Housing Conditions and Children's Respiratory Health

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Understanding how respiratory health risks are associated with housing is essential to designing effective strategies to improve children's quality of life. A survey designed to determine the relationship between respiratory health and housing conditions was completed by 3,423 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 each residence was conducted – including measurements of relative humidity, temperature, and moisture content of walls. Results indicate that: (a) Self-reported visible mould in the home is a significant independent predictor of persistent colds alone as well as of asthma in combination with persistent colds in children. (b) A high percentage of homes (64% of bedrooms, 65% of basements) in Winnipeg have mould CFU levels of ≥100/m³-- the most common genus type being Cladosporium. (c) Self-reported presence of visible mould in the home is significantly associated with measured CFU mould counts ≥ 100/m³, based on air samples taken from both the child's bedroom and basement. (d) Presence of Cladosporium in both the child's bedroom and basement is significantly associated with childhood asthma in combination with persistent cold symptoms. (e) Measurements of relative humidity and/or air temperatures in the child's home are not reliable indicators of high mould CFU counts; moisture content in the walls has a small but significant association with mould CFU counts. The significance of these results for the respiratory health of children is discussed as well as policy directions for healthy housing.

1.0 Introduction

Housing, as a neglected site for public health action, has been identified in a number of recent publications (Dunn, 2002; Haverinen-Shaughnessy et al., 2006; Andriessen, Brunekreef & Roemer, 1998; Spengler et al., 2004; Eman, 2002; Breysse et al., 2004; Bonnefoy et al., 2004; Bornehag et al., 2004). Housing, however, encompasses a very large range of factors, including biological (mould, cockroaches, dust mites, etc.), chemical (tobacco smoke, paints, etc.), and structural (water moisture, heat ventilation, AC, etc.). These make the quantitative evaluation of the impact of these factors on 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.

Although it is unclear whether indoor dampness causes or only aggravates preexisting respiratory conditions, such as asthma, (Breysse et al., 2004) a recent extensive European Community Respiratory Health Survey (ECRHS), involving 38 study centers, 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).

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The relationship between damp or mouldy indoor environments and respiratory problems has been the focus of a number of recent studies (Jaakkola, Hwang, & Jaakkola, 2005; Skorge et al., 2005; Meklin et al., 2002; Curtis et al., 2004; OPSI, 2005; NIOSH, 2003) 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; Gunnbjornsdottir et al., 2003; Engvall, Norrby & Norback, 2001; 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, 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 appears however, contradictory studies 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 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 (moulds, dust mites, pet allergens, etc.) 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 recently established a working group, Population Health and Housing, whose mission is 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, these contain incomplete data on housing and attempts to correlate occupant health with the extant non-specific housing data have failed to demonstrate statistically significant relationships (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* has been launched (Healthy Indoors Partnership, 2002) using the EPA as the centerpiece in its stakeholder dialogues. The World Health Organization's (WHO) Regional office for Europe is also currently undertaking an extensive cross-sectional study to evaluate the relationship between housing and health in seven European cities (Bonnefoy et al, 2003). Thus, it is clear that effort to understand the relationship between housing and health is international in scale and that government attention and resources have accordingly been assigned.

2.0 Objectives

This study is part of a larger project whose objectives 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 sample results; (3) develop a housing data base documenting information such as the history of water damage in the child's home, evidence of structural duress, air leakage, type of mechanical system in the home, relative humidity, wall moisture content, mould count and genus type based on two indoor air samples taken in the basement and child's bedroom; (4) examine the relationship between mould count and home building materials (e.g., concrete block, wooden frame, gypsum board); (5) cross-link the newly created housing database with three Manitoba health databases: *Manitoba physician claim, hospital discharge abstracts,* and *prescription record* to examine links to children's respiratory health[4]*;* and (6) design a Composite Healthy Housing Index (CHHI) to evaluate the risk of mould/moisture in the home and upper respiratory problems of its occupants.

The emphasis of this paper will be on objective #1, 2, and part of 3.

3.0 Definitions

3.1 Asthma: having received a formal diagnosis of asthma from a physician or, if not formally diagnosed with asthma by a physician, over the last 12 months had: 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; and, d) been prescribed steroids.

