SUSTAINABLE HOME ENVIRONMENTS: PROACTIVELY ADDRESSING SICKNESS-RELATED DAMP AND MOLDY ENVIRONMENTS TO REDUCE THE IMPACT ON THE BC HEALTH CARE SYSTEM

by

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Abstract

In developed countries nearly half of a person's life is spend in their home environment. Worldwide, up to 30% of new and remodelled buildings may have indoor air quality issues with the quality of housing in general playing a decisive role in occupant health. Upwards of 50% of homes in North America contain damp or moldy environments with microbial debris being a key element in indoor air pollution. Asthma prevalence has been deemed a by-product of unhealthy home environments, exacerbated by exposure to high levels of mold and dampness. Asthma impacts 28 million people in North America and accounts for over $62 billion in health care costs and economic impact from lost productivity, lost work days, and early death.

This thesis presents literature that demonstrates the link and extent of impact among damp and moldy indoor environments and respiratory disease using asthma as a case study. To quantify the effects, a reliable empirical tool that ranks residential indoor environment condition and predicts associated respiratory health-effect risk in homes has been developed and validated. To support the delivery of potentially significant health benefits and public health care system cost savings, this thesis considers a method, based on economics and risk analysis, to reduce respiratory health impact and validates the basis for a proactive sustainable health care prevention program based on residential mold and dampness remediation.

The financial assessment conducted in this thesis utilizing social cost-benefit risk analysis suggests the direct economic burden on the public health care system (PHCS) from high-use (severe and persistent) mold and dampness-affected asthmatics is $5.4 billion annually in North America with an estimated $2.8 billion in savings from a prevention program available for reallocation purposes and the freeing of system capacity for the over-burdened health care system. A patient-centric component costing analysis was conducted to supplement and support literature

data. A proposed prevention program implementation strategy consists of identifying the mold and dampness affected high-use asthmatics, treating their environment, administering the prevention program, monitoring progress, and maintaining an ongoing record of the continuing reduction in cost impact to the public health care system to ensure program sustainability.

Preface

This thesis contributes the following: 1) the development of the HEALTH^2 model that advances environmental modeling and risk analysis of indoor air quality; 2) the development of a HEALTH^2 tool that can be used to quantitatively assess indoor environments; 3) the development of a HEALTH^2 tool that predicts occupant respiratory health impact from indoor environments; 4) the development of a social cost benefit analysis approach to support a financial-based decision mechanism for the implementation of a sustainable public health care asthma prevention program; 5) a prevention approach to reduce indoor mold and dampness and improve the health of mold and dampness affected high-use asthmatics; and, 6) an implementation plan for a sustainable home environment asthma prevention program.

Supervisors Drs. Lovegrove and Roberts contributed significantly to thesis design and structure, hypothesis development, chapter development, and presentation layout and were co-authors in all publications submitted to journals. The supervisory committee members Drs. Hewage, Sadiq and Mori assisted in concept development, review of thesis content and University requirements, and final overview of content. Dr. Sadiq was also a contributor to the following publication pertaining to this thesis:

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Table of Contents

List of Tables

List of Figures

Acronyms and abbreviations

BRI: Building related illness

CTAS: Canadian Triage Acuity Scale

ETS: Environmental tobacco smoke

$HEALTH^2$: Holistic environmental assessment lay tool for home health

HHI: Home healthiness index

IAQ: Indoor air quality

LCA: Life cycle cost analysis

NGO: Non-government organization

OR: Odds ratio

PHCS: Public health care system

RHS: Resident health score

SBS: Sick building syndrome

SCBA: Social cost benefit analysis

SHS: Second hand smoke

SIRAPP: sustainable IAQ residential asthma prevention program

SWOT: Strength, weakness, opportunity, threat

Glossary

Dampness: “any visible, measurable or perceived outcome of excess moisture that causes problems in buildings, such as mold, mold odor, leaks or material degradation, directly measured excess moisture (in terms of relative humidity or moisture content) or microbial growth” (WHO 2009a). For the purpose of this thesis, dampness is considered an environmental condition and mold development an associated effect. This serves to better define the relationships described herein.

High-use asthma: Depending on the severity of symptoms and conventions used, asthma can be considered controlled or uncontrolled, persistent or intermittent, mild, moderate or severe. Uncontrolled, persistent, moderate to severe asthma culminates in serious exacerbation requiring emergency care (Seung and Mittman 2005). Urgent unscheduled care is evidence of an uncontrolled and/or severe asthma affliction. Severe asthma is considered life threatening; moderate asthma is intermittently health affecting with systemic treatment; and, mild asthma is intermittent occasional with light medication (Bousquet 2010, UMMC 2014). The U.S. EPA (2001) delineates high-use from average asthma (mild to moderate-controlled) when reviewing population based hospital demand characteristics. This thesis utilizes the term high-use for moderate uncontrolled to severe (with a focus on severe) and persistent asthma resulting from indoor mold and dampness. High-use asthma is defined as having at least one debilitating exacerbation despite high-dose inhaled corticosteroid treatment and specialist care (Kupczyk 2012); and may be debilitating from multiple symptoms, culminating in frequent exacerbations requiring emergency care (U.S. EPA 2001).

Indoor air quality: (IAQ) is a term referring to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants (epa.gov/iaq/glossary.html #I Dec.2014). This term is used frequently in literature to reference hazard condition assessment of indoor environments that appear to be limited to physical respiratory health response. Actual industry IAQ assessment is inclusive of light and sound, temperature, humidity, airflow, and other items that comprise “comfort” levels for occupants. A more appropriate term may be “indoor environment quality” or IEQ. For the purpose of this thesis, the terms IAQ and IEQ are equivalent, and that references to IAQ include only the respiratory effects of the indoor environment pertaining to mold and dampness and that all other aspects of IAQ are excluded from discussion and analysis.

Moisture: “(1) water vapour; (2) water in medium, such as soil or insulation, but not bulk water or flowing water” (WHO 2009a).

Moisture problem or damage; water damage: “any visible, measurable or perceived outcome caused by excess moisture indicating indoor climate problems or problems of durability in building assemblies; moisture damage is a particular problem of building assembly durability; water damage is a moisture problem caused by various leaks of water” (WHO 2009a).

Mould (mold): “all species of microscopic fungi that grow in the form of multi-cellular filaments, called hyphae. In contrast, microscopic fungi that grow as single cells are called *yeasts*. A connected network of tubular branching hyphae has multiple, genetically identical nuclei and is considered a single organism, referred to as a *colony”* (WHO 2009a).

Odds Ratio: The odds ratio is the ratio of the odds of an event occurring in one group (exposed) to the odds of it occurring in a control group (unexposed), that then indicates a measure of risk that exposure to the agent will result in an ill-health outcome. For example, a higher OR indicates an increase in the odds of respiratory outcomes in damp and moldy indoor environments with statistical significance if the confidence level does not overlap the null value (e.g. OR=1).

Respiratory ill-health/ ill-health/ Respiratory disease: For the purpose of this thesis, these terms are defined as adverse health consequences to the extent of short term or long term impairment of abilities from respiratory function reduction and are to be considered with the same meaning within similar context. This includes the onset and exacerbation of asthma, upper and lower respiratory irritation and infection not defined as asthma, hypersensitivity pneumonitis and diseases such as allergic broncho pulmonary aspergillosis, chronic rhino sinusitis, bronchitis, and sinusitis that all can be caused by mold exposure (Bush *et al*. 2006).

Ventilation: "process of supplying or removing air by natural or mechanical means to or from any space; the air may or may not have been conditioned" (WHO 2009a).

Definitions used in classifying strength of evidence obtained from WHO (2009a):

Sufficient evidence of a causal relationship: The evidence is sufficient to conclude that a causal relationship exists between the agent and the outcome; that is, the evidence fulfills the criteria for "sufficient evidence of an association" and, in addition, satisfies the following evaluation criteria: strength of association, biological gradient, consistency of association, biological plausibility and coherence and temporally correct association. The finding of sufficient evidence of a causal relationship between an exposure and a health outcome does not mean that the exposure inevitably leads to an outcome. Rather, it means that the exposure can cause the outcome, at least in some people under some circumstances.

Sufficient evidence of an association: The evidence is sufficient to conclude that there is an association. That is, an association between the agent and outcome has been observed in studies in that chance, bias and confounding could be ruled out with reasonable confidence, For example, if several small studies that are free from bias and confounding show an association that is consistent in magnitude and direction, there may be sufficient evidence of an association.

Limited or suggestive evidence of an association: The evidence is suggestive of an association between the agent and the outcome but is limited because of chance, bias and confounding could not be ruled out with confidence. For example, at least one high-quality study shows a positive association, but the results of other studies are inconsistent.

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To the Professionals in the health care field, various medical practices, health provision services, and product suppliers, ICBC, and the politicians who are dedicated to the ideal of health care prevention and those providers struggling to maintain healthcare's ability to provide relevant services to the general public I owe a note of gratitude and continued dedication to the pursuit of prevention-based ideals. Your work does not go unnoticed.

To my long suffering family, your temperament has been taxed with my poor ability to juggle academia with work and time together. You have allowed me to flourish and I am most grateful for that. You know this is only the beginning yet again of a lifelong pursuit and your continued support allows me this most wonderful opportunity to contribute to a society that has

allowed you to grow wings and blossom into the lovely beings you are. I hope in some small way, this serves as a pathway towards the contributions you will continue to make to society and your academic health.

Dedication

I dedicate my work to those who suffer in silence from debilitating environmental disease and to my God and my Lord Jesus Christ from which the well of knowledge inspiration and inspiration flows. My eyes are fixed on the Lord and those things shown to me that must be done on this earth to serve my time and fellow man and woman appropriately.

Chapter 1 Introduction

This thesis proposes a quantitative methodology to proactively assess and recover the indoor air quality of the homes of environmentally affected high-use asthmatics, and a program to effectively reduce costs in the PHCS, both based on a social cost benefit analysis approach. This introductory chapter consists of three main sections. Section 1.1 outlines the research objectives; section 1.2 describes the motivation for this thesis and its significance; and, section 1.3 outlines the thesis presentation structure.

1.1 Objectives

The objectives of this thesis are to:

1. Present literature that demonstrates damp and moldy indoor environments are linked to respiratory impact and that the impact is significant and reversible upon removal of the mold and dampness;
2. Seek out quantitative methods and measure consequential indoor environment conditions to assist in systematically deducing the extent of impact that residential indoor mold and dampness may have on occupant well-being; and to provide a validation method for health care prevention;
3. Provide an economic justification for a prevention program based on the remediation of homes of environmentally affected high-use asthmatics; and,
4. Propose a sustainability-focused health care prevention program utilizing a systems-based implementation plan to facilitate healthy environments within a health care policy framework, including a monitoring plan.

1.2 Motivation and significance of the subject matter

The motivation for this research is based on the goal to significantly modify how reversible respiratory disease due to residential indoor mold and damp environments is approached and addressed to more positively affect individuals, communities, and the fiscal bottom line of health care. Indoor environments, particularly indoor air quality (IAQ), cause or contribute to occupant ill-health through a number of well-defined airborne indoor environmental stressors, conditions, and toxins that cause respiratory distress and disease: including particulates such as micro fine particles, environmental tobacco smoke (ETS), and second hand smoke (SHS); inhaled chemicals, combustion gases, and off gassing; inhaled allergens from animal and rodent dander, dust mites, pollen, dust; and radon that can be enumerated, assessed, determined consequentially, and managed when identified at critical levels based on existing protocols and practices (USEPA 2014(a,b,c,d), Health Canada 2014). These conditions comprise a critical and increasing economic load on the health care system, an increasing social burden on families and the overall fabric of society, a contributing factor to declining productivity in the workplace, and an overall retarding force on our economy in North America (Fisk 1997, 2000, 2001, Getland 2008, Bahadori *et al.* 2009, CDC 2014). Using asthma as a well-documented respiratory disease, the Center for Disease Control and Prevention (2014) determined the impact for 25.7 million U.S. asthmatics alone to be $62 billion in 2013 from medical costs, lost work and school days, and early deaths. Moreover, asthma rates continue to climb (PCAC 2007, CDC 2014). Although some hospitals are reporting significant incidence reductions in ED visits and hospitalizations (AHS 2015), the number of prevalent cases are expected to continue to rise (To *et al.* 2013).This impact is reversible (USEPA 2001, Kercsmar 2006, Burr *et al.* 2007, Cascadia 2009, Kim *et al.* 2011), but the extent of which is not yet well defined.

Microbial debris is a key element in indoor air pollution (WHO 2009a). Household dampness and molds are recognized but not well defined as industry regulators and the IAQ service and health industries have been unable to set limiting criteria for environmental assessment (Lawrence and Martin 2001, WorkSafe B.C. 2014). Although practitioners strongly suspect an *association* exists, researchers have not yet recognized a *causal* level relationship between damp and moldy homes and associated respiratory effects on occupants (NAS 2007, Mendell *et al.* 2011). Addressing these factors through medical or regulatory protocol or prevention measures has not been pursued (Wu *et al*. 2007, Mendell *et al.* 2011). Further affecting medical diagnosis, the limited recognition and attention to damp and moldy indoor environments as consequential is magnified by mold and dampness health effects mimicking flu-like symptoms such as fatigue, malaise, cough, chest pain, sinus congestion, and headache (Bornehag *et al.* 2004, Palaty 2009, UMMC 2014). The most important means of avoiding ill-health is in its prevention (WHO 2009a); but the problem requires recognition before it can be addressed in any manner.

In order to reduce these health hazards, public health, environmental, and workplace safety agencies have focused on occupant-based actions for hazard elimination or other protection methods. As these initiatives, despite even with extensive funding for government programs to intervene through material and usage bans, usage directives, and general public relations mass communication methods, have not eradicated these hazards from homes nor extensively modified the mannerisms necessary to change personal habits. In addition, mold can be a non-visible hazard making it inherently more difficult to motivate health care systems and the general public to more fully address its consequences. An alternate method, with motivation based on substantial financial benefit to stakeholders, including public health regions and affected patients, is proposed to elicit an effective long-term positive shift towards systematically addressing indoor environmental respiratory disease prevention from indoor mold and dampness.

This thesis hypothesizes that a substantial benefit is available in the form of significantly reduced health care costs and substantially improved patient health condition based on a proactive initiative of remediation of indoor residential environments of mold and dampness. This thesis will utilize both researched and developed data for mold and dampness affected high-use asthmatics and consider a sustainable prevention program through the public health care system (PHCS) to test this hypothesis.

1.3 Thesis Outline

Chapter 1 introduces the problem of indoor dampness and mold and consequential ill-health, the author's motivation, and provides an outline of the thesis. Chapter 2 reviews previous research and outlines the extent to which occupant well-being in indoor environments is impacted by mold and dampness, including economic impact on patients, the public health care systems and society at a whole. Chapter 3 introduces the HEALTH^2 model and tool for the quantification of indoor mold and damp environments in relation to occupant health hazard levels. Chapter 4 presents a social cost benefit analysis on the economic effects of addressing mold and dampness in residential environments and defines the benefits to the public health care system, patient, and society at large from a proactive approach. Chapter 5 presents the current and proposed state of the health care industry with respect to diagnosis of environment induced asthma pertaining to indoor mold and dampness; discusses the gaps between regulated workplace environments and unregulated residential environments; proposes an integrated sustainable environmental asthma prevention program with an overview of a proposed pilot project; and concludes with summary findings. Chapter 6 revisits the thesis research objectives and methodology, presents the overall summary conclusions, contributions, and limitations, and concludes with recommended future research.

Chapter 2 Literature Review and Data Description

A comprehensive review of the current literature was conducted in the following areas and organized in sections. Section 2.1 outlines the chapter methodology; section 2.2 reviews extent and effects of illness from indoor environment hazard exposure including subsections 2.2.1 health consequence from mold and dampness exposure, 2.2.2 connection among indoor mold, dampness, and respiratory disease, 2.2.3 asthma representing mold and dampness induced respiratory disease, and 2.2.4, the fraction of asthma attributable to mold and dampness. Section 2.3 reviews the quantification of indoor environment condition assessment including subsections 2.3.1 mold testing methods and shortcomings, and 2.3.2, other assessment methods. Section 2.4 reviews the economic impact of asthma from indoor mold and dampness and the decision-making tools available for assessment, with subsections 2.4.1 the direct burden on the PHCS, 2.4.2 the indirect burden of asthma, 2.4.3 the external burden of illness, and 2.4.4, the benefits of mold and dampness removal. Chapter 2 concludes with section 2.5, the review of occupant and patient health benefits from removal of mold and dampness present in indoor environments.

2.1 Methodology

The literature review was conducted thoroughly by accessing 4 sources: 1) recent peer reviewed journal papers using academic search engines (i.e. Web of Science, Compendex, Pub-Med, and Google Scholar); 2) specific journal tables of contents; 3) public web-based general literature; and, 4) industry sources. Publications were chosen based on study duration, subject matter comprehensiveness and relevance, and study design. In excess of 600 research papers and public documents were reviewed with 231 of those included in the bibliography because: 1) they were specific to the subject matter; 2) the research results were well substantiated; and/or 3) similar literature was not already recorded. Keywords used include: mold, toxic mold, fungi, mycotoxins, dampness, moisture, asthma, allergy, respiratory symptoms, sick building syndrome, IAQ, residential IAQ hazards, social cost benefit analysis, and sustainability. Publications from the past 20 years have been considered to have merit. Older research contains knowledge and methodological limitations, and/or considerations deemed inconsistent with current research except for those that were considered primary citations. The oldest research was included for original subject matter. Statements derived from the author's professional experience were not referenced (see chapters 3, 4, and 5).

Peer-reviewed journal publications were assumed to be accurate except where noted. Differences in study design and language, controls, study sizes, and inherent bias were assessed when important in data interpretation. PHCS cost data was gathered from hospital demand records retrieved from journal research and validated in part and as required with health care professional interviews to fill gaps. Cost and utilization data derived from hospital demand records that could be accurately isolated into the high-use asthma category were compared to and supplemented with data gathered from literature review and in-person surveys with hospital administrators and physicians. Information gathering was conducted face to face and by phone with practitioners in multiple fields, such as medicine, building science, and economics. Interviews were conducted with asthma and allergy care doctors, emergency room, family, and walk in clinic doctors, specialist practitioners and skilled service providers, experts contacted from professional referrals, the Interior Health Authority, and Kelowna General Hospital to gather pertinent information. In each case, topics were provided in an ordered manner for discussion such that information gathering bias was reduced. Refer Table 2-1 for specifics.

Table 2-1 Professional in-person and email surveys

Practitioner type	Interview type	# of indiv.
ED professional	in-person	2
GP/ walk-in	in-person	2
Hospitalist	in-person	1
Asthma specialist	in-person	2
Allergist	in-person	1
Respiratory specialist	in-person	3
	e-mail	1
Pharmacist	in-person	2
Microbiologist	in-person	4
	e-mail	5
Health Administrator	in-person	2
	e-mail	7

2.2 Extent and effects of illness from indoor environmental hazard exposure

People in developed nations spend more than 90% of their time indoors with more than half of that time in their home environments (U.S. EPA 1989). The World Health Organization (WHO), an international organization that leads discussion on health issues, as early as 1984 reported that up to 30% of new and remodelled buildings worldwide may be the subject of complaints related to IAQ (U.S. EPA 1991). This statistic has not changed (U.S. EPA 2014d). Residential housing regularly exhibits problems with indoor contaminant bio-hazards that can cause respiratory ill-health, such as mold, microbial volatile organic compounds (mVOCs), bacteria, and chemical contaminants including formaldehyde, dioxides, ozone, and volatile organic compounds (VOCs), as well as minerals and elements transformed into products and materials used in our environment, including, asbestos and lead, and naturally occurring elements, like radon (CMHC 2011, U.S. EPA & U.S. HUD 2014). As well, buildings are known to develop long-term IAQ related problems from poor operation, deferred maintenance, and inadequate building design for pre-described occupant activities; those problems culminate in ill-health (Fisk et al 2000-2010, U.S. EPA 2011).

The quality of housing conditions plays a decisive role in occupant health (Bonnefoy 2007, WHO 2014b). Exposure to microbial contaminants is clinically associated with respiratory symptoms (WHO 2009a). These impacts are exacerbated by improper ventilation and air mixing, insufficient air filtration, water intrusion and extended high internal moisture levels, and lack of care of habitat (Fisk 2000, ASRAE 2007, 2012), with the prevalence of building dampness or mold environments occurring in 20-50% of North American homes (Verhoeff and Burge 1997, Zock 2002, Fisk *et al.* 2007, 2010, LBNL 2014). The terms “mold” and “dampness” are generally combined in the literature, with discussions pertaining to mold only typically including dampness as background criteria. Dampness is a primary element necessary for mold growth, in addition to metabolic requirements for oxygen and nutrients, and must be present to cause mold sporulation (Park *et al.* 2006).

Epidemiological and population health studies have shown a moderate to strong association between poor residential indoor air quality (IAQ) and asthmatic symptoms and frequency (Bornehag *et al.* 2004, Howden-Chapman 2007, Dales *et al.* 2008, Bernstein *et al.* 2008, Crook & Burton 2010). The Sahakian *et al.* (2008) and Fisk *et al.* (2010) meta-studies observed that dampness and mold in homes are associated with statistically significant increases in respiratory infection and bronchitis. IAQ related problems, particularly toxic mold development from dampness, are found in housing and considered to be a significant contributor to poor health; moreover, occupant health improves upon relocation (Lawrence and Martin 2001, Howden-Chapman 2007). Notwithstanding the many contributing environmental and health factors involved, this thesis will focus on research where specifically mold and dampness has been reported as contributing to the occupant or patient burden of illness to validate a proactive, prevention program. Limitations and overlapping factor discussions and bias considerations are provided in section 6.4.

2.2.1 Mold exposure, dampness, and health consequence

Indoor dampness and mold growth have been identified as risk factors to occupant health (Antova *et al.* 2008, WHO 2009, NYSTMTF 2010, Fisk 2010, Keall *et al*. 2012). Health effects from the type and amount of mold present in a home, the degree of exposure, and the otherwise general existing health condition and history of the occupant can range from insignificant short-term effects to significant allergic reaction and illness (CMHC 2011). High levels of airborne mold affect most of the population to varying degrees (U.S. EPA 2011) but those who are more seriously affected are the environmentally sensitized, immune compromised, or those with underdeveloped immune systems, particularly the elderly and children (Simoni *et al.* 2005, Antova *et al.* 2008, Tischer *et al.* 2011).

Molds are microscopic fungi that are highly adapted to grow and reproduce rapidly in damp to semi-damp environments. Excess moisture leads to growth of fungal colonies that produce spores and hyphae that generate allergens, microbial toxins (mycotoxins or biotoxins), and microbial volatile organic compounds (mVOCs) through the mold lifecycle, all potential health hazards in indoor air (WHO 2009a). Specific molds cause allergenic reactions in some humans and pathogenic (a significant health concern) response in others. A higher level of exposure to living molds or a higher concentration of allergens on spores and mycelia results in an increased risk of illness, although levels and limits that cause illness are not well-understood (Brandt *et al.* 2006, WHO 2009a). In the absence of this knowledge and with it a level of rigor, it is generically recommended that dampness and mold-related problems be prevented (WHO 2009a), without proviso for attended rigor.

