audits. However, it was observed that in many cases, the four condition assessment identifiers produced too few data points to provide an acceptable level of accuracy in the ANOVA statistical analysis. Thus, the data were re-analyzed collapsing the four condition categories into two categories: Excellent/Good and Fair/Poor.

In the statistical analysis of the housing conditions, numerous results were obtained with a large difference between the two means; however, the "n" value or number of data points, was too small in order produce a statistically significant difference between the two means using a probability of less than 0.05. Thus, a $p \leq 0.10$ was used in the subsequent statistical analysis.

The association between housing the conditions and temperature and moisture levels in the homes obtained through statistical analysis is described in the subsequent sections.

4.3.1 Housing Conditions Affecting the Air Temperature in the Children's Home

There were numerous statistically significant associations between housing conditions and air temperature, and surface temperatures within the houses reviewed. No significant correlations were, however, revealed between temperature and air-borne mould levels. Appendix D contains the air temperature and housing condition statistically significant association data, while Appendix E contains the wall surface temperature and housing condition statistically significant association data.

4.3.1.1 Housing Conditions Affecting the Air Temperature in the Children's Bedroom

The housing conditions that were significantly ($p<0.10$) related to the air temperature within the children's bedroom of the audited homes are listed in Table D1 of Appendix D.

4.3.1.2 Housing Conditions Affecting the Air Temperature in the Basement

The housing conditions that were significantly ($p<0.10$) related to the air temperature in the basement of the audited homes are listed in Table D2 of Appendix D.

4.3.2 Housing Conditions Affecting the Wall Surface Temperatures in the Children's Homes

There were numerous statistically significant associations between housing conditions and surface temperatures within the houses reviewed. No significant correlations were, however, revealed between wall surface temperatures and air-borne mould levels. Appendix E contains the wall temperature and housing condition statistically significant association data.

4.3.2.1 Housing Conditions Affecting the Wall Surface Temperatures in the Children's Bedrooms

The housing conditions that were significantly ($p < .10$) related to the wall surface temperature within the child's bedroom of the audited homes are listed in Table E1 of Appendix E.

4.3.2.2 Housing Conditions Affecting the Wall Surface Temperatures in the Basements

Only one variable was confirmed to have a statistical association with wall surface temperatures; absence/presence of a crawlspace. Table E1 in Appendix E summarizes the result.

4.3.3 Housing Conditions Affecting Relative Humidity in the Children's Bedroom and Basements

4.3.3.1 Housing Conditions Affecting Relative Humidity in the Children's Bedroom

The housing conditions that were significantly ($p < .10$) related to relative humidity (Rh) in the children's bedrooms of the audited homes are listed in Table 4.14. The following is a summary of these results.

- Houses in which the exterior cladding was observed to be well maintained had lower relative humidity within the child's bedroom compared to houses where the exterior cladding was in Poor/Fair condition. The relative humidity in the children's bedrooms of homes with exterior cladding rated as Good/Excellent was 1.51% lower than those home in which the exterior cladding was rated as Poor/Fair, (p=0.0946).

- Houses in which no condensation stains along the exterior floor/wall interfaces were visible had a higher mean relative humidity within the children's bedrooms. The relative humidity was 4.23% greater in those houses than in houses in which condensation stains were visible. The mean relative humidity in the children's bedroom for houses exhibiting no condensation stains at the exterior wall/floor interface was 46.16%, compared to 41.93% for houses exhibiting condensation stains at the exterior floor/wall interface, (p=0.0261).

- Newer houses had a lower relative humidity in the children's bedrooms compared to older houses. The mean relative humidity in the children's bedrooms for houses less than 20 years old was 44.97% compared to 46.29% for houses older than 20 years, (p=0.0749).

- Flat or low slope roof systems, such as a membrane, produced a significantly higher relative humidity in the children's bedroom compared to conventional sloped shingle roofs. The mean relative humidity in the children's bedrooms for low slope roofs incorporating a membrane system was 53.70%, 7.70 percent higher than houses incorporating a sloped shingled roof, (p=0.0875).

- Houses with roof systems that had been recently repaired and/or upgraded had a higher relative humidity in the children's bedrooms. The mean relative humidity in the children's bedrooms was 45.47% for houses with Good/Excellent roof repairs compared to 41.49% for houses with Poor/Fair roof repairs, (p=0.0950).

- Houses with good/excellent exterior walls had a higher relative humidity in the children's bedrooms compared to houses in which the exterior repairs were rated as Poor/Fair. Specifically, the mean relative humidity in the children's bedrooms for houses in which the exterior wall repairs/renovations were rated as Good/Excellent was 45.72%, +3.98% higher than houses in which the exterior repairs/renovations were rated as Poor/Fair, (p=0.0397).

- Houses with newer windows produced a higher relative humidity compared to houses with older windows. The mean relative humidity in the children's bedrooms of houses with windows less than 10 years old was 46.85% compared to 45.33% for houses in which the windows were more than 10 years old, (p=0.0325).

- Houses with no visible window condensation had a lower relative humidity compared to homes with window condensation. The mean relative humidity in the children's bedrooms of homes with no window condensation was 45.65% compared to 46.80% for homes with visible window condensation, (p=0.10).

- Houses whose windows were observed to be in Excellent/Good condition also produced a higher relative humidity in the children's bedrooms than houses with windows in Poor/Fair condition. The mean relative humidity in the children's bedrooms in houses with the windows rated in Excellent/Good was 46.50 %, 1.22% higher than homes in which the windows rated as Poor/Fair, (p=0.0999).

Table 4.14. Housing Conditions Affecting Relative Humidity (Rh) in the Children's Bedroom

Housing Conditions (n)	*F*	*P*	*Df*	Mean Rh (%)	Mean Difference (%)
Condition of Exterior Cladding	2.80	0.0946	1,683		
• Good/Excellent (565)				45.79	**-1.51**
• Poor/Fair (120)				47.30	-
Visible Evidence of Condensation at Exterior Wall/Floor Levels	4.97	0.0261	1,677		
• No Condensation (656)				46.16	**+4.23**
• Condensation (23)				41.93	-
Age of House	3.18	0.0749	1,606		
• 0-20 Years (222)				44.97	**-1.32**
• > 20 Years (386)				46.29	-
Type of Roofing Material	2.93	0.0875	1,671		
• Membrane System (4)				53.70	**+7.70**
• Shingles (669)				46.00	-
Roof Repairs/Renovation Condition	2.81	0.0950	1,246		
• Good/Excellent (232)				45.47	**+3.98**
• Poor/Fair (16)				41.49	-
Condition of Wall Renovations/Repairs	4.27	0.0397	1,264		
• Good/Excellent (241)				45.72	**+3.98**
• Poor/Fair (25)				41.74	-
Age of the Windows	4.59	0.0325	1,645		
• 0-10 Years (300)				46.85	**+1.52**
• > 10 Years (347)				45.33	-
Absence/Presence of Window Condensation	2.65	0.100	1,679		
• No Condensation (423)				45.65	**-1.15**
• Condensation (258)				46.80	-
Condition of the Windows	2.72	0.0999	1,607		
• Good/Excellent (341)				46.50	**+1.22**
• Poor/Fair (268)				45.28	-

4.3.3.2 Housing Conditions Affecting Relative Humidity in the Basements

The housing conditions that were significantly ($p < .10$) related to relative humidity (Rh) in the basement of the audited homes are listed in Table 4.15. The following is a summary of these results.

- Houses in which the exterior cladding rated as Excellent/Good had a lower relative humidity in the basements compared to houses with cladding rated as Poor/Fair condition. The mean relative humidity in the basements of homes with Excellent/Good cladding was 45.32%, 2.18% lower than in basements of homes with cladding rated as Poor/Fair, (p=0.0068).

- The number of exhaust fans had a positive effect on humidity control. The mean relative humidity in the basements of homes with 0 or 1 exhaust fan was 46.55%, 1.23% higher than that of basements in houses with two or more exhaust fans, (p=0.0627).

- The frequency of use of exhaust fans also affected the relative humidity in the basements. Houses where the exhaust fans were never used had a mean relative humidity in the basement of 51.92%. This was 6.64% higher than the relative humidity basements of houses where exhaust fans were regularly used, (p=0.0028).

- Newer houses had a lower relative humidity in the basement compared to older homes. The mean relative humidity in the basements of houses less than 20 years old was 44.64% compared to 45.90% for homes older than 20 years, (p=0.0518).

- The mean relative humidity in the basement of homes with roof repairs rated as Excellent/Good was 45.26% compared to 46.88% for basements at homes with roof repairs rated Poor/Fair, (p=0.0640).

- The relative humidity in the basement of houses with windows rated as Excellent/Good was higher compared to that of windows in houses rated as Poor/Fair. The mean relative humidity in the basement where the windows were in Good/Excellent condition was 46.11 %, 1.31% higher than that of houses in which the windows were rated Poor/Fair, (p=0.0455).

- The number of panes of glass in the window system also had a statistically significant effect on the relative humidity in the basement. The mean relative humidity in the basements of houses with single pane of glass windows was 46.79%, compared to 44.67% dual pane of glass in the window units, and 46.00% in the basements of houses with triple pane glass in the windows, (p=0.0581).

Table 4.15. Housing Conditions Affecting Relative Humidity (Rh) in the Basements

Housing Condition (n)	*F*	*P*	*Df*	Mean Rh (%)	Mean Rh Difference (%)
Condition of Exterior Cladding	7.39	0.0068	1,646		
• Good/Excellent (533)				45.32	**-2.18**
• Poor/Fair (115)				47.50	-
Number of Exhaust Fans	3.48	0.0627	1,638		
• 0 or 1 (207)				46.55	**+1.23**
• 2 or More (433)				45.32	-
Use of Exhaust Fans	5.94	0.0028	2,586		
• Never (13)				51.92	**+6.64**
• Often (109)				46.74	**+1.46**
• Sometimes (467)				45.28	-
Age of House (Years)	3.80	0.0518	1, 572		
• 0 to 20 (209)				44.64	**-1.26**
• > 20 (365)				45.90	-
Condition of Roof Material	3.44	0.0640	1,597		
• Good/Excellent (506)				45.26	**-1.62**
• Poor/Fair (93)				46.88	-
Condition of the Windows	4.02	0.0455	1,572		
• Good/Excellent (324)				46.11	**+1.31**
• Poor/Fair (250)				44.80	-
Number of Panes of Glass in Windows	2.86	0.0581	2,637		
• Single Pane (96)				46.79	**+0.79**
• Double Pane (187)				44.67	**-1.33**
• Triple Pane (357)				46.00	-

4.3.4 Housing Conditions Affecting Moisture Content of Walls in the Children's House

4.3.4.1 Housing Conditions Affecting Moisture Content of Walls in the Children's Bedroom

Table 4.16 lists the housing conditions that significantly affected ($p<0.10$) the moisture content of the walls in the child's bedroom of the homes examined. The following is a summary of these results.

- Houses with attics in Excellent/Good had lower wall moisture content levels in the children's bedroom than homes with attics in Poor/Fair condition. The mean moisture content of the walls in the children's bedroom for houses with attics rated as Good/Excellent was 0.933%, while houses in which the attics were rated as Poor/Fair had a mean wall moisture content of 1.573%, ($p=0.0629$).

- Houses with the cladding rated as Excellent/Good had lower moisture content in the walls of the children's bedrooms than houses with the cladding rated as Poor/Fair. The mean wall moisture content in the children's bedrooms for houses in which the cladding was rated as Good/Excellent condition was 1.059% while the houses in which the cladding was rated as Poor/Fair was 1.71%, ($p=0.0886$).

- The walls in children's bedrooms of houses exhibiting structural duress had higher mean moisture contents than those in houses with no structural duress. Houses rated with No Duress had a mean moisture content of 0.819% compared to 1.634% in houses visually observed to exhibit structural duress, ($p=0.0052$).

- The wall moisture content in the children's bedrooms of newer houses was lower than those in older houses. Houses less than 20 years old had a mean wall moisture content of 0.630% compared to 1.482% in walls of houses older than 20 years of age, ($p=0.0083$).

- Statistically, there was a significant relationship between roofing framing type and wall moisture content in the children's bedrooms. Houses incorporating other framing, typically cathedral type ceilings, had a mean moisture content in the walls of 1.640%. The wall moisture content was the highest (1.900%) in site framed roof systems and the lowest (0.603%) was in the walls of homes with conventional pre-engineered truss roof systems, ($p<0.0001$).

- The type of roofing material also had a significant effect on the moisture content in children's bedrooms. The mean wall moisture content in the children's bedrooms of houses with roof systems using a membrane type waterproofing was 5.400% compared to 1.162% in walls of houses using sloped shingle roof systems, ($p=0.0257$).

Table 4.16. Housing Conditions Affecting Moisture Content in the Walls of the Children's Bedrooms

Housing Condition (n)	*F*	*P*	*df*	Mean M.C. (%)	Mean Difference (%)
Condition of the Attic	3.48	0.0629	1,490		
• Good/Excellent (328)				0.933	**-0.64**
• Poor/Fair (164)				1.573	-
Condition of the Cladding	2.91	0.0886	1,679		
• Good/Excellent (562)				1.059	**-0.646**
• Poor/Fair (119)				1.705	-
Water in the Crawlspace	9.93	0.0022	1,96		
• No Water (95)				0.939	**-5.73**
• Water (3)				6.667	-
Absence/Presence of Structural Duress in Home	7.85	0.0052	1,676		
• No Duress (389)				0.819	**-0.815**
• Duress (289)				1.634	-
Age of House (Years)	7.01	0.0083	1,602		
• 0-20 (219)				0.630	**-0.852**
• > 20 (385)				1.482	-
Type of Roof Framing	9.49	<0.0001	2,646		
• Other (5)				1.640	**+1.037**
• Stick Framed (281)				1.900	**+1.297**
• Pre-Eng Truss (363)				0.603	-
Type of Roofing Material	5.00	0.0257	1,668		
• Membrane System (4)				5.400	**+4.238**
• Shingles (666)				1.162	-

4.3.4.2 Housing Conditions Affecting Moisture Content of Walls in the Basements

Only one housing variable was observed to be statistically significant in affecting the moisture content of the basement walls: the absence/presence of water in the crawlspace of the home. Table 4.17 summarizes the result obtained.

- The moisture content in the basement walls of houses with water in the crawlspace was 6.10%, significantly higher than the moisture content of 2.252%

in basement walls in the basement of houses without water in the crawlspace, (p=0.0901).

Table 4.17. Housing Conditions Affecting Moisture Content in the Basement Walls

Housing Condition (n)	Moisture Content in Walls of the Basement (%)				
	F	***P***	***df***	**Mean M.C. (%)**	**Mean Difference (%)**
Absence/Presence of Water in the Crawlspace	2.94	0.0901	1,83		
• No Water (82)				2.252	**-3.848**
• Water (3)				6.100	-

4.4 Housing Conditions and Mould Levels in the Children's Bedrooms and Basements

The data obtained from the home inspections and the biological air samples were correlated utilizing a Chi Squared analysis in order to establish statistical significant associations between the housing conditions as identified in the housing audits, and the mould levels obtained through air sampling in the home. The housing condition data does not follow a normal distribution, thus, non-parametric statistical techniques were required.

The housing conditions were first analyzed with respect to total mould counts (in CFU/m^3) in the children's bedrooms and basements. They were then re-analyzed with respect to the three most prominent mould types: cladosporium, penicillium, and aspergillus.

The relationship between housing conditions, and total mould levels in the home as well as the relationship between housing conditions and mould levels for cladosporium, penicillium, and aspergillus are given in the following sections.

The results are given in terms of percentages. Also given are the χ^2, the degrees of freedom, df, and the probability value p. The chi-squared analysis compares percentages of observed versus expected values, specifically, the actual numbers within the various categories versus quantitative methods which compare means. Small values of χ^2 indicate a good agreement between observed and expected values while large values of χ^2 show poor agreement, that is, expected values are not close to observed values which therefore suggest that the hypothesis in which no statistically significant difference exists between the two groups, expected versus observed values, has a high probability of being wrong and should therefore be rejected.

In the statistical analysis, numerous results were obtained with a large percentile difference between the groups; however, the “n” value or number of data points was too small in order produce a reliable statistically significant difference between the groups using a probability, p of less than 0.05. Thus, a $p \leq 0.10$ was used in the subsequent chi-squared statistical analysis as the cut-off point for statistical significance. In the discussion that follows, only those house conditions that were statistically significantly associated with mould levels ($p \leq 0.10$) are included.

4.4.1 Total Mould Levels (CFU/m^3) and Children’s Bedrooms

As shown in Table 4.18, a statistically significant association was revealed between the type or construction style of home and the total mould levels in the children’s bedrooms. More specifically, it was found that the mould count in the child’s bedrooms in approximately one in every five bungalows or split level homes was at least 400

CFU/m^3 (21.48% and 18.73%, respectively). Only 3.13% of the children's bedrooms of townhouses/semi-detached/row houses reached the same level.

In approximately one in three homes (29.79%) whose crawlspace was rated as Good/Excellent, the mould count in the child's bedrooms was equal to or greater than 200 CFU/m^3 (see Table 4.19). On the other hand, 60.1% of the houses whose crawlspace was rated as Poor/Fair had a similar mould level in the child's bedroom.

A mould count in children's bedrooms of ≥200 CFU/m^3 was present in 63.16% of the houses whose house foundation was constructed from stone or block masonry. Only 43.13% of the houses whose foundation was constructed from cast-in-place concrete had the same mould levels in the children's bedroom (see Table 4.20).

From Table 4.21, the highest percentage (51.45%) of children's bedrooms with at least 200 CFU/m^3 mould count was recorded in houses incorporating stick framed roof systems. A lower percentage of houses (38.48%) with this type of roof construction had a similar mould level in the children's bedrooms.