3.2 Persistent Colds/Respiratory Infections: According to Williamson et al. (1997), persistent colds are defined as having 3 or more respiratory infections/colds in the past year. In this paper, persistent colds were defined as having 4 or more respiratory infections/colds in the past year

3.3 CFU/m^3: the total concentration of culturable microorganisms calculated by dividing the volume of air sampled into the total number of colonies observed on the culture plate. A colony is a

[4] Manitoba's health care databases are among the few population-based health care data sources that exist in the world (79). 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 provided are submitted under a fee-for-service arrangement, and contain information on patient diagnosis 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.

macroscopically 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 limitations on air- borne mould concentrations within residences. Manitoba Workplace Health and Safety (Province of Manitoba, 2001) have provided however, guidelines on air-borne mould limits within the workplace, as summarized below.

- More than 50 CFU/m^3 of a single species (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 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 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 Colony Forming Units (CFU)/m^3. Of the 62 participants in the NIOSH study15% reported asthma, and 36% reported chest symptoms (wheeze or shortness of breath). 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.

The European standard for air-borne mould classifications identifies "low" at 0 to 499 CFU's; "medium" at 500 to 999 CFU's; and "high" at CFU counts greater than 1,000 (CEC, 1994).

For purposes of the current study, a value of 100 CFU/m^3 was set, at which point genus identification of the top three mould types was completed for each sample.

3.4. Relative Humidity: 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 be maintained within the home in the range of 30 to 50 percent. However, it must be recognized that depending upon the house construction and location within Canada, even a relative humidity of 30 percent during the winter months can lead to high levels of condensation (Trechsel et al., 2001).

3.5 Moisture Content (MC) of the Building Material: either (i) the mass of moisture per unit volume of any dry building material or (ii) the mass of moisture per unit mass of any dense dry building material or (iii) the volume of condensed moisture per unit volume of any light dry material (Trechsel et al., 2001).

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

3. 7 Surface Temperature: the temperature of the exposed surface of the object/building surface being measured – usually through a digital contact surface thermometer or infrared device.

4.0 Method

4.1 Participants

A total of 3423 students, drawn from six main school divisions in the city of Winnipeg, Manitoba, Canada participated in this study. The mean age of the students at the time of the survey was 8 years, 5 months (minimum: 7 years, 2 months; maximum: 10 years, 10 months SD: 7.68 months). There were 1695 males, and 1664 females (64 missing information); 1777 were in grade 3 and 1623 in grade 4 (23 missing information).

Table 1. Response Rates for Part 1: Initial Contact Survey by Group

	No Asthma	Asthma	TOTAL
No/Few Colds	1848 (54%)	204 (6%)	2052 (60%)
Persistent Colds	858 (25%)	513 (15 %)	1371 (40 %)
TOTAL	2706 (79%)	717 (21.0%)	3423 (100%)

4.2 Locale

Winnipeg, Manitoba is located in the central Prairie region of Canada. Its climate is known for considerable swings with an average summer time temperature of approximately +23 degrees Celsius but with over 5,900 degree heating days below +18 degrees Celsius and a winter design temperature of -33 degrees Celsius. Winnipeg is also located in the Red River Valley, a flood plain and prone to periodic flooding conditions.

4.3 Materials

Part I: A one-page Initial Contact Survey was designed to obtain parental information on: (a) their 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 (b) the child's home environment including age of home, presence of mould, carpets, number of smokers in the home, presence of cats or dogs, and whether parents/siblings or other relatives have asthma, and (c) number of school days missed in 2004-05 by the child due to respiratory tract infections and/or asthma.

Part 2: 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).

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.

At the same time, measurements were recorded of relative air humidity, temperature, and wall moisture content for each home.

An eight-page Engineering Audit (checklist) was completed documenting, for example, evidence of water damage, structural duress, the type of mechanical system in the home, etc.[5] This allowed an engineering research team to rate the condition of the home's structural and mechanical components.

4.4 Design and Procedure

Step 1: In September 2005, following permission from all six school-division superintendents, the Initial Contact Survey was distributed to the entire grades-3 and -4 school division student population –13,727 children.