Symptoms from mold exposure can include sore throat, nasal congestion or chronic runny nose, cough, wheezing, and increased asthmatic and allergic symptoms that can be diagnosed as flu-like effects (Bornehag *et al.* 2004, Palaty 2009). Inhalation of fungal spores or their toxins can cause infections such as aspergillosis. MVOCs are capable of causing irritation to the eyes and upper respiratory tract, allergic broncho-pulmonary aspergillosis, and sinusitis. Mold exposure is linked to several forms of hypersensitivity pneumonitis (Douwes *et al.* 1998, 2003, IOM 2004). Exposure to mold antigens has long been implicated in the development of symptoms of perennial allergic rhinitis (Seuri *et al.* 2000, Mendell *et al.* 2011).

On one side of the current discussion, the Institute of Medicine (2004) concludes, "standardized methods for assessing exposure to fungal allergens are essential, preferably based on measurement of allergens rather than culturable or countable fungi" in order to obtain a clear understanding of the effects of building-related health issues. While, alternately, current evidence does not appear to support measuring specific indoor microbiological factors to guide health-protective actions from a first approach methodology (USEPA 2014c). It is suggested that qualitative assessments of visible mold, dampness, water damage, or mold odor have more consistent association with health effects (Mendell *et al.* 2011). The lack of a quantifiable disease connection to indoor mold may in part be due to the broad use of the term "mold" that comprises a wide category of specific organisms that may or may not be present or elicit illness in individual humans, partly due to the highly individual responses of human systems to environmental exposures, and partly due to the possible synergistic or antagonistic effects of exposure to multiple other contaminants. The difficulty in quantifying human exposure to mold and dampness is an obstacle in determining cause-and-effect relationships. Accordingly, dose–response relationships and the determination of acceptable reference dosage are not yet achievable.

2.2.2 Residential indoor mold, dampness and respiratory disease

Ill-health in the form of respiratory disease and flu-like symptoms, wheeze, cough, upper and lower respiratory symptoms are associated with indoor mold exposure (Krieger et al. 2010, Mendell *et al.* 2011, AIHA 2013). Adverse response to mold can occur when airborne fungi, in the form of spores or hyphae, are inhaled, absorbed, or ingested (Brandt *et al.* 2006). The prevalence of respiratory symptoms was consistently higher, 50% for lower respiratory and 20-25% for upper respiratory systems, in homes with reported molds or dampness, totalling 37.8% of the 13,495 homes surveyed in Canada (Dales *et al.* 1991). Prevalence was consistently 30% to 50% higher in US research (Zock *et al.* 2002, Fisk *et al.* 2007, Verhoff and Burge 2007, Sahakian *et al.* 2008, IAQ 2014). Verhoeff and Burge (1997) have determined that fungi (mold) cause allergenic disease. Residential dampness and mold are associated with substantial and statistically significant increases in both respiratory infections and bronchitis (Fisk 2010). Fisk further states that effective control of dampness and mold in buildings would prevent a substantial proportion of respiratory infections.

Ill-health from mold ingestion was observed in contaminated buildings, with persistent non-specific symptoms such as headaches, lethargy, and eye, nose, and throat irritation commonly termed sick building syndrome (SBS) or symptoms of clinically diagnosed disease ranging from mild rhinitis to potentially life-threatening hypersensitivity pneumonitis termed building related illness (BRI) (Cooley *et al.* 1998, Williams and Wilkins 1998, Craner *et al.* 1999, Cabral 2010, Straus 2011). Moisture damage and consequent mold contamination have been commonly reported in built structures (i.e. homes, schools, hospitals, work places) with an association noted between dampness or mold and adverse health effects (Bernstein *et al.* 2008). An additional study found poor maintenance and substandard construction practices lead to high levels of moisture and the proliferation of toxic molds (Singh 2010). Research and meta-analyses completed by Fisk *et al.* (2006), Palaty and Shum (2010), and Mendell *et al.* (2011) have determined that sufficient evidence exists to draw an association among mold and dampness in indoor environments and a greater risk for adverse respiratory health conditions including asthma.

2.2.3 Focus and strength of association among asthma and indoor mold and dampness

Although dampness and mold has been consistently associated with numerous other respiratory issues (Mendell *et al.* 2011), this thesis chose asthma as a case study because, 1) it is the single most common chronic disease of childhood, affecting more than three million children in the US (Kercsmar *et al.* 2006), 2) the impact of asthma on the public health care system and economy exceeds $62 billion annually (CDC 2014), 3) asthma rates continue to climb (PCAC 2007), and 4) the environmental and medical impact is known to be reversible (Burr *et al.* 2007). Research has begun to isolate mold, mold allergens, and mycotoxins, alongside dampness that causes mold, as contributing to respiratory ill-health for onset and exacerbation of asthma (WHO 2009a, Mendell *et al.* 2011, Dick *et al.* 2014). Lawrence and Martin (2001) document the consequences of mold exposure in buildings to include asthma, allergies, hypersensitivity disorders, rhitonitis, and severe respiratory infections. Specifically, current asthma is attributable to mold/ dampness in US homes (Mudarri and Fisk 2010); with a 30 to 50% increase in respiratory health outcomes (Sahakian *et al.* 2008). Asthma is a chronic inflammatory respiratory disease that causes the airway to narrow, reducing air flow in and out of the lungs during an attack (WHO 2014a). Asthma onset and exacerbation are two conditions addressed in the literature. Inhaled substances and particles are the strongest risk factors for developing asthma. Medication and trigger avoidance can reduce severity (WHO 2014a).

Molds can trigger asthmatic episodes; therefore sensitive individuals with asthma should avoid contact with or exposure to molds (U.S. EPA 2011). Mold fungal spores were the cause of a seven-fold increase in asthma emergency department (ED) admissions, which equated to 8.8% of ED admissions for asthma among children (Dales *et al.* 2000). A 3 to 15 fold increase was observed in building related disease symptoms and building related asthma from exposure to significant levels of *Stachybotrys chartarum* and *Aspergillus species* (Williams *et al.* 1998). To avoid ill-health associated with respiratory distress, allergies and asthma from microbial contaminants, the most important action is to prevent dampness and microbial growth where we congregate indoors (WHO 2009a). Accordingly, asthma was chosen as a representative respiratory disease to review the benefits of proactive environmental remediation of damp and moldy indoor home environments notwithstanding numerous other respiratory afflictions, such as, bronchitis, allergic rhinitis, and respiratory infections along with asthma that may be solely or partly mold and dampness induced. Further analysis for the other potential environmentally-induced respiratory diseases and infections from mold and dampness is left for further research.

Onset and exacerbation of asthma has its roots in many aspects of life and is affected by: ethnicity, age, sex/gender, obesity, socio-economic status, nutrition levels, existing health and genetics, ETS, SHS, wood smoke, pet dander, gases, and other environmental stressors (Dick *et al.* 2014, WHO 2014a). Accordingly, this thesis in its methods has chosen to validate a proactive prevention program for mold and dampness in indoor home environments, a program that will consider mold and dampness as one of the many possible factors associated with asthma. From a review of a number of workplace and residential studies, Jaakkola *et al.* (2002) attributed asthma in part to mold exposure. Environment-induced asthma can be caused by high levels of exposure to mold, dust mites, and cockroaches (Kercsmar *et al.* 2006), or exacerbated by dampness and molds in homes (Dales *et al.* 1991, Fisk *et al.* 2007, 2010). Exposure to specific molds (*Aspergillus fumigatus*, A*lternaria alternata, Penicillium chrysogenum, Stachybotrys chartarum*) are associated with onset and exacerbation of asthma (Dales *et al.* 1991, 2000, Bornehag *et al.* 2004, Health Canada 2004, IOM 2004, Bush *et al.* 2006, Kercsmar *et al.* 2006, Fisk 2007, 2010, Holme *et al.* 2010); bronchial inflammation and constant allergic response in asthmatics (Srikanth *et al.* 2008); and dyspnea, wheeze, cough, eczema and respiratory infection (Mendell *et al.* 2011). Asthma incidence and prevalence has been deemed a by-product of unhealthy home environments (Rosenstreigh *et al.* 1997, Nafstad *et al.* 1998, Engvall *et al.* 2001, Zock *et al.* 2002, Zureik *et al.* 2002, Daisey *et al.* 2003, Perry *et al.* 2003) that can be caused and/or exacerbated by exposure to high levels of mold and dampness (Dekker and Dales *et al.* 1991, Kercsmar *et al*. 2006, Antova *et al.* 2008, U.S. EPA 2014).

Further, the literature identifies an association between exposure to mold and/or dampness, and irritative and non-specific respiratory symptoms, as well as the exacerbation and development of respiratory disease such as asthma (Sahakian *et al*. 2008, Mendell *et al.* 2011). Specifically, recent research associates indoor mold burden and particular molds to the onset and exacerbation of asthma in children (Mendell *et al.* 2011, Reponen *et al.* 2011, 2012, Kennedy and Grimes 2013) with Mendell *et al.* (2011) noting the evidence is strongly suggestive of causality. Jaakkola and Jaakkola (2004) determined an increased risk of asthma with indoor molds, providing an OR of between 1.3 and 2.2 with some evidence that a dose-response relationship and more severe mold-related health issues exist with a higher OR and increasing evidence that severity of asthma is increased by indoor molds. Further, Jaakkola *et al.* (2005) identify parental atopy (increased genetic disposition) and exposure to molds as strengthened independent effects on the development of asthma. The incidence of asthma in children more than doubled between 1980 and

1995 (CDC 2005). Research has identified *Aspergillus* and *Penicillium species*, among other fungi, as agents responsible for the onset or exacerbation of asthma. The Public Health Agency of Canada (2007) highlights *Aspergillus fumigatus* as a common pathogen that is associated with invasive aspergillosis in immune-suppressed patients in a number of case studies. A number of other reviewed journal papers and government articles measured this association as significant to very strong with mold and mycotoxin inhalation likely resulting in chronic SBS or asthma related symptoms through cross-sectional studies (Hodgson *et al.* 1998, Health Canada 2004, 2010, Crook and Burton 2010, Singh and Kim 2010). A number of asthma focussed studies identified a strong relationship between mold and adverse health impact in indoor environments based on site related experience, particularly the onset or exacerbation of asthma and other physical responses resulting in wheeze and flu-like symptoms in moldy environments (O'Connor *et al.* 2004, Simoni *et al.* 2005, Mendell *et al.* 2011). Alternately, the much higher incidence (OR 1.80 (95% CI:1.68-1.93)) of reporting asthma in the aboriginal population has insufficient evidence for determining environmental or social basis for that incidence (Ospina *et al.* 2012).

In addition to the disease itself, pharmaceutical use to treat asthma is detrimental. Side effects include osteoporosis, increased risk of heart and vascular problems, cataracts, glaucoma, diabetes, insomnia, anxiety, tremors, headaches, growth retardation and the compounding of other serious medical conditions (U.S. EPA 2001). A summary of recent supporting studies and research is provided in Table 2-2.

Table 2-2 Summary of recent supporting studies and research: indoor dampness, mold, and asthma symptoms.

Study	Agent of Interest	Conclusions
Dales *et al.* (1991, 2008)	Indoor dampness and mold	Respiratory symptoms increase with indoor dampness and mold
Koskinen *et al.* (1999), NYC (2008)	Indoor damp environments	Association with asthma, allergy, and respiratory symptoms
CDC (2002)	Prevalence of asthma in general population	Increase in asthma prevalence from 1980 – 1999. Noted success in intervention programs.
IOM (2004)	Fungal contamination and health impact	Strong association between stachybotrys exposure and health impact.
Jaakkola *et al.* (2005)	Home dampness, molds and asthma	Cross-sectional study on parental atopy and mold odor exposure on asthma development with an incidence rate ratio of 2.44 (95% CI: 1.07-5.60) indicating a 144% increase in new cases compared to no exposure; but not for visible mold or moisture.
Kercsmar *et al.* (2006)	Indoor dampness, mold and asthma	Reduction of asthma symptoms after environmental remediation.
CDC (2006)	Indoor dampness, mold, and asthma	There is sufficient evidence of an association between an increase in asthma symptoms in asthmatics and damp and moldy indoor environments.
Hope and Simon (2007)	Indoor dampness and mold	Respiratory symptoms occurred with indoor dampness and mold.
Howden - Chapman (2007)	Indoor dampness, cold and respiratory symptoms	Marked decrease in doctor/ hospital visits after renovation.
Health Canada (2007)	Indoor mold and asthma	Association with asthma symptoms.
Sakakian *et al.* (2008)	Indoor dampness, mold and asthma	Association between dampness, mold, and asthma. 1.56 (95%CI: 1.30-1.86) for current asthma and 1.37 (95%CI: 1.23-1.53).
Antova *et al.* (2008)	Indoor mold and respiratory health	Indoor mold consistently associated with respiratory ill-health.
Fisk *et al.* (2010)	Indoor dampness and mold	Statistically significant increase in respiratory infections.
Cabral (2010)	Indoor dampness and airborne fungi	Association between fungal growth and sick houses and buildings
Pongracic *et al.* (2010)	Fungal contamination in homes and asthma	Association with cause of poor asthma and need for home renovations
Reponen *et al.* (2011 & 2012)	Indoor mold and asthma	2.6 (95%CI: 1.10-6.26) OR that 1 yr old children will have asthma from a high ERMI house (hydrophilic inclined environment). Parental asthma, house dust mite were also risk factors for asthma. Three mold species were significantly associated with asthma OR 2.2 (95%CI: 1.8-2.7).
Mendell *et al.* (2011)	Indoor dampness and mold	Consistent positive associations: asthma development; asthma exacerbation; with no confirmed association with ever diagnosed or current asthma.

Study	Agent of Interest	Conclusions
Keall *et al.* (2012)	Dampness and mold and respiratory health in homes	An 11% increase in the odds of an asthma attack over the next 12 months after increase in dampness and mold detected.
Quansah *et al.* (2012)	Dampness and molds and risk of asthma development	From 16 studies, mold exposure to asthma onset had an OR 1.5 (95%CI: 1.25-1.80); dampness 1.31 (95%CI: 1.12-1.56); visible mold 1.29 (95%CI: 1.04-1.60); and mold odor 1.73 (95%CI: 1.19-2.50).
Deck *et al.* (2014)	Visible mold exposure and asthma risk	OR 1.5 (95%CI: 1.4-7.1)

The Sahakian *et al.* (2008) study findings from six studies are further detailed in Table 2-3 which relates mold and dampness to asthma with an odds ratio (OR) range of 1.1 to 4.7 at a 95% level of confidence for 9 of 14 results. The overall results from Tables 2-2 and 2-3 indicate 47 study outcomes with sufficient evidence and 5 study outcomes without sufficient evidence of an association. The results also demonstrate that environmental effects can be subtle and may vary by study and studies vary in assessment focus that can lead to difficulty in determining consistent effects levels overall.

Table 2-3 Epidemiologic studies investigating an association among indoor dampness or mold and new-onset asthma or new-onset asthma-like symptoms that use odds ratios as a measure of risk.

Reference	Study design	Environmental exposure	Health outcome	OR (95% CI)
Adults				
Flodin and Jönsson (2004)	Longitudinal case-control study(20–65 years old)	Reported workplace dampness (mold or moisture damage)[a]	New-onset physician-diagnosed asthma at age 20–65 years	4.7 (1.5–14.3)
Gunnbjörnsdóttir *et al.* (2006)	Prospective study with a 7.9-year follow-up period (mean age at follow up: 40 years)	1.Reported dampness 2.water damage, leakage, or mold growth) in the home[b]	New-onset asthma attack or current use of asthma medications[c]	1.1 (0.9–1.4)
			New-onset wheeze[c]	1.3 (1.1–1.5)
			New-onset nocturnal dyspnea[c]	1.3 (1.1–1.6)
			New-onset nocturnal cough[c]	1.3 (1.1–1.4)

Reference	Study design	Environmental exposure	Health outcome	OR (95% CI)
Jaakkola *et al.* (2002)	Population-based incident case-control study (21–63 years old)	Reported visible mold or mold odor at work[c] and 1. No wall-to-wall carpet at work 2. Wall-to-wall carpet at work	New-onset physician-diagnosed asthma with both reversible airways obstruction and a history of at least one asthma-like symptom	1.4 (0.9–2.1) 4.6 (1.1–19.4)
Children				
Wickman *et al.* (2003)	Prospective study of a birth cohort from age 2 months to 2 years of age	Reported water damage, windowpane condensation, visible mold, or mold odor when child was 2 months of age	Three or more episodes of wheezing after age 3 months and either use of inhaled steroids or symptoms suggestive of bronchial hyper-reactivity	1.7 (1.3–2.4)
Emenius *et al.* (2004)	Nested case-control study of a birth cohort (2 years old)	1.One sign of dampness based on home inspection 2.Three or more signs of dampness based on home inspection	Three or more episodes of wheezing after age 3 months and either use of inhaled steroids or symptoms suggestive of bronchial hyper-reactivity	1.3 (0.8–2.2) 2.7 (1.3–5.4)
Pekkanen *et al.* (2007)	Population-based incident case-control study (1–7 years old)	1. Mold odor based on current home inspection 2.Visible mold based on current home inspection 3.Visible mold in main living area based on current home inspection 4. Water damage in main living area based on current home inspection	New-onset physician-diagnosed asthma or new referral to hospital after two or more attacks of wheezing	4.1 (0.6–26.0) 1.2 (0.7–2.1) 2.6 (1.2–5.8) 2.2 (1.2–4.0)

a Present for 3 or more years and occurred at least 3 years before year of asthma diagnosis.
b Present any time in between the initial and follow-up survey.
c Present during the past year.

Although more recent published guidance documents support a stronger association, some credible organizations have yet to conclude that indoor mold exposure is a risk factor for asthma. For example, the World Health Organization website (WHO 2014a) excludes indoor mold and dampness from its list of fundamental asthma causes:

"The fundamental causes of asthma are not completely understood. The strongest risk factors for developing asthma are a combination of genetic predisposition with environmental exposure to inhaled substances and particles that may provoke allergic reactions or irritate the airways, such as:

- *indoor allergens (for example, house dust mites in bedding, carpets and stuffed furniture, pollution and pet dander)*
- *outdoor allergens (such as pollens and molds)*
- *tobacco smoke*
- *chemical irritants in the workplace*
- *air pollution.*

Other triggers can include cold air, extreme emotional arousal such as anger or fear, and physical exercise. Even certain medications can trigger asthma: aspirin and other non-steroid anti-inflammatory drugs, and beta-blockers (which are used to treat high blood pressure, heart conditions and migraine)".

This exposes a fundamental challenge – the acknowledgement of mold as an indoor environmental hazard worthy of remedial action, and to elevate it to critical or primary research status. Critical research conclusions opposing a strong association between indoor mold and adverse health conditions in home environments include Hardin *et al.* (2002), Kuhn and Ghannoum (2003), ACOEM (2011), and Dick *et al.*, (2014). However, Hardin (2002) recognizes scientifically documented mold-related human disease with objective clinical evidence. This includes that asthma can be due to sensitization to mold; but not for "new mold-related illnesses" stating, that a causal level association between fungal mycotoxins and health consequences is weak and unproven. To support this conclusion, the Institute of Medicine (IOM 2004) was referenced. However, IOM (2004) concluded that the studies reviewed suggest a strong association, and biological plausibility between *Stachybotrys chartarum* exposure and health effects. Further, Hardin (2002) does not address other clinically noted pathogenic or toxigenic fungi that are derived indoors from damp environments such as *Chaetomium globulum* and *Aspergillus niger*. Kuhn and Ghannoum (2003) provide that some molds are human pathogens and their review of the evidence regarding indoor mold exposure and health concluded two things: 1) there is a lack of well-substantiated supportive evidence of serious illness due to Stachybotrys making such claims inconclusive; and, 2) an urgent need for studies using objective markers of illness is recommended. A more recent association assessment by Dick *et al.* (2014) between environmental exposure and development of asthma in young children questions any single exposure and suggests interaction among the many possible environmental factors complicates results and that asthma risk may be related to diversity of exposure, not exposure per se. Denning *et al.* (2006) considered that mold exposure is highly variable, common to both indoors and outdoors, and is difficult to measure. Together their argument against a strong association determination at this time is to be considered.

2.2.4 Fraction of Asthma attributable to indoor mold and dampness

Asthma affects more than 28 million North Americans from a well-documented array of contributing factors for both onset and exacerbation, as presented in section 2.2.3, including mold and dampness. The fraction for mold and dampness affected asthmatics has been researched. Mudarri and Fisk (2007) attribute 21% (95% CI: 12 to 29) of the onset and exacerbation of asthma to indoor mold and dampness. The Zuriek *et al.* (2002) study of multiple countries attributes 22.1% (no confidence interval) and Jaakkola *et al.* (2002) calculated the attributable factor to be 35.1% (95% CI: 1.0 – 56.9) from workplace mold contact based on an adjusted odds ratio (OR) of 1.55 (95% CI: 1.01-2.32). Odds ratios compared to relative ratios are typically higher values as noted in Jaakkola's work and by replacing RR for OR in the calculation the attributable fraction is adjusted to 20.8%. The mean value of 21.3% (95% CI: 20.7 to 21.9) is used in calculations to value the overall population size of those affected by mold and dampness to define that demographic. This is summarized in Table 2-4. Research into the interplay between contributing factors and possible overlapping effects has not been conducted.

Table 2-4 Fraction of Asthma attributable to indoor mold and dampness

Mudarri & Fisk 2007	21.00%	95%CI: 12-29
Zureik *et al.* 2002	22.10%	no CI
Jaakkola *et al.* 2002	20.80%	35.10%*
	Mean	**21.30%**
	SD	**0.57%**

* Adjusted for OR to RR for 20.8%

2.3 Quantifying indoor environment condition assessment

The current industry indoor environment assessment methods are based on visual, qualitative assessment with limited quantitative measuring of the condition of the indoor environment for moisture levels, size of surface mold staining, and in some instances, bulk and air testing. Prescriptive methods are undertaken to define in situ conditions in relation to the status quo or optimal state, taking into account: visual staining; active water; relative humidity; odour; ventilation and filtration; cleanliness and hygiene (NYSTMTF 2010, IICRC 2014). Current sampling techniques for molds are not considered useful and may misrepresent conditions (Worksafe BC 2002, CDC 2005, WHO 2009a, Mendell *et al.* 2011, CMHC 2013, U.S. EPA 2001, 2013). There is a need for simple assessment methods that quantify the risk of respiratory ill-health in homes (Keall *et al.* 2012).Quantitative assessment becomes a critical component to progress beyond the limitations of current methods (Haverinen 2002, Keall *et al.* 2012).