A similar trend was obtained in children's bedrooms which recorded mould counts of at least 400 CFU/m^3. 23.91% of houses with stick-framed roofs had a mould content at least 400 CFU/m^3 in the children's bedrooms while the percentage of houses with truss-type roofs that had a similar mould level was only 16.01%.

Statistically, the condition of the roofing membrane was also significantly associated with the total mould count in the children's bedrooms, as shown in Table 4.22. There was a higher percentage of homes with roof systems rated as Good/Excellent mould counts in the children's bedrooms equal to or greater than either 200 CFU'm^3 or 400 CFU/m^3 compared to homes with roof systems rated as Poor/Fair.

More specifically, in houses with roof systems rated as Good/Excellent, 46.36% of children's bedrooms had a mould count greater or equal to 200 CFU/m^3 and 21.07% of children's bedrooms had a mould count greater or equal to 400 CFU/m^3. On the other hand, for houses with roof conditions rated as Poor/Fair, the percentage of houses that had mould levels $\geq$ 200 CFU/m^3 and $\geq$ 400 CFU/m^3 in the children's bedrooms were 32.63% and 11.58%, respectively.

A significant association was observed between wall stains in the house and the total mould count in the children's bedrooms. As shown in Table 4.23, where no wall stains were observed, typically from condensation, the total air-borne mould count was equal to or greater than 200 CFU/m^3 in 45.90% of the children's bedrooms. The percentage of houses with wall stains where the total air-borne mould count was equal to or greater than 200 CFU/m^3 in the children's bedrooms was 36.80%.

A statistically significant association was observed between the total mould level in the children's bedrooms and the type of windows in the houses. As shown in Table 4.24, the percentage of houses where the mould count in the children's bedrooms was at least 100

CFU/m^3 was 45.56% in houses with wood framed windows and 43.52% in houses with plastic windows. Only 28.00% of the houses with aluminum framed windows had similar mould count levels in children's bedrooms.

The age of the windows was associated with total mould counts in the children's bedrooms of at least 200 CFU/m^3 and 400 CFU/m^3. As shown in Table 4.25, homes with newer windows (less than 10 years old), had a higher percentage of children's bedrooms with total mould counts equal to or greater than both 200 and 400 CFU/m^3 compared to homes with older windows (more than 10 years old). 46.53% of the houses with windows less than 10 years old had total air borne mould in the children's bedrooms of equal to or greater than 200 CFU/m^3 and 25.69% had mould counts equal to or greater than 400 CFU/m^3. On the other hand, the percentage of houses with older windows with similar mould count levels in the children's bedrooms was only 40.18% and 14.66%, respectively.

Table 4.18. Percentage of Houses of various Types or Styles with Total Mould Level ≥ 400 CFU/m^3 in the Children's Bedrooms

Type/Style of Home	% of Homes with Total Mould Count ≥ 400CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Bungalow, n=298	78.52	21.48	6.412 3 0.0932
Split Level, n=299	81.27	18.73	
Townhouse/Semi-Detached/Row, n=32	96.88	3.13	
Other, n=33	78.79	21.21	

Table 4.19. Percentage of Houses with Crawlspaces with Total Mould Level ≥ 200 CFU/m^3 in the Children's Bedrooms

Crawlspace Condition	% of Houses with Total Mould Count ≥ 200/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Poor/Fair, n=10	40.00	60.00	3.305 1 0.0593
Good/Excellent, n=47	70.21	29.79	

Table 4.20. Percentage of Houses with Different Types of Foundations, with Total Mould Level ≥ 200 CFU/m^3 in the Children's Bedrooms

Foundation Type	% of Houses with Total Mould Count ≥ 200/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Stone/Block, n=19	36.84	63.16	3.010 1 0.0828
Concrete, n=640	56.88	43.13	

Table 4.21. Percentage of Houses with Different Roof Types, with Total Mould Level ≥ 200 CFU/m³ and ≥ 400 CFU/m³ in the Children's Bedrooms

Roof Type	% of Houses with Mould Count ≥ 200/m³		χ^2 df *p*-value	% of Houses with Mould Count ≥ 400/m³		χ^2 df *p*-value
	No (%)	Yes (%)		No (%)	Yes (%)	
Stick, n=276	48.55	51.45	10.637 2 0.0028	76.09	23.91	7.481 2 0.0178
Trusses, n=356	61.52	38.48		83.99	16.01	
Other, n=5	60.00	40.00		60.00	40.00	

Table 4.22. Percentage of Houses, with Different Condition of Roof Materials with Total Mould Level ≥ 200 CFU/m³ and ≥ 400 CFU/m³ in the Children's Bedroom

Roof Material Condition	% of Houses with Mould Count ≥ 200/m³		χ^2 df *p*-value	% of Houses with Mould Count ≥ 400/m³		χ^2 df *p*-value
	No (%)	Yes (%)		No (%)	Yes (%)	
Poor/Fair n=95	67.37	32.63	6.141 1 0.0132	88.42	11.58	4.595 1 0.0321
Good/Excellent n=522	53.64	46.36		78.93	21.07	

Table 4.23. Percentage of Houses, with Wall Stains, with Total Mould Level ≥ 200 CFU/m³ in the Children's Bedrooms

Wall Stains	% of Houses with Total Mould Levels ≥ 200CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
No, n=536	54.10	45.90	3.400 1 0.0652
Yes, n=125	63.20	36.80	

Table 4.24. **Percentage of Houses with Different Window Frame Construction, with Total Mould Level ≥ 100 CFU/m^3 in the Children's Bedrooms**

Window Frame Type	% of Houses, with Total Mould Count ≥ 100/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Wood, n=417	54.44	45.56	5.601 2 0.0608
Plastic, n=193	56.48	43.52	
Aluminum, n=50	72.00	28.00	

Table 4.25. **Percentage of Houses with Different Age of Windows, with Total Mould Level ≥ 200 CFU/m^3 and ≥ 400 CFU/m^3 in the Children's Bedrooms**

Age of Windows in Years	% of Houses with Total Mould Count ≥ 200/m^3		χ^2 df *p*-value	% of Houses with Total Mould Count ≥ 400/m^3		χ^2 df *p*-value
	No (%)	Yes (%)		No (%)	Yes (%)	
0-10, n=288	53.47	46.53	2.569 1 0.1090	74.31	25.69	12.005 1 0.0005
>10, n=341	59.82	40.18		85.34	14.66	

4.4.2 Total Mould Levels (CFU/m^3) and Basements

The following housing conditions were significantly associated with the total mould count in the children's basements. The age of home, exterior clutter, wall stains, floor stains, crawlspaces, roof framing, roof condition, window frames, age of windows, and condition of doors. The results are discussed below.

From Table 4.26, the percentage of houses greater than 20 years old which had total air-borne mould counts equal to or greater than 200 CFU/m^3 in the basement was 47.66%, while 35.89% of the houses less than 20 years old had similar total air-borne mould levels.

A statistically significant association, although weak, was found between the condition of the exterior clutter and the total level of the air-borne mould in the basement of the study houses, as shown in Table 4.27.

More specifically, 49.40% of the basements in the houses of our study identified as Poor/Fair with respect to exterior clutter had total air-borne mould level equal to or greater than 200 CFU/m^3, whereas houses identified as Good/Excellent with respect to exterior clutter, 41.75% of the basements had a total air-borne mould CFU level equal to or greater than 200 CFU/m^3 (p=0.854).

As shown in Tables 4.28 and 4.29, a significant association was observed between the total air-borne mould level in the basements and the absence/presence of stains on the floors and walls of the houses. A highly significant statistical association was found for wall stains while a weak association was found for floor stains.

Specifically, 46.42% of the houses with no visible wall stains had basement total air-borne mould levels equal to or greater than 200 CFU/m3. However, only 33.88% of the houses with visible wall stains had total air-borne mould levels equal to or greater than 200 CFU/m3 (p=0.0124).

A weak association was observed between the total air-borne mould level in the basement and stains on the floors of the houses. As shown in Table 4.29, 44.25% of the basements with no visible stains on the walls of the houses had a total air-borne level equal to or greater than 200 CFU/m3, whereas, in houses with visible stains on the floors, 23.81% had total air-borne mould in the basement equal to or greater than 200 CFU/m3 (p=0.0633).

A weak statistical association was found between the presence/absence of a crawlspace in the house and the total air-borne mould level in the basements. House construction for these foundation types compared houses which incorporated full-depth basement and houses which utilized a full depth basement over part of the house but also incorporated a partial crawlspace section, typical for houses built in the 1960's area of River Heights in Winnipeg, MB. We therefore looked at the impact a crawlspace may have on the total air-borne mould levels in the basements of houses because crawlspaces are often unprotected, that is, have no concrete slab, only exposed soil.

From Table 4.30, 44.71% of the houses which did not have a crawlspace had total air-borne mould levels equal to or greater than 200 CFU/m^3 in the basement, whereas, in houses with crawlspaces, 35.48% of these houses had total air-borne mould levels equal to or greater than 200 CFU/m^3 (p=0.0972).

Statistical strong associations were found between the type and condition of the roofs of the homes and the total air-borne mould level in the basements. As shown in Table 4.31, 60.00% of the houses with cathedral type roof systems had total air-borne mould equal to or greater than 200 CFU/m^3 in the basement, compared to 49.62% of houses with sick framed attics, and 39.13% of houses with engineered truss attic systems (p=0.0186).

A very strong association was found between the type and condition of the roof and the total air-borne mould level in the basement of equal to or greater than 400 CFU/m^3, as shown in Table 4.32. In this case, 60.00% of the houses with cathedral or low slope roof framing had total air-borne mould levels equal to or greater than 400 CFU/m^3 in the basements compared to 25.94% of houses with stick framed roof systems and 21.45% of the houses with pre-engineered truss roof systems (p=0.0025).

The condition of the roofing system was also statistically associated with basement air-borne mould. As shown in Table 4.32, houses with roof systems in Good/Excellent condition, the percentage of basements with mould levels equal to or greater than either 200 or 400 CFU/m^3 was higher than basements of houses with roof materials in Poor/Fair condition.

More specifically, 45.45% of the houses with the roof material condition identified as Good/Excellent had total air-borne mould levels in the basement equal to or greater than 200 CFU/m^3. In the houses with the roof system rated as Poor/Excellent, 35.87% of the basements had total air-borne mould counts equal to or greater than 200 CFU/m^3 (p=0.0884).

A similar relationship between the condition of the roof and the air-borne mould in the basements at the 400 CFU/m^3 was observed. However, the association was much stronger than that of the 200 CFU/m^3 level, as shown in Table 4.32. Specifically, 25.30% of the houses with the roof system rated as Good/Excellent had total air-borne mould levels in the basements of equal to or greater than 400 CFU/m^3 compared to 15.22% of the houses with roofs rated as Poor/Fair (p=0.0366).

A statistically significant association was observed between the mould level in the basement and the type of window frames. As shown in Table 4.33, 25.56% of the homes with wood windows and 23.53% of the homes with plastic framed windows produced total mould count levels equal to or greater than 400 CFU/m^3 in the basements, while 10.64% of the homes with aluminum window frames produced similr mould count levels (p=0.0753).

The age of the windows produced a statistically significant association with total mould count in the basement of equal to or greater than 200 CFU/m^3 as shown in Table 4.34. 49.10% of homes with windows up to 10 years old had a total air-borne mould counts in the basements of equal to or greater than 200 CFU/m^3 compared to 39.76% of the basements in homes in which the windows were greater than 10 years old (p=0.0208).

A weak statistical association was observed between the condition of the exterior doors and the total mould count as shown in Table 4.35 30.68% of the houses with exterior doors in Poor/Fair condition had total air-borne mould levels equal to or greater than 400 CFU/m^3 in the basements. On the other hand, 22.20% of houses with exterior doors rated as Good/Excellent had air-borne mould levels in the basements equal to or greater than 400 CFU/m^3 (p=0.0834).

Table 4.26. Percentage of Houses of Various Ages with a Total Mould Count ≥200 CFU/m3 in Basements

Age of House	**% of Houses with Total Mould Count ≥ 200CFU/m^3**		**χ^2 df *p*-value**
	No (%)	Yes (%)	
0-20 Years n=209	64.11	35.89	7.486 1 0.0062
>20Years n=363	52.34	47.66	

Table 4.27. Percentage of Houses, with Various Conditions of Exterior Clutter, with a Total Mould Level of ≥200 CFU/m^3 in Basements

Exterior Clutter	**% of Houses with Total Mould Count ≥ 200CFU/m^3**		**χ^2 df *p*-value**
	No (%)	Yes (%)	
Poor/Fair n=168	50.60	49.40	2.959 1 0.0854
Good/Excellent n=479	58.25	41.75	

Table 4.28. Percentage of Houses, with Wall Stains, with a Total Mould Level ≥200 CFU/m³ in Basements

Wall Stains	% of Houses with Total Mound Count ≥200CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
No n=517	53.58	46.42	6.253 1 0.0124
Yes n=121	66.12	33.88	

Table 4.29. Percentage of Houses, with Floor Stains, with a Total Mould Level ≥200 CFU/m³ in Basements

Presence of Floor Stains	% of Houses with Total Mould Count ≥ 200CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
No n=617	55.75	44.25	3.450 1 0.0633
Yes n=21	76.19	23.81	

Table 4.30. Percentage of Houses, with Crawlspace, with a Mould Level ≥200 CFU/m³ in Basements

Crawlspace Present	% of Houses with Total Mould Count ≥ 200CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
No n=539	55.29	44.71	2.751 1 0.0972
Yes n=93	64.52	35.48	

Table 4.31. Percentage of Houses, with various Roof Types, with a Total Mould Count ≥ 200 CFU/m^3 and 400 ≥CFU/m^3 in Basements

Roof Type	% of Houses with Total Mould Count ≥ 200CFU/m^3		χ^2 df *p*-value	% of Houses with Total Mould Count ≥ 400CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)		No (%)	Yes (%)	
Stick n=266	50.38	49.62	7.253 2 0.0186	74.06	25.94	5.348 2 0.0025
Trusses n=345	60.87	39.13		78.55	21.45	
Other n=5	40.00	60.00		40.00	60.00	

Table 4.32. Percentage of Houses, with various Conditions of Roofing Material, with Total Mould Count of ≥ 200/m^3 and ≥ 400/m^3 in the basement.

Roof Material Condition	% of Houses with Total Mould Count ≥ 200CFU/m^3		χ^2 df *p*-value	% of Houses with Total Mould Count ≥ 400CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)		No (%)	Yes (%)	
Poor/Fair n=92	64.13	35.87	2.903 1 0.0884	84.78	15.22	4.367 1 0.0366
Good/Excellent n=506	54.55	45.45		74.7	25.30	

Table 4.33. Percentage of Houses, with Various Types of Window Frames, with a Total Mould Count of in the ≥ 400/m^{3}Basement

Window Frame Type	% of Homes with Total Mould Count ≥ 400CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Wood n=403	74.44	25.56	5.173 2 0.0753
Plastic n=187	76.47	23.53	
Aluminum n=47	89.36	10.64	

Table 4.34. Percentage of Houses, with various Ages of Windows, with a Total Mould Count of ≥ 200 CFU/m^3 in Basements

Age of Windows	**% of Houses with Total Mould Count ≥ 200CFU/m^3**		**χ^2 df *p*-value**
	No (%)	Yes (%)	
0-10 Years n=277	50.90	49.10	5.344 1 0.0208
>10 Years n=332	60.24	39.76	

Table 4.35. Percentage of Houses, with Various Conditions of Exterior Doors, with Total Mould Level ≥ 400 CFU/m^3 in Basements

Condition of Door	% of Homes with Mould Counts ≥ **400CFU/m^3**		**χ^2 df *p*-value**
	No (%)	Yes (%)	
Poor/Fair n=88	69.32	30.68	2.997 1 0.0834
Good/Excellent n=500	77.80	22.20	

4.5 Housing Conditions and Specific Mould Type in Children's Houses

The effect of housing conditions on three specific mould types was also examined. These mould types include Cladosporium, Penicillium, and Aspergillus. These three types were selected because Cladosporium was the most prevalent mould type identified in our study while Aspergillus was only present in the indoor samples. In addition, Aspergillus and Penicillium are extensively studied by the research community for affecting indoor air quality and thus, may impact the respiratory health of children.

The housing conditions statically significantly associated with the specific mould type and level are summarized in the following sections.

4.5.1 Housing Conditions and Cladosporium Levels in Children's Homes

4.5.1.1 Cladosporium Levels (CFU/m^3) and Children's Bedrooms

A statistically significant association was shown between the type/style of house and the cladosporium level in the children's bedrooms. As shown in Table 4.36, 41.71% of children's bedrooms had cladosporium levels of equal to or greater than 200 CFU/m^3 compared to bedrooms in split level or 2/3 storey homes where 34.04% of bedrooms had similar levels of cladosporium. Bedrooms in townhouses recorded the lowest number of homes with cladosporium levels equal to or greater than 200 CFU/m3 (p=0.0534).

A statistically significant association was found between the size of the home and cladosporium counts both greater than or equal to 200 and 400 CFU/m^3, as shown in Table 4.37. For homes greater than 1,500 square feet, 48.15% of children's bedroom had cladosporium levels equal to or greater than 200 CFU/m^3, compared to 35.01% of the bedrooms in houses less than 1,500 square feet in size. Also, 22.22% of the bedrooms in houses greater than 1,500 square feet had cladosporium counts greater than or equal to 400 CFU/m3 compared to 13.45% of the bedrooms in houses of the children's bedrooms which had cladosporium levels that were less than 1,500 square feet in size.

The condition of the foundation walls produced a statistically significant association with cladosporium levels in the children's bedrooms as shown in Table 4.38. 46.97% of the children's bedrooms in houses in which the condition of the foundation walls was rated as Poor/Fair recorded cladosporium levels equal to or greater than 200 CFU/m3. On the other hand, 34.85% of the children's bedrooms had cladosporium levels equal to or greater than 200 CFU/m3 in houses where the condition of the foundation walls were rated as Good/Excellent (p=0.0379).