Step 2: Based on the returned parent surveys (3423 or 25% response rate), children were categorized into four groups: (1) No Asthma and Few or No Colds, (2) No Asthma and Persistent Colds, (3) Asthma and Few or No Colds, and (4) Asthma and Persistent Colds.

Step 3: Following 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 sample[6]. A total of 715 consent forms were returned (see Table 2), giving a response rate of 85.1 percent. These parents were contacted by phone and a time for housing inspection was arranged.

Table 2. Response Rates for Part 2 by Group

	No Asthma	Asthma	TOTAL
No/Few Colds	202 (28.3 %)	72 (10.1 %)	274 (38.3 %)
Persistent Colds	224 (31.3 %)	217 (30.3 %)	441 (61.7 %)
TOTAL	426 (59.6 %)	289 (40.4 %)	715 (100%)

Step 4: Inspections were conducted by trained engineering graduate assistants under the supervision of two Professional Engineers (Polyzois and Wells, two of the authors of this paper). Each home was visited by a two-member team. The inspection process is detailed below.

Home Visit #1

First, air samples were collected in the child's bedroom (Area 1) and in the basement (Areas 2) of each home using a Biotest Hycon RCS Air Sampler device. A simultaneous control or outdoor sample was taken in each neighborhood so that a comparison of indoor and outdoor mould spore counts could be conducted. 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 Air Sampler was run for four minutes at each location. The impeller device and barrel housing were dismantled and

[5] The checklist is too long to be included as an Annex. A request for a copy can be made to the prime author.

[6] Once we received and documented the responses from the Initial Contact Surveys, we categorized the respondents into four groups: (Asthma and Respiratory Infections; Asthma and No Respiratory Infections ; No Asthma and Respiratory Infections; and No Asthma and No Respiratory Infections. Based on the IOM (2004) study, we initially assumed a prevalence of mold and/or dampness of 25% in the homes, we would have an 80% power of detecting a relative risk of 1.51 for asthma exacerbation or upper respiratory illnesses if we have 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.

disinfected after each resident sampling. 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 count of greater than 100 CFU/m^3.

Testing was carried out in the spring of 2006 (April, May, and June) while building moisture content was anticipated to be higher due to condensation and before windows were not routinely opened during the day. A total of 1911 air samples were taken from 715 homes. Of the air samples where the 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 7.

On the same day of the air sampling:

(a) A brief one-page Housing Inspection Protocol was completed by each 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 measures were taken in all rooms using a Delmhorst Digital Hygrometer/Air Temperature Unit.

(c) The surface temperatures of all windows and walls in each room were measured using an infra-red temperature probe.

(d) A Delmhorst pin-type penetrating moisture meter was used to measure the moisture content of the building surfaces, specifically the interior walls.

(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.

<u>Home Visit #2</u>

In a subsequent home visit, an extensive eight-page Engineering Audit of each residence was conducted. The audit recorded the structural condition of the home (e.g., windows, walls, roof, basement), the type of mechanical system used in the home (e.g., furnace, air conditioning, humidifier), the absence/presence of effective groundwater management (e.g., sump-pit/weeping tile), and presence of visible moisture damage, mould and associated building envelope problems.

This paper presents the statistical analysis of the Initial Contact Survey results as well as initial results for the biological air sampling conducted in 715 residences. The data analysis for the engineering audits was in progress at the time of writing this paper and will be presented under a separate article. Preliminary results for humidity, temperature, and moisture content are, however, presented.

5.0 Results

Question #1: What is the relationship between selected aspects of the child's home environment and his/her respiratory health?

The information requested in the Initial Contact Survey requested the following information to be filled in by the parent/guardian of the child: 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; 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; number of cats or dogs in the home. Only significant results are reported (see Table 3). The first five variables listed in the table are analyzed using Logistic Regression (due to binary distribution of these variables); the last two are count variables and, thus, are analyzed using Poisson Regression analysis. In the new analysis, the multiplicity of the tests carried out was taken into account by applying the Bonferroni factor to both Table 3 and 4. Since there were 17 variables in the Initial Contact Survey, probabilities of less than 0.05/17=0.0029 were considered significant. The data show that self-reported visible mould in the home (basement, bathroom, kitchen) as well as the presence of rodents are significantly associated with persistent colds. In contrast, carpeting in the home and smokers in the home are significantly associated with asthma. Finally, a significant genetic association (parents, siblings, or other relatives with asthma) was observed for persistent colds in combination with asthma, indicating that those with asthma tend also to be more prone to colds, than those without asthma.