2.3.1 Mold testing methods and shortcomings

Dormant mold spores can pose health risks from exposure (FDoH 2011). Subsequent water events will render those spores viable again and possibly allergen and mycotoxin producing (National Archives 2014). When future indoor environmental dampness or spore contact with wet surfaces, such as nasal passages or throats occur, at water content level required for viability, spores become viable and thus begin to sporulate and create airborne allergenic material or toxins which may lead to asthma or other respiratory events. The conditions co-exist, but mold on its own is a cause for concern; and dampness alone is not (Jaakkola *et al.* 2002, Fisk 2010).

Hazards in indoor environments can be identified and measured using a number of capturing and monitoring methods. However there are no human health-based threshold limit values for airborne or bulk mold concentrations in indoor environments as a determination of acceptable concentration levels for indoor mold and as such assessment remains qualitative (U.S. EPA 2014c, WorkSafe 2003, 2014a,b). A strategy is required to focus in on solutions that include: what is to be measured; how sampling should be conducted; number and types of samples; and whether sampling is of the ambient or personal airborne type (WHO 2009a). Each method has its constraints that must be factored into IAQ protocols for assessment and monitoring over time or capturing the existing condition of the indoor environment accurately. As such, where high levels of accuracy are required, several overlapping methods are used, but with limitation.

Mold testing is conducted through bulk or air sampling for the determination and measurement of viable (culture based) or non-viable (non-culture based) spores, or molecular analysis (MBL 2014). For non-culture spore analysis, microscopy and spore counting is used. Culture based analysis requires more thorough microbiological assessment for general classification. Non-viable air testing collects discrete amounts of airborne debris by drawing air through a micro-cassette using vortex action to deposit the debris on a slide. Typical air volumes are 45 to 150 litres depending on expected contamination levels. Microscopic analysis determines extent of non-viable microbial deposit by counting spores within defined species groupings (by image) as well as providing quantitative measurements for dust, dander, and lint levels for further assessment. Non-viable mold testing is documented as spores per cubic meter collected by mechanized methods such as impaction samplers (Burkard, Allergenco) and cassette samplers

(Air-O-cell) or in spore types from tape lift or dry swab sampling. Viable air testing is conducted using drop plates (petri dishes) of agar specific to molds of interest and by mechanized methods (Anderson air sampler), that draw air over the plates for more systematic, orderly, consistent deposition. In this manner, spore genus can be determined from cultivation. This determines the amount of viable spores and genera in the air space tested in colony forming units (CFU). Each collection method has limitations and may not determine all types of fungal spores living or dormant (MBL 2014). Specialized testing is required to measure allergens, mVOCs, bacteria, and B-glucans.

Shortcomings in biological air testing include limited time and space assessment that does not, in general, determine a statistically accurate representation of the distribution of fungal products in the indoor environment tested over time (MDH 2014). The actual test and assessment methods are described by ASTM (2014) or NIOSH (2003) protocols, which assist in defining common criteria from test results that can be compared over time from project to project. Sample analysis is to be conducted by a certified lab. Testing for viable and non-viable molds; bacteria; and chemical compounds can become prohibitively expensive for residential clients. Due to the inherent shortcomings in testing and specifically how testing methods are applied, a technique developed by U.S. EPA-sponsored research for estimating the level of mold impact under scrutiny is the mold specific quantitative polymerase chain reaction (MSQPCR) analysis, currently in the prototype stage (Vesper 2011). This requires more specialized equipment and specialized control analyses, but provides DNA level mold identification and ranking in relation to a database of indoor (hydrophilic type) and outdoor specific molds for comparative purposes. The hydrophilic type indoor molds are more concerning.

2.3.2 Assessment methods for mold and dampness in indoor environments

IAQ regulation and assessment requirements pertaining to mold legislated for commercial, institutional, and public buildings to maintain worker health is a complaints driven process (Worksafe 2014a). The process does not include empirical measurements for assessment and validation. Withdrawal of complaint (without merit), or instituting methods to reduce future complaints/issues by fiat are resolution methods (U.S. EPA 2013, WorkSafe 2014). To facilitate evaluation and guidance for the reduction of environment induced respiratory disease from mold and dampness, a reliable empirical indoor environment risk assessment tool is needed (Keall *et al.* 2010).

Although an assessment tool was not pursued, Haverinen (2002) proposed using a diagnostic approach to understand environmental effects on unhealthy residential occupants and comparing study results identified in his paper. More recently, a housing environmental assessment model with empirical validation has been suggested as a basis for improving respiratory health through the eliminations of mold and dampness (Keall *et al.* 2010, 2012). Predicting building related respiratory symptoms with environmental exposure response relationships and suggesting indices of exposure to dampness and mold can support action to prevent building-related respiratory disease (Park *et al.* 2004). However, all models developed to date to evaluate the risk of mold causing health impacts in homes have shortcomings (Vereecken and Roels 2012). These shortcomings include non-conclusive, non-predictive conditions, and an incomplete evaluation method to assess the composite of environmental factors that comprise indoor environments. The models found in literature fall into four categories - deterministic; predictive; index; and dose response – as listed in Table 2-5.

Table 2-5 Existing indoor environmental assessment models/ tools

Name	Category	Reference	Qualities	Limitations
ERMI	Deterministic	Vesper *et al*. (2007)	DNA based mold ID. Identifies moisture based molds and may allow for mold burden estimates.	Not health predictive. Does not include a visual assessment or measure airborne molds.
Walk thru only	Deterministic	CMHC, Health Canada, U.S. EPA (2012)	Inexpensive. Immediate. Helpful in finding visual evidence. Health predictive	Qualitative. Non-empirical.
IEA–Annex 14	Deterministic	Acco, Leuven (1990)	Proposes a time dependent relative humidity threshold	Component of holistic assessment. Not health predictive.
Time of wetness	Deterministic	Adan (1994)	Determines water availability/ WC/RH for mold growth.	Component of holistic assessment. Not health predictive. No general conclusion
Johansson mold growth indices	Deterministic	Johansson *et al.* (2010)	Estimates mold growth on surfaces from RH and temp.	Component of holistic assessment. Not health predictive.
Fungal index	Deterministic	Abe *et al.* (1996)	Environmental capacity for mold growth based on *e. herbariorum.*	Reliability questionable. Component of holistic assessment. Not health predictive.
VTT model	Predictive	Hukkan Viitanen (1999)	Mold index for mold growth prediction model based on response time and material influence.	Based on various assumptions. Empirical. Component of holistic assessment. Not health predictive.
Isopleth models	Predictive	Ayerst (1969) Smith & Hill (1982) Clarke *et al.* (1999) Sedlbauer (2001)	Based on RH, water activity, temperature, exposure time, mold risk inter-relationships.	Component of holistic assessment. Not health predictive.
Respiratory hazard index (RHI)	Index	Keall *et al.* (2012)	A count of housing characteristics linked to respiratory health of occupants.	Not inclusive of the house as a system. Linear assessment tool. Not flexible to home type variability.
Healthy housing index (HHI)	Index	Healthyhousing. org.nz/research (2014)	House condition measurement tool of how likely occupants will suffer ill-health.	Study stage only. No detailed information provided for assessment.
I	Predictive	Haverinen *et al.* (2001,2002,2003, 2006)	Housing characteristics associated with excess moisture and consequential damages and health impacts such as asthma	Certain environmental characteristics compared to risk of moisture damage were favourable but not occupant health conditions (asthma).
HHSR	Deterministic	UK 2006 ISBN-10:185 1128965	Guidance on risk assessment approach to all house hazards	Broad brush, generic approach. Incomplete.

Name	Category	Reference	Qualities	Limitations
IEQAT	Dose/response	Ncube *et al.* (2012)	For environmental hazard assessments – chemical only	Requires fugacity coefficients and permissible exposure limits.
Other IEQ models	Deterministic	Chang *et al.* (2009) Lai *et al.* (2009)	Inclusive of light and sound, thermal, IAQ. AHP based.	Based on quality of life, not ill-health based.

These models and tools assess elements of indoor environmental quality using deterministic, predictive, dose/response, and index methods. No one model or tool is predictive of the whole environment, but all support the identification or valuation of components of the indoor environment. Only the Respiratory hazard index model is health predictive.

Environmental characteristics and methods introduced in these models can serve as components of a holistic indoor home environment model. For example, Haverinen *et al.* (2001, 2002, 2003, and 2006) identifies housing type components that predict health response using a simple moisture damage classification tool. Other components that affect indoor environments are the building envelope, ventilation, filtration, exacerbated by nutrient levels and occupant loads that allow mold growth (CMHC 2013, U.S. EPA 2013). The building envelope defines the extent of the conditioned living environment and protects the indoor environment from external elements (CMHC 2013). Moisture and airborne debris control is managed by indoor and external ventilation and extent of air filtration (ASHRAE 2007). A well designed building envelope reduces the risk of moisture intrusion and defines the dew point location for dampness analysis (WHO 2009a, U.S. HUD 2013, CMHC 2013). Mold activity does not exist without both moisture and nutrients present, as source factors for mold growth (Park *et al.* 2006). Molds obtain nutrients through the decomposition of organic sources inherent in building components, such as cellulose. This is exacerbated by dust, lint, organic debris, and nutrients normally present from occupant storage and poor home hygiene levels that support extensive microbial growth (WHO 2009a, U.S. HUD 2009, Health Canada 2010, Vesper 2011). With mold proliferation a function of moisture and nutrient levels, poor quality ventilation and inadequate filtration systems lead to poor indoor environments

(WHO 2009a). These primary elements in a damp environment amplify the effects of mold growth.

In addition to housing component factors, the literature identifies family lifestyle and non-adherence to environmental medical prevention guidelines as a significant risk factor for the onset or exacerbation of asthma and respiratory disease (CDC 2005, U.S. HUD 2005-2013, CMHC 2013). Nutrient development, biological airborne debris and other indoor contaminants, and excess moisture developed from human activities including cooking and bathing, household size, and occupant burden (storage levels and types, moisture generation, systems utilization), are shown to be modifier factors in the development of mold growth in moist environments (U.S. EPA 2013, U.S. HUD 2013, CMHC 2013). Alternately, outdoor air exchange is critical to the reduction of indoor contaminants and the extent of environmental tobacco smoke (ETS) as part of airborne particulate loading in general (U.S. HUD 2006, 2009, WHO 2009a). Quantitative mold measurement through sampling is not significantly correlated with respiratory health effects (WHO 2009a).

Combined, these source (e.g. moisture and nutrients), building (e.g. ventilation), and modifier (e.g. human activity) factors provide a holistic view of an indoor environment from which health impact risk may be predicted based on building environment as a complete system, rather than its individual parts, within a science of reasoning. Table 2-6 summarizes these 13 primary risk factors, and their references, as the key indoor environment characteristics, utilized alongside the fundamentals of building science to provide a comprehensive assessment.

Table 2-6 Key indoor environmental building condition factors

	Factors	Description	Symbol*	References
1	Visual dampness	Open water on surfaces	S_{11}	IOM (2004), Rockwell (2005), U.S. HUD (2006, 2009), NYSTMTF (2010), U.S. EPA (2013).
2	Relative humidity	Active airborne moisture	S_{12}	Park *et al.* (2008), U.S. HUD (2009), WHO (2009), Mendell *et al.* (2011), ASHRAE (2012)
3	Moisture history	History of water leaks or floods	S_{13}	National Archives (2015)
4	Nutrient loose	Dust/cellulose/dirt	S_{21}	IOM (2004), ASHRAE (2007), U.S. HUD (2009), Vesper (2011), U.S. EPA (2013)
5	Nutrient dense	Wood, paneling	S_{22}	U.S. HUD (2009), Vesper (2011)
6	Particulate load	Dust/ cleaning levels	M_3: M_{31}-M_{34}	CMHC (2012), U.S. EPA (2012)
7	Occupant load	Storage/ clutter/ debris	M_{32}	U.S. HUD (2006), Krieger *et al.* (2010), CMHC (2013), U.S. EPA (2013)
8	Mold growth**	Odor/rot/dampness	M_{33}	IOM (2004), Mendell *et al.* (2011)
9	Mold stain	No odor/ dry	M_{34}	NYSTMTF (2010), IICRC S-512 (2014)
10	Air filtration	Filter type and capacity	M_2	ASHRAE (2007), WHO (2006, 2009)
11	Passive outdoor air	Operating windows, fresh air piping.	M_{111}	BC building code (2009), ASHRAE (2007)
12	Mechanical outdoor air	Air exchange on a timer or humidistat	M_{112}	Seppanen *et al.* (2002), ASHRAE (2007), U.S. HUD (2009), WHO (2009). Sundell *et al.* (2011).
13	Air ventilation	Mechanical indoor air circulation.	M_1:M_{11}/M_{12}	ASHRAE (2007), WHO (2006, 2009)

This table provides the most recent references that support the 13 key building and environment factors that form the basis for the HEALTH^2 model. The relationship between the key factors and model symbols (noted as factors in the paper) are also provided. *These symbols are further discussed in chapter 3. **Characteristic (factor) assessment can include air sampling for mold to estimate the likelihood of exposure (Dillon *et al.* 1999). Sampling, though, is discouraged for mold analysis due to the variability of results (U.S. EPA 2001, CDC 2005).

2.4 Economic decision-making tools and burden of illness for environmental asthma

In addition to physical assessment, economic assessment has been used to compare and prioritize alternatives and justify remedial action within the larger context of the competition for scarce resources across the public health care system (PHCS). Burden of illness studies estimate the economic impact of a particular disease on society in monetary terms, to highlight the cost that a particular "underappreciated" disease is extracting from society (Ramsay and Sullivan 2003). For this research, economic evaluation decision-making tools in public health were investigated, specifically those that might be useful in policy analyses and justification of health care prevention programs. The theory of economic decision-making seeks pareto-optimum solutions that allocate available resources to maximize utility and public welfare (Simon 1959). The principles of health economics utilize pareto theory as a basis for efficiency and equity (Parkin 2009). In this thesis, the burden of illness has been estimated through a social cost benefit analysis (SCBA) that draws from this welfare economics theory and enumerates direct, indirect, and external costs and benefits, and their distribution, to determine optimal solutions. For the purpose of this thesis, direct costs are defined as those incurred as part of the transaction between the PHCS (e.g. service provider) and patient (e.g. consumer), for example, the delivery of medical goods and services for illness treatment (Ramsay and Sullivan 2003). Indirect costs are those indirectly incurred, usually at some earlier or later time, such as lost productivity and yearly drug regimen (U.S. EPA 2001). External costs are those not perceived by either the service provider or consumer, that are typically paid by society as a whole, for example, loss of well-being, welfare, additional services provided to the marginalized (Fraser *et al.* 2009). The SCBA benefits would be the alternative, such as reduction in product and service requirements in the form of cost reduction or savings.

SCBA results can be presented in various forms, including: net present value (NPV), benefit/cost ratios (B/C), internal rate of return (IRR), cost effectiveness (CE), and payback periods (PP) (Fraser *et al.* 2009). In most policy analyses involving public programs, governments become involved in providing a service to society (e.g. clean water, proper sanitation) that addresses some market failure and/or public need (e.g. defence, health care), not need to make a positive NPV. In those cases, the most common SCBA techniques used include NPV, B/C, CE, and PP. The first three techniques incorporate the time value of money over the life of the program, whereas the fourth (PP) ignores it. Each has their own advantages and disadvantages, and provides different ways to look at the SCBA results depending on the decision and topics involved (Fraser *et al.* 2009). Therefore, these techniques will be investigated to analyze the prevention program envisioned in this research.

NPV > 0 is desirable, as it is the difference between the present value of total benefits and total costs generated by a project, showing by exactly how much benefits exceed (or fall short of) costs, as shown in equation 1:

$$NPV = \sum_{t=0}^{n} \frac{(Benefits - Costs)_t}{(1+r)^t} \qquad (1)$$

Where:

r = discount rate
t = year
n = analytic horizon (in years)

Yearly financial inflow/outflow is discounted back to its present value (PV). NPV is the sum of all terms. B/C > 1 is desirable, as it provides a ratio (sometimes noted as BCR, see equation 2 below) of the relative size of expected benefits to costs, a useful metric illustrating whether and by what proportion the forecast benefits of a policy might outweigh its forecast costs. Policy changes implement the alternative with the highest benefit-cost ratio to increase welfare from a utilitarian perspective.

$$BCR = \frac{PV_{benefits}}{PV_{cost}} \qquad (2)$$

Where:

$PV_{benefits}$ = present value of benefits
PV_{costs} = present value of cost

PP is a simplistic method of economic analysis that refers to the period of time required to recoup the funds expended on an investment, or to reach the break-even point (see equation 3 below). It is the least accurate of economic techniques used, but is also simplest to calculate and use, hence it is popular. Usually if PP is used, it is used with at least one other technique for reference. PP < 1 or 2 years are commonly used in government analyses (Sayed and Leur, 2009).

$$\text{Payback period} = \frac{\text{Initial costs}}{\text{Net annual benefits}} \tag{3}$$

CE analysis techniques are used most commonly when government programs are provided without expectation of cost recovery, when NPV < 0 and B/C < 1 can be expected. CE then presents results on a unit service cost basis, such as the cost to the PHCS and society to treat each patient (Bobinac *et al.* 2014, WHO 2009b). Related to CE is the concept in health care policy analysis of health loss in quality-adjusted life-years (QALY) or health gain in disability-adjusted life-years (DALY), which are both measures of health adjusted life-years (HALY).

There has been a recent surge in the use of the HALY approach as an outcome measure to evaluate public health interventions. HALY is a cost effectiveness-based metric used to justify public health policy decisions, focusing on patient quality of life (QoL) improvement; but it has its detractors and complexity challenges in developing data. It is also primarily used as a comparative tool between competing medical procedures based on finding the more cost efficient solution to various competing options to reduce subsidization or increase reimbursement (Ryen and Svensson 2014).

The concept of willingness to pay (WTP) is another measurement means for decision making. A willingness to pay (WTP) more for homes with better indoor air quality has been shown to be an attribute but based on heightened awareness of health benefits and economic well-being of the buyer as part of a demand for healthful living products and healthy homes (Wellington *et al.* 2005). HALY, and use of willingness to pay (WTP), for the CE approach is not a decision making method that has direct applicability to this thesis because the program envisioned for cost savings to the PHCS is not a reimbursement, subsidization or a willingness to pay issue.

As well, a prevention program, as envisioned, is not a comparative analysis of different intervention options, which is a criterion of QALY (Bobinac *et al*. 2014). Therefore, QALY/DALY/HALY/WTP methods are not used in this thesis. Alternately, the SCBA approach is utilized in this thesis as the time value of money and verification of a position NPV is critical to determining whether a prevention program is feasible based on the optimal solution of reduced health care costs and reduced health impact. In order to validate direct, indirect, and external cost components for SCBA calculation, the following Table 2-7 was derived.

Table 2-7 Health Care Cost Data Variable Definition

Public health care system (PHCS)	
A	Emergency Department admission
B	Critical care bed stay
C	Standard care bed stay
D	Hospital - daily drugs
E	Hospital - exit drugs
F	Doctor (GP + spec.) visits
Patient and Society	
G	Ambulance
H	Yearly Drug Regime
I	Lost days/ productivity
J	Early retirement
K	Mortality
Externalities	
L	Loss of well-being (QoL)
M	Nurse visits/ direct in-house care / family
N	Loss of patient's societal contributions
O	Welfare
P	Long term disability
Q	Low cost housing subsidy
R	Social worker/ special needs

Sources: U.S. EPA 2001, Univ. Kent UK 2012

2.4.1 The direct burden of asthma from mold and dampness in homes on the PHCS

Burden of illness studies have been conducted that developed direct costs associated with indoor mold and dampness and the onset and exacerbation of asthma among other respiratory health impacts (Krahn 1990, Health Canada 1997, Sueng 2005, Braman 2006, PHAC 2007, Sadatsafavi *et al.* 2010). In assessing the studies, higher research value was given to Canadian studies, although American and UK studies were helpful in confirming some cost boundaries.

Bahadori *et al.* (2009) was useful in verifying overall costs from a significant number of sources (68 articles from 2,073 unique citations).

Asthma treatments consume a significant percentage of PHCS budgets including doctor and emergency department (ED) visits, hospital bed stays, and medicines (Health Canada 2002, CDC 2002, PHAC 2007, Sadatsafavi *et al.* 2010). Onset and ongoing asthma exacerbations are the primary cause of doctor and ED visits as well as overnight hospital stays (CDC 2000, Stockman 2003, PHAC 2007). The ED is the admission point for emergency care. If the patient then requires hospitalization, that will be characterized as a hospital bed stay. Surveys found 28% to 56% of asthma patients required ED treatment and 6.9% to 10.1% required hospitalization (Glaxowellcome 2000, CHIS 2003, Seung and Mittman 2005, Braman 2006, Rowe *et al.* 2010, Sadatsafavi *et al.* 2010). The U.S. EPA (2001) determined 1.67 ED visits and 0.732 subsequent hospital admissions for high-use patients per year. A recent study overview on the source of ED visits in the U.S. identifies asthma as the most common reason for those less than 18 years of age to seek ED intervention (Weiss *et al.* 2014). The same study did not identify asthma as common for immediate discharge, which underlines the significant impact on the health care system by extent of ED visits and by the high percentage of ED visits that become hospital admissions.

Determining the respiratory impact, particularly asthma, of mold and dampness affected homes on occupants and the public health care system (PHCS), in part, is found through the PHAC, U.S. EPA, and CDC asthma statistics, supplemented with cumulative statistical information provided from research (Dales *et al.* 1991, Howden-Chapmen *et al.* 2007, and Fisk *et al.* 2010). The extent of asthma impact on occupants varies from mild controlled intermittent to severe uncontrolled persistent, primarily based on heredity, environmental exposure at childhood, and lifestyle. Braman (2006) indicates that the economic burden of the most severe asthmatics is

50% of all direct and indirect costs, although such cases make up only 10-20% of the asthma population. Table 2-8 provides a summary of the more germane data pertaining to asthma based impacts on the PHCS.

Table 2-8 Research summaries of asthma impacts on patients and the PHCS

- PHAC (2007)* key asthma facts:
  - Respiratory disease in Canada attributable to asthma (2005): 2,817,200 people
  - Hospitalization in Canada from asthma: 202,317* per year
  - Direct health care cost in Canada for asthma care (2000): $705.4 mil/yr
  - Indirect health care cost in Canada for asthma care (2000): $840.0 mil/yr
- CDC (2002); episode of asthma attack y1999 USA population: 10,488,000
  - 1999 annual # of doctor office visits due to asthma: 10,808,000
  - 1999 annual # of emer. room visits due to asthma: 1,997,000
  - 1999 annual # of hospital stays for asthma: 478,000 (subsequent to ED visit)
- U.S. EPA (2013): 25.9 million have asthma, including 7 million children (2010)
  - Asthma accounts for 15 million doctor office and outpatient visits and 2 million ED visits each year (2010).
  - The cost of asthma in hospital stays and lost work and school is $56 billion annually (2011).
- Howden-Chapman (2007): 38% reduction in hospital visits after homes remediated; 54% reduction in sick days from school and 39% reduction in lost work days in New Zealand.
- Kercsmar (2006): 90% reduction in asthma impact after remediation of homes for at risk patients.