Three housing conditions relating to the roof system of the homes inspected produced statistically significant associations with respect to cladosporium levels in the children's bedrooms. The specific roof system independent variables are summarized below.

The type of roof structure, that is, whether or not the roof of the house is framed with conventional dimensional lumber on-site at the time of construction, pre-engineered wood trusses, or a joist type system produced a statistically significant association with cladosporium levels in the children's bedrooms, as shown in Table 4.39.

Cathedral type ceilings, utilizeing joist framing system produced the highest percentage of bedrooms (66.67%) in which cladosporium levels were equal to or greater than 400 CFU/m^3. However, it should be noted that a very small sample size comprised this type of framing system, n=3. The percentage of houses with similar levels of cladosporium in children's bedrooms were 14.29% for houses with stick framed roofs and 14.22% for houses with pre-engineered truss roof systems (p=0.0379).

The roof material type was separated into two primary systems, a conventional shingle type roof, typically used on sloped roofs, and a low slope roof, which utilizes a membrane type roofing system, such as felt/asphaltic system protected by a gravel ballast. A statistically significant association was found when comparing the two roofing systems in relation to cladosporium levels in children's bedrooms. As shown in Table 4.40, 14.29% of the children's bedrooms in homes with shingle roofs had cladosporium levels greater than or equal to 400 CFU/m^3 while 50% of the children's bedrooms in houses utilizing a membrane type roofing system had similar cladosporium levels (p=0.0443). The number of homes with membrane type roofing, however, was very small (n=4).

The condition of the roof waterproofing system also produced a statistically significant association in relation to cladosporium levels in the children's bedrooms. As shown in Table 4.41, 39.23% of children's bedrooms in houses with roof waterproofing systems in Good/Excellent condition were found to have cladosporium levels equal to or greather than 200 CFU/m3, while 23.21% of children's bedrooms in houses in which the roof waterproofing systems were rated Poor/Fair had cladosporium concentrations equal to or greater than 200 CFU's in children's bedrooms ($p=0.0214$).

The age of the windows in the houses of the study was observed to produce a statistically significant association with cladosporium levels in children's bedrooms. As shown in Table 4.42, 41.88% of children's bedrooms in houses with windows less than 10 years of age were observed to have cladosporium levels equal to or greater than 200 CFU/m^3 while 32.68% of the bedrooms in homes with windows more than 10 years old had cladosporium levels in children's bedrooms equal to or greater than 200 CFU/m^3 ($p=0.0582$).

The association held for cladosporium levels equal to or greater than 400 CFU/m^3. 19.90% of bedrooms in houses with windows less than 10 years of age had cladosporium levels equal to or greater than 400 CFU/m^3 while 9.76% of bedrooms in houses with windows greater than 10 years of age had cladosporium levels equal to or greater than 400 CFU/m^3 ($p=0.0044$).

A statistically significant association was found between cladosporium levels in children's bedrooms and the type of exterior doors of the houses. As shown in Table 4.43, 33.05% of the children's bedrooms in houses with wood doors and 40.85% of children's bedrooms in houses with metal/aluminum doors had cladosporium levels equal to or greater than 200 CFU/m^3. 85.71% of the children's bedrooms in houses with plastic doors had similar cladosporium levels, greater than or equal to 200 CFU/m^3 (p=0.0077).

Table 4.36. Percentage of Houses of Various Construction Type with Cladosporium Levels of ≥200 CFU/m^3 in Children's Bedrooms

Type/Style of Home	% of Houses with Mould Count ≥200CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Bungalow n=187	58.29	41.71	7.666 3 0.0534
Split or 2/3 Story n=188	65.96	34.04	
Townhouse n=22	86.36	13.64	
Other n=20	65.00	35.00	

Table 4.37. Percentage of Houses of Various Sizes with Cladosporium Levels ≥ 200 CFU/m^3 and ≥ 400 CFU/m^3 in Children's Bedrooms

House Area Square feet	% of Houses with Mould Count ≥ 200CFU/m^3		χ^2 df *p*-value	% of Houses with Mould Count ≥ 400CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)		No (%)	Yes (%)	
< 1,500 n=357	64.99	35.01	3.481 1 0.0621	86.55	13.45	2.900 1 0.0887
>1,500 n=54	51.85	48.15		77.78	22.22	

Table 4.38. Percentage of Houses, with Various Conditions of the Foundations, with Cladosporium Levels ≥ 200 CFU/m^3 in the Children's Bedrooms

Foundation Condition	**% of Homes with Mould Count ≥ 200CFU/m^3**		**χ^2 df *p*-value**
	No (%)	Yes (%)	
Poor/Fair n=66	53.03	46.97	3.472 1 0.0624
Good/Excellent n=330	65.15	34.85	

Table 4.39. Percentage of Houses, with Various Types of Roof Structure, with Cladosporium Levels ≥ 400 CFU/m3 in Children's Bedrooms

Type of Roof Structure	**% of Houses with Mould Count ≥ 400CFU/m^3**		χ^2 df *p*-value
	No (%)	Yes (%)	
Stick Framed n=196	85.71	14.29	6.54 2 0.0379
Pre-Eng Trusses n=204	85.78	14.22	
Other (Flat/Cathedral) n=3	33.33	66.67	

Table 4.40. Percentage of Houses, with Various Roofing Material Type, with Cladosporium Levels ≥ 400 CFU/m3 in Children's Bedrooms

Roof Material Type	% of Houses, with Various Roofing Material Type, with Cladosporium Levels ≥400 CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Shingles n=413	85.71	14.29	4.046 1 0.0443
Membrane/BUR n=4	50.0	50.0	

Table 4.41. Percentage of Houses, with Various Conditions of Roof Material, with Cladosporium Levels ≥ 200 CFU/m^3 in Children's Bedrooms

Roof Material Condition	% of Houses with Mould Count ≥ 200CFU/m^3		χ^2 **df** ***p*-value**
	No (%)	Yes (%)	
Poor/Fair n=56	76.79	23.21	5.293 1 0.0214
Good/Excellent n=339	60.77	39.23	

Table 4.42. Percentage of Houses of Various Ages with Cladosporium Levels 200 ≥CFU/m^3 and ≥400 CFU/m^3 in Children's Bedrooms.

Age of Windows	% of Houses with Mould Count ≥ 200/m^3		χ^2 **df** ***p*-value**	% of Houses with Mould Count ≥ 400/m^3		χ^2 **df** ***p*-value**
	No (%)	Yes (%)		No (%)	Yes (%)	
0-10 Years n=191	58.12	41.88	3.587 1 0.0582	80.10	19.90	8.130 1 0.0044
>10 Years n=205	67.32	32.68		90.24	9.76	

Table 4.43. Percentage of Houses, with Various Types of Doors, with Cladosporium Levels ≥ 200CFU/m³ in Children's Bedrooms

Door Type	% of Houses with Mould Counts ≥ 200 CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
Wood n=236	66.95	33.05	9.738 2 0.0077
Plastic n=7	14.29	85.71	
Metal/Alum. n=164	59.45	40.85	

4.5.1.2 Housing Conditions and Cladosporium Levels (CFU/m³) in the Basements

Significant statistical associations were found between six housing conditions and cladosporium levels in the basements of the study homes: the general condition of the houses; wall stains; the condition of the roofing material; the presence/absence of any roof renovations; and, the type of windows. These are discussed below.

As shown in Table 4.44, 33.85% of basements of houses whose condition was rated Good/Excellent had cladosporium levels equal to or greater than 200 CFU/m^3 while 12.50% of basements in houses who's condition was rated Poor/Fair had cladosporium levels equal to or greater than 200 CFU/m^3 in the basements, (p=0.0142).

A statistically significant association was found between stains on the walls, typically due to moisture from condensation, and cladosporium levels in the basements of the houses inspection. As shown in Table 4.45, basements in 27.40% of the houses inspected with visible stains on the walls had cladosporium levels equal to or greater than 200 CFU/m^3 in the basements. Also, 37.65% of the basements in the houses with no visible stains on the walls had cladosporium levels equal to or greater than 200 CFU/m^3 ($p=0.0975$).

A statistically significant association was found between the condition of the roofing material of the houses and cladosporium levels in the basements. As shown in Table 4.46, 39.94% of the basements in houses in the study in which the condition of the roofing system was rated as Good/Excellent had cladosporium levels equal to or greater than 200 CFU/m3, compared to 20.34% of the basements in houses in which the condition of the roofing system was rated Poor/Fair ($p=0.0041$).

This association held for cladosporium levels in the basements equal to or greater than 400 CFU/m^3. In this study, 23.17% of the basements in houses with the condition of the roof systems rated as Good/Excellent had cladosporium levels equal to or greater than 400 CFU/m^3 compared to 6.78% of the basements in houses in which the condition of the roofing system was rated Poor/Fair ($p=0.0042$).

A statistically significant association between houses with renovated roofs and cladosporium levels in the basement was found. As shown in Table 4.47, 8.33% of the basements in houses in which roof repairs or alterations had been completed had cladosporium levels in the basement equal to or greater than 200 CFU/m^3 compared to 36.57% of the basements in houses in which no repairs had been completed (p=0.0443).

The associations also held for cladosporium levels equal to or greater than 400 CFU/m^3. No basements in houses in which roof repairs or alterations had been completed had cladosporium levels equal to or greater than 400 CFU/m3, compared to 20.40% of the basements in houses in which roof repairs or alterations were not completed (p=0.0679).

Statistical significant associations were also found between cladosporium levels in the basements of the study houses and the age and type of windows in the houses. As shown in Table 4.48, 25.54% of basements in houses with windows that were less than 10 years old had cladosporium levels equal or greater than 400 CFU/m3, compared to 15.94% of the basements in houses in which the windows were more than 10 years old (p=0.0188).

The type of windows in the study houses also produced a statistically significant association for cladosporiium levels in the basement. As shown in Table 4.49, 23.33% of the basements in houses with plastic windows had cladosporium levels in the basement equal to or greater than 400 CFU/m3, compared to 20.83% of the basements in houses with wood framed windows and 0.00% of basements in houses with aluminum windows (p=0.0379).

Table 4.44. Percentage of Houses of Various Condition with Cladosporium Levels ≥200 CFU/m^3 in Basements

General Home Condition	% of Houses with Mould Counts ≥ 200CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Poor/Fair n=32	87.50	12.50	6.014 1 0.0142
Good/Excellent n=257	66.15	33.85	

Table 4.45. Percentage of Houses, with and without Wall Stains, with Cladosporium Levels ≥200 CFU/m^3 in Basements

Wall Stains	% of Houses with Mould Counts ≥ 200 CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
No n=340	62.35	37.65	2.746 1 0.0975
Yes n=73	72.60	27.40	

Table 4.46. Percentage of Houses, with various condition of Roof Material, with Cladosporium Levels 200≥ CFU/m³ and 400 ≥CFU/m³ in the Basements

Roof Material Condition	% of Houses with Mould Count ≥ 200 CFU/m³		χ^2 df *p*-value	% of Houses with Mould Count ≥ 400CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)		No (%)	Yes (%)	
Poor/Fair n=59	79.66	20.34	8.246 1 0.0041	93.22	6.78	8.193 1 0.0042
Good/Excellent n=328	60.06	39.94		76.83	23.17	

Table 4.47. Percentage of Houses, with and without Roof Renovations, with Cladosporium Levels ≥ 200 CFU/m³ and ≥400 CFU/m³ in Basements

Roof Renovations	% of Houses with Mould Count ≥ 200CFU/m³		χ^2 df *p*-value	% of Houses with Mould Count ≥ 400CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)		No (%)	Yes (%)	
No n=402	63.43	36.57	4.044 1 0.0443	79.60	20.40	3.052 1 0.0679
Yes n=12	91.67	8.33		100.00	0.00	

Table 4.48. Percentage of Houses, with Windows of varying ages, with Cladosporium Levels 400 ≥ CFU/m3 in the Basements

Age of Windows	% of Houses with Mould Counts ≥ 400 CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
0-10 Years n=184	74.46	25.54	5.518 1 0.0188
>10 Years n=207	84.06	15.94	

Table 4.49. Percentage of Houses, with various types of Windows, with Cladosporium Level 400 ≥ CFU/m3 in Basements

Type of Window	% of Houses with Mould Count ≥ 400CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Wood n=264	79.17	20.83	6.54 2 0.0379
Plastic n=120	76.67	23.33	
Aluminum n=26	100.00	0.00	

4.5.2 Housing Conditions and Penicillium Levels in Children's Houses

Five independent housing conditions were found to be statistically significantly associated with penicillium levels in the children's bedrooms: The type of foundation; the roof type; the type of window frames; the age of the windows; and, the condition of the exterior doors. There were also several housing conditions which were found to be statistically significantly associated with penicillium levels in the basements of the study houses. These will be discussed below.

4.5.2.1 Housing Conditions and Penicillium Levels (CFU/m^3) in the Children's Bedrooms

As shown in Table 4.50, 40.00% of the children's bedrooms in houses on masonry foundation walls had penicillium levels greater than or equal to 100 CFU/m3 compared to 11.19% of children's bedrooms in houses constructed on concrete foundation walls (p=0.0527).

Statistically significant associations were also found between the roof structural system and penicillium levels in the children's bedrooms. As shown in Table 4.51, a higher percentage of children's bedrooms in houses that did not have an attic space, 27.78% had penicillium levels equal to or greater than 100 CFU/m3 than in houses that had an attic space, 9.68% (p=0.0127).

Three statistically significant associations were found between pencillium levels in the children's bedrooms and the condition of the windows and doors of the houses. As shown in Table 4.52, 23.08% of children's bedrooms in houses with plastic windows, that is, PVC or Fiberglass windows had penicillium levels equal to or greater than 100 CFU/m^3 , compared to 8.25% of children's bedrooms in houses with windows made from wood frames, and 100% of children's bedrooms in houses with aluminum or metal framed windows (p=0.0182).

The age of the windows was also found to be statistically significantly associated with penicillium levels in the children's bedrooms. As shown in Table 4.53, 18.84% of the children's bedrooms in houses with windows that were less than 10 years of age, had penicillium levels equal to or greater than 100 CFU/m3 compared to 5.71% of the children's bedrooms in houses in which the windows were greater than 10 years old (p=0.0182).

The condition of the doors was also statistically associated with penicillium levels in children's bedrooms. As shown in Table 4.54, 80.83% of the children's bedrooms in houses with doors in Fair/Poor condition had penicillium levels equal to or greater than 100 CFU/m3 compared to 8.33% of the children's bedrooms in houses that had door conditions rated as Good/Excellent (p=0.0607).

Table 4.50. Percentage of Houses, with various types of Foundations, with Penicillium Levels ≥ 100 CFU/m3 in the Children's Bedrooms

Foundation Type	**% of Houses with Mould Counts ≥ 100CFU/m^3**		χ^2 **df** ***p*-value**
	No (%)	Yes (%)	
Stone/Block Masonry n=5	60.00	40.00	3.754 1 0.0527
Concrete n=143	88.81	11.19	

Table 4.51. Percentage of Houses, with Different Types of Roof Structures, with Penicillium Levels ≥ 100 CFU/m3 in the Children's Bedrooms

Roof Type (Sloped/Flat)	% of Houses with Mould Count ≥ **100 CFU/m^3**		χ^2 **df** ***p*-value**
	No (%)	Yes (%)	
Attic Space n=124	90.32	9.68	4.887 1 0.0271
Cathedral Roof Style n=18	72.22	27.78	

Table 4.52. Percentage of Houses, with various types of Window Frames, with Penicillium Levels ≥ 100 CFU/m3 in the Children's Bedrooms

Window Frame Type	% of Houses with Mould Counts ≥ 100 CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Wood n=97	91.75	8.25	5.713 2 0.0064
Plastic n=39	76.92	23.08	
Aluminum n=10	90.00	10.00	

Table 4.53. Percentage of Houses with various ages of windows with Penicillium Levels ≥ 100 CFU/m3 in the Children's Bedrooms

Age of Windows	% of Houses with Mould Levels ≥ 100 CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
0-10 Years n=69	81.16	18.84	5.578 1 0.0182
>10 Years n=70	94.29	5.71	

Table 4.54. Percentage of Houses with various conditions of Exterior Doors, with Penicillium Levels ≥100 CFU/m3 in Children's Bedrooms

Door Condition	CFU ≥ 100/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Poor/Fair n=24	79.17	20.83	3.236 1 0.0607
Good/Excellent n=108	91.67	8.33	

4.5.2.2 Housing Conditions and Penicillium Levels (CFU/m^3) in Basements

Statistically significant associations between various housing conditions and penicillium levels in basements of the houses audited are discussed below.

As shown in Table 4.55, 33.33% of the basements in houses whose condition was rated Poor/Fair had penicillium levels equal to or greater than 100 CFU/m3 compared to 15.38% of the basements in houses rated Good/Excellent (p=0.0484).

Elements contributing to relative humidity within the home were also found to have a statistically significant association with basement penicillium levels. As shown in Table 4.56, houses with plants produced a higher percentage of basements (14.29%) penicillium levels equal to or greater than 100 CFU/m3 than houses with aquariums (11.29%) or hot-tubs (10.00%); p=0.0114.

Two housing conditions pertaining to the roof system of the houses in the study were found to be statistically significantly associated with penicillium levels in the basements.

As shown in Table 4.57, houses constructed with an attic and the condition was rated Good/Excellent had a higher percentage of basements (21.59%) with penicillium levels equal to or greater than 100 CFU/m3, compared to houses with attics rated as Poor/Fair (10.71%); p=0.093.

A statistically significant association was found between pencillium levels in the basement and the type of roof framing for the houses. As shown in Table 4.58, 17.92% of the basements in stick framed roof systems had penicillium levels equal to or greater than 100 CFU/m3 in the basements compared to 13.64% of the basements in houses that used pre-engineered roof truss systems (p=0.0187).