Table 3: Association of Survey Variables with Childhood Persistent Colds and/or Asthma (χ^2)

Variable	Effect of Persistent Cold	Effect of Asthma	Effect of Interaction of Cold and Asthma
1. Those Who Reported Visible Mould:			
- In Basement	**13.44****	0.279	0.0014
- In Bathroom	**23.85*****	**9.27***	**7.02****
- In Kitchen	**26.26*****	0.482	1.19
2. Those Who Reported Rodents (mice) in Home	**8.91***	0.128	0.069
3. Those Who had Asthmatic Parents	**17.08*****	**34.04*****	0.295
4. Those Who had Asthmatic Siblings	8.74	**23.23*****	0.147
5. Those Who had Other Asthmatic Relatives	**38.96*****	**15.29*****	0.210
6. Number of Rooms Carpeted in Home	0.01	**10.21***	0.24
7. Number of Smokers Living in home	1.98	4.22	1.69

***p<.0029** ****p<.0006** *****p<.0001** ******p<.000006**

Three separate multivariate analyses, using step-wise logistic regressions, were subsequently run to determine independent predictors of persistent colds and/or asthma compared to the control group: no asthma + no colds (see Table 4). Table 4 summarizes the results of these analyses. In table 4, there were three variables. Therefore, probabilities of less than 0.05/3=0.0167 were considered significant.

Table 4: Independent Predictors of Childhood Persistent Colds, Asthma, and Asthma + Colds

Survey Variable	Persistent Colds		Asthma		Persistent Colds + Asthma	
	Odds Ratio (95 % CL)	χ^2 value	Asthma Odds Ratio (95 % CL)	χ^2 value	Persistent Colds + Asthma Odds Ratio (95 % CL)	χ^2 value
Self-Reported Mould (anywhere in home)						
-In Basement	**1.248(1.003,1.552)**	3.96			**1.371(1.055,1.781)**	5.57
-In Bathroom	**1.324(1.083,1.617)**	**7.53***	**1.559(1.122,2.165)**	**7.01***		
-In Kitchen	**2.764(1.636,4.671)**	**14.43*******				
Total Smokers living in Home	**1.173(1.033,1.333)**	**6.062***			**1.186(1.011,1.391)**	4.87
Asthmatic Parents	**1.352(1.074,1.701)**	**6.59***	**2.259(1.588,3.215)**	**20.51*******	**2.685(2.101,3.430)**	**62.42*******
Asthmatic Siblings			**1.857(1.277,2.699)**	**10.51****	**1.918(1.472,2.498)**	**23.32*******
Other Asthmatic Relatives	**1.557(1.310,1.851)**	**25.24*******			**2.005(1.614,2.490)**	**39.57*******

***p<.0017** ****p<.0033** *****p<.00033** ******p<.0001**

Persistent Colds: Children with reported mould in their home were more likely to have persistent colds compared to the group with neither condition. The odds ratios ranged from 1.248 to 2.764. Children who have asthmatic parents or other relatives were 35.2 % and 55.7%, respectively, more likely to have persistent colds.

Asthma: Children with asthmatic parents were over two times more likely to have asthma compared to those with neither asthma nor persistent colds. Children with asthmatic siblings were 85.7% more likely to have asthma.

Persistent Colds and Asthma: Children with reported mould in their home were 37.1% more likely (based on basement mould counts) to have persistent colds in combination with asthma. In addition, children with asthmatic parents, siblings or other relatives were 1.92 to 2.68 times more likely to suffer from both conditions.

Question #2: What is the most common type of air-borne mould found in Winnipeg homes?

A high number of Winnipeg homes (65%) were found to have air-borne mould CFU levels (all species) of at least 100/m^3 (see Table 5).

Table 5: Number of Homes by Area Tested by Minimum CFU Cutoff Levels (all Species) – **all Months** Combined.