* PHAC 2007 fig 5.6 & 5.7. Canada population by demographic 2004 CANSIM Table 051-0001

The variance of attributable costs and number of asthmatics with severe response levels is challenging though. Direct health care costs range from as low as $200 for mild controlled asthma to over $6,000 from Canadian references and $15,000 per person-year from U.S. references for severe uncontrolled (high-use) asthmatics (Stockman 2003, Sadatsafavi *et al.* 2010). Sadatsafavi *et al.* (2010) concluded 4.7% of the asthmatic population in his study was severe uncontrolled (high-use), consuming 60% of the overall health care budget. Given a total health care budget of $43.2

million (2013) in British Columbia (BC), this data suggest that the direct impact on the BC PHCS for ongoing treatment for severe asthma patients ranges from $331 to $6,366 per year. The U.S. EPA (2001) set the incremental direct medical cost of high-use asthmatics at $3,940 - $4,135 per year depending on patient age. When reviewed through process specific cost categories, the cost per high-use patient year is anticipated to be higher. These high costs expose an enormous economic impact and opportunity for the PHCS to benefit from isolating and addressing the source of health impact for mold-affected severe or high-use asthmatics. A summary of direct historic costs to the PHCS for high-use asthma care is provided in Table 2-9.

Table 2-9 Historic direct cost per patient to the PHCS for high-use asthma health care

Research	**Base**	**2014 adjust**	**$$ adjust CDN**	**lost prod adj.**	**$$ adjusted**
Ojeda *et al*. (2013)	$6,395 USD	0.9 %	17.0%	($1,600)	$5,949
U.S. EPA (2001)	$4,038 USD	21.6%	17.0%	0	$5,745
Sadatsafavi *et al.* (2010)*	$5,656 CAD	11.56%	0.00%	0	$6,310
Stockman (2003)	$3,572 USD	19.22%	17.0%	0	$4,982
Kim *et al.* 2012 - severe	$5,141 USD	0.70%	17.0%	0	$6,057
Kim *et al.* 2012 – uncontr.	$7,010 USD	0.70%	17.0%	0	$8,259
* 2006 costs					
				Mean	**$6,217**
				SD	**$1,001**

$$ adjustments to 2014 are based on Statscan CPI medical services subcomponent. The Canada/ USD adjustment is based on the median conversion rate in 2014.

These data, and specifically their variability and regional uniqueness, have been difficult to validate particularly due to coding variations between hospital regions, component cross-over, range of asthma severity, and the lack of detail in data provided. For example, from published studies, hospitalization costs vary from 18 to 63% of the total cost of health care. Drug costs vary from 30 to 70%. The range is found even greater in other countries due to different cultural values and methods of calculating costs. For example, worldwide meta-studies include direct costs and indirect costs. The annual mean for the burden of illness worldwide ranges from $151 to $679,091

(USD) per patient (Bahadori *et al.* 2009). To provide a higher level of confidence in asthma care costs for high-use patients, a more thorough heath care cost analysis was conducted in chapter 4 from the data developed in this chapter.

The Center for Disease Control and Prevention (CDC 2014) determined the overall impact from respiratory disease for 25.7 million U.S. asthmatics to be $61.7 billion yearly for medical cost, lost work and lost school days, and early death. As a subset, the economic burden of respiratory disease from mold contaminated damp indoor environments may exceed $50 billion dollars yearly (Fisk *et al*. 2001 through 2010). In Canada, the yearly cost impact for 2.5 million asthmatics accounts for nearly $5.7 billion in direct costs of health care, including hospitalization, physician visits, research, and drugs, and a further $6.7 billion for indirect expenses associated with disability and mortality (PCAC 2007). The impact comprises a critical and increasing economic load on the PHCS (Bahadori *et al.* 2009, CDC 2014), an increasing social burden on family and the overall fabric of society (Gelfand 2008), declining productivity in the workplace, and an overall retarding impact on our economy in North America (Fisk *et al.* 2007, 2010). Moreover, asthma rates continue to climb (PHAC 2007, CDC 2014).

From these data a significant variation in costs and category breakdown of costs was found. Canadian direct health care costs based on severity ranged tenfold from mild controlled to severe uncontrolled per asthmatic-year. The breakdown of medication versus hospitalization costs in dollar amounts and as a percentage varied drastically between studies and between geographic regions. Cost characteristics also varied by hospital ownership, and hospital teaching status. The mean cost of asthma was higher in private hospitals and non-teaching hospitals; higher in investor-owned hospitals and lower in non-profit and public hospitals. This research used information from public hospitals in democratic societies that were akin to regional hospitals in Canada or the USA to ensure results were reflective of similar culture and administrative means and methods.

Further, research on residential indoor environments suggests that there are knowledge gaps in determining the benefits of achieving residential ill-health solutions accurately (Kercsmar *et al.* 2006, Howden–Chapman *et al.* 2007, Fisk *et al.* 2007, 2010). The cost benefit range is shown to be very low or very high on a macro scale as provided by health regions and hospitals, depending on the extent and effectiveness of treatment. However, research provides data on the patient-centric approach to health care utilization and costing, and suggests that remission of asthma symptoms has been found with environmental remediation. Therefore, for this research, it is postulated that remediation of severe asthmatics' environments will achieve financial benefit based on median values and this thesis has taken the approach that a patient-centric utilization and cost accrual evaluation would be necessary to confirm the cost boundary with some certainty. The assumption is tested by sensitivity analysis in section 4.2.4. Due to the broad data variance, it was determined to conduct further analysis from the statistical data summarized in Table 2-10 using the Monte Carlo Simulation method to draw conclusions within reasonable bounds.

Table 2-10 PHCS direct process specific costs

A 1 ED visit costs

Research	**Base**		**2013**	**$$ adj**	**$$ CDN 2013**		
KGH (2010)	$238	CAD	5.40%		$251		
Malone (2001)	$234	USD	25.50%	2.5%	$301		
Seung (2005)	$290	USD	14.80%	2.5%	$341		
Sadatsafavi (2010)	$300	CAD	12.56%		$337		
Awadh (1999)	$324	CAD	32.30%		$428		
						Mean	**$331.62**
					n=5	**SD**	**58.09**

				Range	Mean		
A 2	**ED visits per year**	US EPA (2001)		1.66 - 1.66	1.66		
		Kupczyk (2012)		1.125-2.0	1.56		
		Kercsmar(2006)		1.4 - 1.4	1.4		
		KGH (2013)		1.0 - 3.0	2	**Mean**	**1.894**
		Sadatsafavi (2010)		1.86-3.85	2.85	**SD**	**0.52**
					n=5		
B 1	**Critical care bed charge**						
		KGH (2013)		2949 (2010)	3108 (2013)	**Mean**	**$3,108**
	* SD assumed at $ 100				*n=1*	**SD**	**100**
C 1	**Standard care bed charge**			**$/ night**			
		KGH (2013)		1075 (2013)	1075		
		Ontario (2013)		1010 (2013)	1010		
						Mean	**$1,043**
					n=2	**SD**	**32.50**
B 2	**Yearly hospital admissions for EMSUP**						
	Based on ED visits			**1.894**			
		Adams (2000)	67%	1.27			
		Seung (2005)	56%	1.06			
		KGH (2013)	90%	1.70			
		NAEPP (1996)	17%	0.32			
						Mean	**1.09**
					n=4	**SD**	**0.50**
B 2a	**Hospital admissions total duration per visit**						
			days				
		Malone (2001)	3.8				
		Stockman(2003)	3.85				
		Stockman(2003)	2.38				
		Seung (2005)	2.8				
		NEAPP (1996)	4.4				
		KGH (GP)(2013)	8.5				
		KGH (H) (2013)	7.5				

B 3 **Duration of hospital admissions in critical care**

KGH (2013) 1-2 days

therefore (B 2a - B 3):

* SD assumed at 1.0 per **C 2**

Mean	**1.5**
SD	**1.0**

C 2 **Hospital admissions standard care***

days
2.3
2.35
0.88
1.3
2.9
7
6

*__B 2a__ values less **B 3** mean of 1.5

n=7

Mean	**3.25**
SD	**2.17**

D 1 **Daily hospital drug cost**

	$/day (2013)
Seung (2005)	5.55
KGH (2013)	18.00

n=2

Mean	**$11.78**
SD	**$6.23**

D 2 **Drug duration** 3-5 days

3

5

n=2

Mean	**4**
SD	**1**

E **Exit hospital drugs**

		weight*
Moderate	115	23/34.4
Severe	175	11.4/34.4

Total	**$134.87**
SD	**33.72**

* weight based on moderate to severe normalized population

* SD assumed at 25% per D2

F 1 **Physician / clinic visit costs**

		CDN	**2013**	**Total**
Seung (2005)	28	1.025	14.80%	32.95
Malone (2001)	47	1.025	25.50%	60.46
USEPA (2001)	185.8	1.025	25.50%	239.01
Sadatsafavi (2010)*	60-110.4= 85	1.000	12.50%	95.85

* 2006 costs

n=4

Mean	**$107.07**
SD	**$79.37**

F 2	**Physician/ clinic visit frequency**			
	USEPA (2001)	3.49	moderate to severe	
				Mean 3.49
	* SD assumed at 50% per B2		*n=1*	**SD** 1.75

USD to CDN $$ conversion was 2.5% when the analysis was completed in 2013.

Those studies specific to mold and dampness induced asthma noted in Tables 2-2, 2-3 and in Table 2-10 and the direct cost summary provided in Table 2-9 appear to support a cost benefit analysis to determine the burden of illness implications from environmental mold and dampness induced asthma with the PHCS.

2.4.2 The indirect burden of asthma from mold and dampness in homes

The indirect burden of asthma from mold and dampness in homes includes ambulance, yearly drug regime, lost workdays and productivity, early retirement, and mortality costs to the patient and to society is described in Table 2-7. Literature provides the following data for the components noted above in Table 2-11.

Table 2-11 Indirect cost component summary

	Subject		**Calculations**				
G	**Ambulance**			**2013**	**CAD**	**TOTAL**	
	Seung (2005)		$195	14.80%	2.50%	$229.5	
	USEPA (2001)	40-50% (ave. 45%)		Of mod-severe asthmatics take ambulance			
	KGH doctors		50%	Of mod-severe asthmatics take ambulance			
		229.5* 45%		103.3			
		229.5* 50%		114.8			
							Mean $109.05
					n=3		**SD** $5.75
H	**Yearly drug regime**	**total**		100%^			
		co-pay personal		30%			
		Co-pay insurance		70%			
							weight*

Totals	Moderate	1200	1600	low - high	23/34.4
Pharmacies**	Severe	1800	2400	low - high	11.4/34.4
	Weighted range	1555.8	2074.45		

Mean	**$1,815.13**
SD	**$259.32**

* weight based on moderate to severe normalized population *n=2*
** from Kelowna pharmacies 2013
^ total personal + insurer cost valued

I Lost work days/ Lost productivity **Value**

Ojeda *et al.* (2013)	7.9*200	1580	*
Godard *et al.* (2002)	8.6*200	1720	*
Singh *et al.* (2009)	27*200	5400	*
Kim *et al.* (2011)	2761.2	2855.81	**

n=4

Mean	**$2,888.95**
SD	**$1,531.85**

* burdened salary set @ $50,000 with 250 work days/year (CDN, 2013)
** adjusted to CDN 2.5%, 2013

J Early retirement No specific data available.

K Mortality Kim 2011 6.10% total indirect costs

The tabulated data results in Table 2-11 are incomplete for full assessment usage. Another approach, provided in Table 2-12 calculates indirect cost impact from literature based on direct cost and total cost of asthma factored back to ratios of indirect versus direct asthma cost.

Table 2-12 Indirect cost impact from direct cost analysis

Source	**Range**	**Median**
Bahadori[1] (2009)	16.3-92.3%	54.30%
Bahadori[2] (2009)	49.2-112.8%	81.00%
AAFA (2011)		81.20%
Lee (2011)		81.80%

n=4

Mean	**74.6%**
SD	**11.7%**

[1]Derived from table 3 where direct cost exceeded indirect cost vs. total asthma cost
[2]Derived from table 7 relating to loss of productivity vs. total asthma cost

As a check, Table 2-12 indirect cost impact valuation based on a total PHCS direct cost would determine the indirect cost to be $ 7,460 at 74.6% of direct cost. Table 2-11 component summation totals to $ 4,813 with a SD of $1,795 exclusive of early retirement and mortality costs. These results indicate the Table 2-12 indirect cost result is within reason in comparison to the alternate incomplete option.

2.4.3 The external burden of illness by not addressing mold and dampness in residential indoor environments

In addition to direct and indirect costs of asthma on the PHCS, there are also external costs to patient, family and society including the impact on personal well-being, family, and industry, as well as an overall effect on community and society. Effects on family include loss of income, lost productivity of direct family caregiver, including parents of asthmatic children, or even loss of work (U.S. EPA. 2001). Impact on society includes economic support for patients through: 1) welfare provision; 2) special needs trained care workers conducting site visits; 3) subsidizing public transportation and housing; and, 4) bolstering reduced volunteer workforce support for public events (U.S. EPA 2001, Van Den Berg 2007). Effects on industry contribute to higher overhead costs and reduced profits whereby less capital is distributed through society. The impact on family increases stress levels affecting overall mental health (Wright *et al.* 1998). Kim *et al.* (2011) determined the externality cost of asthma on society was 100% of direct and indirect costs with a SD of 15.7% as provided in Table 2-13.

Table 2-13 Externality impacts to society

Kim *et al.* (2011)	100%	Direct	+ Indirect	
			Mean	**100%**
			SD	**15.70%**

2.4.4 Benefits of removing mold and dampness from indoor environments

The adverse effects of mold and dampness impacting the health care system and the private sector including respiratory disease and other health impacts are well known and specifically described in this thesis. Reversibility of those effects is presented in literature (EPA 2001, Kercsmar 2006, Howden 2007, Burr 2007). Research on allergic mice resulted in severe asthma response from mold allergen and fungi being reversed when ingested fungal material in macrophages was eliminated (Denning *et al*. 2006). Bernstein *et al.* (2008) observed a 99% reduction in microbial and endotoxin contamination, a 20% decrease in work symptoms, a 30% decrease in nasal symptoms, and a 40% decrease in respiratory symptoms after ultra violet (UV) irradiation of indoor environments. Kercsmar *et al.* (2006) reported the rate of asthma acute care visits was reduced by 90% after remediation of mold and damp affected homes. With the reduction of mold and dampness in homes, patient health was improved and the frequency of urgent clinical visits was reduced (Burr *et al.* 2007, Bernstein *et al.* 2008, Takaro *et al.* 2011, AIHA 2013). The health effects from indoor mold were reduced by 30 to 80% when buildings with sick building syndrome (SBS) issues were cleaned (Cooley *et al.* 1998, Harrison *et al.* 1992, Fisk 2007). The cleaning methods included removing fungally damaged surfaces, washing down walls and horizontal surfaces with soap and water or microbial detergents, cleaning surfaces of HVAC systems and ductwork and filters, steam cleaning carpets and furnishings, correcting water leaks, and educating occupants about indoor air quality benefits (Raw *et al.* 2004). This supports the need to prevent damp conditions and subsequent mold growth and remediate consequential molds and dampness in indoor environments from onset (PHAC 2007; Kilburn 2009).

PHCS benefits for removal of mold and dampness from indoor environments from review of summary literature include reduction in ED and overnight stay frequency by 62%, with Hospital admissions reduced by 72%. Hospital drug costs were reduced by 59% possibly from the downgrading of asthma affects after remediation or reduction of health affected patients. Further, physician/ clinic visits were reduced by 88.7%. Research results are provided in Table 2-14.

Table 2-14 Reduction in PSHC costs with residential remediation

A2	Howden (2007)	**ED admission**	-38.00%		
	USEPA (2001)		-33.90%		
	Kercsmar (2006)		-90.90%		
	Kercsmar (2006)		-87.00%	**Mean**	**-62.45%**
				SD	**26.58%**
B2	USEPA (2001)	**Hospitalization**	-72.50%	**Mean**	**-72.50%**
	* SD assumed at 42.6% of 72.5 per A2			**SD**	**30.90%**
D1	Burr *et al.* (2007)	**Medication**	-59.00%	**Mean**	**-59.00%**
	* SD assumed at 25% OF 59% per D2			**SD**	**14.75%**
F2	USEPA (2001)	**Clinic visits**	-88.30%		
	Kercsmar (2006)		-90.90%		
			-87.00%	**Mean**	**-88.73%**
				SD	**1.62%**

The reduction in indirect and external costs also appear significant, including impact reductions ranging from 39% to 88% in lost work days, improvements in work productivity, and reductions in drug use (U.S. EPA 2001, Burr *et al.* 2007, Cascadia 2009, Kim *et al.* 2011). The U.S. EPA (2001) intervention values are based on drug therapy, training, education, and trigger reduction. Table 2-15 summarizes research results in this area.

Table 2-15 Reduction in indirect and externality costs

Reduction in Indirect costs			
U.S.EPA (2001)	Lost workdays	-39.00%	
Cascadia (2009)	Lost WD/ incr. prod.	-40.30%	
	ave.	-39.65%	
U.S.EPA/Kerc (2006)	Ambulance	-88.83%	
Burr *et al.* (2007)	Yearly drug regime	-59.00%	
Burr *et al.* (2007)	breathing issues	-52.00%	No medical comparatives
Kim (2011)	Mortality		No reduction information
			Mean **-44.5%**
			SD **19.3%**
Reduction in Externalities*			
* no direct data from literature. Use mean of PHCS impact reductions - not weighted			
Howden (2007)	ED admission	-38.00%	
U.S.EPA (2001)	ED admission	-33.90%	
Kercsmar (2006)	ED admission	-90.90%	
Kercsmar (2006)	ED admission	-87.00%	
U.S.EPA (2001)	hospitalization	-72.50%	
U.S.EPA (2001)	clinic visits	-88.30%	
Kercsmar (2006)	clinic visits	-90.90%	
Kercsmar (2006)	clinic visits	-87.00%	
U.S.EPA (2001)	Lost workdays	-39.00%	
Cascadia (2009)	Lost WD/ incr. prod.	-40.30%	
			Mean **-66.8%**
			SD **24.2%**

Some component reduction values for indirect and external costs were difficult to deduce from literature. For example, lost work days were valued as a percentage reduction in U.S. EPA (2001) but in man days by Fisk and Mudarri (2007) with no correlation to total man days to determine a percentage valuation for analysis. The reduction percentage was necessary for cost benefit analysis. Included in the lost work days percentage from Cascadia (2009) was lost productivity, which couldn't be extricated from the data, giving a less than conservative valuation but comparative to the U.S. EPA (2001) value. The cost benefit of these reductions is provided in chapter 4. With limited externality cost reduction component values defined in literature, the reduction valuation was determined as the mean of direct and indirect reductions as presented in Table 2-15.

Commercial building health studies through LEEDS building assessment programs provided additional data, including a 30% decrease in sick days and a 10% net increase in productivity upon environmental cleanup of mold and dampness (Cascadia 2009). This provides for a private sector approach to health and wellness benefits in proactively addressing SBS in buildings that includes mold and dampness. A benefit cost (B/C) assessment was conducted by Holcomb (1994) that indicated an overall cost savings in the range of $35,000 to $70,000 per year per building or approximately $100 per worker per year by reducing SBS symptoms when taking into account reduced absenteeism due to illness in a building of workers (600 to 700 daytime occupants). The cost to upgrade buildings could achieve a 2.5 year payback on investment (Cascadia 2009). More recently, Fisk et al. (2011) identified a direct medical cost savings in reduced SBS symptoms of $180 - $185 per worker per year and over $1,000 in worker increased performance with increased ventilation rates and outdoor air.

Researchers analyzing the life cycle costs (LCA) of occupant well-being and productivity in building environments designed using Leadership in Energy & Environmental Design (LEED) demonstrated the financial benefits of increasing IAQ in buildings (Singh and Syal, *et al.* 2009). Reviewing the net benefits of LEED building indoor environment designs provides further evidence in favor of proactively instituting capital expenditures in a prevention program to reduce health care expenditures in the prevention of poor IAQ as similar conditions and circumstances exist in homes. Beyond the economic principles, commercial and residential buildings involve similar products and installation techniques in construction. Yet, residential environments have far higher probability for dampness and mold than commercial buildings, for several reasons, including: more extreme living environments, more variable occupant hygiene, lower product and operating standards and maintenance, and, lower levels of housekeeping than expected in commercial buildings. These forecast economic benefits are therefore expected to be conservative when referenced against residential environmental remediation estimates.

The research results from Singh and Syal *et al.* (2009) have been significant in showing that the health and productivity benefits outweighed the initial building outlay costs. These benefits, similar to other studies researched (Kats 2003, Stegall 2004, Langdon 2004, 2007), valued in reduced absenteeism for asthma/ respiratory allergies/ depression/ stress and increased productivity, monetized to $1,000 per affected person per year (97% of which was measured from productivity gains). The total annual economic benefits measured were $69,601 and $250,694 respectively per building or an IRR of 167% and 50%; B/C of 31 and 10; and PP of 0.6 and 2 years respectively. With the costs incrementally smaller than the benefits in both cases, the NPV was >1. By assuming the registered gains have been equally distributed over the entire population of the two office buildings, the savings per worker are approximately $1,200 per year using an inflation rate of 3%, and a discount rate of 6% over 25 years for the increased cost of construction for measured indoor air quality improvements. The other LCA studies reviewed provided B/C ratios greater than 1 (Kats 2003, SBW 2003, Ries *et al.* 2006, Romm and Browning 1994), and therefore NPV >1, comparatively, suggesting significant direct benefits from proactive reduction in mold-affected commercial environments.

Kercsmar's (2006) residential field study demonstrated that remediation of the home significantly reduced symptom days and health care use for asthmatic children living in moldy homes. Moreover, based on another home-based field study, Nurmagambetov *et al.* (2011) estimated the economic value of multicomponent interventions for reducing asthma morbidity, through the inclusion of household education and remediation combined to provide a B/C ratio range of 5.3 to 14. These data appear to support the argument for a proactive prevention home remediation program for mold-affected high-use asthmatics based on a LCA with a NPV >1, a B/C of at least 10, and payback of 2 years or less from an SCBA economic evaluation. A positive NPV with payback period less than two years would appear sufficient to justify the consideration for a pilot implementation program for the private sector and thus for the PHCS.

2.5 Occupant and patient health and PHCS benefits from removing mold and dampness from indoor environments

Apart from the direct, indirect, and external cost impacts of asthma, the literature was also reviewed to identify research demonstrating the economic benefits to the PHCS, the patient, and to society by reducing dampness and mold in indoor home environments. The occupant or patient health benefits from removing mold and dampness from indoor residences, includes: 1) reduction in anemia and general malaise; 2) increased productivity; 3) decreased sick days and missed school days; 4) increased well-being and functional efficiency; and, 5) reduction in mental health issues (Bornehag *et al*. 2001, 2004, Burr *et al.* 2007, Howden-Chapman *et al.* 2007, Bernstein *et al.* 2008, Fisk 2001, 2007, 2010). The direct patient benefits from removal of dampness and mold from homes include reduction in the occurrence of respiratory infections, urgent physician and emergency department (ED) visits, hospitalization, and drug use; reduction of side effects from drug consumption; and an increased sense of well-being subsequent to environmental remediation (U.S. EPA 2001, Howden-Chapman *et al.* 2007, Fisk *et al.* 2010, Takaro *et al.* 2011, Cochrane 2015). The effectiveness of home remediation on the health reduction of occupants has been assessed and found to be relevant with moderate quality evidence; however, the research also found that proper home remediation is a critical success factor (Cochrane 2015).