A statistically significant association was also found between penicillium levels in the basement and the condition of the windows. As shown in Table 4.59, 22.11% of the basements in houses in which the condition of the windows was rated Good/Excellent had basement penicillium levels equal to or greater than 100 CFU/m3 compared to 9.88% of the basements in houses in which the condition of the windows was rated Poor/Fair (p=0.0293).

A statistically significant association was found between the type of doors and penicillium levels in the basements. As shown in Table 4.60, none of the basements in which utilized plastic framed doors, typically PVC or fiberglass, had penicillium levels in the basements equal to or greater than 100 CFU/m^3.

On the other hand, 22.26% of basements in houses utilizing metal or aluminum framed doors, and 11.93% in houses with wood framed doors, had penicillium levels in the basements equal to or greater than 100 CFU/m^3 (p=0.0132).

The condition of the doors was also found to be statistically significantly associated with basement penicillium levels. As shown in Table 4.61, a higher percentage (28.57%) of basements in houses in which the condition of the doors was rated Poor/Fair condition had penicillium levels in the basements equal to or greater than 100 CFU/m3 compared to 13.38% of basements in houses whose door condition was rated Good/Excellent (p=0.0313).

Table 4.55. Percentage of Houses, with Various Conditions with Pencillium Levels ≥ 100 CFU/m3 in Basements

Condition of Home	**% of Houses with Mould Counts ≥ 100CFU/m^3**		**χ^2 df *p*-value**
	No (%)	Yes (%)	
Poor/Fair n=18	66.67	33.33	3.517 1 0.0484
Good/Excellent n=130	84.62	15.38	

Table 4.56. Percentage of Houses, with Various Sources Contributing to Humidity, with Penicillium Mould Levels ≥ 100 CFU/m^3 in Basements

Elements Contributing to Humidity	% of Houses with Mould Counts ≥ 100 CFU /m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Aquarium n=62	88.71	11.29	7.000 3 0.0114
Hot Tub n=10	90.00	10.00	
Plants n=35	85.71	14.29	
Other n=1	0.00	100.00	

Table 4.57. Percentage of Houses, with Various Conditions of the Attic, with Penicillium Levels ≥ 100 CFU/m^3 in Basements

Condition of Attic	% of Houses with Mould Count ≥ 100 CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Poor/Fair n=56	89.29	10.71	2.822 1 0.093
Good/Excellent n=88	78.41	21.59	

Table 4.58. Percentage of Houses, with Various Types of Roof Framing, with Penicillum Levels ≥ 100 CFU/m³ in Basements.

Roof Framing Type	Percentage of Houses with Mould Count ≥ 100 CFU /m³		χ^2 df *p*-value
	No (%)	Yes (%)	
Stick n=106	82.08	17.92	5.765
Trusses n=88	86.36	13.64	2
Other n=1	0.00	100.00	0.0187

Table 4.59. Percentage of Houses, with Various Conditions of Windows, with Penicillium Levels ≥ 100 CFU/m³ in Basements

Condition of Windows	% of Houses with Mould Count ≥ 100 CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
Poor/Fair n=81	90.12	9.88	4.751 1 0.0293
Good/Excellent n=95	77.89	22.11	

Table 4.60. Percentage of Houses, with Various Types of Door Frames, with Penicillium Levels ≥ 100 CFU/m³ in Basements

Door Frame Type	% of Houses with Mould Counts ≥ 100 CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
Wood n=109	88.07	11.93	4.565
Plastic n=3	100.00	0.00	2
Aluminum n=84	77.38	22.26	0.0132

Table 4.61. Percentage of Houses with Various Conditions of Doors with Penicillium Levels ≥100 CFU/m^3 in the Basements

Condition of Doors	% of Houses with Mould Counts ≥ 100 CFU /m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Poor/Fair n=28	71.43	28.57	4.151 1 0.0312
Good/Excellent n=157	86.62	13.38	

4.5.3 Housing Conditions and Aspergillus Levels in Children's Houses

Aspergillus levels, in both children's bedrooms and basements, were statistically analyzed with respect to housing conditions. Due to the small number of homes with Aspergillus levels greater than or equal to 100 CFU/m^3, only associations that were found to be statistically significant at a probability of 0.10 are included.

4.5.3.1 Housing Conditions and Aspergillus Levels (CFU/m^3) in the Children's Bedrooms

A statistically significant association was found between the size of the home and aspergillus levels in children's bedrooms. As shown in Table 4.62, 3.57% of children'ts bedrooms in homes less than 1,500 square feet had aspergillus levels equal to or greater than 200 CFU/m3 compared to 33.33% of children's bedrooms in houses greater than 1,500 square feet in size (p=0.0461).

Elements contributing to relative humidity within the home were also found to be statistically significantly associated with aspergillus levels in children's bedrooms. As shown in Table 4.63, 40.00% of the children's bedrooms in houses containing a significant number of plants had aspergillus levels equal to or greater than 200 CFU/m3, compared to 0.00% of children's bedrooms in houses with hot-tubs or aquariums (p=0.0809).

Evidence of stains on the walls, typically due to moisture from condensation, were also found to be statistically significantly associated with aspergillus levels in children's bedrooms. As shown in Table 4.64, 12.5% of the children's bedrooms in houses with visible stains on the walls had aspergillus levels equal to or greater than 400 CFU/m3 compared to 0.00% of children's bedrooms in houses with no visible stains (p=0.0784).

The number of exhaust fans in the home was found to be statistically significantly associated with aspergillus levels in the children's bedrooms. As shown in Table 4.65, 25.00% of children's bedrooms in houses with three or more fans had aspergillus levels equal to or greater than 200 CFU/m3 compared to 0.00% of children's bedrooms with none, and 1 or 2 exhaust fans (p=0.0408).

Table 4.62. Percentage of Houses of Various Size with Aspergillus Levels ≥ 200 CFU/m3 in Children's Bedrooms

Square Footage of Home	% of Houses with Mould Counts ⩾ 200 CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
<1,500 n=28	96.43	3.57	3.977 1 0.0461
>1,500 n=3	66.67	33.33	

Table 4.63. Percentage of Houses, with Various sources of Humidity, with Aspergillus Levels 200 ≥ CFU/m³ in Children's Bedrooms

Elements Contributing to Humidity	CFU ≥ 200/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
Aquarium n=8	100.00	0.00	5.029 3 0.0809
Hot Tub n=3	100.00	0.00	
Plants n=5	60.00	40.00	
Other n=0	0.00	0.00	

Table 4.64. Percentage of Houses, with or without wall stains, with Aspergillus Levels ≥400 CFU/m3 in Children's Bedrooms

Presence of Wall Stains	% of Houses with Mould Count ≥ 400 CFU/m³		χ^2 df *p*-value
	No (%)	Yes (%)	
No n=24	100.00	0.00	3.097 1 0.0784
Yes n=8	87.50	12.50	

Table 4.65. **Percentage of Houses, with varying number of exhaust fans, with Aspergillus Levels 200 ≥ CFU/m^3 in Children's Bedrooms**

Exhaust Fans	**% of Houses with Mould Count ≥ 200 CFU/m^3**		**χ^2 df *p*-value**
	No (%)	Yes (%)	
0 n=3	100.00	0.00	6.400
1 or 2 n=21	100.00	0.00	2
3 or More n=8	75.00	25.00	0.0408

4.5.3.2 Housing Conditions and Aspergillus Levels (CFU/m^3) in the Basements

There were two housing conditions that were found to be statistically significantly associated with aspergillus levels in basements: presence/absence of wall stains and window usage. As shown in Table 4.66, 5.88% of the basements in houses with visible stains on the walls had aspergillus levels equal to or greater than 400 CFU/m3 compared to 0.00% of basements with no visible stains (p=0.0491).

Table 4.67 shows the percentage of basements (8.33%) of houses with windows regularly open where aspergillus levels 400 CFU/m3 were recorded. None of the basements in houses with open windows in the summer had aspergillus levels in the basement equal to or greater than 400 CFU/m3 (p=0.0255).

Table 4.66. Percentage of Houses, with or without Wall Stains, with Aspergillus Levels ≥ 400 CFU/m3 in Basements

Presence of Wall Stains	% of Houses with Mould Counts ≥ 400 CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
No n=65	100.00	0.00	3.871 1 0.0491
Yes n=17	94.12	5.88	

Table 4.67: Percentage of Houses with Windows Open/Closed, with Aspergillus Levels ≥ 400 CFU/m3 in Basements

Window Usage	% of Houses with Mould Count ≥ 400 CFU/m^3		χ^2 df *p*-value
	No (%)	Yes (%)	
Regularly Open n=12	91.67	8.33	4.987 1 0.0255
Summer Only n=59	100.00	0.00	

4.6 Housing Conditions and Respiratory Health

The housing conditions in the study homes were statistically analyzed in relation to the respiratory health of the child occupants. The statistically significant results are summarized in the following sub-sections.

4.6.1 Basement Carpets and Asthma

As shown in Table 4.68, a small but significant statistical association was found between stains on basement carpets and the absence/presence of asthma (Group 2). A significantly higher percentage of children with asthma (41.63%) did not have extensive basement carpet stains in the basement compared to (22.22%) of children with asthma living in houses with extensive carpet stains in the basement (p=0.0456). As explained in the Part 1 results, this may be attributed to the proactive measures taken by parents with asthmatic children to provide a clean environment for their children.

Table 4.68. Basement Carpet Stains and Childhood Asthma

Basement Carpet Stains	**% of Children with Clinical Asthma (Group 2)**		**χ^2 df *p*-value**
	No (%)	Yes (%)	
No Stains n=12	58.37	41.63	3.997 1 0.0456
Stains n=59	77.78	22.22	

4.6.2 Furnace Filters and Asthma

During the basement audits, the heating system was reviewed in order to determine the presence/absence of a furnace filter. Where accessible, the furnace filter was identified. The results pertain whether or not a disposable filter was present when appropriate.

As shown in Table 4.69, 41.92% of children with asthma lived (Group 2) in houses with removable furnace filters compared to 23.32% of children living in houses in which no filters were present (p=0.0349). As in the case of carpet stains, the importance of furnace filters was statistically significant with respect to the presence/absence of asthmatic children in the home.

Table 4.69. Furnace Filters and Childhood Asthma

Furnace Filter	% of Children with Clinical Asthma (Group 2)		χ^2 **df** ***p*-value**
	No (%)	Yes (%)	
No Filter n=37	75.68	24.32	4.448 1 0.0349
Filter Present n=563	58.08	41.92	

4.6.3 Respiratory Conditions and the Condition of the Attic

A statistically significant association was found between the condition of the attics in the study homes and the respiratory health of the children living in the homes. Significant findings are shown in Table 4.70 and are summarized below.

In general, homes in which the attics were observed to be in Good/Excellent condition had a statistically significant higher percentage of children with asthma, and asthma in combination with persistent colds compared to homes in which the attics were observed to be in Fair/Poor condition. Children with asthma lived in 12.28 % of the homes in which the attics were in good or excellent condition compared to 6.59% of the homes in which the attics were in Poor/Fair condition; (p=0.0510).

Table 4.70: Respiratory Conditions and the Condition of the Attic

Condition of Attic	% of Children and their Respiratory Condition				χ^2 df *p*-value
	Group 4 Few Colds No Asthma (%)	**Group 3** Persistent Colds (%)	**Group 2** Asthma (%)	**Group 1** Asthma + Persistent Colds (%)	
Poor/Fair n=167	34.13	31.14	6.59	28.14	7.771 3 0.0510
Good/Excellent n=334	24.85	29.94	12.28	32.93	

4.6.4 Respiratory Conditions and the Condition of the Crawlspace

A statistically significant association was found between the condition of the crawlspace in the study homes and the respiratory health of the children living in their houses. Table 4.71 summarizes the results obtained but significant findings are summarized below.

In general, houses in which the crawlspace was observed to be in Good/Excellent condition had a statistically significant higher percentage of children with respiratory conditions compared to homes in which the crawlspaces were observed to be in Poor/Fair condition; p=0.0100.

- In our study, 80.00% of the children in houses in which the crawlspace was in Poor/Fair condition had no asthma and few colds per year (Group 4), compared to only 25.00% of the children in which the crawlspace was rated in Good/Excellent condition.

- Children with asthma (Group 2) lived in 10.42 % of the houses in which the crawlspace was observed to be in Good/Excellent condition compared to 0.00% of the houses in which the crawlspace was in Poor/Fair condition.

- Similarly, 18.75% of the children in houses with crawlspaces in Good/Excellent condition experienced persistent colds (Group 3) compared to 10.00% of the children in houses in which crawlspace was in Poor/Fair condition.

- 45.83% of the children in homes with the crawlspace in Good/Excellent condition experienced asthma in combination with persistent colds (Group 1) compared to 10.00% in which the homes with crawlspace was rated in Poor/Fair condition.

Table 4.71. Respiratory Conditions and the Condition of the Crawlspace

Condition of Crawlspace	% of Children and Respective Respiratory Respiratory Condition				χ^2 df *p*-value
	Group 4 Few Colds No Asthma (%)	**Group 3** Persistent Colds (%)	**Group 2** Asthma (%)	**Group 1** Asthma + Persistent Colds (%)	
Poor/Fair n=10	80.00	10.00	0.00	10.00	11.349 3 0.0100
Good/Excellent n=48	25.00	18.75	10.42	45.83	

4.6.5 Respiratory Conditions and the Number of Window Panes

A statistically significant association was observed between the respiratory condition of children in the study homes and the number of panes of glass in the window system. The relationship varied depending upon the respiratory condition of the children. The results are summarized in Table 4.72 while significant findings are summarized below.

- In general, a higher percentage of children that do not suffer from persistent colds or asthma (Group 4) lived in homes in which only single panes of glass were present in the windows.

- Children with diagnosed asthma lived in 12.21% of the houses with triple pane windows, compared to 8.54% of houses with dual pane, and 4.90% of houses with single pane windows; (p=0.0110).

- The statistical results for children with persistent colds (Group 3) varied. 42.16% of children with persistent colds (Group 3) lived in houses with single pane windows compared to 26.63% of children that lived in houses with dual pane windows, and 30.65% of children that lived in houses with triple pane windows.

Table 4.72. Respiratory Conditions and the Number of Window Panes

Number of Panes of Glass in Windows	**% of Children and Respective Respiratory Respiratory Condition**				**χ^2 df *p*-value**
	Group 4 Few Colds No Asthma (%)	**Group 3** Persistent Colds (%)	**Group 2** Asthma (%)	**Group 1** Asthma + Persistent Colds (%)	
Single Pane n=102	20.59	42.16	4.90	32.35	16.563
Double Pane n=199	35.68	26.63	8.54	29.15	6
Triple Pane n=385	27.01	30.65	12.21	30.13	0.0110

4.7 Summary of Findings

Due to the number of statistically significant associations, the major findings obtained from the statistical analysis of the data are summarized below in point form. For clarity, the results are grouped in various categories.

4.7.1 Statistical Analysis of the Results from the Initial Contact Survey

- The average age of the houses in this study was 31.6 years. There was little variation in the age of houses or the years children living in the houses for each of the four categories of children's health examined.

- The data show that the children's respiratory health is significantly associated with self-reported visible mould in the home. Children with reported mould in their home were more likely to have persistent colds compared to those with no reported mould.

- Children with asthmatic parents, asthmatic relatives, or asthmatic siblings were more likely to have asthma.

- Children with reported mould in their basement were more likely to have persistent colds in combination with asthma.

- Children with asthmatic parents, siblings or other relatives had more than double the odds of having asthma and persistent colds.

- Children with smokers living in the home were more likely to have persistent colds in combination with asthma.

- No statistically significant associations were found between respiratory health and the age of the home or the number of years living in the home.

4.7.2 Analysis of Air Sampling Data

- A high number of Winnipeg homes, 63.6% of children's bedrooms were observed to have air-borne mould of at least 100 CFU/m^3.

- 65.1% of basements were found to have air-borne mould levels (all species) of at least 100CFU/m^3.

- A surprisingly high number of children's bedrooms in Winnipeg homes, 18.9% were observed to have air-borne mould of at least 400 CFU/ m^3.

- 23.3% of basements were found to have air-borne mould levels (all species) greater than 400CFU/m^3.

- Cladosporium was the most common mould genus type found in Winnipeg homes with total mould levels greater than or equal to 100CFU/m^3 (98.2% of children bedrooms; 97.8% of basements), followed by Alternaria (82.4% of children bedrooms; 77.0% of basements) and Penicillium (35.4% of children bedrooms; 48.8% of basements).

- Cladosporium and alternaria were the most prominent of the exterior air samples with total mould levels greater than or equal to 100 CFU/m^3. Aspergillus was absent from the top 10 exterior moulds identified in the control, or Area 3, sampling.

- As ambient temperatures increased, cladosporium levels, both interior and exterior, increased significantly in the month of June. Results also show that there was significant communication between the exterior and interior for air-borne moulds.

4.7.3 Association between Survey and Air Sampling Data

- For the air sampling results in the month of April, a statistically significant association was found between occupant-reported visible mould in the house and air-borne mould levels for all species combined at $\geq$ 100CFU/m^3 and $\geq$ 200CFU/m^3 in the children's bedroom.

- A statistically significant association was also observed between self-reported visible mould and air-borne mould counts within the basement for mould levels

$\geq$ 100CFU/m^3 and $\geq$ 200CFU/m^3 for all testing months combined. For April, this association held for mould levels $\geq$ 300 CFU/m^3.

4.7.4 Air Sampling Results versus Respiratory Health

- Analyses of the data show an association between cladosporium CFU levels from air samples taken in April and the children's asthma in combination with persistent colds (Group 1), respiratory health condition.

- The average concentration of air-borne cladosporium levels in association with asthma in combination with persistent olds (Group 1) was 125 CFU/m^3 for the children's bedroom and 131 CFU/m^3 for the basements of the homes in our study.

- No statistically significant association was revealed between respiratory health and penicillium and/or aspergillus in this study.