Number of Homes by Area Tested	Minimum CFU Cutoff Levels			
	$\geq$ 100/m^3	$\geq$ 200/m^3	$\geq$ 300/m^3	$\geq$ 400/m^3
Child's Bedroom # (%) n = 715	451(65)	293 (41)	186 (26)	133 (19)
Basement # (%) n = 669*	444 (65)	292 (44)	201 (30)	158 (24)

*Not all homes had basements

When air-borne mould test results were analyzed for April alone, the most common test month in the current study, similar patterns were observed: 52-53% of home have air-borne mould CFU levels (all species) of at least 100/m^3 (see Table 6).

Table 6: Number of Homes by Area Tested by Minimum CFU Cutoff Levels (all Species) – **April Alone**

Number of Homes by Area Tested	Minimum CFU Cutoff Levels			
	≥ 100/m^3	≥ 200/m^3	≥ 300/m^3	≥ 400/m^3
Child's Bedroom # (%) n = 289	150 (52)	71 (25)	25(9)	11 (4)
Basement # (%) n = 274*	150 (53)	74 (27)	43 (16)	27 (10)

*Not all homes had basements

For all homes with CFU counts ≥ 100/m^3, then, the genus type for the top three moulds was identified and measured separately. The ten most common types of mould identified in all the homes tested are reported in Table 7. Cladosporium was the most common mould found in Winnipeg homes.

Table 7. The Ten Most Common Types of Mould Identified in the Target Homes by Area: Child's Bedroom and Basement

Type of Mould Identified		# of Homes Where Mould Was Identified In Child's Bedroom*	# of Homes Where Mould Was Identified In Basement*
1	Cladosporium	455 (62%)	373 (51%)
2	Alternaria	381 (52%)	292 (40%)
3	Penicillium	162 (22%)	175 (24%)
4	Mycelia-Sterilia	126 (17%)	62 (8.5%)
5	Aspergillus	33 (4.5%)	66 (9.0%)
6	Ulocladium	29 (4.0%)	13 (1.8%)
7	Mucor	23 (3.1%)	16 (2.2%)
8	Epicoccum	19 (2.6%)	18 (2.5%)
9	Fusarium	19 (2.6%)	13 (1.8%)
10	Pithomyces	18 (2.5%)	10(1.4%)

*Based On Air Sampling Where Total Count was ≥ 100 CFU/m^3

Given the prevalence of Cladosporium, the number of homes tested by minimum Cladosporium CFU cutoff levels was examined to identify the range of CFU levels obtained (see Table 8). The great majority of the homes fell in the CFU ≥ 100/m^3 cutoff level.

Table 8: Number of Homes by Area Tested by Minimum Cladosporium CFU Cutoff Levels – **all Months** Combined.

Number of Homes by Area Tested	Minimum Cladosporium CFU Cutoff Levels			
	≥ 100/m^3	≥ 200/m^3	≥ 300/m^3	≥ 400/m^3
Child's Bedroom # (%) n = 455	315 (69)	159 (35)	96 (21)	62 (14)
Basement # (%) n = 444*	256 (58)	144 (32)	89 (21)	60 (14)

*Not all homes had basements

Question #3: What is the relationship between self-reported visible mould in the home and the presence of tested air-born mould (measured in CFU/m³)?

For the month of April, a significant association was found between occupant-reported visible mould in the house and air-borne CFU levels (all species combined) $\geq 100/m^3$ and $\geq 200/m^3$ in the child's bedroom (see Table 9).

Table 9: The Presence of Self-Reported Indoor Mould and Air Sample Results from **Child's Bedroom**

Self-Reported Indoor Mould	Air Sample Results			
	Bedrooms with $CFU \geq 100/m^3$ # (%)	Bedrooms with $CFU \geq 200/m^3$ # (%)	Bedrooms with $CFU \geq 300/m^3$ # (%)	Bedrooms with $CFU \geq 400/m^3$ # (%)
	ALL MONTHS COMBINED			
No (n=367)	222 (60%)	143 (39%)	87 (24%)	61 (17%)
Yes (n=348)	228 (65%)	149 (43%)	98 (28%)	71 (20%)
$\chi 2$	2.76	1.26	2.08	1.95
	FOR APRIL ONLY			
No (n=146)	66(45%)	27 (19%)	9 (6.2%)	1 (0.70%)
Yes (n=143)	84 (59%)	44 (31%)	16 (11%)	10 (7.0%)
$\chi 2$	**5.86***	**5.87***	2.31	--

***p<.05** ****p<.01**

A significant association was found between self-reported visible mould and tested air-borne mould within the basement $\geq 100/m^3$ and $\geq 200/m^3$ for all testing months combined. For April, this association held for CFU levels of greater than 300 and 400 CFU/m³ as well (see Table 10).