Further, an implementation program through the PHCS may be effective by piggybacking a generally accepted ED medical process such as the “acute asthma management tool kit”, a three level response format (CTAS levels 1, 2, and 3) used for treatment of asthmatics in the ED (VHPHC 2006). Another protocol for consideration would be the “Adult Emergency Department Asthma Care Pathway” (OLA 2014). Mild severity is considered CTAS level 3 for adults. A severe asthmatic state is CTAS level 2 or 1. The program may reduce the impact on the ED and accrue the financial, health, and public relations benefit to the PHCS.

2.6 Summary

The burden of illness from indoor environmental hazard exposure with respect to respiratory disease from mold and dampness exposure was reviewed with a focus on that fraction of asthma affected by mold and dampness. Cochrane (2015), a gold standard for meta-analysis bias assessment that weights study results according to quality of study methodology and bias, has concluded that properly implemented home remediation does have beneficial patient results. Quantification of indoor environment assessment was considered with respect to testing and other methods and the limitations present for accurate assessment. Review of the economics of poor IAQ and economic decision making was conducted for the direct, indirect, and external health and fiscal impacts of environmental asthma, with the valuation of mold and dampness removal considered along with identification of occupant and patient benefits.

Chapter 3 Holistic Environmental Assessment Lay Tool for Home Healthiness [1]

This chapter introduces the first building science based tool to quantitatively assess indoor air environments for respiratory-based health risk, the **H**olistic **E**nvironmental **A**ssessment **L**ay **T**ool for **H**ome **H**ealthiness (HEALTH^2). The focus of this chapter is on the assessment of the indoor environmental quality in residences with the following objectives: 1) present the development of the HEALTH^2 tool; 2) calibrate the model to reflect realistic results; 3) conduct data analysis and summarize results of initial HEALTH^2 tool validation; 4) present the estimated benefits of the HEALTH^2 tool; and, 5) discuss software development and data gathering.

This quantitative risk based tool is intended to assist residential IAQ/IEQ practitioners and, ultimately, residential occupants in better understanding the indoor environments in which they reside. Building on research reviewed earlier, this chapter describes the development of a reliable empirical prediction tool for the assessment of occupant health risk specifically due to residential indoor mold and dampness. The HEALTH^2 tool empirically links building environment conditions with potential respiratory health effects, specifically dampness and mold, using building science factor assessment to reliably evaluate critical environmental conditions pertaining to respiratory health. Results have been calibrated through a theoretical set of specific environmental conditions and verified with data collected from historical records and a web-based e-survey conducted through the University of British Columbia, Okanagan campus.

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[1] A version of Chapter 3 has been published. [Hostland, C.], Lovegrove, G., Roberts, D., and Sadiq, R. (2015). HEALTH^2: A Holistic Environmental Assessment Lay Tool for Home Health. *Canadian Journal of Civil Engineering publication.* 42(4): 241-249. Also see list of publications page iv.

3.1 Tool Development

A six step process was used to develop the HEALTH^2 tool, including: 1) identification of key building environment and lifestyle IAQ risk factors from epidemiological and building science research; 2) analysis of factors using relational factor association to identify and assemble inter-relationships and correlations; 3) formulation of the model to provide structure; 4) assessment and ranking of the environmental factors based on building science and expert knowledge; 5) assembly of data and validation; and 6) calibration and use of the model, using theoretically generated indoor IAQ factor values from a modeled domain. These steps are described in more detail below.

3.1.1 IAQ factor identification

The focus on building characteristics and relevant IAQ factors is to develop a comprehensive quantitative method of assessment. Guidelines published by WHO (2009a) refer to building characteristics that prevent adverse health effects linked to dampness and mold. Existing deterministic, predictive, index, and dose response indoor environmental models noted in Table 2-4 are incomplete. Environmental characteristics and methods are introduced, but no single model or the collection of models address the indoor environment as a whole. The extent of moisture damage and health response may be more fully defined if correlated to the key building factors that comprise the indoor environment to predict conditions more specifically. To a greater extent Haverinen *et al.* (2001, 2003, and 2006) identifies housing characteristics, but not building factors, that predict health response from a simple moisture damage classification. This research adds to the current literature by suggesting the extent of moisture damage, nutrient load, and mold development correlates to degree of health impact. Further, the relationship may be more fully defined if health is correlated to the sum of specific building factors that comprise the indoor environment (Table 2-6).

The building envelope, visual dampness, humidity and nutrient levels, ventilation and filtration of airborne debris, and occupant load are factors that influence the extent of contamination of the conditioned living environment (IOM 2004, Rockwell 2005, ASHRAE 2007, CMHC 2013a, U.S. EPA 2013). A well-designed building envelope reduces the risk of moisture intrusion and identifies the location of the dew point to reduce dampness effects during design (WHO 2009a, U.S. HUD 2013, CMHC 2013a). Nutrients from decomposing organic sources inherent in building components, such as cellulose, supported by dirt and other organic debris from poor home hygiene, and moisture are source factors for mold growth (IOM 2004, Park *et al.* 2006, WHO 2009a, U.S. HUD 2009, Health Canada 2010, Vesper 2011). Mold odor and excess moisture developed from human activities including cooking and bathing, population size, and occupant burden (storage levels and types, moisture generation, systems utilization), have been shown to be modifier factors in the development of mold growth in damp environments (U.S. HUD 2006, Krieger *et al.* 2010, Mendell *et al.* 2011). Further, delivery of outdoor air is critical to reduction of indoor contaminants and the extent of environmental tobacco smoke (ETS) as part of airborne particulate loading in general (U.S. HUD 2006, 2009, ASHRAE 2007, WHO 2009, Sundell *et al.* 2011). In addition to housing component factors, the literature identifies family lifestyle and non-adherence to environmental prevention guidelines as a significant risk factor for onset or exacerbation of asthma and respiratory disease (CDC 2005, U.S. HUD 2005, 2006, 2007, 2009, 2013, CMHC 2013b). These have been combined as source and modifier factors to provide a holistic indoor environment model from which health impact risk may be predicted. Airborne mold measurement was excluded as a factor in the modeling, due to conflicting opinions from the literature and a lack of consensus among regulating bodies on specific numerical limits (Worksafe BC 2002, WHO 2009a, Mendell *et al.* 2011, CMHC 2013a, U.S. EPA 2013).

3.1.2 Factor association and model flow

A primary research focus was to establish the inter-relationships between the factors, and several analysis methods were used to explore this. Fuzzy logic was considered, but found inadequate to adequately describe the factor inter-relationships. Subsequently, cognitive mapping was used and revealed environmental and health inter-relationships that helped to align constituent parts in the model. Cognitive mapping is used to accumulate spatial knowledge, allowing the "mind's eye" to visualize images in order to reduce cognitive load and enhance learning. This type of non-technical boundaryless-based thinking can also be used as a metaphor for undertaking non-spatial tasks using spatial knowledge (imagery or perceived relationship association) to assist in the processing of the task (Ross 2004). Cognitive mapping supplemented the technical determination of associative relationships and relative significance between key environmental and building factors based on field knowledge. This was a first step in developing an understanding of the key factors that affect the health of occupants in indoor environments. Figure 3-1 summarizes the results.

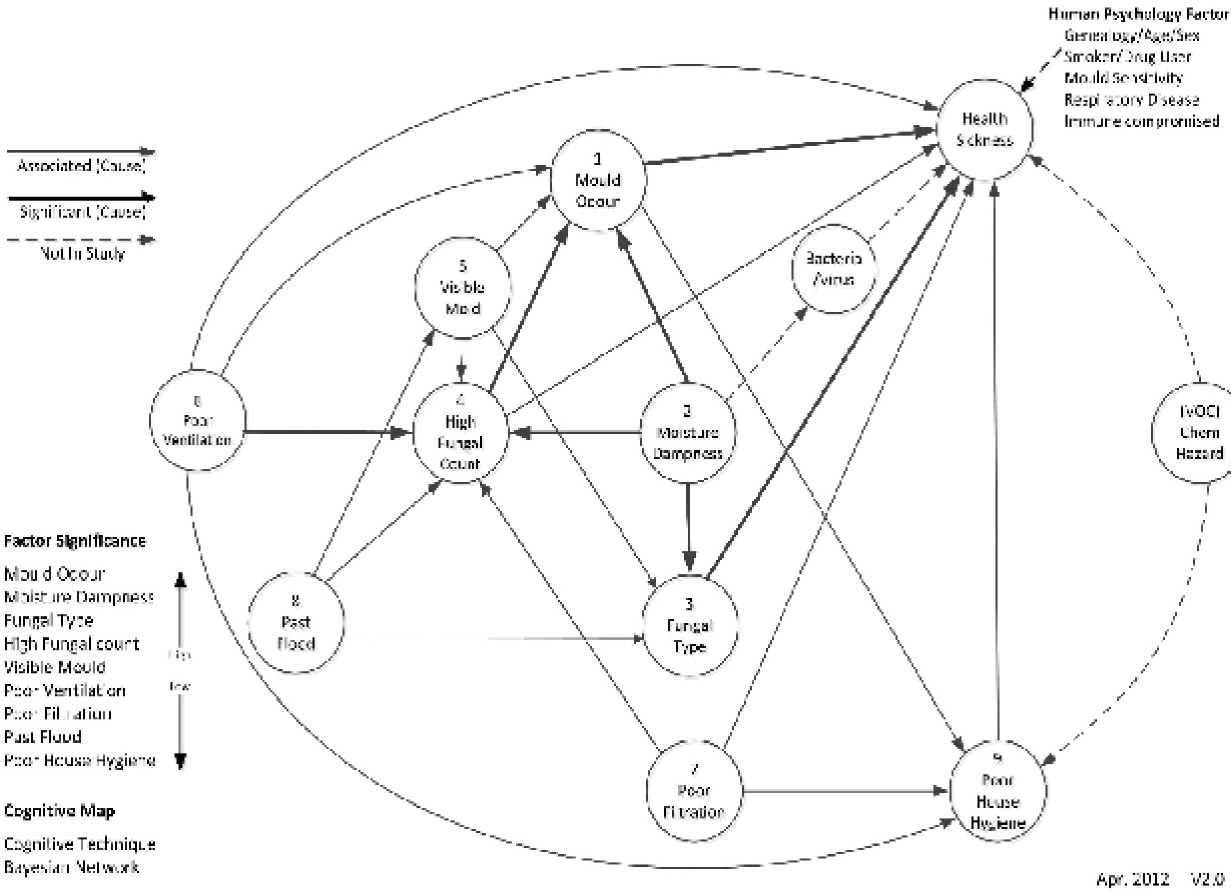
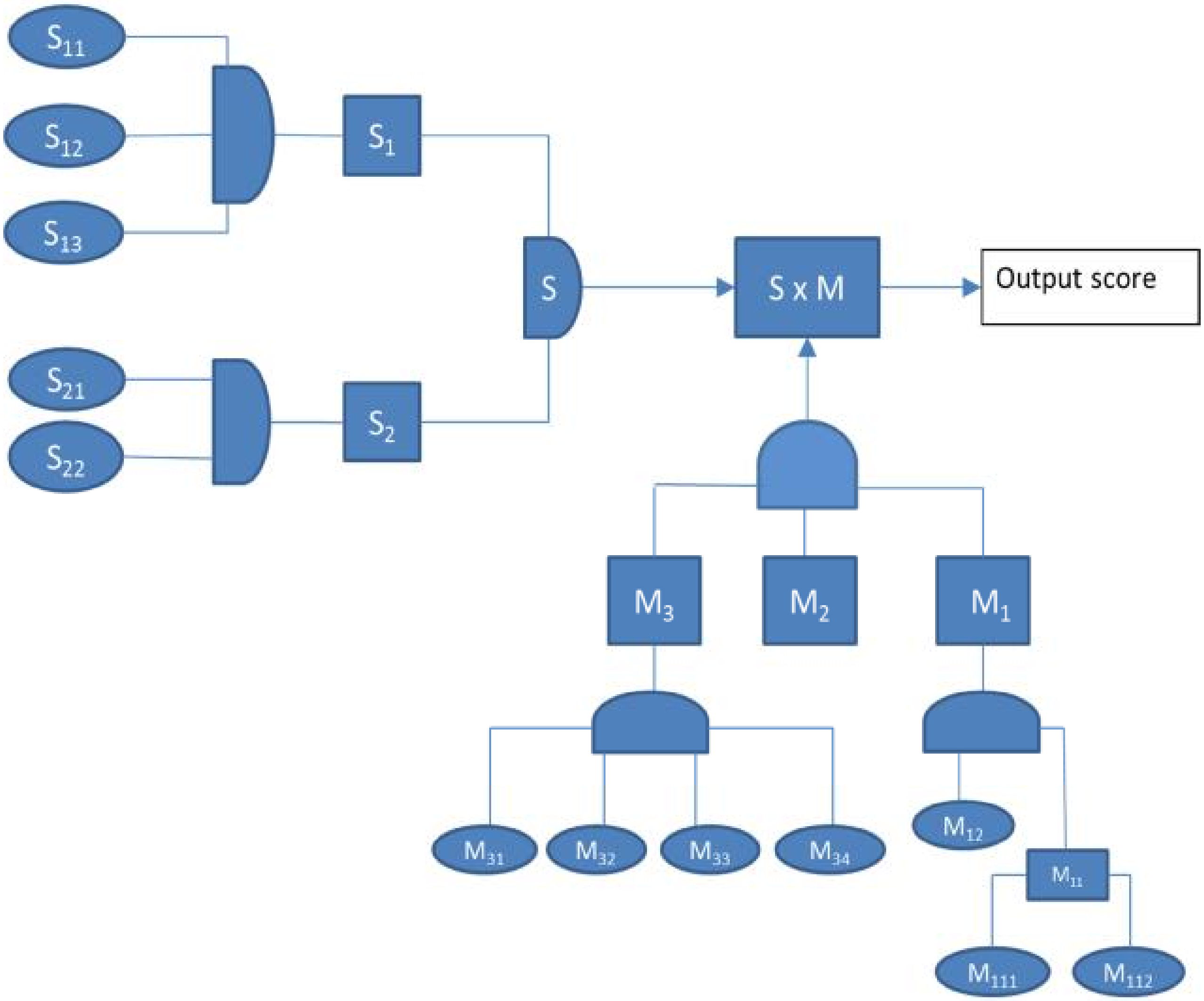


Figure 3-1 Factor assignment cognitive map

The mapping exercise helped to identify key environmental factor associations and levels of factor significance. The cognitive mapping process was completed based on professional experience subjected to scientific peer review. This process exposed health condition as an output factor and that a relative but specific association existed between the various environmental input factors and occupant health results that could form the basis for an analytical model. The overall association between source and modifier factors and how they combine to form an output value is presented in Figure 3-2 following from factor identification and relationship analysis, based on the premises that:

1) Nutrients and moisture as prime source factors must combine first to generate mold before site conditions can affect (amplify) mold proliferation;
2) The remaining factors are prime modifiers that amplify the effects of mold growth arising from nutrient and moisture combination;
3) Sub factors describe different prime nutrient and moisture or modifier sources or conditions;
4) Sub factors have been considered additive, significant proliferation of mold growth is of a multiplicative nature that would not be represented reasonably by addition of prime factors;
5) The source and modifier factors combine by multiplication after all factor treatments are concluded;
6) Sufficiently damp and moldy environments contribute to residential respiratory sickness.



This figure represents the original concept of a process flow and factor relationship structure. Source factors are treated separately from modifier sub factors then combined to provide an output score for the home.

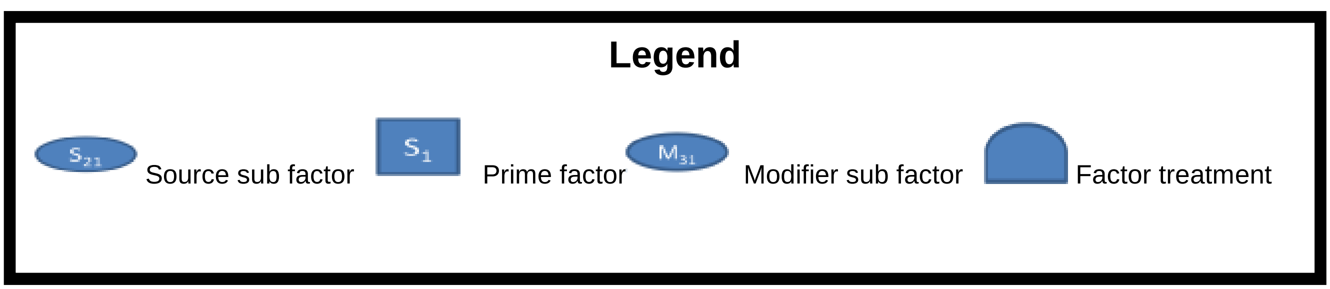


Figure 3-2 Factor relationship analysis diagram

Table 3-1 presents the 16 source and modifier factors and sub factors developed from the analysis of factors, derived from the 13 primary indoor environmental building condition and lifestyle risk factors previously noted in Table 2-5. Subsequent analysis of the HEALTH^2 verification expanded the data set to 16 source and amplification factors where the additional factors were determined based on report and site assessment details. These factors have been assessed through the relationships and flow described in

Figure 3-2. The factor relationship analysis diagram combines the relationships determined through the cognitive mapping exercise and literature review into a process flow chart that culminates in a residence output score later to be described as a home healthiness index (HHI) score. Each factor within the investigative scoring input template (Appendix D) was then given a value range (i.e. 1-2, 1-10, etc.) based on its specific effect on the composite building condition and other factor relationships. The line item values are summed to a maximum amount noted for each factor and then inputted into the model for analysis.

Table 3-1 HEALTH^2 model source (S) and modifier (M) factors

Model Factor	**Model Factor Description**
S_{11}	Active Moisture – surface/solid (measured by moisture content MC)
S_{12}	Active Moisture – airborne (measured as relative humidity (RH)
S_{13}	Past Moisture – measured based on history and cause type
S_{21}	Nutrient cellulose: organic – spun/glue drywall backing, cardboard/paper, dust/dirt
S_{22}	Nutrient cellulose: dense – dimen. lumber, paneling, plywood, OSB, particle type
M_1	Ventilation level – composite of M_{11} to M_{12}
M_2	Filtration - type and capability extent represented by integer values
M_3	House Hygiene - composite of M_{31} to M_{34}

Model Factor	Model Factor Description
M_{11}	Outdoor air supply – extent of type/amount represented by integer values
M_{111}	Passive outdoor air exchange extent represented by integer values
M_{112}	Mechanical outdoor air exchange extent represented by integer values
M_{12}	Mechanical indoor air circ. extent – extent of type/amt. represented by integer values
M_{31}	Particulate load (dust/ETS) – extent of amount represented by integer values
M_{32}	Occupant/ storage load – extent of amount represented by integer values
M_{33}	Mold growth/rot/odor/damp extent – extent of amount represented by integer values
M_{34}	Mold stain/ no odor/ dry extent – extent of type/amount represented by integer values

The 13 key building condition factors form the basis for the 16 model factors with the symbols noted in the table above with each factor descriptor. These factors are then defined into source (S) and modifier (M) factors for clarity.

3.1.3 Model formulation

With the identification and analysis of the relevant IAQ factors, the confirmation and validation of factor inter-relationships, and the development of a factor relationship analysis diagram for the HEALTH^2 model, an analytical structure was overlain on the relationship diagram to develop a model structure to provide empirical results in Table 3-2. Decision theory using pair-wise analysis through prioritization assists in formulating an analytical model structure from process flow, to determining factor weighting, and then organizing the process output. Subsequently, the Analytical Hierarchy Process (AHP) was used as a structure to quantify the factor inter-relationships. The benefit of AHP is in determining the relative merit of members of a set of alternatives, as opposed to selecting a single alternative or merely ranking them. This capability distinguishes AHP from other decision making techniques (Fraser *et al.* 2009). AHP is a structured methodology for organizing and analyzing otherwise complex issues. In this case the members are known factors. Factor relationships and weighting is a knowledge-based determination. The results output will be quantitative – as required. Refer to Appendix C for the detailed AHP scoring scheme.

The relationship values for each factor matrix for the Okanagan Valley in BC were determined through personal professional experience and expert knowledge of the individual items and their relative importance by comparative weight. Three levels of AHP were applied in this structure to complete the source and modifier analysis based on the IAQ factor input (sub factor) values identified. The resultant third level source and modifier values are the result of the multiplication of weighted values, independent of each other, subsequently multiplied together to develop the Home Healthiness Index (HHI) score (Table 3-2). Line by line site condition input is provided at the sub-factor level on the $HEALTH^2$ model structure input template (Appendix D).

Table 3-2 $HEALTH^2$ model structure and sample HHI calculation

Factor	Input Values	Weight	CR		CR		CR	Output Score	
Moisture rating									
S11	8	0.709							
S12	7	0.231	7.6						
S13	5	0.060							
Nutrient rating				0.833	7.9		7.9		
S21	10	0.900	9.5	0.167					
S22	5	0.100							
Particulate Load									
M31	5	0.099						**HHI SCORE**	36.4
M32	8	0.058	1.8						
M33	1	0.615							
M34	1	0.228							
Filtrat. rating M2	10		10	10 = none		0.649	4.6		
Ventilation rating						0.279			
M111	4	0.167	9			0.072			
M112	10	0.833	10=none	0.900	8.9				
M12	8		8	0.100					

CR = composite results for each of three AHP calculation levels.

The resulting HEALTH^2 tool empirically assesses the indoor environment for the extent of mold and dampness contamination and provides a resultant home healthiness index (HHI) score. That value is then compared to a database of existing Okanagan residential environmental assessments to determine its ranking from an indoor environmental condition perspective. It was then hypothesized that capturing that respiratory health condition of occupants while determining the HHI of a residence might give an opportunity to determine if there was a statistically valid correlation that could help to predict respiratory health response in a residence based on a developed HHI score. If the hypothesis was proven statistically valid, an output of predicted resident health (RHS) score could then be developed from an HHI assessment. This is addressed in section 3.1.5. A sample template for S11 is provided in Table 3-3. The input values for the model factors and sub-factors allow for the widest possible range of specific building conditions, as determined from direct site inspection or remote assessment by occupant interview.