4.7.5 Air Sampling Results versus Home Environmental Conditions

- Results indicated an unclear pattern between the total mould count in the home and relative humidity, air temperature, surface temperature measurements, and moisture content of the building materials. Although a statistical association cannot be necessarily ruled out, the data obtained in our study is highly skewed, thereby masking possible associations. It is important to note that the data obtained in this study represents a snap-shot in time for the conditions in the home, thus, the reason for significant variations in results.

4.7.6 Housing Conditions and the Interior Environment

There were many statistically significant associations between housing conditions in relation to interior temperatures, relative humidity and building moisture content. Some of the more significant observations from the statistical analysis of the data are presented below in bullet form.

- Houses in which the exterior doors were rated in Good/Excellent condition had a mean temperature of +20.78^{o} C in the child's bedroom, +0.58^{o} C warmer than houses in which the exterior doors were rated in Poor/Fair condition.

- The mean temperature in the children's bedroom in houses which the house foundation was rated in Good/Excellent, was +20.75^{o} C, +0.48^{o} C warmer than in houses which the foundation was rated as Poor/Fair.

- Houses constructed from masonry or other building materials were significantly warmer in the child's bedroom compared to conventional wood frame (23.42^{o} C for masonry/other versus +20.65^{o} for wood frame).

- The basements in houses in which the structural condition was rated as Good/Excellent had mean air temperatures of +19.47^{o} C, +0.55^{o} warmer than in houses whose condition was rated as Poor/Fair.

- Houses with no significant visible condensation stains on the walls were warmer in the children's bedroom compared to homes with stain areas greater than 1.0 square feet in size.

- Houses with no evidence of window condensation had higher wall surface temperatures in the children's bedroom compared to homes in which window condensation was observed.

- Houses in which the exterior cladding was observed to be well maintained had a lower relative humidity within the children's bedroom compared to houses with exterior cladding in Poor/Fair condition.

- Flat roof systems, such as a membrane, produced a significantly higher relative humidity in the children's bedroom compared to a conventional sloped shingle roofs.

- Roof systems that had been recently repaired and/or upgraded had a higher relative humidity within the children's bedroom.

- Houses in which repairs to exterior walls were rated as Good/Excellent produced a higher relative humidity in the children's bedroom compared to houses in which repairs were in poor condition.

- Houses with newer windows produced a higher relative humidity compared to houses with older windows.

- Houses in which the windows were observed to be in good condition also produced a higher relative humidity in the children's bedroom.

- The number of exhaust fans in the house was confirmed to have a positive effect on humidity control. The reported use of exhaust fans also was confirmed to be effective at humidity control.

- Newer houses had a lower relative humidity in the basement compared to older homes.

- Houses in which the windows were observed to be in good/excellent condition produced a higher relative humidity in the basement compared to homes with poor/fair condition windows.

- Attics observed to be in good/excellent condition produced lower wall moisture content levels in the children's bedroom walls.

- Houses with the cladding in good/excellent condition produced a lower moisture content in the walls of the children's bedroom.

- Houses exhibiting structural duress had higher moisture contents in the walls of the children's bedroom.

- Newer houses had lower wall moisture content in the children's bedroom compared to older homes.

- There was a highly statistically significant relationship between roofing framing and children's bedroom wall moisture content. Homes incorporating cathedral type ceilings or older style stick framed attic roof systems had a mean moisture content in the walls more than double compared to conventional pre-engineered truss roof systems.

- Houses with water in the crawlspace had a significantly higher moisture content within the walls of the homes, (6.10%) compared to houses without water in the crawlspace (2.25%).

4.7.7 Housing Conditions and Air-Borne Mould Levels within the Home

The data obtained from the house inspections and biological air sampling were analyzed utilizing a Chi Squared analysis in order to establish statistical significant associations between the housing conditions identified in the housing audits and the results from air-sampling. Due to the large number of statistically significant associations revealed, only major findings or associations are summarized below in bullet form.

- Houses in our study with foundations in poor/fair condition had a much higher number of houses with total air-borne mould greater than 200 CFU/m^3 than houses with foundations rated as good/excellent.

- Houses with masonry foundation wall systems produced a higher percentage of houses with total mould levels greater than or equal to 200 CFU/m^3 in the children's bedroom compared to houses with concrete foundation walls.

- Houses with roof systems observed to be in good/excellent condition had a higher number children's bedrooms with total mould levels of equal to or greater than either 200 CFU/m^3 and 400 CFU/m^3 compared to homes with roof systems in poor/fair condition.

- 46% of houses with wood and 43.5% of houses with plastic framed windows had mould levels equal to or greater than 100 CFU/m^3 in the children's bedroom, compared to 28% of houses with aluminum windows.

- Houses with newer windows produced a higher percentage of homes with total mould levels in the basement equal to or greater than both 200 CFU/m^3 compared to houses with older windows. This relationship held also for the children's bedroom. A higher percentage of houses with newer windows had a total mould count in the children's bedroom equal to or greater than both 200 and 400 CFU/m^3 compared to homes with older windows.

- Older houses had a higher percentage of basements with total air-borne mould counts greater than 200 CFU/m^3.

- Houses with low slope or cathedral type roof systems had a higher percentage of basements with total air-borne mould compared to houses with conventional attic framed systems.

- It was observed that houses that had roof systems in good/fair condition had a higher percentage of basements with mould levels equal to or greater than both 200 and 400 CFU/m^3.

- Houses with large area produced a greater number of children's bedrooms with cladosporium levels greater than or equal to 200 and 400 CFU/m^3.

- Houses that contained a high number of plants produced a higher number of basements with penicillium levels equal to or greater than 100 CFU/m^3, compared to houses with aquariums and hot-tubs.

- Houses with large area produced a greater number of children's bedrooms with aspergillus levels greater than or equal to 200 CFU/m^3.

- The number of plants was the only variable which produced the highest number of houses with aspergillus levels equal to or greater than 200 CFU/m^3 in children's bedrooms, compared to aquariums and hot-tubs.

- In general, exhaust fans did not have any effect at controlling aspergillus levels in the children's bedroom.

4.7.8 Housing Conditions and Respiratory Health

- A small but significant statistical association was found between significant stains in basement carpets and the absence/presence of asthma. 41.6% of houses with asthmatic children did not have extensive basement carpet stains in the basement, compared to 22.2% of houses with asthmatic children in houses with extensive carpet stains.

- 41.9% of houses with asthmatic children had removable furnace filters compared to 24.3% of houses of asthmatic children in which no filters were present.

- Houses in which the attics were observed to be in good/excellent condition had a statistically significant higher percentage of children with asthma, and asthma in combination with persistent colds, compared to homes in which the attics were observed to be in poor/fair condition.

- It is well established in the literature that crawlspaces in homes with no protective ground cover and/or standing water produce higher levels of air-borne mould. However, in our study, homes in which the crawlspace was observed to be in good/excellent condition had a statistically significant higher percentage of children with respiratory conditions compared to homes in which the crawlspaces were observed to be in poor/fair condition. Caution is required on the interpretation of the data as the number of data points was relatively small with n=10.

- A statistically significant association was observed between the respiratory conditions of children in the study houses and the number of panes of glass in the windows. The relationship varied depending upon the respiratory condition. In general, a higher percentage of children that do not suffer from either persistent colds or asthma lived in homes in which only single panes of glass were present in the windows. Children with diagnosed asthma were present in 12.21% of the houses with triple pane windows, compared to 8.54% of the houses with dual pane and 4.90% of the houses for single pane windows.

5.0 ANALYSIS AND DISCUSSION OF RESULTS

Housing as a neglected site for public health action has been identified in many recent publications. There is strong empirical evidence that suggests that damp, cold, and mouldy housing is associated with asthma and other chronic respiratory symptoms. One of the program goals of this study was to identify those housing conditions that are statistically associated with water damage, high humidity, moisture etc., that may lead to mould growth in the home. The results of this research program are intended to fill a void in the current knowledge base in the building science design and assessment community for the evaluation of the conditions within the homes which may affect the respiratory health of children. The program was developed to determine the absence or presence of a causal relationship between the respiratory health of the house occupants, housing conditions, and interior biological growth. Moisture levels and biological growth, both visible and air-borne were also examined for statistically significant associations with house building condition variables and the impact these variables may have on the respiratory health of the child occupants.

The analysis of the results presented in Section 4 of this thesis is discussed below. For clarity, the discussion addresses each of the following research areas of the program: the initial survey statistical results; the results from air sampling; the housing conditions and interior environmental conditions; housing conditions and indoor air-borne mould levels; and, housing conditions and the respiratory health of the children in the study houses.

5.1 The Initial Survey Results

The average age of the homes in our study was 31.6 years. The statistical analysis showed that there was no significant association between the age of the houses and the respiratory health of the children in our study. There was however, a statistically significant relationship between the age of the house and air-borne mould concentrations, the details of which will be discussed further in Section 5.3.

The data in our study showed that the children's respiratory health is significantly associated with self-reported visible mould in the home. Children with reported mould in their home were statistically more likely to have persistent colds compared to those with no reported mould. In general, there are fewer healthy children (Few or No Colds/No Asthma) when mould is present in the home. The results obtained correlate well with a recent extensive European Community Respiratory Health Survey (ECRHS), involving 38 study centers, which not only found a significant association between self-reported mould exposure and asthma symptoms in adults, but also a higher prevalence of asthma in centers with high self-reported mould exposures (Zock et al., 2002).

We observed that the presence of cats and dogs was not observed to be significantly associated with either condition, asthma and/or asthma in combination with persistent colds. We hypothesize that parents with children that are asthmatic or have animal related allergies would have been proactive at not having such pets in their houses.

The results showed that children with smokers living in their house were more likely to have persistent colds in combination with asthma. The results clearly are in support of the extensive body of research linking second smoke to respiratory health (Make Your Home and Care Smoke Free, Health Canada, 2008).

It was observed, qualitatively, that a concentration of houses with children who reported to suffer from persistent colds appears along the two main rivers bisecting Winnipeg, the Red River and Assiniboine River (see Figures 4.1 and 4.2). Vegetation tends to be greater along the banks of these rivers compared to adjacent neighborhoods situated away from the river banks, thus, increased communication between interior and exterior moulds is anticipated to be a potential cause of higher indoor mould concentrations, particularly with respect to Cladosporium. Our outdoor air sampling confirmed consistent and significant increases in Cladosporium concentrations from early spring to early summer. Results are consistent with findings of other researchers (Haverinen et al., 2003;

Reponen et al., 1994; Stark et al., 2003) in which Cladosporium concentrations increase significantly with increasing ambient temperatures.

The results obtained in this study, therefore, validate the effectiveness of using a mass survey distribution when attempting to assess the relationship between a occupant health and interior housing conditions. In addition, there appears to be a reasonable association between home owner observations with respect to observable mould and that of trained building scientists.

5.2 Biological Sampling Analysis

Biological sampling was utilized in order to determine the types of air-borne mould frequently found in the houses within Winnipeg and the surrounding area. The analysis of 1911 home air samples revealed 25 different mould genus types. The top three types identified in the houses were Cladosporium, Alternaria, and Penicillium. The top three exterior, or control moulds, were Cladosporium, Alternaria but Mycelia-Sterilia. It is interesting to note that Aspergillus was identified only indoors. No Aspergillus was identified in the outdoor samples suggesting Aspergillus to be related to interior conditions.

Air sampling took place over the months of April through June of 2006. Results confirm the findings of other researchers who report that mould counts in the homes tend to increase significantly in the late spring/early summer, largely due to the influx of large amounts of outside moulds, especially cladosporium

(Haverinen et al., 2003, Reponen et al., 1994, Stark et al., 2003). Cladosporium was the most common mould found in Winnipeg houses.

A statistical analysis was carried out to determine the association between self-reported mould in the houses and total air-borne mould measured in CFU/m^3. The use of Total Mould Counts in CFU/m^3 was based on published results of previous researchers (Haas D., Habib J., Galler H., Buzina W., Schlacher R., Marth E., &Reinthaler F.F. (2007); Gent, J., Ren, P., Belanger, K., Triche, E., Bracken, M., Holford, T. (2002); and Godish, Godish, hooper, Hooper, Cole (1996).

A statistically significant association was found between occupant-reported visible mould in the house and air-borne mould levels in the children's bedroom for April. A statistically significant association was also found between self-reported visible mould and air-borne mould within the basements of the homes for all testing months combined, in addition to April alone.

The results obtained confirm that the presence of visible mould within the home is a good indicator that high air-borne mould levels greater than 100, 200, and 300 CFU/m^3 are likely to be present within the children's bedroom and basement of the home. Thus, from an inspection protocol perspective, biological air sampling is likely unnecessary when visible mould is present on the interior surfaces of the home. This conclusion is supported by other research publications

(Lstiburek, J, 2002). The question, however, that has been extensively debated in the literature and has yet to be answered is “how much is too much?”. Until this question is fully addressed, data from biological air sampling enriches the data base from which invaluable conclusions will eventually emerge.

The data were analyzed to provide an opinion on the absence/presence of a statistical association between the air sampling results, based on mould genus type and mould levels and the presence of persistent colds and/or asthma in the children. Jacob et al. (2002) report that sensitized children exposed to high levels of Cladosporium and Aspergillus were more likely to suffer from symptoms of rhinoconjunctivitis including pink eye and runny nose and/or congested nose – a finding the current study supports, particularly in relation to persistent colds in combination with asthma.

The effect of mould on the respiratory health of individuals has been the subject of extensive research. A significant complicating factor is the dosage response rate or sensitivity that individuals may experience with respect to exposure to different kinds of moulds. A Kruskal-Wallace Non-Parametric Test (the non-parametric equivalent of an ANOVA of normally distributed data) of the distribution of cladosporium spores by area of the houses in our study (child’s bedroom or basement) revealed an association between Cladosporium levels from air samples in the children’s bedroom (Area 1) taken in April and the children’s asthma in combination with persistent colds (Group 1). An association, for all months, was confirmed between cladosporium levels from air samples taken in the basements (Area 2) and children's asthma in combination with persistent colds. Thus, further research is warranted to establish guidelines for acceptable mould levels in the homes where children reside.

No statistical association was found for Aspergillus and/or Penicillium and respiratory health. Although such an association cannot be ruled out since we only identified the three top genus types if the total mould count was equal to or greater than 100 CFU/m^3, it is possible that there were higher penicillium levels in houses with total mould counts less than 100 CFU/m^3.

Cladosporium is primarily an outdoor mould species. The research results from this program re-affirm this statement. The mean cladosporium counts for Area 3 (outdoor sample) in our study for April and May were 333.6 and 327.7 CFU's/m^3, respectively. However, 11 bedrooms and 27 basements in our study had total mould counts greater than 400 CFU's/m^3 in April alone. In addition, 62 bedrooms and 84 basements had cladosporium levels greater than 400 CFU/m^3 in our study. Gent, J., et al. (2002) concluded that "…mould and water leaks are significantly associated with cladosporium but not penicillium." Research has also confirmed that the typical North American home provides a food source for cladosporium. Thus, in addition to exterior sources of cladosporium, there are interior sources also within the home.

When Cladosporium finds its way into the indoor environment, it grows on clothes and foodstuffs (Jacob et al. 2002). A number of studies have linked Cladosporium to an increase risk of allergic reactions (Jacob et al. 2002; Jovannovic, et al., 2004; Gent et al. 2002; Huang & Kimbrough 1997).

Current standards of acceptable limits for mould genera in homes vary dramatically, reflecting the uncertainty in the results from various research studies. The Commission of European Communities report, for example, classifies mould counts of 1-499 CFU/m^3 as low risk (CEC, 1994). This range, however, may be too broad. In the research conducted by Gent et al. (2002), 37% of the 900 homes tested had undetectable counts of Cladosporium, while 44% had counts between 1 and 499 and only 16% had counts greater than 500 CFU/m^3. Curtis et al. (2004) report that indoor fungal levels above a range of 150-1000 CFU/m^3 are considered to be sufficient to cause human health problems.

A study on indoor moulds within European schools (Simoni, 2011) concluded that children exposed to total viable mould concentrations equal to or greater than 300 CFU/m^3 in the classrooms experienced a statistically significant higher proportion of dry and/or persistent cough at night.

Throughout our program, our data were analyzed in detail with specific mould genus types in mind and at no point was a statistically significant association revealed between children's respiratory health and aspergillus and/or penicillium. Thus, a significant conclusion in this research is that cladosporium is in fact not necessarily a considerably less potent genus type compared to aspergillus and/or penicillium.

Thus, the results show that mould itself does not necessarily cause asthma; rather, the mould exposure promotes an allergic response which aggravates persistent colds which in turn exacerbates the child's asthma, hence the Group 1 statistical association.

The results obtained are consistent with results published in the current literature. Research by Stark P., et al. (2003) concluded that "…total indoor fungal levels (comprised mostly of cladosporium) were associated with an increased risk of asthma in adults." In addition, research by Garrett M.H., et al. (1998) concluded "Respiratory symptoms were marginally more common with exposure to cladosporium or total spores in winter."

Research completed as late as 2012 also concluded "Cladosporium species have the ability to trigger allergic reactions to sensitive individuals. Prolonged exposure to elevated spore concentrations can elicit chronic allergy and asthma…". Regarding the source of cladosporium, the paper also states: "The concentration of Cladosporium species in indoor air is influenced by outdoor concentrations and indoor growth sources."

Thus, a significant conclusion in the program is that cladosporium is in fact not necessarily a considerably less potent genus type compared to aspergillus and/or penicillium and that indoor sourcesw of cladosporium are present.

Gestetal (2012) state that a mould count greater than 300 CFU/m^3 is a health hazard. The results of our study suggest that guidelines for air-borne levels of cladosporium mould levels in children's bedrooms and the basement of homes should be lower than concentrations presently reported in the literature. We found that cladosporium levels of 125 CFU/m3 is more appropriate for houses.