Table 10: The Presence of Self-Reported Indoor Mould and Air Sample Results from the **Basement** (All Months Combined and April)

Self-Reported Indoor Mould	Air Sample Results			
	Basements with $CFU \geq 100/m^3$ # (%)	Basements with $CFU \geq 200/m^3$ # (%)	Basements with $CFU \geq 300/m^3$ # (%)	Basements with $CFU \geq 400/m^3$ # (%)
	ALL MONTHS COMBINED			
No (n = 348)	213 (61%)	138 (40%)	98 (28%)	83 (24%)
Yes (n = 321)	221 (69%)	154 (48%)	103 (32%)	76 (24%)
χ^2	**4.28***	**4.7***	1.22	0
	FOR APRIL ONLY			
No (n = 140)	63(45%)	29 (21%)	15 (11%)	9 (6.4%)
Yes (n = 134)	81 (60%)	45 (34%)	28 (21%)	18 (13%)
χ^2	**6.55****	**5.75***	**5.36***	**3.78***

***p<.05** ****p<.01**

Question #4: What is the relationship between tested air-borne mould in the home (based on CFU/m³counts) and persistent colds and/or asthma among child occupants?

A Kruskal-Wallace Non-Parametric Test of the distribution of Cladosporium spores by area of the home (child's bedroom or basement) revealed the following results (see Table 11). Analyses show a significant association between Cladosporium CFU levels from air samples taken in April and asthma in combination with persistent colds.

Table 11: Cladospiorium CFU Counts by Area in the Home (Child's Bedroom or Basement) by Respiratory Condition of Child, **April only**

April CFU Counts for Cladosporium by Area in the Home	Condition of Child Occupant				χ^2
	No Persistent Colds No Asthma	Persistent Colds	Asthma	Persistent Colds And Asthma	
Area 1: Bedroom Median (25 %ile, 75%ile)	100 (50,125)	94 (63,137)	84(44,138)	125(88,181)	**11.73****
Area 2: Basement Median (25%ile, 75%ile)	94 (63,150)	81 (44,113)	112 (69,162)	134 (72,219)	**9.58***

***p<.05 **p<.01**

Question #5: What is the relationship between tested air-borne mould in the home and room environmental conditions (air temperature, surface temperature, relative humidity, and building moisture content)?

During the air sampling procedure, relative humidity in the air, air temperature, lowest wall surface temperature, and wall moisture contents were measured using a pin-type penetration moisture meter. The mean measurements for each parameter are summarized in Table 12.

Table 12: Mean Relative Humidity, Air Temperature, Wall Surface Temperature and Wall Moisture Content by Area in the Home

	Relative Humidity (%)			Air Temperature (Degrees Celsius)			Wall Surface Temperature (Degrees Celsius)		Wall Moisture Content (%)	
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 1	Area 2	Area 1	Area 2
Mean	46.4	47.1	45.9	20.7	19.3	17.5	18.9	14.2	1.28	2.54
SD	9.04	7.86	16.1	2.25	1.79	4.96	2.19	2.34	3.82	4.13
Min	21.0	24.6	17.5	14.3	12.9	3.0	11	6.60	0.00	0.00
Max	74.8	76.9	95.3	39.7	23.3	40.8	26	20.6	36.1	36.1

Note: Area 1: Child's Bedroom, Area2: Basement, Area 3: Exterior (control)

A non-parametric Spearman rank test was run comparing air-borne mould counts (all species combined) and the various home environmental properties measured: relative humidity, air temperature, wall surface temperatures, and moisture content of the building materials.