Table 3-3 HEALTH^2 tool structure & sample scoring template for section S11

Factor	**Description**	**Maximum value**	**House value**
S11	**Active Moisture (SC)**		
a	> 48 hr water ponding	5	____
b	roof/plumb leak < 48 hrs/ intermittent	1	____
c	roof/plumb leak > 48 hrs/ reoccuring	3	____
d	condensation on window glass	1	____
e	Puddling water in window channel	3	____
f	unvented operating clothes dryer	2	____
g	moldy/ dirty humidifier	1-2	____
h	blg surface SC 15-20%	1	____
i	blg surface gt 1 sm SC 20-30%	2	____
j	blg surface gt 1 sm SC gt 30%	4	____
0 = best	**TOTAL (max 10)***		

Template inputs by the tool user are translated into line item factor input values for the HEALTH² tool, modified by the various regional cognitive multiplier matrix criteria (e.g. single family residences, central BC/ lower mainland area urban climates – Appendix E), and computed by weights into composite source and modifier values through three levels of refinement by AHP. The resulting final source and modifier values have been multiplied together to obtain the HHI value for the particular home as illustrated in Table 3-2. Refer to Figure 3-3 for an example of the indoor house hygiene level matrix, with the specific normalized weighting vector.

Matrix 1: Indoor house hygiene levels (0-9)

	M31	M32	M33	M34	Relative weight	Normalized relative weight
M31	1	2	0.2	0.3	0.589	0.099
M32	0.5	1	0.14	0.2	0.344	0.058
M33	5	7.14	1	1	3.656	0.615
M34	3.33	5	1	1	1.351	0.228
					5.939	1.000

Legend

M31 Dust/dirt/ETS level

M32 Occupant/ storage load

M33 Mold growth/odor/damp/rot

Figure 3-3 Example multiplier matrix

The multiplier matrix from the HEALTH² model supports the knowledge based pair wise analysis to set factor weighting. Rationale and value setting is described in Appendix C.

3.1.4 Calibration

To verify test results, derived HHI values should be comparable with similar types of homes with similar indoor environments; but dissimilar for different environmental conditions. For example, an environmentally impacted home should measure a significantly higher HHI value than a clean, well-cared for home with little to no adverse environmental or lifestyle conditions. The HEALTH^2 tool was calibrated as such using a theoretical set of specific environmental conditions based on a wide range of well-known indoor environments, including: house #1 - lower standard; house #2 - mid-standard; and house #3 - premium standard for the Okanagan region of British Columbia.

House #1 is modeled as a contemporary two to three bedroom 1970's bungalow on a heated crawlspace meeting the basic building code requirements for its day with a low insulation level poorer quality building envelope. House #1 includes a non-insulated dirt crawlspace with no ventilation, single pane aluminum sliding windows, electric baseboard heat, no mechanical ventilation or filtration, no outdoor passive fresh air, and is inhabited by a small single family. House #2 is a later 1980s mid-standard single family home constructed with a better quality building envelope, increased insulation levels, added mechanical ventilation and fresh air supply with a forced air furnace, kitchen and washroom extraction fans, and double pane thermally broken windows. House #3 is a newer constructed single family premium standard residence with an air/vapor tight building envelope, high insulation levels, mechanical fresh air and recirculatory air handling systems, advanced mechanical air filtration, higher quality thermal windows, high efficiency heating and mechanical ventilation, reduced carpeting, and ventilated storage areas.

Each of these three home types were evaluated with the HEALTH^2 tool over four IAQ factor value scenarios for a total of 12 (3 x 4) test applications to assess the output factor valuations (i.e. the HHI value range).Scenario one: pristine, clean environment, light occupancy, and well maintained with some attention to indoor air/environment quality (clean and dry environment). Scenario two through four identify specific nutrient and moisture loads systematically introduced into the home. Scenario two: poor level of maintenance, low level of care (increased nutrient base), higher occupancy load (larger family or multi-family residence), and no attention to indoor environment quality. Scenario three: Scenario one with an active moisture event (> 48 hrs.) and visible mold growth. Scenario four: Scenario two with an active moisture event (> 48 hrs.) and visible mold growth. The HEALTH^2 tool calibration results provided in Table 3-4 reflect expected results in general.

Table 3-4 Calibration of theoretical HHI results

	Condition 1 Pristine	**Condition 2 Overload**	**Condition 3 Pristine + water**	**Condition 4 Overload + water**
low quality housing stock	8.8	20.2*	20.0-47.4* mid 34.9	35.0-75.0* mid 50.0
mid-range housing stock	1.2	10.4	9.8-52.1* mid 21.4	21.3-54.0* mid-44.6
Premium housing stock	0.9	8.3	7-28.3* mid 11.2	20.1-34.2* mid 25.5

* Conditions are considered likely to very likely to have mold contamination that may cause consequential respiratory health issues. A range of values for likely to very likely was calculated with a mid-point (median) value noted to indicate the sensitivity of certain site effects to cause a wide range of values.

Low or substandard building environments are more susceptible to the development of indoor fungal contaminants (higher HHI value and associated health impacts) than higher quality building environments. This is consistent with the literature reports where introduction of nutrients through lack of hygiene, excess storage, building systems overload, and moisture at varying degrees has been associated with mold growth (Kercsmar ***et al.*** 2006, Antova ***et al.*** 2008, Jacques 2011).

3.1.5 Connecting factored indoor environments to potential health consequence

The HEALTH^2 tool is intended to quantitatively assess indoor environments and rank them in relationship to each other. In doing so, after the development of a regional, provincial, state, or national database, ranking values might allow for limits setting for acceptable indoor environments in relation to occupant health. The theoretical residence home healthiness index values were generally found to be consistent with field results and professional IAQ experience in the Okanagan/ Shuswap region of British Columbia. For example, it was found qualitatively that a clean and pristine premium home (HHI 0.9) was very unlikely to have a health-affecting environment from site assessment records, but the indoor environment becomes moderately likely with a change of conditions that include poor maintenance, increased occupants and storage, and corresponding nutrient loading from poor housekeeping (HHI 8.3). These homes inspected well, exhibited little or no critical factor issues, non-concerning air test results; and no occupants with flu-like symptoms. Those occupants were generally interested in IAQ but not suffering from respiratory distress, or had concerns based on un-substantiated beliefs.

Alternately, homes became likely environments from professional opinion for expected respiratory concerns with the addition of active moisture intrusion (HHI mid. 25.5). With the pristine clean environment, a water event longer than 48 hours can elevate the home in the model from unlikely to moderately likely (HHI mid. 11.2) to have a respiratory health affecting environment. It was found that the lower standard home, with a substandard building envelope, and non-existent ventilation and filtration system that is quite unlikely to have a respiratory health affecting environment (HHI 8.8) becomes likely with an occupant/ storage overload and reduced care and maintenance of the space (HHI 20.2). This possibility steadily increases to a much higher chance and value (HHI mid. 50.0) with a moisture event extending over 48 hours. As such, the qualitative field-assessment results appeared to match the numerical results from the HEALTH2 assessment.

From an overview of the output values presented in Table 3-2 it appeared the HHI values fell into a 5 scale range of 0-10 indicating very unlikely (1) to unlikely (2) to have a respiratory health effecting environment for all three housing types; 10 – 20 (3) moderately likely; 20-30 likely (4); to 30+ (5) very likely to have a respiratory health affecting environment for the mid and low quality housing stock range. In other words, the HHI condition values appeared to predict within a broad range whether it was likely to very likely for the home to have a possible respiratory health affecting environment in a pattern for which scale ranges could be developed for an overall resident health score (RHS). These theoretically calibrated scores and qualitative potential respiratory health determinants were then assessed and validated using actual real world data (section 3.2.1).

Figure 3-4 provides the data input and output process flow diagram for the $HEALTH^2$ tool.

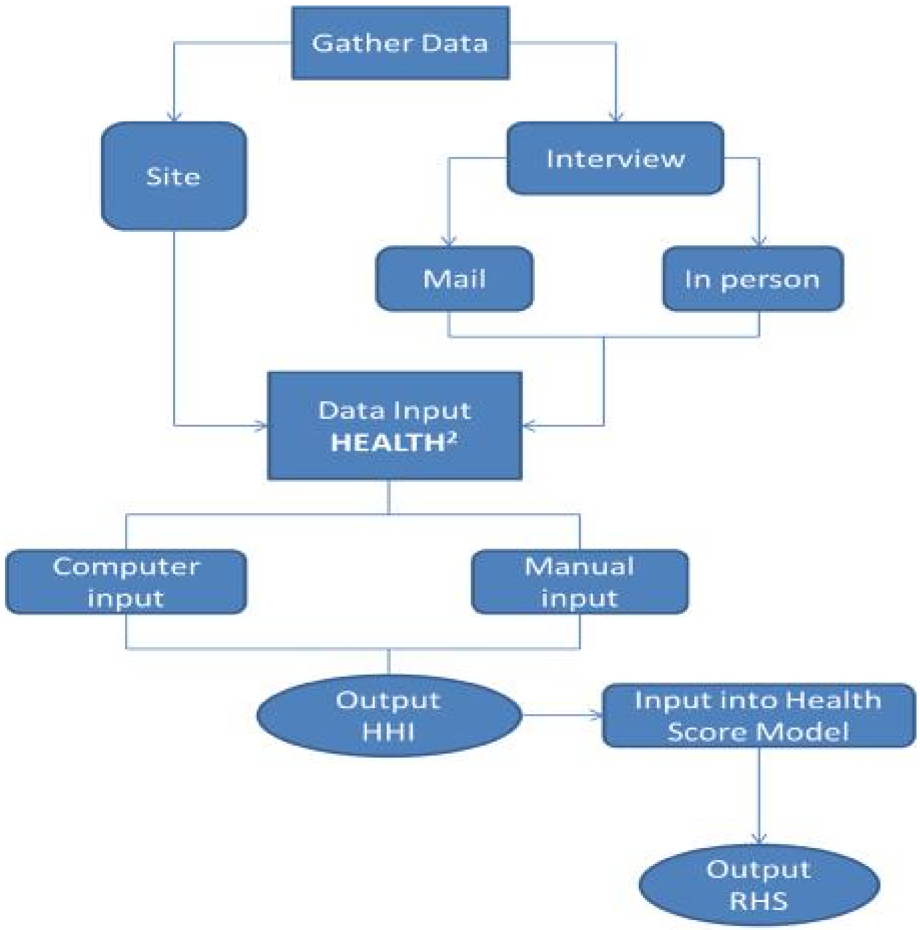


Figure 3-4 HEALTH^2 model process flow diagram

This diagram outlines the HEALTH^2 model process from data gathering, model inputting, to home health index (HHI) and resident health score (RHS) output values.

The flow diagram includes two outputs: 1) HHI results and 2) an expected RHS based on the HHI results. The HHI is useful alone in deducing value ranges for certain indoor conditions, but the more potentially valuable element is the link with respiratory health response in the form of a RHS that would not only allow for a quantitative method to rank indoor environments, but predict indoor resident health based on risk assessment.

3.2 Validation of Results

A HEALTH^2 tool overview and process has been presented in this chapter along with analysis of the building factors identified as critical to indoor environmental assessment. Model formulation and tool calibration using a theoretical set of specific environmental conditions based on a wide range of well-known indoor environments was then completed. This section validates the theoretical results and connects a valid quantitative relationship between the home healthiness index (HHI) derived from the factored indoor environment analysis and potential resident respiratory health consequence in the form of the resident health score (RHS). The validation of the $HEALTH^2$ building and occupant health assessment tool completes the process of model development and verification.

3.2.1 Data Collection

Data were gathered from two sources to validate the $HEALTH^2$ tool: 1) historical data (n=195) based on Okanagan BC customer contact from direct onsite environmental assessments conducted from 2007 – 2013; and 2) E-survey data from recent Okanagan home buyers (n=74). Direct onsite data gathering entails a rigorous assessment by a professional trained in assessing indoor environments for mold and dampness using the investigative template presented in Appendix D for data capture and analysis. The data gathering also included a summary of health issues presented by the occupant at the time of assessment order and confirmed on site. The health information was general in nature but usually formed into conclusion whether the occupant suffered from long duration flu-like symptoms, whether they had been hospitalized or treated for some form of respiratory distress recently, whether at home only or also when outdoors, and to what extent. The historical data investigations contained an inherent bias towards suspected unhealthy homes and occupant sickness because the studies were performed specifically upon request by concerned or affected homeowners. As such, the e-survey was conducted to provide a balanced dataset. The data for each was then sorted through the purview of the factors derived in this chapter for the $HEALTH^2$ model with health questions added. Where the original surveys did not include specific factors, assumptions based on personal professional expertise and scientific research was made within the context of the individual assessments to provide complete data sets. The templates for the assessments are provided in appendix A for the e-survey and appendix B-1 and B-2 for the combined historic and e-survey data.

3.2.1.1 Historical Data

The site assessments followed a prescribed professional protocol and format. This included a pre-site determination of the basis for occupant concerns and the scope of work assessment; a detailed visual site assessment was then conducted using an input template protocol; and where necessary, bulk and air sampling to fit the scope requirements derived by the pre-assessment. A high percentage of site assessments included microbial sampling in some form that was excluded from the analysis. Of interest, most requests for conducting a whole house visual IAQ assessment and testing were made after occupant sickness appeared to abate when away from their home for a period of time, as little as 8 hours a day (work for example). Otherwise, clients wanted IAQ assessments and testing based on their environmental concerns whether founded on science or not.

Over 600 field investigations conducted from January 2007 through to October 2013 were included in the initial dataset. Investigation data that were incomplete, focused on environmental issues other than mold and dampness such as chemical, lead, asbestos hazards, animal allergens, radon, bacterial, or viral issues, or corrupted due to data entry error, or provided inconclusive results was excluded from the data set. Investigations for other IAQ related specific concerns were excluded from the dataset. Specific environmentally contaminated sites not derived from residential usage (i.e. illegal and legal marijuana grow ops and meth labs) were also excluded. Data that was clearly defined from indoor environmental mold or dampness concerns from residential occupancy was then used in this research. The qualified data set comprised 194 discrete environmental site investigations in houses and small office buildings. Site assessments were conducted based on pre-verification that the client's health concerns were specific to their indoor environment or a strong belief that their indoor environments may be causing them harm to the point of physical illness. Alternately, assessment was conducted based on client concerns that their indoor environment would be harmful based on their own visual assessments revealing the possible presence of mold in their home. These premises formed the basis for the historic site assessment results obtained.

The historic data were compiled and analysed for factor relationship and results relevance. Initially, a total of 8 factor scopes were determined to be of environmental importance from the data: A) total fungal assessment; B) *Stachybotrys, Chaetomium, Penicillium-Aspergillus* fungi present; C) humidity/ moisture/ staining/ water intrusion issues; D) building related sickness; E) clutter/ debris/ dust; F) detectable odours; G) building air filtration systems; and H) building ventilation systems. Factor D was ultimately determined to be a response condition and was thereafter made a comparative variable. Statistical analysis was conducted to test for a positive association between factor D sickness and all the other factors. Data were initially scrutinized through analysis of variance (ANOVA) and odds ratio based assessment. Overall, the conclusions were not statistically significant, but preliminary results pointed to a particular relationship between sickness and inadequate ventilation/ fresh air; and sickness and inadequate filtration. This information formed the basis for the development of the $HEALTH^2$ model and tool concept and after the development of the $HEALTH^2$ model and tool; the data were then assessed for inclusion using the developed scoring template.

3.2.1.2 E-Survey Data

In order to balance the health and environment focus of the historic data noted above, a self-reporting survey was also designed and conducted. It gathered building and health responses from Okanagan home buyers who had pre-purchase home inspections for single family residences conducted from 2005 to 2011. The entire response database was utilized and not altered in any way. There was no prior evidence of any health related or indoor environmental issues in the homes surveyed. Potential occupant interviewees were contacted by email and asked for their participation in an indoor environment study. They were asked to follow a link to an internet based questionnaire to fill out. Their results were emailed to a UBC website that segregated responses from internet addresses to maintain confidentiality. The E-survey study was approved by the UBC Research Ethics Board to solicit by internet, gather, and utilize the data. The cohort of adults was emailed an introductory letter that included instructions for accessing and filling out the survey. Only one response per residence was accepted. There were 74 e-survey responses from a database of 2403 homebuyers, which met the minimum response rate for a valid survey.

The survey document and summary of results are provided in Appendix A. The questionnaire was designed to gather house characteristics and health responses to a set of criteria that eventually became the HEALTH^2 assessment tool templates subsequently developed for this thesis. The resulting data were assessed and adjusted to reflect the HEALTH^2 data input requirements using the scoring template to derive HHI scores and subsequently RHS values.

3.2.2 Validation Method and results

The calibrated HEALTH^2 tool was statistically validated using the complete set of data provided in section 3.2.1 modified through the HEALTH^2 scoring template with the data score summary provided in Table 3-5 with the low, high, and average health and house scores for the e-survey and historical data accumulated separately and combined. Although other methods exist to choose data to perform model validation (e.g. keep separate 25% of the original data set for validation; use only 75% for model calibration, 50/50, etc.), for this research it was determined to use the entire data set for both model calibration and validation because of the calibration methodology of using reproducible site conditions and ultimately because the validation process confirmed the calibration output values. This allowed a broader range of data to provide more robust output results.

Table 3-5 E-survey and Historical Data Summary

E-Survey (n=74)				**Historical** (n=195)				**Combined** (n=269)			
Health Score		House Score		Health Score		House Score		Health Score		House Score	
low	1	low	2	low	1	low	1.8	low	1	low	1.8
high	1	high	11.1	high	5	high	69.7	high	5	high	69.7
average	1	average	2.84	average	1.63	average	7.55	average	1.46	average	6.25

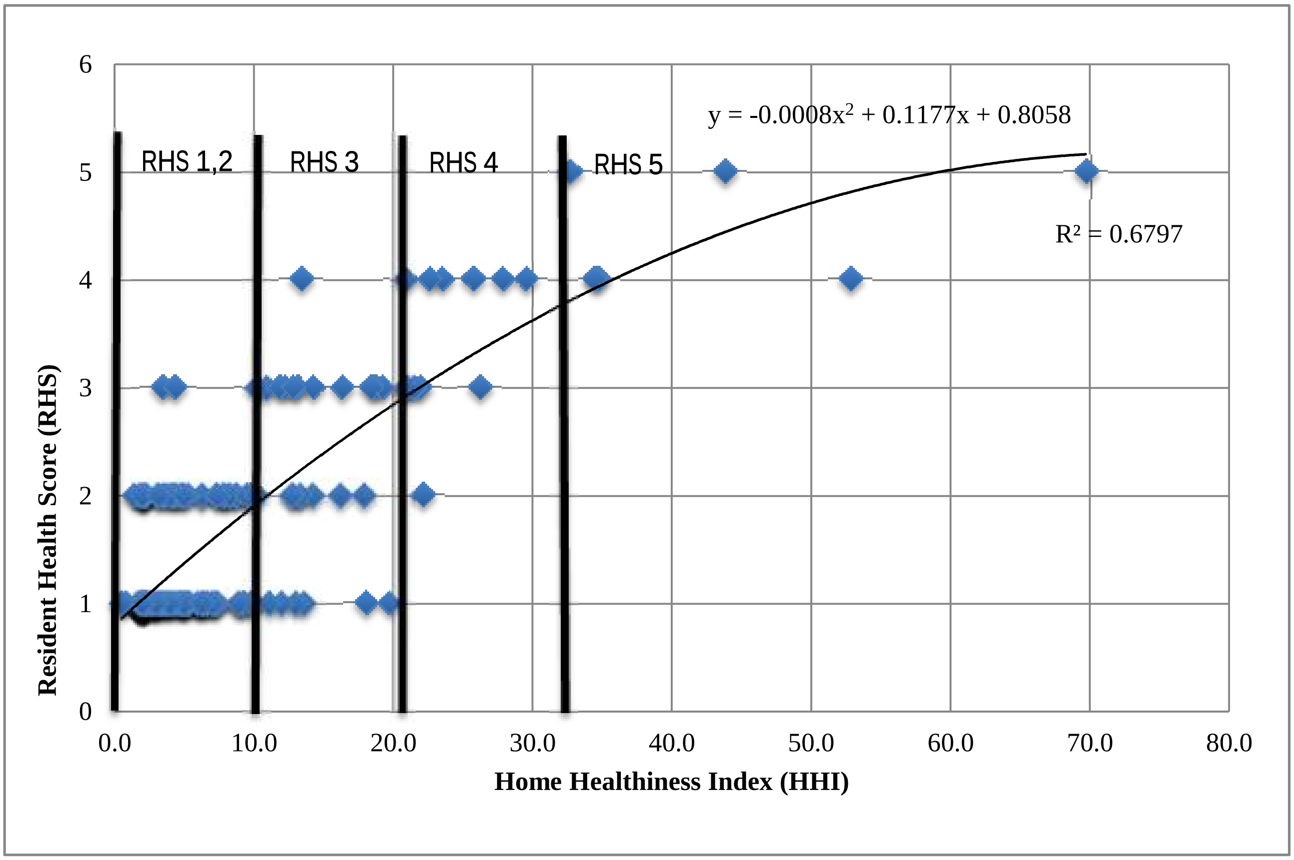
Data developed from two sources: 1) remote assessment via e-survey of home buyers who bought between 2005 and 2012; and 2) Okanagan BC residential environmental site inspections conducted from 2007 – 2013 (historical).

The HEALTH^2 template data set values for each residence for the various factors were derived and inputted into the HEALTH^2 tool to obtain the home healthiness index (HHI) score. The resident health score (RHS) based on the occupants' reported health condition was then calculated. The HHI score for each residence was then recorded on an excel spreadsheet against the street address. To blind the two part analysis, the HHI and RHS values from the data set were separated for each particular residence. The HHI column was then hidden on the spreadsheet. Then, the RHS value was recorded on the excel spreadsheet from the data set based on address/RHS couplet drawn from a random number generator.

Beyond developing a database of HHI scores for ranking new home environment assessments in a particular region, the historic and e-survey data were evaluated for corresponding occupant respiratory health impact obtained from the data sets using a numeric scoring system. Initially a 5 level environment-based health condition scale was set. A 2 or 3 level scale was found to be too coarse; a larger scale range not defendable. A 5 level scale was chosen in relation to respiratory health conditions observed in the literature to score the data. For predictive purposes, a score of 1 suggests the existing indoor environment condition would not predict occupant respiratory health issues. A score of 2 suggests minimal possibility for respiratory health issues such as cough or light wheeze. A score of 3 indicates an occupant might be somewhat or lightly hindered by respiratory issues with consistent coughing and wheeze requiring limited medication and mild inhaler use. A score of 4 indicates the occupant might likely be hindered by function affecting heavy cough, loss of breath, and persistent wheeze that requires prescription medication and consistent doctor visits. A health score of 5 suggests the occupant may have serious respiratory issues with unplanned emergency room visits and extended hospital stays with heavy medication. The RHS was plotted against the HHI to determine whether a relationship existed between home hazard condition and occupant respiratory health response.

3.2.3 Accuracy of Model

The home healthiness index (HHI) and resident health score (RHS) were compared using the difference of means of the variables with multi-variance analysis (ANOVA) for independent samples (sample size n = 269, see Appendices B-1 and B-2 for data). Results were plotted in and are presented in Figure 3-5 inclusive of the data from the e-survey.



The graph of data results shows the relationship between home healthiness (HHI) and predicted resident health (RHS) is 68% explained by home healthiness and 32% explained by other health risk factors such as genetics, age, gender, etc. The graph suggests that environments with HHI values greater than 20 are a respiratory risk for the residents. Alternately the data indicates residents with health scores of 4 or greater live in damp and moldy home environments. Samples size n=269.