The effect of mould on the respiratory health of individuals has been the subject of extensive research. Sensitivity of individual responses to various mould types and air-borne concentrations significantly hampers the ability to formulate appropriate guidelines. More research, is therefore required to establish guidelines for acceptable mould levels in homes.

5.3 Housing Conditions and Interior Environmental Conditions

Recent studies have shown significant associations between home dampness and the risk of developing respiratory health disorders. The World Health Organization concluded "The presence of many biological agents in the indoor environment is due to dampness and inadequate ventilation. Excess moisture on almost all indoor materials leads to growth of microbes, such as mould, fungi and bacteria…" *WHO guidelines for indoor air quality: dampness and mould, 2009.*

The relationship between moisture in the home and its effect on respiratory health has been the subject of considerable research (Jaakkola, Hwang, & Jaakkola, 2005; Skorge et al., 2005; Meklin et al., 2002; Curtis et al., 2004; OPSI, 2005; NIOSH, 2003). Determining quantitatively the level of moisture in a house, however, has been a challenge since it is affected by many variables. Furthermore, it is not always clear whether precipitation penetration- or condensation-related damage is the primary source of moisture within the house.

Some researchers have attempted to measure "moisture damage" in order to examine its effect on health (Haverinen et al. 2002; Pekkanen et al., 2007). Others have used "dampness" as a measure of respiratory health risk (Peat et al., 1998; Williamson et al., 1997; Andriessen et al., 1998; Bornehag et al., 2004; Jaakkola et al., 2005; Wan & Li, 1999). Dampness has been used interchangeably by various researchers to mean water damage in the house, high internal water activity (or relative humidity), condensation, etc. Water damage is difficult to quantify and it is subject to interpretation by home owners.

Since this is an engineering thesis, my contribution to knowledge is to identify those housing conditions that are statistically associated with water damage, high humidity, moisture etc.,that may lead to mould growth in the home. To accomplish this objective, we adopted well established inspection protocols (National Research Council's Protocols for Building Condition Assessments, Health Canada, and HUD's Healthy Housing Inspection Manual, etc.) The inspection protocols include both physical measurements and visual observations. We took measurements of Rh, temperature, and moisture and conducted visual inspection of all homes. In addition, we carried out short interviews with residents, as required by Health Canada Guidelines.

In addition, measures to increase the air-tightness of the home in an effort to decrease energy consumption costs can have a negative consequence on air quality by reducing passive natural air changes (Iversen, Bach & Lundqvist, 1986). The reduction in air changes tends to increase relative humidity which, in turn, aggravates condensation within the home.

Questionnaires are often used, at least as a starting point to establish the absence/presence of moisture damage within the dwelling and the health of the occupants. Problems arise due to misunderstanding of the types of water damage present and whether or not the moisture sources identified are having any harmful impact on the health of the residents (Said, et al., 1999). Inspectors, trained in building science matters are therefore often utilized to assess the conditions within the home in relation to the absence/presence of water-related damage and the cause(s) of that water-related damage. Thus, contradictions arise between building inspectors and the occupants when attempting to assess water-related damage and the possible impact on the health of the occupants. On the other hand, water activity (relative humidity or building material moisture content) can easily be measured and correlated to health data.

However, according to Ross et al. (2000), there is no association between respiratory tract symptoms and home temperature and humidity. This finding was confirmed in our study. While the mould count was correlated with persistent colds particularly when combined with asthma, there was no association between spot measurements of relative humidity, moisture content or temperature and air-borne mould count.

According to Garrett et al. (1998), the lack of a strong association between humidity and fungal spore concentration may be due to the fact that humidity measured at the time of sample collection may not estimate well the microclimate which determines the possibility of fungal growth. This conclusion is similar to the results in our study. Although a statistical association cannot be necessarily ruled out, the data obtained in our study were highly skewed thereby masking possible associations.

It is important to note that the data obtained in this study represent a snap-shot in time for the conditions in the home, thus, the reason for significant variations in results. Data logging of the environmental parameters, where multiple measurements are obtained over-time within each home could lead to statistically significant associations if high humidity homes were correlated with homes containing relatively higher concentrations of air-borne mould.

Relative humidity has a pronounced effect on interior condensation levels within homes, particularly during the heating season. For example, we found that the mean air temperature in the children's bedrooms was 20.7^o Celsius. The mean relative humidity measured in the children's bedrooms was 45.9%. The dew point for these conditions was calculated to be 8.9^o C. Increasing the relative humidity by 10 % raises the dew point significantly, +12.2^o C, thereby increasing the condensation potential and, thus, the moisture content in the walls.

The results were analyzed to evaluate the relationship between housing conditions and moisture levels within the homes; that is, to evaluate the effect of the independent variables associated with the design and construction of houses on moisture levels. We therefore analyzed the housing condition data in order to identify those housing conditions that are statistically associated with water damage, high humidity, moisture etc. that may lead to mould growth in the home.

A clear difference was noted in the levels of relative humidity and moisture content present in newer homes as compared to older homes (older than 20 years). Newer homes, constructed after 1990, were found to have lower levels of relative humidity and wall moisture content. Newer homes tend to incorporate exhaust fans for moisture control, including the use of central ventilation systems such as heat recovery ventilators in which mechanically induced air changes occur.

The data were equally informative in terms of what housing variables were not significantly related to interior moisture levels. Although the presence of HRVs was not observed to have a statistically significant impact on reducing relative humidity, the presence of exhaust fans was highly beneficial at reducing the relative humidity and, thus, the condensation potential in the bedrooms and basements of the houses reviewed. Mechanically induced air changes are generally very effective at helping to control humidity levels within the home when they are appropriately designed and commissioned. It is postulated that too few of the study homes were equipped with heat-recovery ventilators (HRV) to generate a statistically significant association for humidity and moisture control.

It was noted that the type of roofing material had a significant impact on relative humidity within the children's bedroom. Houses which utilized a low-slope roof system in which the waterproofing was a membrane versus shingles had a mean relative humidity of 7.70% higher versus conventional sloped/shingled roof systems. The high humidity is indicative of the inability for the roof system to dry out under winter condensation conditions.

Poor condition cladding produced higher relative humidity levels within the children's bedroom and basement than in homes where cladding was in excellent condition. Cladding in poor condition was also associated with increased moisture content of the walls in both the children's bedroom and basement—possibly related to increased levels of precipitation penetration into the wall system.

Wall cladding is a primary barrier to water intrusion in residential construction. Once this barrier is compromised, there is a danger of water intrusion into the interior of the wall system, leading to mould growth. Thus, the data in this study suggest that when viewing multiple houses from the exterior, any damage to the exterior wall systems should trigger an inspection of the interior surfaces of the exterior walls and floors.

The data also produced statistically significant associations that on the surface, are difficult to rationalize. For example, children's bedrooms with no visible condensation on the walls or floor/ceiling interfaces had a statistically significant higher mean relative humidity; 4.23% higher than houses with visible condensation stains. We know that condensation will reduce the moisture levels in the air and that higher wall temperatures will accommodate higher relative humidity. The data correlates well when the wall surface temperature data is reviewed in conjunction with relative humidity. There was a statistically significant association between wall surface temperature and visible condensation on the walls; homes with no condensation had a marginally higher wall surface temperature, with a mean of 0.33^{o} Celsius (p=0.0599).

The largest impact on building material moisture content, however, was observed when ponding water was present in the crawlspace of the study homes. Bedrooms in houses with visible water in the crawlspace had interior building material moisture content, on average, 5.73% higher than homes with no water in the crawlspace. Clearly, a poor condition crawlspace can lead to damaging levels of moisture within the home. Thus, it is important that crawlspaces be upgraded to meet current Part 5 National Building Code requirements for grading, drainage provisions (sump-pit and pump), an exhaust fan, and continuous polyethylene ground cover sealed to all terminations.

The results, when reviewed overall, however, strongly indicate that any measures used to increase the air-tightness of the house generally result in an increase in air-borne moisture levels (Rh) within the house, both in the bedroom and basement.

The vast majority of interior finishes in the houses that were examined consisted of painted gypsum wall board. Drywall, composed of gypsum sandwiched between two layers of cellulose based paper has a very low tolerance for moisture. Levels over 0.50%, as measured by a penetrating type moisture meter, can have a significant impact on reducing flexural strength (McGowan, 2007).

Thus, even a minor increase in moisture content can have harmful consequences on the durability of the gypsum wall board.

The statistical analysis confirmed that houses with attics in poor condition, indicative of condensation had higher moisture content in the interior walls of the children's bedroom. Other independent housing variables which produced higher mean levels of moisture in the interior walls of the children's bedrooms included poor condition of the cladding, presence of structural duress, and the type of roofing system. Houses incorporating a flat membrane system roof had a mean moisture content in the children's walls of 5.4%, well beyond the point of stability for drywall.

All the independent variables which produced high interior building material moisture levels can be attributed to high levels of moisture in the home and/or the inability of the substrate to dry out. For example, a shingled roof system generally permits drying to both the interior and exterior. A flat membrane system roof will provide only marginal drying to one side, the interior side only, if cross-ventilation is provided in the design and construction. The current National Building Code, (2010) requires at least one square foot of ventilation for every 150 square feet of roof area for flat or cathedral roof systems, which may be insufficient to accommodate the moisture deposition associated through air leakage into the roof system. The inability to dry-out is an aggravating factor for cumulative moisture levels in building materials which leads to both decay and biological growth (Trechsel, 2001).

A potential indoor air quality concern was raised by the statistical analyses results between windows and moisture content of the house. Houses with newer windows and windows which were observed to be in good/excellent condition had statistically significant higher mean relative humidity levels than homes with windows rated as poor/fair.

Air leakage through the rough opening and window components of poor/fair rated windows create passive air changes. These air changes can have a pronounced effect at reducing winter/spring humidity levels within the home. For example, exterior air at – 15^{o} C may have a relative humidity over 90%, when this air infiltrates the house and is heated to $+20^{o}$ C, the relative humidity of this air becomes less than 10 percent. Thus, the dilution effect is important at reducing the relative humidity in the home and thus, condensation levels. It is well established that newer windows tend to produce much more air-tight houses, thus, increasing levels of relative humidity are anticipated, the results of which were confirmed in this study.

The data obtained in this study can be used to develop check lists for indicators of interior moisture levels. Based on the causative relationship between moisture and biological growth (mould), the results obtained also identify key areas in typical “house maintenance” that can be effectively targeted for reducing, not only interior moisture levels, but also, indirectly, biological growth.

Most significantly, caution is required when measures are introduced to increase the energy efficiency of the home through window replacement programs. Creating energy efficient houses typically is associated with reducing air leakage and thus, passive air changes. The reduction in passive air changes will negatively impact indoor air quality, thus, if significant reductions in passive air changes are introduced, measures should be implemented to also address corresponding increases in relative humidity and air-borne contaminants. These measures could include additional exhaust capacity and possibly the introduction of heat recovery ventilators (HRV) to provide mechanically induced air changes in the home.

5.4 Housing Conditions and Indoor Air-Borne Mould Levels

Although numerous studies have been conducted in order to try and find a relationship between mouldy indoor environments and respiratory health (Jaakkola, Hwang, & Jaakkola, 2005), the bulk of research has linked damp conditions and biological growth potential (Trechsel, 2001). There are however, numerous independent housing variables which may directly impact the levels of air-borne mould in the home. In our study, a statistically significant association between numerous housing conditions and biological growth were observed.

Under the present study, a chi-square analysis was utilized to look at statistically significant associations between housing conditions and air-borne mould levels within the children's bedroom and basement. The biological air sampling was broken down into four sub-categories; Total mould level in CFU/m^3; Cladosporium levels in CFU/m^3, Pennicillium levels in CFU/m^3, and Aspergillus levels in CFU/m^3.

Cladosporium is primarily an outdoor mould species. However, Gent, J., et al. (2002) concluded that "…mould and water leaks are significantly associated with cladosporium but not penicillium." As reported earlier, the air sampling results showed significant levels of cladosporium within the houses tested. Research has confirmed that the typical North American home provides a food source for cladosporium. Thus, in addition to exterior sources of cladosporium, there are interior sources also within the home, consistent with the results of the present study.

The results of our study also indicate that a reduction in passive air changes in the home can have a statistically significant effect on air-borne mould levels. The exterior mould concentration results confirmed that significant increases in Cladasporium occur as spring and summer approach. Similar results were not obtained for Penicillium. The results are indicative of communication of exterior Cladasporium with the interior.

An important finding in our study was the statistically significant association in high levels of interior air-borne mould in houses that had newer windows and/or windows in good condition. This finding held for total mould counts on Cladasoporium and Penicillium. The findings strongly suggest that more air-tight homes, typically a by-product of replacing aged and deteriorated windows, are having a negative effect on indoor air quality.

Similarly, houses with roof systems and the materials that were observed to be in good/excellent condition recorded higher mean levels of air-borne mould. It is postulated that roof systems in good/excellent condition will generally lead to less passive air changes and thus, higher levels of moisture and/or air-borne mould.

Conversely, houses with masonry foundation systems, versus cast-in-place concrete, typically had higher mean levels of air-borne mould in the children's bedroom, consistent with older homes. The results suggest that the source of Penicillium may, therefore, be related to the basement of the home. Penicillium is common in basements on stored materials such as paper boxes and other cellulose based materials (Godish, 2012).

Aspergillus was not recorded in the outdoor control samples, therefore suggesting the source must be related to the interior of the homes. We observed that houses with visible wall stains had a statistically significant association with higher mean values of air-borne Aspergillus. This result compares, interestingly, to the associations of wall stains with total mould counts, Cladosporium level, and the Penicillium level. Houses with no wall stains had statistically significant higher levels of these two mould types, therefore, further suggesting that the Aspergillus source is likely related to the cellulose of the drywall (Kalliokoski, 2000). The number of exhaust fans also had a negative effect on aspergillus concerntrations, suggesting that spores are drawing into the conditioned space from the exterior walls due to the negative pressure created by running exhaust fans.

Research is generally consistent in that reducing interior air-borne mould levels is necessary for good indoor air quality. This statement was re-affirmed in our study but a significant component to this finding is the impact that the reduction in passive air changes in the home results in aggravating higher levels of air-borne mould in the home. The previous conclusion in Section 5.3 on ensuring sufficient air changes in the home, remains consistent not only for indoor moisture levels but also helping to reduce interior air-borne mould levels and thereby enhancing indoor air quality. The results between housing conditions and mould levels confirm that exhaust fans are highly effective at reducing relative humidity but may aggravate air quality if aspergillus is present within the exterior walls of the home.

5.5 Housing Conditions and Respiratory Health

A chi-squared analysis of the data from the housing conditions and child asthma/persistent cold survey results was carried out. As discussed earlier, the analysis of the house mould concentration results showed a significant association between Cladosporium and asthma in combination with persistent colds (Group 1).

We then completed a statistical analysis in order to establish which housing conditions could be statistically associated with respiratory health. Five statistically significant relationships were revealed:

a) A significantly lower proportion of houses with extensive stains on the carpets had children with asthma, compared to houses with no carpet stains.

b) A considerably higher number of houses with furnace filters had children with asthma compared to houses without disposable furnace filters.

c) Fewer asthmatic children lived in houses in which the attics were in poor/fair condition than in houses in which the attics were in good condition.

d) Houses in which the crawlspaces were in poor/fair condition had no asthmatic children, whereas 10.42% of the houses in which the crawlspaces were in good/excellent condition had asthmatic children. Similarly, a considerably higher number of houses with good/excellent condition crawlspaces had children with asthma in combination with persistent colds, an indication of parents being proactive in ensuring that crawlspaces are kept in good condition.

e) More children with asthma lived in houses with triple pane windows than in houses with double or single pane windows.

It is not always easy to draw meaningful conclusions from these results. However, some studies (Prescott, 2003) have suggested that homes in which significant effort is implemented to keep them very clean while the children are at a very young age may negatively impact the child's respiratory health by reducing the effectiveness of the immune response. The term used in the literature is "hygiene hypothesis" which postulates that by denying children access to certain bacteria at young immune development age increases the susceptibility to allergic responses. Propensity for development of asthma is a by-product for lack of exposure to certain pathogens at a young age, while the immune system in children is still developing.

Indeed, several publications (Hulin M., Simoni M., Viegi G., Annesi-Maesano I. (2012); Simpson J., Brooks C., Douwes J. (2008); Simoni M., Cai G., Norback

D., Annesi-Maesano I., Lavaud F., Sigsgaard T., Wieslander G., Nystad W., Canciani M., Viegi G., Sestini P., (2011); Sironi M., Clerici M. (2010) have suggested that pathogen rich environments are no longer present in our industrialized world, including our houses, particularly at younger ages. Simpson (2008) concludes that it has become increasingly clear that development of the immune system is critical while children are growing and that development of the immune system maybe dependent on some form of pathogen exposure.

Another possible causal factor may relate to volatile organic compounds (VOC's) in newer home furnishing products such as carpets and window coverings. Research suggests a link between exposure to aromatic VOC's and respiratory diseases due to an induced inflammatory response in the lungs (Mogel, 2011).

A statistically significant lower percentage of children with asthma lived in homes with extensive carpet stains, poor condition attics and poor condition crawlspaces compared to children in houses with no carpet stains, attics and crawlspaces in good condition. This suggests that there may be an inverse relationship between home cleanliness and respiratory health, which is consistent with the "hygiene hypothesis". Thus, parents that are highly proactive at implementing home cleanliness strategies to reduce their children's exposure to mould and bacteria at a young age may be increasing the child's probability of developing an allergic response to environmental moulds. Recall that our results showed no statistically significant association between mould and asthma, the only association revealed was for Group 1, persistent colds in combination with asthma. However, further analysis of the data is ultimately required, including looking at factors such as years in the home, for example, in order to re-affirm whether or not the "hygiene hypothesis" potentially explains the inverse association observed in our data between home cleanliness factors and respiratory health in children.