Table 13: Correlation Summary of Total Mould Count (CFU/m^3) – All Species Combined by Area – and Various Room Environmental Conditions

Total Mould Count by Area in the Home	Room Environmental Conditions			
	Relative Humidity	Air Temperature	Surface Temperature	Moisture Content
Area 1: Child's Bedroom				
n	692	692	691	688
Spearman Rank Coefficient	**-0.106****	**+0.092***	0.00083	**+0.134*****
Area 2: Basement				
n	644	645	641	594
Spearman Rank Coefficient	0.008	**-0.102****	**-0.185*******	**+0.110****
Area 3: Outside House				
n	159	159	N/A	N/A
Spearman Rank Coefficient	**+0.158***	**+0.212****		

***p<.05 **p<.01 ***p<.001 ****p<0001**

Results indicate an unclear pattern between the total mould count in the home and both relative humidity and air/surface temperature measurements. However, a small but significant correlation was found between wall moisture content and air-born mould, as measured by CFU/m^3. This correlation held for both the child's bedroom and the basement.

4. Discussion

Housing as a neglected site for public health action has been identified in a number of recent publications. There is strong empirical evidence that suggests that damp, cold, and mouldy housing is associated with asthma and other chronic respiratory symptoms. The objectives of this study were to examine the relationship between housing and respiratory health/asthma among grade-three and -four children in Winnipeg, Manitoba, Canada; compare the presence of self-reported indoor mould and air sample results; develop a housing data base documenting information on the environmental and building conditions within the home; and, examine the relationship between mould count and home building materials.

Although the data input for the Part 2 housing condition audits remains to be completed, statistical analysis of the 3,423 survey results has revealed that children with reported mold in their home are more likely to have persistent colds; asthmatic children living in homes with visible mould also tend to be more prone to persistent colds than those without asthma. Carpeting is a significant aggravator for asthma but not persistent colds. No significant correlation was observed for the age of the home or whether or not the residents own their own home – and persistent colds and/or asthma. Similarly the presence of cats and dogs was not observed to be significantly associated with either condition. We hypothesize that parents with children that are asthmatic or have animal related allergies would have been proactive at not having such pets.

The analysis of 1911 home air samples revealed 25 different mould genus types. The top three types identified were Cladosporium, Alternaria, and Penicillium. Air sampling took place over the months of April through June. Results confirms 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). 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). 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 combination with asthma.

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. Our study showed that Cladosporium during the month of April ranged from 84 CFU/m^3 to 125 CFU/m^3 in the children's bedrooms and from 81 CFU/m^3 to 134 CFU/m^3 in the basement of the homes. The analysis of the results showed a significant association between Cladosporium and asthma in combination with persistent colds.

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 primarily responsible for the source(s) of moisture within the home. Indeed, 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.

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.

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 misunderstandings in 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) 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 relative humidity or temperature and mould count. According to Garrett et al. (1998), the lack of a strong correlation 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.

However, in our study, there was a small but significant association between measured moisture content of the walls and the mould count. Thus, it seems that moisture measurements of the walls, using a penetration-type moisture meters, are a better indicator of moisture damage than either visual observations or measurements of relative humidity. These measurements can then be used as a reliable indicator of the presence/absence of air-borne mould, as measured by CFU/m^3. Of all the air samples analyzed in our study that had mould counts greater than 100 CFU/m^3, Cladosporium contributed to one of the three genus types identified. Gent et al. (2002) reported that mould and evidence of condensation are associated with high concentration of Cladosporium. Similar results were reported by researchers in Finland (Pasanen et al., 1992) who found that damp houses have significant indoor sources of Cladosporium. Garrett et al (1998) however, were surprised to see high concentrations of Cladosporium in rooms with relative humidity of less than 60% and speculated that dry conditions are more conductive to the dispersal of Cladosporium spores.

The next stage of our research will focus on correlating our housing condition data base with the results of the biological air sampling in order to establish which building conditions – including but not limited to the building structure type, foundation type and mechanical system – have the greatest impact on CFU levels within the home. Ultimately, it is anticipated that the data will enable development of recommended cut-off points for CFU levels for mould within the home in order to minimize the deleterious effects mould have on the respiratory health of children.

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