Figure 3-5 Relation between observed HHI input and predicted RHS

The hypothesis that an independent relationship exists between the damp and moldy environmental condition of the home (HHI) and respiratory health condition of the resident (RHS) with the data assessed is shown to have validity The increase in indoor environment mold and dampness measured by HHI value correlates to a measured increase in respiratory ill-health of the occupant as measured by RHS. The analysis of variance (ANOVA) results provide a 99% confidence level with $F_{0.01, 2, 266} = 4.61 < 282$. Appendix F (ANOVA analysis and graph) contains further details of this validation exercise. The goodness of fit value of 0.68 indicates the data points fit the assumed quadratic curve in equation 5: $y = -.0008x^2 + 0.1177x + 0.8058$. The observed outcomes replicate the model by explaining 68% of the variability of the RHS. This suggests that 32% is explained by other health risk factors, which are speculated to be unique personal health conditions, genetics, gender, age, or ethnicity, which could be considered in future research.

The data results in Figure 3-5 also indicate that the HHI values for the combined data generally correlate with the following theoretical health condition boundaries: a HHI value of 0-10 indicating the home is health safe from environment derived respiratory conditions with an RHS of 1 or 2; a HHI value of 10-20 indicating a chance of light respiratory issues with an RHS of 3; a HHI value of 20 – 32 indicating possible function affecting environments with an RHS of 4; and, a HHI value of +32 scores indicating a potential for moderate to severe respiratory issues with an RHS of 5 (Table 3-6).

Table 3-6 Resident Health Score (RHS) description with corresponding Home Healthiness Index (HHI) score

Resident Health Score (RHS)	**Description**	**Corresponding Home Healthiness Index (HHI) score**
1	no respiratory health issues	**0-10**
2	minimal respiratory health issues	**0-10**
3	light respiratory issues (hindrance)	**10+**
4	Moderate respiratory issues (function affecting)	**20+**
5	severe respiratory issues (hospital)	**32+**

Resident respiratory health is predicted based on HHI score (see also Figure 3.5).

3.3 Discussion

The development of the HEALTH^2 tool was undertaken in an attempt to quantify indoor environments for IAQ assessment validation purposes and to help fill the knowledge gap somewhat between medical fact and perceived occupant health response to certain indoor environments. The results are useful in that a correlation is verified. The extent of which may be open to critique at this juncture, but a first step to quantify indoor environments has been accomplished and opportunity for use is described below and opportunity for further development is described in chapter 6.

The criteria for use of the HEALTH^2 tool would be: 1) regulatory based for verification of indoor environments for remedial programs or guidance to professionals; 2) a first step introductory analysis tool for residential occupants to provide next step guidance; 3) a professional tool for environmental professionals under strict regulatory control; and/or, 4) a beta testing tool for research purposes. Each would require the development of its own specific guidelines for use.

The prediction of health risk for a future occupant or for comparative purposes for an existing respiratory health affected occupant follows from site specific data analysis. The caveat is that the assessment is done because a potential occupant has a history of a respiratory condition and requires some verification prior to occupancy, or the occupant wants some level of verification their home is or isn't the potential cause for their illness onset or exacerbation. This predictive tool is significantly limited to the type of environmental and site condition, the occupant's health history, and other conditions not known or yet developed. The tool might be used as part of a sustainable health care program verification method to assess indoor environments for health recovery potential after remediation.

For the purpose of this thesis, to proactively assess residential IAQ for high-use asthmatics, the home health index (HHI) and expected occupant health outcome (RHS) would be verified against candidate assessment in the hospital emergency department (ED) or asthma care centre. Upon determination of a patient being a candidate by a medical professional, pertinent information about their home environment would be gathered from the candidate in person, or if necessary, by phone or mailed-in survey, and inputted in the $HEALTH^2$ model. The home healthiness index (HHI) output value from the $HEALTH^2$ model is compared to the resident health score (RHS) score to determine a match between occupant health issues and home environment. An HHI score of 32 or higher with an environmentally sensitive high-use asthmatic resident, for example, would constitute a fit and the patient would be a candidate for a site remediation program.

The use of the $HEALTH^2$ tool simplified for general public use could reduce or eliminate the upfront cost of testing and professional assessment, thereby reducing the impediment to residents seeking solutions to their health concerns. For general use, a residential healthiness analysis can be conducted through the same process flow from data gathering to HHI and RHS output for residential, industrial, or commercial building occupants. HHI and RHS scores would then form the basis for determining remedial efforts. The $HEALTH^2$ tool does not eliminate the requirement for professional assessment when residential conditions warrant intervention. If professional assessment is not warranted, an educational component can assist the patient in addressing non-threatening environmental concerns resulting from the questionnaire without significant cost. By adding an education component to the transaction, government regulatory bodies, medical and environmental professionals alike can add value at a point of connection when the general public is most aware.

3.4 Software development and data gathering opportunity

The HEALTH^2 survey tool in the context of IAQ industry assessment protocol lends itself to rapid technology transfer and early adoption best implemented through an online software-based program. It would then assist users by making access across an accessible internet platform readily available and, as well, gather developed data for better refinement of the program and dissemination of results over other regions and countries for comparative purposes. A significant value in having a quantification model based on factor analysis is to engender the knowledge in a software program. HEALTH^2 has been subsequently developed as an online tool, which is in Beta testing at this time. The program can be found at https://health2.ok.ubc.ca.

This knowledge-based, on-line, 24/7 access approach with professional collaborators could be managed through a secure server to ensure data security, survey standards, and minimal data entry errors. For example, environmental consultants could use the HEALTH^2 algorithm to develop knowledge matrices for their own regional locations to assist in determining defensible hazard levels for evacuation safety purposes, and perhaps, to assist regulating bodies to set simple quantified guidelines for health and safety. Moreover, the medical profession could utilize the software-based assessment tool to link environmentally affected respiratory patients to remedial site measures to reduce reactive health care costs through interview and remote survey and occupant action. A simplified web accessible version allows homeowners to assess their own homes for critical conditions before attempting support through healthcare, service and product suppliers, or environmental consultants.

3.5 Summary

The HEALTH^2 model and tool were developed and verified in this chapter with section 3.1 outlining the tool development complete with factor identification, association, model flow formulation, and model calibration; section 3.2 provided a validation of the theoretical results from a combination of historic and E-survey data along with data collection methodology and results. The accuracy of the model and tool was verified at a 99% level of confidence with a goodness of fit of 0.68 that explained all but 32% of the data being due to indoor environment conditions pertaining to mold and dampness. The criteria for the use of the HEALTH2 tool was outlined along with how it may be utilized in a mold and dampness prevention program for health living and reduced PHCS utilization. The $HEALTH^2$ model and tool software development and usage opportunities conclude the chapter.

Chapter 4 Social Cost Benefit Analysis

This chapter discusses the economic impact of the effect of mold and dampness induced respiratory illness has on the PHCS, patients, and society at large by presenting the results of a social cost benefit analysis (SCBA) using a fraction of the severe (high-use) asthmatic population affected by residential indoor mold and dampness as a case study. The yearly PHCS cost savings in BC is projected to be $31 million after the first year with an overall societal savings of $97 million and $2.8 billion PHCS cost savings after the first year with $8.7 billion in overall societal savings North America-wide. For ease of data collection and research in this thesis, these results only reflect the high-use asthma demographic that represents 1.4% of the asthma population in North America. This is acknowledged as conservative, due to it over-representing PHCS asthma care costs per patient, but under-representing the overall potential cost savings from the larger uncontrolled asthma demographic. The benefit of an asthma prevention program for high-use asthmatics sponsored and managed by the PHCS is discussed along with the resulting distribution of costs and benefits.

Chapter methodology is provided in section 4.1. A direct cost benefit analysis considering utilizing the PHCS for an intervention program is provided in section 4.2 along with a sensitivity analysis; with the indirect and external and program costs provided in section 4.3. The indirect and external cost benefit for proactive remediation of indoor environments is evaluated in section 4.4. The summary SCBA estimate of direct, indirect, and external costs and benefits of a prevention program is provided in section 4.5. In addition to conducting the SCBA, an estimate of how these calculated costs and benefits are distributed across the PHCS, patient, and society is presented in section 4.6. A discussion of these results, including estimated program cost savings, economic modelling, and conclusions, is given in section 4.7 with a chapter summary provided in section 4.8.

4.1 Methodology

The literature developed PHCS health care cost data variables are provided in Table 2-7. For the impact of high-use asthmatics on the public health care system (PHCS), estimates of direct costs (denoted as PHCS, items A to F in Table 2-7) have been assembled for each component of health care utilization from onset of respiratory distress to recovery for each event cycle. For the purposes of this thesis, the PHCS costs are considered costs determined within a hospital setting although PHCS costs do include prescription and other medical service plan costs within the BC health care system. Those elements are allocated to the indirect costs section as presented in Table 2-7 (under Patient and Society items G-K). Data gathering was complicated by different regional asthma categorizations and non-delineation of controlled versus uncontrolled asthma with the mild, moderate, and severe categorization outlined in Canadian literature and high-use categorization presented by the U.S. EPA (2001). Data that could not be properly categorized into high-use or severe uncontrolled asthma was not used in this study. The data were provided in chapter 2 and summarized in Tables 2-8 through 2-15. In addition to direct costs, the indirect and external cost impacts were found in the literature to be estimated via simple ratios of direct costs. The prevention program costs and benefits were then developed. A sensitivity analysis was conducted verify the patient-centric data gathering against broad spectrum valuation provided in literature.

Previous research such as Sadatsafavi *et al.*(2010) focused on the cost of care of the aggregate asthmatic population Averaged cost data across levels of severity does not expose the more significant highs and lows of cost of care. However, for asthma, the cost of care has been confirmed to be directly related to severity (Serra-Batlles *et al.* 1998, Godard *et al*. 2002). This thesis builds on that research to isolate the high-use asthma cohort and the related costs to the public health care system (PHCS) as a basis for confirming viability of a sustainable home environmental remediation asthma-prevention program. Cost savings from reduction in healthcare utilization subsequent to environmental remediation was calculated using impact reduction factoring found in the literature as described and summarized in Tables 2-14 and 2-15.

For highly variable data, Monte Carlo Simulation-based (MCS) risk analysis was used to test how much the output results were influenced by the variability of the data. The MCS relies on repeated random sampling to obtain numerical result accuracy by running cost based scenario simulations (U.S. EPA 1997). Simulations are based on variable inputs to provide the overall output mean value, confidence interval, and confidence levels. Uncertainty and risk becomes measurable. Probability distributions are considered for the data type being analysed. Estimated costs of remediating home indoor environments and administering the prevention program were also included to provide an overall cost and benefit value for each program scope described in sections 4.2 through 4.5 inclusively. Refer to section 4.2 for the specific process used in this determination.

In addition to the direct costs derived from the PHCS MCS assessment, the indirect and external cost benefits were then developed as part of a SCBA. The results of the MCS cost benefit analysis are provided for the direct costs and overall benefits to the PHCS. The overall SCBA was then derived from the compiled data to provide the patient and societal cost impact and cost benefit value at the Provincial level (for PCHS-related calculations), and at the National level (for national and international cost benefit comparisons). The economic basis for or against a proactive health care prevention program targeting mold-affected high-use asthmatics considered: 1) cost effectiveness; 2) payback period (PP); 3) net present value (NPV); and, 4) internal rate of return (IRR). NPV and PP were utilized based on practicality and accuracy of results. The distribution of resulting SCBA costs and benefits to the PHCS, Society, and patient was estimated using information derived from the assessment to determine health equity conditions. That is, to what extent does the PHCS, society, or the patient benefit from program implementation and does it fit the effort and commitment undertaken.

4.2 Cost benefit analysis for the PHCS

Estimates of the direct costs and benefits (i.e. all of which accrue to the PHCS) are described below and summarized in section 4.2.3. A sensitivity analysis was conducted to verify accuracy of assessment, as discussed in section 4.2.4.

4.2.1 Direct costs for untreated high-use Asthmatics

The cost data and utilization rate details are provided in section 2.4 and summarized in Table 4-1. The data, developed from the literature and surveys, encompass all the elements of high-use asthma patient utilization through the PHCS for the patient when debilitated by onset or exacerbation of their asthma condition. Refer to Table 2-10 for category details and references.

Table 4-1 Cost to public health care system (PHCS)

Category	**Subject**	**Min**	**Max**	**Mean**	**SD**
A1	Emergency Dept. costs per visit	$251	$428	$331	$58
A2	Emergency Dept. visits per year	1.4	2.85	1.894	0.52
B1	Critical care bed charge	$3,108	$3,108	$3,108	$100
C1	Standard care bed charge	$1,010	$1,075	$1,043	$32.50
B2	Hospital admissions per year	1.1	1.7	1.1	0.5
B3	Critical care duration (days)	1.0	2.0	1.5	1.0
C2	Standard care duration (days)	0.9	7	3.3	2.2
D1	Daily hospital drug cost	$6	$18	$12	$6
D2	Drug use duration (days)	3	5	4	1
E	Exit hospital drugs	$115	$175	$135	$34
F1	Physician/ clinic costs/visit	$33	$239	$107	$79

Category	Subject	Min	Max	Mean	SD
F2	Physician/ clinic visit frequency	3.5	3.5	3.5	1.8

This table summarizes data found in literature and derived in table 2-10, augmented by a survey sample of health care professionals for validating risk assessment using MCS.

The scope of asthma care delivered by the PHCS is categorized as components A through F provided in Table 2-7 and described in section 2.4. The cost calculation for each component is presented in Table 2-10 (section 2.4.1) and summarized in Table 4-1. The total cost of care to the PHCS for each individual high-use asthmatic is provided as a cost function represented as equation (4), which simulates the PHCS cost of care for one patient. The MCS simulation sums the various cost components and their frequency of utilization using the SD valuation to determine the characteristics of the normal distribution from the data chosen. Those cost components are presented as variables that vary across the range of values provided in Table 4-1 from the gathered cost data organized into minimum, maximum, mean and standard deviation (SD) values. The normal function was used for each cost component as the most appropriate probability distribution. The equation was inputted into an excel spreadsheet based Monte Carlo Simulator. Values for each run of the simulation were recorded on the spreadsheet. The data used to fill each component of the cost function for each iteration was randomly gathered using a random number generator. After 10,000 iterations, the mean, minimum, and maximum values of the sum total were derived to determine the direct cost impact per patient per year based on equation (4):

$$\text{PHCS total direct cost per patient} = A1*A2+B1*B2*B3+C1*B2*C2+D1*D2+E+F1*F2 \quad (4)$$

The summary output value provides the mean cost value from a simulation of 10,000 iterations of the cost function within a defined confidence interval at a determined confidence rate. The scenarios are described in sections 4-2 to 4-4 and summarized in section 4-5. The direct cost to the PHCS for a high-use asthmatic from the data provided in Table 4-1 is calculated from the MCS to be $10,000 (98% CI: 5000-15000). That is, the median value is $10,000 within a range of 5,000 – 15,000 that contains 98% of the result values calculated in the MCS. Alternately, it is reasonable to assume the mean cost to the PHCS of $10,000 per person-year based on the data developed from research and survey as reliable.

To determine impact population size, the breakdown of the asthma population with respect to severity is provided in part 'A' of Table 4-2. The percentage of all mild, moderate and severe asthmatics was found in 3 of the 9 references. Five of the references focussed on severe only and one focussed on mild only. The results provided that 11.1% (normalized) of asthmatics as being severe with a SD of 4.7%. Table 4-2 part 'B' summarizes the percentage of controlled vs. controlled for asthma overall. From 3 references, the uncontrolled amount was determined to be 58.8% with a SD of 3.3%. This thesis uses the term high-use asthma for moderate to severe persistent uncontrolled asthma. For this demographic there is no clearly defined population fraction, but it appears to range from 4.7% of the asthma population (Sadatsafavi *et al.* 2010) to upwards of 20% accounting for the parameters outlined in Table 4-2. Table 4-2 sets 11.1 * .588 = 6.5%. Further, there was no literature that defined the variation in range of the uncontrolled component from mild to severe, except the WHO universal definition of severe asthma defines it as uncontrolled, with risk of severe exacerbations or death (Bush and Zar 2011). This might place the severe uncontrolled at 11.1% of the asthma population alone with the moderate to severe fraction not valued. With these variables, acting conservatively for the purpose of this thesis, the fraction of asthma population considered as severe uncontrolled has been determined to be 6.5%.

Table 4-2 Asthma severity as a fraction of the population

A. Relationship mild to severe		**Mild%**	**Moderate %**	**Severe %**
Sadatsafavi *et al.* (2010)		67.1	25.5	7.4
USEPA (2001)		70.0	25.0	5.0
AIA (1999)		57.0		
Smith *et al.* (1997)				20.0
Serra-Battles *et al.* (1998)				14.0
Antonicelli *et al.* (2007)				7.8
Braman (2006)	(10-20 – ave. 15)			15.0
NAEPP (1996)		70.0	20.0	10.0
Kim *et al.* (2011)	(10-20 – ave. 15)	0.0	0.0	0.0
	Mean	**66.0**	**23.5**	**11.2**
n=9	**SD**	**5.3**	**2.5**	**4.7**

B. Relationship uncontrolled to controlled

		Uncontrolled	**Controlled**
Sadatsafavi *et al.* (2010)		63.5%	36.5%
Seung & Mittmann (2005)		57.0%	43.0%
ICES (2006)		56.0%	44.0%
	Mean	**58.8%**	**41.2%**
n=3	**SD**	**3.3%**	**4.1%**

The high-use demographic of the asthma population and the environmental damp and subcomponent is provided in Table 4-3 as 11.1% severe and 58.8% uncontrolled, with the fraction of asthmatics mold and dampness affected at 21.3% (Table 2-4). Multiplied together, the mold and dampness affected severe (high-use) asthmatic is estimated to be 1.4% of the total asthma population. From that, the total population of (mold affected high-use) patients is estimated to be 4,400 (95%CI: 2500-6350) from 318,051 asthmatics (STATSCAN 2011) in BC (Table 4-3). This was then extrapolated to 35,000 patients in Canada, and 360,000 in North America using PHCS asthma population records between British Columbia, Canada, and the United States to provide a general scale of impact (STATSCAN 2011, CDC 2014).

Table 4-3 Affected population and cost per high-use asthmatic

Source	Population/ Value	Total population/ Total cost
Asthmatics BC 2011	318,051[+]	
% high-use	11.1% +/- 4.7% SD	
% uncontrolled	58.8% +/- 3.2% SD	
% environ. affected	21.3% +/- 0.6% SD[++]	**4,400 (95% CI: 2500-6350)**
Projected High-use Asthmatics Canada 2011	(2,511,890[+++]*.111*.588*.213)	**35,000**
Projected High-use Asthmatics USA 2011	(25.7 mil[++++] *.111*.588*.213)	**360,000**
Median cost per high-use asthmatic per MCS		**$10,000 (98% CI: 5000-15000)**

[+] STATSCAN 2011
[++] see section 2.4.4 for calculation and references
[+++] STATSCAN 2011
[++++] CDC (2010 stats, 2014 vitalsigns)

By not proactively treating the indoor environment, the median direct cost per patient-year to the PHCS of the mold and dampness affected high-use asthmatic is calculated to be $10,000 (98% CI: 5000-15,000). The MCS analysis projects the total yearly cost to the PHCS to high-use asthmatic health care in British Columbia to be $44 million (98%CI: 14M-74M), based on the cost per person multiplied by the estimated cohort of 4,400 high-use asthmatics in British Columbia. This extrapolates to an annual $350 million cost impact in Canada and $4.0 billion in North America.

4.2.2 PHCS cost benefit from environmental remediation

The cost benefits through reduction of health effects and health care requirements due from proactive environmental remediation is described in section 2.4.4. Literature provides that the frequency of ED visits is reduced after remediation by 62.5% with hospital admissions reduced by 72.5%. ED and bed costs do not change. Hospital drug costs are reduced by 59% and physician/ clinic visits are reduced by 88.7% (Table 2-14). Reduction in hospital care duration (bed stay) was not calculated as there was insufficient information to make a determination, which should result in an overall conservative valuation. The direct financial benefit to the PHCS from reduction in health care requirements through environmental remediation is presented in Table 4-4. The actual time before a decrease in health impact from uncontrolled asthma attacks after environmental remediation, depending on severity, can range from several days to a week or two before the effects of reduction is seen (Stockman 2003, Seung and Mittman 2005, UMMC 2014). For simplicity, this analysis considers the reduction in health care requirements to commence immediately upon remediation of the home environment. The PHCS cost reduction component values noted in Tables 2-14 and 2-15 were inputted into the MCS providing PHCS cost savings of $7,100 (98%CI:3,600-11,000) per high-use asthma patient-year, using the data developed in section 2.4. The mean values and standard deviations of the cost component values found in literature are summarized in Table 4-4 for reduction in health care costs, along with the NPV cost savings value.

Table 4-4 Reduction in direct health care costs due to remediation

Category	**Subject**	**Mean**	**SD**
A2	ED visits per year	-62.45%	26.58%
B2	Hosp. admissions per year	-72.50%	30.90%
D1	Daily hosp. drug cost	-59.00%	14.75%
F2	Physician/ clinic visit frequency	-88.73%	1.62%
	Cost savings per high-use asthmatic in person-years	**$7,100**	**(98%CI: 3,600-11,000)**

4.2.3 Direct cost-benefit analysis

The results of the MCS assessment indicate the PHCS net benefit for the projected 4,400 high-use asthmatics in B.C. is $31 million (98%CI: 16M-49M) for an asthma prevention program after the first year. This can be extrapolated to $250 million (98%CI: 120M-390M) in PHCS net benefit cost savings for 35,000 affected high-use asthmatics in Canada and $2.5 billion (98%CI:

1.5B-4.5B) for 395,000 affected in North America based on the relative asthma populations. This indicates the NPV payback could be within the first year with a NPV benefit-cost of >>1.

4.2.4 Sensitivity analysis for PHCS valuation

The MCS analysis determined the total yearly cost to the PHCS for the high-use asthmatic demographic in British Columbia to be $44 million. Sadatsafavi *et al.* (2010) identified $56 million in the Province of BC health care budget for asthma care on a broad analysis basis with 60% or $43 mil in 2013 being consumed by the high-use asthmatic. This matches the overall MCS analysis value. Alternately, Sadatsafavi *et al.* (2010) determined that 4.7% of the asthma population of 126,404 that accessed hospital services, averaged over the 5 yr. study 1996-2000, comprised 5941 high-use patients who consumed $43 million a year or $7,300 per patient-year of PSHC costs. The difference with the MCS component assessment value is the number of projected high-use patients (5941 vs. 4400) and the industry mean of $6,200 (95%CI: 5200-7200) which overall appears to be within reason.