6.0 CONCLUSIONS

This research thesis focused on the relationship between the respiratory health of children in relation to the building science considerations of the homes in which they reside. The first part of the investigation consisted of a statistical analysis of a home occupant response survey, received from the parents of 3,423 children in grades 3 and 4 from the Winnipeg and surrounding area, on the interior conditions of the home and the respiratory health of their child.

The second component of the research program consisted of a statistical analysis between the housing conditions, namely, absence/presence of visible mould, the respiratory health of the children and associated building conditions of the houses as reported by the occupant and the actual conditions as observed by engineering audits. The engineering audits conducted in a subset of 715 homes, consisted of a multi-disciplined review, including structural, building enclosure, and mechanical systems, supplemented with on-site field measurements of the air-borne mould concentrations within and outside the home (measured in colony forming units (CFU) per cubic meter), as well as in-situ environmental conditions such as air and surface temperatures, relative humidity, and moisture content of the interior building walls.

Based on the results of this investigation, the following major conclusions were drawn:

- Self-reported visible mould in the home correlated with the presence of air-borne mould above 100, 200, 300, and 400 CFU/m^3. The results showed that there are fewer healthy children when mould is present in the home.

- The analyses of our data showed an association between Cladosporium levels in the house with children's asthma in combination with persistent colds. The results suggest that Cladosporium may promote allergic responses in children which aggravate a child's pre-existing asthma condition. Thus, mould exposure by itself may not necessarily cause asthma in children. Our study showed an association between Cladosporium levels and asthma in combination with persistent colds during the month of April.

- The effect of mould on the respiratory health of individuals has been the subject of extensive research. A significant complicating factor is the dosage response rate or sensitivity that individuals may experience with respect to exposure to different kinds of moulds. The results of our study suggest that guidelines for air-borne levels of Cladosporium mould in children's bedrooms and the basement of homes should be lower than concentrations suggested by other researchers. Perhaps, a limit of 125 CFU/m^3 would be appropriate. Clearly, more research is warranted to establish accurate guidelines for acceptable mould levels in the homes where children reside.

- No statistically significant associations were found between respiratory health and the age of the home or the number of years living in the home, although newer homes had lower wall moisture content in the child's bedroom compared to older homes.

- A statistically significant association was observed between numerous housing conditions and air-borne mould levels in the home. A significant finding was that measures used to increase the air-tightness of the home clearly had a negative impact on indoor air quality by increasing the relative humidity and air-borne mould levels within the home.

- The results of this study confirm the importance of reducing both air-borne and visible mould in the home. Furthermore, the study confirms that if measures are implemented to increase the air-tightness of the residence, such as new windows, introduction of a means to mechanically ventilate the residence is required to force air changes in order to reduce moisture and air-borne mould levels within the home.

- A statistically significant association was observed between several housing conditions and the respiratory health of the children in the study. Housing conditions were compared to the respiratory health data and five statistically significant relationships were revealed:

    a) A significantly lower proportion of houses with extensive stains on the carpets had children with asthma, compared to houses with no carpet stains.

    b) A considerably higher number of houses with furnace filters had children with asthma compared to houses without disposable furnace filters.

    c) Fewer asthmatic children lived in houses in which the attics were in poor/fair condition than in houses in which the attics were in good condition.

    d) Houses in which the crawlspaces were in poor/fair condition had no asthmatic children, whereas the houses in which the crawlspaces were in good/excellent condition had asthmatic children.

    e) More children with asthma lived in houses with triple pane windows than in houses with double or single pane windows.

Studies have suggested that homes in which significant efforts are implemented to keep very clean while the children are at a very young age may negatively impact the children's respiratory health by reducing the effectiveness of the immune response. The term used is the "hygiene hypothesis" and postulates that children denied access to certain types and levels of biological contamination at young immune development increases the susceptibility to allergic responses. A number of observations from our study tend to support this hypothesis. Parents that are highly proactive at implementing home cleanliness strategies to reduce their children's exposure to mould and bacteria at a young age may be increasing the child's probability of developing an allergic response to environmental moulds. Further analysis of the data is ultimately required, including looking at factors such as years in the home, for example, in order to re-affirm whether or not the "hygiene hypothesis" potentially explains the inverse association observed in our data between home cleanliness factors and respiratory health in children.

The results obtained in this study reveal that there was no statistically significant association between air-borne mould levels within the house and development of asthma. The results show, however, that air-borne mould aggravates the allergic response which in turn, exacerbates asthma in Grade 3 and 4 children. Implementing measures which increase the air-tightness of the house, and decrease the ability for the building materials to dry out will in turn increase moisture levels and air-borne biological mould levels.

The engineering audits confirm that there are many housing variables that affect the temperature, relative humidity and moisture levels within the home, and thus, air-borne mould levels. The results obtained in this investigation can therefore be used at the design stage to improve durability and air quality in the home, thereby decreasing respiratory health related problems in children. However, further collaborative work is required between the medical field, education, and engineering to develop strategies that will not reduce the child's immunity response development.

6.1 Recommendations for Further Research

Further research is recommended to explore the relationship between air tightness of homes with interior moisture levels and air-borne mould levels. Ideally, a CGSB Blower Door test should be conducted on a statistical sampling of the homes reviewed in order to establish which independent variables affecting air-tightness in homes are statistically significant in affecting both moisture and air-borne mould levels. The air-tightness results, specifically air-changes per hour could be analyzed in relation to the housing variables reviewed in our study for statistically significant associations. The results would enable targeting the specific housing conditions at the design stage for implementation to help improve indoor air quality.

Further research is also suggested in understanding the "hygiene hypothesis" and its association with housing conditions. Specifically, the effect that an excessively clean interior environment may have on the respiratory health of children. Further collaborative work is required between the medical field, education, and engineering to develop strategies that improve housing conditions and thus, the respiratory health of the child but also do not reduce the child's immunity response development.

The impact that air-borne levels of volatile organic carbons and associated concentrations, from sources such as new furnishings within the home, should also be further explored in relation to the respiratory health of children.

Using data loggers to monitor interior temperature and relative humidity over longer periods of time, preferably months should also be considered in order to establish seasonal variations in the interior environment which may affect indoor air quality. The results would also more accurately establish whether or not house humidity has in fact, a statistically significant association with interior air-borne mould.

The next phase of this program will include cross-linking the respiratory health survey results with the Manitoba Health data bases. The Manitoba Health Services Insurance Plan (MHSIP) maintains several electronic databases, which are housed at the Manitoba Centre for Health policy for research purposes. The

MHSIP registration file contains a record for every Manitoba resident and provides information on birth date, sex, and geographic locations including medical history, hospital admissions and prescription information.

Ultimately, this program will provide the initial step in the development of a Healthy Home Condition Index, which can be utilized, multi-regionally, to assess the existing housing stock and the impact that the individual building science components, including material type, design, and operating conditions have on the control of heat, air, and moisture, and its resulting influence on indoor air quality. The results of the research are potentially broad, including linking the respiratory health of the child to both housing conditions and its impact on school absenteeism.

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Appendix A: Initial and Follow-Up Contact Surveys

Housing Conditions

Can Affect a Child's Respiratory Health

Part 1: Initial Contact Survey

A. Health Background

1. My child is in grade 3.

Yes No

2. My child's birthday is _________________

Day/Month/Year

3. The name of my child's school is: ________________

4. My child has been formally diagnosed with asthma by a physician.

Yes No

5. Over the past 12 months (Sept. 2004 -Sept. 2005), how many times has your child:

a) had an asthma attack? _________ times

b) gone to emergency due to an asthma attack? _________ times

c) been hospitalized due to an asthma attack? _________ times

d) been prescribed oral steroids? _________ times

6. My child suffers from persistent (4 or more/year) colds with symptoms such as coughing, congestion, breathlessness, sore throat or wheezing.

Yes No

7. Over the past 12 months (Sept. 2004 -Sept. 2005), how many times has your child:

a) had a cold (see above symptoms)? _________ times

b) gone to the doctors because of cold symptoms? _________ times

c) been hospitalized due to cold symptoms? _________ times

B. Home Environment

8. Do you rent or own your home?

Rent Own

9. What is the approximate age of your home? ____ years____ months

10. How long have you lived in this home? ____ years ____months

11. Is there mould or mildew anywhere in your home?

Yes No

Where? ____

12. How many smokers are in your home? ________

13. How many smoke inside your home? ________

14. How many rooms in your home are carpeted? ________

15. How many cats or dogs do you have in your home?

Cats________ # Dogs ________

16. Do you have any rodents?

Yes No

17. Do parents, siblings, or any close relative suffer from asthma?

Yes No

Housing Conditions
Can Affect a Child's Respiratory Health
PART 2: FOLLOW-UP SURVEY

A. History of Home

1. What is the age of your home? ___ years___ months

2. Do you rent or own your home? Yes No

3. How long have you lived in this home? ___ years ___ months

4. Has your home been subject to flooding in the past 10 years? Yes No

Explain: ____
____
____

5. Have there been any renovation over the past 5 years to your home? Yes No

Explain: ____
____
____

B. Dampness, Relative Humidity, Excess Water, Mould in Home

In the past 12 months (September 2005-2006), have you had:

6. Water damage to your home? Yes No

Where? ____________________________________
____

7. Water in the basement? Yes No

8. Excessive condensation on windows or walls? Yes No

In which room(s)? ______________________________
____
____

9. Damp stains on the wall and/or ceiling surfaces? Yes No

In which room(s)? ______________________________
____

10. Any plumbing-related moisture damage? Yes No

In which room(s)? ________________________________
____
____

11. Mouldy odor? Yes No

In which room(s)? ________________________________
____
____

12. Visible mould on any surface? Yes No
In which room(s)? ________________________________
____
____

B. Environmental Exposure

13. Is there mould or mildew anywhere in your home? Yes No
Where? ____
____
____

14. How many smokers are there inside your home? ______ # smokers

15. How many smoke <u>inside</u> your home? ______ # who smoke inside home

16. How many rooms in your home are carpeted? ______ #of rooms carpeted
Which room(s)? ________________________________
____
____

17. How many cats do you have in your home? ____ # of cats

18. How many cats do you have in your home? ____ # of dogs

19. Do you have any rodents? Yes No

20. Do parents, siblings, or any close relative suffer from asthma? Yes No
Who?____
____

Appendix B:

Air Testing Form and Environmental Measurements

HOUSING INSPECTION PROTOCOL STUDY ID# INIc09

Address:	Anywhere, Winnipeg	
Date of Inspection: 10:30 A.M.	Monday, April 10, 2006	Time of Inspection:
Inspection Team:	Team 1	

OUTSIDE INSPECTION				
B. Measurement (record)				
	Location			
	Outside			
1. Air Relative Humidity (%)				
2. Air Temperature (Degrees C)				
3. Air Sample (take one sample and record Filter Number)				

HOUSING INSPECTION PROTOCOL STUDY ID# INIc09

INSIDE INSPECTION				
B. Measurement (record)				
	Location			
	North Wall	East Wall	West Wall	South Wall

Child's Bedroom:

1. Relative Humidity (%)				
2. Air Temperature (Deg C)				
3. Lowest Conact Temp (Deg C)				
4. Moisture (%)				
5. Air Sample (Record Filer No.)				
6. Air Leakage via smoke wand at windows	☐ In	☐ Out		☐ n/a

2nd Bedroom:

1. Relative Humidity (%)				
2. Air Temperature (Deg C)				
3. Lowest Conact Temp (Deg C)				
4. Moisture (%)				
5. Air Sample (Record Filer No.)				
6. Air Leakage via smoke wand at windows	☐ In	☐ Out		☐ n/a

Family Room:

1. Relative Humidity (%)				
2. Air Temperature (Deg C)				
3. Lowest Conact Temp (Deg C)				
4. Moisture (%)				
5. Air Sample (Record Filer No.)				
6. Air Leakage via smoke wand at windows	☐ In	☐ Out		☐ n/a

Kitchen:

1. Relative Humidity (%)				
2. Air Temperature (Deg C)				
3. Lowest Conact Temp (Deg C)				
4. Moisture (%)				
5. Air Sample (Record Filer No.)				
6. Air Leakage via smoke wand at windows		☐ **In**	☐ **Out**	☐ **n/a**

Basement:

1. Relative Humidity (%)				
2. Air Temperature (Deg C)				
3. Lowest Conact Temp (Deg C)				
4. Moisture (%)				
5. Air Sample (Record Filer No.)				
6. Air Leakage via smoke wand at windows		☐ **In**	☐ **Out**	☐ **n/a**

Please record any visual observations of moisture spots, mould, or anything unusual (use reverse side)

Appendix C: House Inspection Protocol Forms

Address:			
Date of Inspection:	**Time of Inspection (circle one): 1: am 2: pm**		
Inspection Crew:			
	OUSIDE INSPECTION		
	A. Visual Assessment		
2	Square footage of home (main floor only) sq.ft.		
			General Condition:
3a	Type of House 1: Bungalow 2: Split Level 3: Two-Storey 4: Three-Storey 5: Townhouse 6: Semi-detached 7: Row housing 8: multi-story Apartment 9: Other	3b	1: Poor 2: Fair 3: Good 4: Excellent
4a	Style of construction: 1: Frame 2: Brick 3: Other	4b	1: Poor 2: Fair 3: Good 4: Excellent
6a	Windows and doors: 1: wood 2: plastic	6b	1: Poor 2: Fair 3: Good 4: Excellent
12a	Evidence of structural renovations: walls 1: Yes 2: No	12b	1: Poor 2: Fair 3: Good 4: Excellent
13a	Evidence of structural renovations: roof: 1: Yes 2: No	13b	1: Poor 2: Fair 3: Good 4: Excellent
6	Evidence of condensation on basement walls? 1: Yes 2: No		
7	Evidence of condensation on main walls? 1: Yes 2: No 3: NA		
8	Evidence of condensation on windows? 1: Yes 2: No 3: NA		
9a	Evidence of damp stains on walls (measurement of worst case)? 1: Yes	9b	1: Less than 6x6 in. sq 2: 6x6 to 12x12 in. sq 3: 1 to 2 ft. sq

	2: No		4: More than 2 ft. sq

B. Measurements (record)						
1	Relative humidity (%)	1a: Outdoor				
2	Temperature (Degrees C)	2a: Outdoor				
3	Air samples (take one sample and record Filter Number)	3a: outside				

C. Visual Observations: Structural/Mechanical			General Condition
1a	Foundation walls 1: Stone/Rubble 2: Concrete 3: Concrete Block	1b	1: Poor 2: Fair 3: Good 4: Excellent
3a	Roof:	3b	1: Poor 2: Fair 3: Good 4: Excellent
4a	Attic: 1: Yes 2: No	4b	1: Poor 2: Fair 3: Good 4: Excellent 5: NA
6a	Crawlspace 1: Yes 2: No	6b	1: Poor 2: Fair 3: Good 4: Excellent 5: NA
23a	Condition of the home outside (cleanliness)	23b	1: Poor 2: Fair 3: Good 4: Excellent
24a	Condition of the home outside (clutter)	24b	1: Poor 2: Fair 3: Good 4: Excellent
31a	Caulking (windows/doors)	31b	1: Poor 2: Fair 3: Good 4: Excellent
32a	Condition of exterior cladding	32b	1: Poor 2: Fair

			3: Good 4: Excellent
33a	Condition of gutters and down pipes	33b	1: Poor 2: Fair 3: Good 4: Excellent

Address:			
Date of Inspection:		**Time of Inspection (circle one): 1: am 2: pm**	
Inspection Crew:			
	1st FLOOR INSPECTION		
	A. Visual Assessment		
			General Condition:
1a	Windows: 1: wood 2: plastic 3: NA	1b	1: Poor 2: Fair 3: Good 4: Excellent
2	Window usage: 1: Regularly open? 2: Summer only? 3: Year round? 4: Do not open 5: NA		
3a	Evidence of structural renovations: floor: 1: Yes 2: No	3b	1: Poor 2: Fair 3: Good 4: Excellent
4a	Evidence of structural renovations: walls: 1: Yes 2: No	4b	1: Poor 2: Fair 3: Good 4: Excellent
5	Evidence of condensation on floor? 1: Yes 2: No		
6	Evidence of condensation on walls? 1: Yes 2: No		
7	Evidence of condensation on bathroom walls? 1: Yes 2: No 3: NA		
8	Evidence of condensation on windows? 1: Yes 2: No 3: NA		
9a	Evidence of damp stains on walls (measurement of worst case)? 1: kitchen 2: Bathroom	9b	1: Less than 6x6 in. sq 2: 6x6 to 12x12 in. sq 3: 1 to 2 ft. sq 4: More than 2 ft. sq

	3: Laundry room 4: Other room 2: None		
10	Evidence of damp stains on ceilings (measurement of worst case)? 1: kitchen 2: Bathroom 3: Laundry room 4: Other room 2: None	10b	1: Less than 6x6 in. sq 2: 6x6 to 12x12 in. sq 3: 1 to 2 ft. sq 4: More than 2 ft. sq
11	Evidence of plumbing related moisture damage? 1: kitchen 2: Bathroom 3: Laundry room 4: Other room 2: None		
12	Evidence of mouldy odour ? 1: Yes 2: No		
13a	Visible mould on any surface of the kithchen? 1: Yes 2: No 3: NA	13b	1: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square
14a	Visible mould on any surface in the washrooms? 1: Yes 2: No 3: NA	14b	1: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square
15a	Visible mould on any ceiling? 1: Yes 2: No	15b	1: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square
16a	Visible mould on any of the closets? 1: Yes 2: No	16b	11: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square
17a	Visible mould on any of the laundry room? 1: Yes 2: No 3: NA	17b	1: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square

B. Measurements (record)							
1	Relative humidity (%)	1a: North wall	1b: East wall	1c: West wall	1d: South wall	1e: Bathroom	1e: Laundry room
2	Temperature (Degrees C)	2a: North wall	2b: East wall	2c: West wall	2d: South wall	2e: Bathroom	2e: Laundry room

3	Moisture (%)	3a: North wall	3b: East wall	3c: West wall	3d: South wall	3e: Bathroom	3e: Laundry room
4	Air samples (Take two samples and record Filter Number under proper location)	4a: Near North wall	4b: Near East wall	4c: Near West wall	4d: Near South wall	4e: Bathroom	4e: Laundry room

C. Visual Observations: Structural/Mechanical			General Condition
1a	Walls: 1: Stone/Rubble 2: Concrete wall 3: Concrete Block 4: Wood	1b	1: Poor 2: Fair 3: Good 4: Excellent
11a	Fireplace? 1: Yes 2: No	11b	1: Poor 2: Fair 3: Good 4: Excellent
12a	Wood Stove? 1: Yes 2: No	12b	1: Poor 2: Fair 3: Good 4: Excellent
17a	Gas appliances other than heating? 1: Yes 2: No	17b	1: Poor 2: Fair 3: Good 4: Excellent
18a	Cleanliness	18b	1: Poor 2: Fair 3: Good 4: Excellent
19a	Clutter	19b	1: Poor 2: Fair 3: Good 4: Excellent
20a	Odours	20b	1:Wood Smoke 2: Cigarette Smoke 3: Musty VOCs 4: Air Fresheners 5: Perfumes 6: Cleaning Fluids 7: Candles
21	Vents blocked? 1: Yes 2: No 3: Partially		
22a	Draperies	22b	1: Poor

	1: Light Fabric 2: Heavy Fabric 3: Plastic 4: None		2: Fair 3: Good 4: Excellent
23a	Carpets? 1: 0 - 25% 2: 25- 50% 3: 50- 75% 4: 75- 100%	23b	1: Poor 2: Fair 3: Good 4: Excellent
24a	Caulking (windows/doors)	24b	1: Poor 2: Fair 3: Good 4: Excellent

Address:			
Date of Inspection:		**Time of Inspection (circle one): 1: am 2: pm**	
Inspection Crew:			
2^{nd} FLOOR INSPECTION			
A. Visual Assessment			
			General Condition:
1a	Windows: 1: wood 2: plastic 3: NA	1b	1: Poor 2: Fair 3: Good 4: Excellent
2	Window usage: 1: Regularly open? 2: Summer only? 3: Year round? 4: Do not open 5: NA		
3a	Evidence of structural renovations: floor: 1: Yes 2: No	3b	1: Poor 2: Fair 3: Good 4: Excellent
4a	Evidence of structural renovations: walls: 1: Yes 2: No	4b	1: Poor 2: Fair 3: Good 4: Excellent
5	Evidence of condensation on floor? 1: Yes 2: No		
6	Evidence of condensation on walls? 1: Yes 2: No		
7	Evidence of condensation on bathroom walls? 1: Yes 2: No 3: NA		
8	Evidence of condensation on windows? 1: Yes 2: No 3: NA		
9a	Evidence of damp stains on walls (measurement of worst case)? 1: kitchen 2: Bathroom 3: Laundry room	9b	1: Less than 6x6 in. sq 2: 6x6 to 12x12 in. sq 3: 1 to 2 ft. sq 4: More than 2 ft. sq

	4: Other room 2: None		
10	Evidence of damp stains on ceilings (measurement of worst case)? 1: kitchen 2: Bathroom 3: Laundry room 4: Other room 2: None	10b	1: Less than 6x6 in. sq 2: 6x6 to 12x12 in. sq 3: 1 to 2 ft. sq 4: More than 2 ft. sq
11	Evidence of plumbing related moisture damage? 1: kitchen 2: Bathroom 3: Laundry room 4: Other room 2: None		
12	Evidence of mouldy odour ? 1: Yes 2: No		
13a	Visible mould on any surface of the kithchen? 1: Yes 2: No 3: NA	13b	1: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square
14a	Visible mould on any surface in the washrooms? 1: Yes 2: No 3: NA	14b	1: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square
15a	Visible mould on any ceiling? 1: Yes 2: No	15b	1: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square
16a	Visible mould on any of the closets? 1: Yes 2: No	16b	11: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square
17a	Visible mould on any of the laundry room? 1: Yes 2: No 3: NA	17b	1: Spots less than 1 x 1 in. sq 2: Spots 1x1 in. to 2 x2 in. sq 3: Areas 2x2 in to 6x6 in. sq 4: More than 6 in. square

B. Measurements (record)							
1	Relative humidity (%)	1a: North wall	1b: East wall	1c: West wall	1d: South wall	1e: Bathroom	1e: Laundry room
2	Temperature (Degrees C)	2a: North wall	2b: East wall	2c: West wall	2d: South wall	2e: Bathroom	2e: Laundry room

3	Moisture (%)	3a: North wall	3b: East wall	3c: West wall	3d: South wall	3e: Bathroom	3e: Laundry room
4	Air samples (Take two samples and record Filter Number under proper location)	4a: Near North wall	4b: Near East wall	4c: Near West wall	4d: Near South wall	4e: Bathroom	4e: Laundry room

C. Visual Observations: Structural/Mechanical			**General Condition**
1a	Walls: 1: Stone/Rubble 2: Concrete wall 3: Concrete Block 4: Wood	1b	1: Poor 2: Fair 3: Good 4: Excellent
11a	Fireplace? 1: Yes 2: No	11b	1: Poor 2: Fair 3: Good 4: Excellent
12a	Wood Stove? 1: Yes 2: No	12b	1: Poor 2: Fair 3: Good 4: Excellent
17a	Gas appliances other than heating? 1: Yes 2: No	17b	1: Poor 2: Fair 3: Good 4: Excellent
18a	Cleanliness	18b	1: Poor 2: Fair 3: Good 4: Excellent
19a	Clutter	19b	1: Poor 2: Fair 3: Good 4: Excellent
20a	Odours	20b	1:Wood Smoke 2: Cigarette Smoke 3: Musty VOCs 4: Air Fresheners 5: Perfumes 6: Cleaning Fluids 7: Candles
21	Vents blocked? 1: Yes 2: No 3: Partially		
22a	Draperies	22b	1: Poor

	1: Light Fabric 2: Heavy Fabric 3: Plastic 4: None		2: Fair 3: Good 4: Excellent
23a	Carpets? 1: 0 - 25% 2: 25- 50% 3: 50- 75% 4: 75- 100%	23b	1: Poor 2: Fair 3: Good 4: Excellent
24a	Caulking (windows/doors)	24b	1: Poor 2: Fair 3: Good 4: Excellent

Appendix D: Housing Conditions Affecting the Air Temperature in the House

Table D1. Housing Conditions Affecting the Air Temperature in the Children's Bedrooms

Housing Condition (n)	*F*	*p*	*df*	Mean Air Temp. (°C)	Mean Temp. Difference (°C)
Attic Condition	8.78	0.0032	1,494		
• Good/Excellent (331)				20.91	**+0.66**
• Poor/Fair (165)				20.25	-
Clean Home	5.50	0.0193	1,683		
• Good/Excellent (543)				20.80	**+0.51**
• Poor/Fair (142)				20.29	-
Crawlspace Water	3.27	0.0738	1,96		
• No Water (95)				20.31	**-2.49**
• Water (3)				22.80	-
Door Condition	4.91	0.0270	1,620		
• Good/Excellent(532)				20.78	**+0.58**
• Poor/Fair (90)				20.20	-
Exterior Clutter	5.47	0.0196	1,686		
• Good/Excellent (512)				20.80	**+0.47**
• Poor/Fair (176)				20.33	-
Foundation Condition	3.88	0.0492	1,640		
• Good/Excellent (534)				20.75	**+0.48**
• Poor/Fair (108)				20.27	-
House Age	3.79	0.0521	1,606		
• 0 to 20 Years (222)				20.92	**+0.39**
• > 20 Years (386)				20.53	-
House Construction	12.96	0.0003	1.683		
• Masonry/Other (9)				23.42	**+2.77**
• Wood Frame (676)				20.65	-
House Construction Condition	3.26	0.0719	1,424		
• Good/Excellent (396)				20.84	**+0.79**
• Poor/Fair (30)				20.05	-
Roof Type	3.51	0.0304	2,650		
• Other (5)				19.14	**-1.68**
• Stick Framed (282)				20.41	**-0.41**
• Trusses (366)				20.82	-
Size of House, Sq. Ft.	5.62	0.018	1,666		
• < 1,500 (569)				20.62	**-0.59**
• > 1,500 (99)				21.21	-
Absence/presence of window condensation	2.85	0.0918	1,679		
• No Condensation				20.81	**+0.31**
• Condensation				20.50	-

- Houses in which the exterior doors were rated as Good/Excellent had a mean temperature of +19.51 ^{o}C in the basement , +0.39 ^{o}C warmer than houses in which the exterior doors were rated as Poor/Fair condition, (p=0.0623).

- In homes in which the house foundation was constructed from concrete, the mean temperature in the basement was +19.35 ^{o}C, +0.79 ^{o}C warmer than houses in which the foundation was constructed from stone and/or concrete block, (p=0.0696).

- The basements in houses in which the structural condition were rated as Good/Excellent had mean air temperatures of +19.47 ^{o}C, +0.55 ^{o}C warmer than houses rated as Poor/Fair condition. (p=0.0719).

- Houses in which no condensation was observed on the windows were marginally warmer in the basement with a mean temperature of +19.44 ^{o}C compared to +19.19 ^{o}C for bedrooms in which condensation was typically observed on the windows, (p=0.0780).

Table D2: Housing Conditions Affecting the Air Temperature in the Children's Basements

Housing Conditions (n)	***F***	***p***	***df***	**Mean Air Temp. (°C)**	**Mean Difference (°C)**
Attic Condition	4.08	0.0440	1,467		
• Good/Excellent (313)				19.51	**+0.35**
• Poor/Fair (159)				19.16	-
Door Condition	3.49	0.0623	1,588		
• Good/Excellent (503)				19.40	**+0.39**
• Poor/Fair (87)				19.01	-
Foundation Type	3.30	0.0696	1,639		
• Concrete (624)				19.35	**+0.79**
• Stone/Block (17)				18.56	-
House Construction Condition	2.72	0.0997	1,400		
• Good/Excellent (372)				19.47	**+0.55**
• Poor/Fair (30)				18.92	-
Absence/Presence of Window Condensation	3.12	0.0780	1,643		
• No Condensation (403)				19.44	**+0.25**
• Condensation (242)				19.19	-

- Houses in which the exterior doors were rated as Good/Excellent had a mean temperature of +19.51 °C in the basement , +0.39 °C warmer than houses in which the exterior doors were rated as Poor/Fair condition, (p=0.0623).

- In homes in which the house foundation was constructed from concrete, the mean temperature in the basement was +19.35 °C, +0.79 °C warmer than houses in which the foundation was constructed from stone and/or concrete block, (p=0.0696).

- The basements in houses in which the structural condition were rated as Good/Excellent had mean air temperatures of +19.47 ^{o}C, +0.55 ^{o}C warmer than houses rated as Poor/Fair condition. (p=0.0719).
- Houses in which no condensation was observed on the windows were marginally warmer in the basement with a mean temperature of +19.44 ^{o}C compared to +19.19 ^{o}C for bedrooms in which condensation was typically observed on the windows, (p=0.0780).
- The mean temperature in a child's bedroom in houses containing crawlspaces without any visible water was +20.31 ^{o}C, -2.49 ^{o}C cooler than houses with visible water in the crawlspace, (p=0.0738).
- The mean temperature in the child's bedroom of houses in which the house foundation was rated as Good/Excellent was +20.75 ^{o}C, +0.48 ^{o}C warmer than houses in which the foundation was rated as Pool/Fair, (p=0.0492).
- Houses constructed from masonry or other building materials were significantly warmer in the child's bedroom compared to conventional wood frame; 23.42 ^{o}C for masonry/other versus +20.65 ^{o}C for wood frame, a difference of +2.77 ^{o}C, (p=0.0003).

- The child's bedroom in houses whose construction was rated as Good/Excellent condition had mean air temperatures of +20.84 ^{o}C, +0.79 ^{o}C warmer than houses whose condition was rated as Poor/Fair, (p=0.0719).

- Houses less than 1,500 square feet had marginally cooler child bedrooms, +20.62 ^{o}C, compared to +21.21 ^{o}C (difference of 0.59 ^{o}C) for houses larger than 1,500 square feet, (p=0.018).

- Houses in which no condensation was observed on the windows were marginally warmer in the child's bedroom with a mean temperature of +20.81^{o}C compared to +20.50 ^{o}C for bedrooms in which condensation was typically observed on the windows, (p=0.0918).

Appendix E: Housing Conditions Affecting the Wall Surface Temperatures in the House

Table E1: Housing Conditions Affecting the Wall Surface Temperatures in the Children's Bedroom

Housing Conditions (n)	*F*	*p*	*df*	Mean Air Temp. (°C)	Mean Temp. Difference (°C)
Attic Condition	8.75	0.0032	1,493		
• Good/Excellent (330)				19.09	**+0.60**
• Poor/Fair (165)				18.49	-
Water in the Crawlspace	4.47	0.0370	1,96		
• No Water (95)				18.69	**-2.78**
• Water (3)				21.47	-
Door Condition	7.97	0.0049	1,619		
• Good/Excellent (531)				19.00	**+0.72**
• Poor/Fair (90)				18.28	-
Presence of Structural Duress in the Home	3.33	0.0686	1,679		
• No Duress (391)				19.02	**+0.31**
• Duress (290)				18.71	-
Condition of Foundation Wall	3.70	0.0548	1,639		
• Good/Excellent (533)				18.96	**+0.45**
• Poor/Fair (108)				18.51	-
Age of House	3.55	0.0600	1,605		
• 0-20 Years (221)				19.11	**+0.35**
• > 20 Years (386)				18.76	-
General House Condition	8.81	0.0032	1,424		
• Good/Excellent (396)				19.06	**+1.22**
• Poor/Fair (30)				17.84	-
Size of House (Sq. Ft.)	6.23	0.0128	1,665		
• < 1,500 (568)				18.83	**-0.60**
• > 1,500 (99)				19.43	-
Wall Stain Area (Sq. Ft.)	4.83	0.0299	1,119		
• < 1.0 (47)				19.39	**+0.91**
• > 1.0 (74)				18.48	-
Absence/Presence of Window Condensation	3.55	0.0599	1,678		
• No Condensation (422)				19.02	**+0.33**
• Condensation (258)				18.69	-

- The wall surface in children's bedrooms in which attics were rated as Good/Excellent had a mean temperature of +19.09 ^{o}C, +0.60 ^{o}C warmer than houses with attics rated as Poor/Fair, ($p=0.0032$).

- The wall surface temperatures in the children's bedrooms were generally higher in homes in which water was present in the crawlspace compared to houses with dry crawlspaces. Specifically, houses with crawlspaces in which no water was observed in those crawlspaces produced a mean wall surface temperature of +18.69 ^{o}C in the child's bedroom, 0.78 ^{o}C cooler than houses with water in the crawlspace, ($p=0.0370$).

- Wall surface temperatures in the children's bedrooms were on average higher when the exterior doors were rated as Good/Excellent. The mean wall surface temperature with exterior doors rated as Good/Excellent condition was +19.00 ^{o}C, +0.72 ^{o}C higher than the wall surface temperature for houses with exterior doors rated as Poor/Fair, ($p=0.0049$).

- Houses with no observable structural duress produced higher wall surface temperatures in children's bedrooms. Specifically, houses observed to exhibit no structural duress produced a mean wall surface temperature in children's bedrooms of +19.02 ^{o}C, +0.31 ^{o}C higher than houses with visible structural duress, ($p=0.0686$).

- The mean wall temperature in children's bedrooms of houses with foundation walls rated as Good/Excellent was +18.96 ^{o}C, +0.45 ^{o}C higher than houses where the foundation walls were rated as Poor/Fair, (p=0.0548).

- The mean wall surface temperature in children's bedrooms of newer homes was higher than those in older homes. Specifically, in homes less than 20 years of age, the mean wall surface temperature in the child's bedroom was +19.11 ^{o}C, +0.35 ^{o}C higher than inhomes greater than 20 years of age, (p=0.0600).

- The wall surface temperature in the children's bedrooms of houses rated as Good/Excellent was +19.06 ^{o}C, +1.22 ^{o}C higher than in homes rated as Poor/Fair condition, (p=0.0032).

- The wall surface temperatures in the children's bedrooms of smaller homes were generally lower than those in larger homes. Specifically, houses less than 1,500 square feet in size produced a mean wall surface temperature in children's bedrooms of +18.83 ^{o}C, 0.60 ^{o}C lower than those in houses larger than 1,500 square feet, (p=0.0128).

- The walls in children's bedrooms in homes with no significant visible condensation stains on the walls were warmer than those in homes with stain areas greater than

1.0 square feet in size. Specifically, where moisture stains were less than 1.0 square feet, the mean wall surface temperature in the children's bedrooms was +19.39 ^{o}C , +0.91 ^{o}C higher than those in homes in which condensation stains were greater than 1.0 square feet, (p=0.0299).

- The wall surface temperatures in children's bedrooms in which no evidence of window condensation was present were higher than those in homes in which window condensation stains were present. The mean wall surface temperature in the children's bedrooms of homes with no window condensation stains was +19.02 ^{o}C, +0.33 ^{o}C higher than those in houses in which condensation on the windows was observed, (p=0.0599).

Table E2: Housing Conditions Affecting the Wall Surface Temperatures in the Basement

Housing Conditions (n)	***F***	***p***	***df***	Mean Air Temp. (°C)	Mean Difference (°C)
Absence/Presence of Crawlspace	3.52	0.0613	1,633		
• No Crawlspace (547)				14.05	**-0.50**
• Crawlspace (88)				14.55	**-**

- Only one variable was observed to be statistically significant when examining wall surface temperatures in the basements of the audited homes. Houses in which no crawlspaces were present had a lower mean wall temperature of 0.50 degrees Celsius compared to houses with crawlspaces.