4.3 Indirect and externality costs for not remediating proactively

4.3.1 Indirect costs

Indirect costs were defined in Table 2-7 to include: 1) ambulance; 2) out of hospital yearly drug regime; 3) lost workdays/ lost productivity; 4) early retirement; and, 5) mortality. These indirect costs do not accrue to the PHCS; but to patients and society. Several studies have estimated the indirect cost impacts of high-use asthmatics as ratios of direct costs, as shown in Table 2-12. The simple median value of the ratios would be 74.6% of the direct cost, with a standard deviation of 11.7%. The mortality component had insufficient data to determine a value, leaving the resulting valuation conservative.

4.3.2 Externality costs

The various externality components have insufficient data to be individually valued without further research being conducted. These unvalued components include: 1) loss of house/ mental stress; 2) community support/ transportation; 3) child care; 4) transition counselling/ social worker special needs; and 5) loss of patient societal contributions. An overall externality value has been estimated by Kim *et al.* (2011) as 100% of the sum of direct and indirect costs including productivity loss with a standard deviation of 15.7% (Table 2-13). The estimated external cost was adjusted to exclude the productivity loss component addressed previously in indirect cost estimates.

4.3.3. Program implementation and one-time costs for intervention

Additional cost line items beyond that outlined in Table 2-7 to address asthma care for the high-use asthmatic would be for systems programming, infrastructure and management, along with program implementation requirements should a prevention program be initiated to capture the benefits outlined in section 4.2.3 and remediation of the verified mold and dampness affected residence. The intent of this thesis program concept is to connect cost factors with system benefits and therefore it is proposed that an asthma prevention program be implemented within the PHCS based on the premise the program would generate savings accrued from reduction in health care demand from the target population that would cover or exceed the ongoing costs of the program. Chapter five provides details of a proposed intervention program, with program costs provided herein. The program considers infrastructure and manpower to be reallocated within the health care system with no new personnel or long term infrastructure requirements; however, initial start-up costs would be incurred during lead up to and initial year implementation including personnel training, management and administration of the program. For this, at a Provincial level, a one-time transition allocation of $500,000 over six months has been included in the calculation which is intended to support a program implementation task force to coordinate its launch and monitor near term results. This budget for transition can be broken down into: 1) management implementation team – 3 persons at $200,000; 2) reallocation of administrators – 2 persons at $100,000; 3) reassigned medical clerks – 4 persons at $100,000; 4) a SIRAPP administrator at $50,000; and 5) $50,000 for overhead including temporary office space. A more accurate transition budget would be determined once the program specifications and implementation process was defined by a task force or the project implementation team, but suffice to say, the requirements will include not only the management team, but also administrative support, reassignment of medical clerks, a SIRAPP administrator, and temporary office space.

The one-time remediation of a suspect indoor environment of the mold and dampness affected high-use asthmatic is accomplished by eliminating free moisture and any visible mold in the home and by utilizing prescribed removal techniques in the event of moisture and mold proliferation (NYSTMTF 2010, UMMC 2014). The one-time cost of removing mold and dampness from homes to the extent health impact is reduced can vary from a few thousand to tens of thousands of dollars depending on the extent of the underlying environmental issues. These issues can range from an intermittent plumbing leak to large floods; from poor building envelopes to significant ventilation and filtration deficiencies. Data obtained from surveying professional mold remediators in the Okanagan for homes that have not been catastrophically damaged by flood and were built with a good level of care suggest that the cost range for typical mold remediation and moisture related repairs is $1,500 - $10,000 CAD (2014). Kercsmar *et al.* (2006) identified the median cost to remediate a home for mold to be $3,500. Combined, this provides a median value of $4,500 (95%CI: 4,000-5,000) for the cost input valuation. Remediation of mold-affected environments includes removing mold contamination, sanitizing the affected environment, and cleaning the air of airborne fungal debris with high-efficiency particulate air filtration. Observations from personal professional experience of clearance testing hundreds of remediation projects in the years 2000 through 2012 support this remediation cost data valuation.

With little to no means to independently enact environmental correction, incorporating the one-time cost of remediation into the year-one program cost is necessary as the majority of asthmatics are tenants, youth under 18, and the fiscally challenged (PHAC 2007). These year-one program costs have been included in the summary cost-benefit Table 4-5.

4.3.4 Total of direct, indirect, and externality costs for status quo

From the preceding calculations, the total direct, indirect, and external impact costs are summed from MCS assessment to be $34,000 (98%CI: 17,500-51,600) per patient-year as a total cost for not remediating the homes of mold and dampness affected high-use asthmatics. This projects to $153 million (98%CI: 80M-230M) for British Columbia, $1.2 billion (98%CI: 0.6B – 1.8B) for Canada, and $14 billion (98%CI: 6.6B-20.4B) for North America.

4.4 Indirect and Externality benefits of remediating proactively

The estimated reduction in indirect and external costs from remediation is provided in Table 2-10 using the methodology described in section 2.1. While there are expected externality benefits, no reliable research was found in the literature on externality benefit valuations. Therefore, following from how externality costs were estimated, the externality benefits were estimated as 100% of direct and indirect reduction values, which was calculated to be a 67% cost reduction with a SD of 24%. From the MCS analysis, the sum of indirect and external benefits was estimated at $15,000 (98% CI: 7,000-23,000) per patient-year.

4.5 Summary of benefits from SCBA

The overall cost-benefit of remediating indoor environments is calculated as the difference between 'Current costs' and 'New costs', and shown in the column labelled 'Net Cost Savings'. The overall direct, indirect and externality SCBA valuation is in the form of benefits estimated at $97 million (98%Cl: 49M-147M) for remediation of environmentally affected homes of high-use asthmatics in British Columbia after year one, as shown in Table 4-5. This extrapolates to $800 million (98%CL: 420M-1.2B) in SCBA savings for Canada and $8 billion (98%CL: 4.5B-14B) for North America. The largest cost savings are from the SCBA externality impact reductions and then the PHCS (direct costs) impact reductions.

Table 4-5 SCBA Summary of total costs and benefits in BC

BC Population	**Current Cost**	**New Cost****	**Net Cost Savings**
Direct (PHCS)	43.8	12.1	31.7
Indirect	32.8	18.1	14.7
Externalities	76.7	25.7	51.0
Total	**153.3**	**55.9**	**97.4**
Remediation/admin cost 1st year			(20.3)
		Total	**77.1***

* Millions of dollars
** New Costs to PHCS after implementation of Prevention Program

The first year remediation and administration cost summary was calculated from the cost of remediation multiplied by affected population or $4,500 x 4,400 plus the one time administration and set up budget of $500,000 for a total of $20.3 million dollars.

4.6 Estimated distribution of costs and benefits

The estimated distribution of costs and benefits from the implementation of a prevention program for 4,400 high-use asthmatics in BC is provided herein. From calculations carried out in sections 4.2 through 4.5, the direct cost to the PHCS broken down to patient level totals an estimated $10,000 per patient-year without program intervention. The cost to society and the patient is an estimated combined additional $24,000 per patient-year. This provides the estimated total of $34,000 per patient-year in total PHCS, society and patient costs of non-intervention (i.e. current costs, in the absence of a prevention program). The corresponding direct benefit to the PHCS for intervention totals an estimated $7,100 per patient-year (PPY) benefit plus an estimated $15,000 per patient-year to patients and society with intervention totalling to $22,100 in net savings per patient-year or a reduction of 65% overall in total impact costs. Table 4-6 provides an overall summary of the economic impact costs and benefits from the SCBA analysis for damp and moldy indoor environments per patient-year for British Columbia with a projection to the total impact incurred in North America in the first and second years. The summary costs and benefits are based on the estimated candidate population (4400 in BC and 395,000 in NA). The addition to the candidate population each year has not been estimated nor incorporated into the projection. The NPV for a lifetime of program savings has not been calculated for two reasons: 1) the longevity of a mold and dampness induced high-use asthmatic has not been researched; and 2) the increased longevity from removal of mold and dampness triggers from the high-use asthmatic’s residential environment has not been researched. A projection of health care savings into the future would be available after several years of study of PHCS utilization from the first batch of candidates.

Table 4-6 Summary of BC and NA impact costs and benefits

Impact cost				**Impact Savings**			
	PPY*	**BC (mil)**	**NA (mil)**		**PPY**	**BC (mil)**	**NA (mil)**
Direct	$10,000	44	3,950	**Direct**	$ 7,100	31	2,800
Indirect	$ 7,150	33	2,800	**Indirect**	$ 4,500	15	1,750
External	$16,850	76	6,650	**External**	$10,500	51	4,150
Total	$34,000	**153**	**13,400**	**Total**	$22,100	**97**	**8,700**
				1st year Costs**		(20.3)	(1,800)
				1st year Savings		**76.7**	**6,900**

*Per Patient-Year
**First year costs for program set up and remediation

4.7 Discussion

The data component scopes as described in Table 2-7 are cost components of the Government through the PHCS, the patient, or society in general in the form of direct, indirect and externality cost benefit impacts. Split PHCS/patient costs have been allocated to the indirect category when not specifically hospital costs for the purpose of defining PHCS costs as hospital costs for simplicity of presentation. For example, the ambulance charge is partially or totally covered by the PHCS depending on the need level of the patient but is allocated as in indirect cost per Table 2-7 as it is not a direct hospital cost. Similarly, the drugs specified for asthmatics are made available and covered by the PHCS to a large extent, but dispensing fees and above fee schedule costs are charged to the patient. The component cost is considered indirect per Table 2-7 because it is not a hospital cost.

Lost productivity is considered an indirect cost as an employer’s economic loss and cost to society with higher prices or lower employment and loss to the owners in reduced profits that do not circulate back into the economy. Similarly, lost additional work days is considered an indirect cost as it affects the real income of the individual and it indirectly affects their quality of life and indirectly affects society in reduced available cash for circulation in the economy. The patient has less disposable income to pay for drugs causing secondary health and family issues. As an externality, loss of function for the patient increases absenteeism also reducing take home pay, but also adversely impacts their family in caregiver demand, society in lost volunteer hours, and increases demand for special needs services such as handicap (handi-dart) transportation, community nursing care, and low cost housing subsidy. Very low income earners obtain further financial assistance from the various level of Government.

From analysis, the highest benefit for program development appears to rest with the PHCS (direct cost) and society (indirect and externality costs) in reduced health care and health care services utilization, and higher community involvement of healthier people. Along with an inbred skillset for health care and health care service provision, this supports the use of the PHCS for implementation of a prevention program. The benefit to the patient is better health, mobility, improved indoor environment, and corresponding quality of life, which leads to more community involvement and less demand on society.

The results of the SCBA, including MCS to test sensitivity of the economic analysis results, suggest a statistically significant economic benefit for implementing an intervention-based prevention program. In fact, the identification of environmentally affected asthmatics and the remediation of their homes appear warranted on an economic basis alone, although the huge benefits to society and the individual from a social standpoint cannot be overstated. The high-use asthmatic patient cohort is a particularly important segment of the asthma population for initial remediation focus for program success due to the high component cost and cost savings element and expected significant health benefits that will be quite visible with the patient upon remediation of their home environment. Prevention based on health betterment is noteworthy, but medical protocol does not appear to easily embrace the concept. With significant potential for economic benefits calculated in these results added to the argument, it would seem prudent to pursue. Current health care promoted prevention protocols would remove the patient from the trigger, but this is not practicable for occupants living with indoor mold and dampness. However, removal of the environmental trigger via remediation is practical. By removing consequential molds and dampness from indoor environments, the cost savings to society are shown to be significant.

However, research indicates long term failure in prevention programs is unfortunately the norm due to a variety of stressors including gaps and overlaps in programming, demographic shifts, program design, lack of tailoring to specific local conditions, and an unsustainable funding model (AFMC 2014). Validated cost savings and demonstrated health betterment through ongoing comparison monitoring and highlighting is believed to be key in the long term success of a successful prevention program. Redirecting savings to other health care programs and health benefits to thousands of individual patients would be practical outcomes of the program and should be highlighted to expose the merits of the prevention program on an ongoing basis. This will be discussed further in chapters five and six.

It may be argued that reduced healthcare system utilization in the care of high-use asthmatics would not generate system savings for other disease centers or free up space for other ED, hospital, and care needs due to existing system overload. Literature on the savings potential and impact reduction are well described in this thesis, but if no system savings exist, this undermines a priority of the Government of British Columbia's new health care mandate towards patient-centered care framework that includes "appropriate reallocations from the acute to the community services sector must become part of future health authority planning and going forward a majority of net new funding must be assigned to developing primary and community services" (MoH 2015). The argument that no cost savings exist as the PHCS is overloaded and any reduction in load will be filled with the overload is to be considered. Further research would be required to address this potential issue should the PHCS consider the prevention program suggested by the thesis.

The thesis, though, does fit with the Ministry of Health's initiative to find ways to reduce cost and increase capacity supported by a UBC Okanagan Research January 2012 submission to the Ministry of Health through the Select Standing Committee for Health Sustainability offering sustainable ways to reduce cost through SCBA-based program implementation. One of the six desired outcomes of the BC Health System priority setting program is effective chronic disease prevention associated care and treatment costs [priority #2] (MoH 2014b).

4.8 Summary

In this chapter, a cost benefit analysis for a proactive intervention program in the remediation of the indoor environments of mold and dampness induced high-use asthmatics for the PHCS and a SCBA was conducted. The results indicate a possible significant financial benefit from the undertaking. Literature on the overall cost benefit impact from a macro level developed in chapter two was deemed inadequate and a patient-oriented fiscal assessment was conducted with results assessed through a MCS analysis to obtain reliable results. The results generally correlated with literature. This methodology assisted in the formulation of chapter 5 structure and overall program development. The following chapter lays out a possible sustainable prevention program for the PHCS to implement.

Chapter 5 Current and proposed state of health care in asthma prevention

This chapter discusses the current state of the health care industry pertaining to asthma diagnosis for mold and dampness and proposes an environmental asthma prevention program. Statements derived from the author's professional experience were not referenced. Section 5.1 discusses the current state of the health care industry with subsections 5.1.1 diagnosis of asthma impact from mold and dampness, 5.1.2 professional IAQ investigations and concerned occupants, 5.1.3 current IAQ product and service industry and, 5.1.4 the environmental consulting industry. Section 5.2 discusses regulation-based IAQ solutions. Section 5.3 discusses IAQ and mold and dampness information derived from government and NGO involvement. Section 5.4 overviews an integrated approach utilizing industry and PHCS, including subsections 5.4.1 education, 5.4.2 prevention, and 5.4.3 sustainability. Section 5.5 presents a proposed "sustainable IAQ residential environmental asthma prevention program" (SIRAPP) with the key elements necessary for its success, including subsections 5.5.1 program overview, 5.5.2 a proposed shift towards patient outreach, away from ED patient admissions, with an implementation strategy outline, 5.5.3 program next steps, 5.5.4 a SWOT analysis that considers the strategic strengths, weaknesses, opportunities, and threats that would influence SIRAPP success, 5.5.5 the monitoring requirements for tracking SIRAPP effectiveness and to identify any needed refinements, 5.5.6 the description of how SIRAPP would be used to secure program sustainability and, 5.5.7 concludes with the overview of a proposed pilot project. Section 5.6 concludes with the chapter summary.

5.1 Current state of health care industry

5.1.1 Diagnosis of environmental asthma for mold and dampness effects

Health assessment in relation to specific indoor mold environments is not generally included in medical curricula nor in the procedures generally laid down in medical protocol

(Lawrence and Martin 2001). In the existing health care system, doctors are not easily able to draw conclusions outside their professional field, particularly without verified disease pathways or diagnosis protocol for indoor mold induced sickness, without access to environmental conditions that may be triggering the effect, or without a method to validate the patient's indoor environment in relation to the effect. As such, prevention is limited, and prescription is restricted to medication. Health care professionals may share in the concern regarding the possible impact of indoor environmental mold and dampness and offer general advice but remain limited to effect change in the means and methods to deduce and treat, without an overall program change. This thesis proposes a means to assist the health care system towards a more robust prevention model pertaining to indoor mold and dampness asthma onset and exacerbation.

Medical researchers that have reviewed PHCS responses associated with asthma onset and exacerbation incidence associated with clinic, hospital, and emergency room visits have found the following protocols could be given more attention: 1) professional treatment methods; 2) professional asthma education and action plans; 3) patient avoidance coping; and, 4) patient self-management attitudes (Bahadori *et al*. 2009, Al-Jahdali *et al*. 2012). Assessment of the patient's home environment is currently not included in general protocol. Proper and timely medical treatment and trigger reduction action plans are essential to controlling asthma and the more extreme effects (U.S. EPA 2014). Removal of the patient from environmental triggers is a well-known means to control the exacerbation of asthma (U.S. EPA 2014). But, it is difficult to avoid environmental triggers when they occur in home environments for occupants who have no means of recourse such as tenants, children, and fixed income earners who comprise a major part of the demographic (PHAC 2007). Moreover, over 60% of asthmatics are considered uncontrolled and lack the means to deal with the cause of their asthma (Sadatsafavi 2010). Given that and three of the four noted protocols that focus on patients systematically avoiding better health choices, direct intervention by society may be the key to successful health improvement (U.S. EPA 2001).

The PHCS handles walk in or ambulatory short term asthma care through its emergency department (ED). In British Columbia, ED protocols for acute asthma care are provided to the health regions through the Provincial Emergency Services Project in a document developed by Vancouver Coastal Health and Providence Health Care called the “acute asthma management tool kit”. The tool kit describes roles, responsibilities, and process flow in a three level response format identified as CTAS levels 1, 2, and 3 used for treatment of adult and pediatric asthmatics in the ED (VHPHC 2006). Another protocol in use in the ED is the “Adult Emergency Department Asthma Care Pathway” put out by the Ontario Lung Association (OLA 2014). The Asthma Center (TAC 2014) was also accessed for reference to ED protocol for acute asthma care.

If the patient is having a mild asthmatic attack, the approach is to place them on oxygen and administer a bronchodilator to assist breathing and discharge the patient after a positive initial response. Mild severity is considered CTAS level 3 for adults and requires assessment and 1^{st} bronchodilator within 30 minutes to determine eligibility for clinical (asthma care) pathway (EDACP) or discharge. If the asthmatic patient enters the emergency room in a severe state (CTAS level 2 or 1), they are placed in the emergency care resuscitation area until stabilized, which may include an extended hospital stay of 3-5 days in intensive care or longer depending on severity and response time. CTAS level 1 is near death condition asthma. In addition, KGH hospital procedure is to culture sputum and check white blood counts for abnormalities with a CTAS level 2 or 1. The patient when discharged after a good response is achieved is given an inhaler, and a prescription for additional medication based on severity and education pamphlets (VHPHC 2006). If the respiratory issues are due to their home environment, then quite possibly the cycle of respiratory ill-health continues. This is a critical factor in the present medical system assessment protocols because continuing to assess the patient independent of their environment can lead to a delay in diagnosis, misdiagnosis, or, non-diagnosis (Wu et al. 2007). The medical directive focus is on reactive treatment measures for early release and balancing medication so the patient has a reduced chance of exacerbation requiring more potent medication. Table 5-1 summarizes the four types of assessments that taken together might provide a holistic consideration for all aspects of a patient's condition.

Table 5-1 Medical professional focii

Professional Service Providers	**Medical treatment**	**Home assessment**	**Mold specific assessment**	**Environmental focus**
Family doctor	yes	no	no	no
Walk in Clinic	yes	no	no	no
Allergy Specialist	yes	no	yes	yes
Naturopath	yes	no	yes	yes
Respiratory therapist	yes	no	yes	yes

While all provide medical assessments, only specialists are trained to conduct mold-specific assessments. Specific assessment of the home environment is excluded, despite efforts within the medical profession, such as those published by the University of Connecticut in tandem with the U.S. EPA (Storey et al. 2004). A challenge in diagnosing a building-related illness appears to be the inclusion of the home in the medical diagnosis. A two part treatment methodology may be considered: medical assessment and site environmental assessment.

5.1.2 Professional IAQ investigations and concerned occupants

From this researcher's professional investigations as an IAQ consultant from over 600 consultations between 2002 and 2012, the primary concern of occupants was fear that mold in their homes might be causing adverse, unknown health effects. Reports of long-term flu-like symptoms were prevalent. On closer investigation of respondents who did not pinpoint mold as a primary concern, mold was indeed determined to be a possible cause of their health concerns. In approximately 25% of the cases, consultations occurred after medical or hospital visits resulting from flu-like symptoms and repeated occurrence of symptoms. Occupant health concerns remained. Approximately 5% of the calls occurred after the purchase of IAQ equipment (e.g. ionizers, ultraviolet (UV) irradiation, and portable HEPA cleaners), which failed to resolve health concerns. Of those remaining, a large proportion of consultations were with young mothers or mothers to be with concerns about potential mold issues that ended up not being indoor environmental or mold issues. This anecdotal evidence suggests that the general public is generally aware that mold impacts health, but that confusion remains on its cause, proliferation, and indoor impacts, and requirement for health-based remediation.

The accuracy of information from patient self-diagnosis using a combination of internet, home remedy, and alternative medicine can vary significantly. Resources that are available on the internet are not always evidence-based, can cause confusion, and delay action towards proper diagnostic determination - to the detriment of the patient. People do not generally make the link between specific ill-health and indoor air quality stressors, that can further delay initial assessment (Buttersworth 2000). Patients do, however rely heavily on medical professionals for proper and timely assessment. Beyond medical professionals, the appropriate professionals to confer with on health related indoor environmental issues include the environmental consulting engineer (ECE), the industrial hygienist (IH) who specializes in indoor environmental hazards, and their technical counterparts, the IAQ consultant. Knowledgeable suppliers and product-based service agents can also be consulted.

5.1.3 Current IAQ product and service industry

The professional consultant approach can be expensive and complicated, and the occupant usually has neither the necessary time nor money (U.S. EPA 2011). The less daunting and increasingly available approach is to seek IAQ related products and services directly from product based providers. Products include portable air purification systems, self-administered mold testing, air scenting agents, and air “freshness” products. Services include carpet and duct cleaning and whole house customized air filtration and mechanical ventilation systems. The IAQ product and product service industry has developed and evolved through an unregulated business environment and to some extent is based on lowest price and salesmanship. As such, gathering information to make an informed decision can be fraught with confusing alternatives, competing designations, and value judgments which may lead to misinterpretation of environmental requirements, improper diagnosis, and costly misdirection (Lawrence and Martin 2001). Table 5-2 contains a summary of service provider competencies deduced from an industry review between 1999 and the present in the Okanagan region of British Columbia. As the industry matures, it is possible that the confusion will be reduced and overlapping technologies and services will merge into a more seamless delivery system with a primary focus on the best interests of the consumer.

Table 5-2 Service industry gaps

Products and Services	**Are services science based?**	**Third party accredited?**	**Primarily client health focused[2]?**	**Client health relevant?[3]**	**Cost range**
Envir. Consultant	Yes	Yes	Yes	Yes	$1,000 – 5,000
IAQ Consultants	Yes	Yes	Yes	Yes	$ 500 – 1,000
IAQ products	Possibly	No	No	No	$ 300 – 2,000
Service providers[1]	Possibly	Possibly	No	Possibly	$ 200 – 5,000

[1] Service providers install IAQ products, but may not be accredited third party professionals

[2] Product and non-accredited service providers are usually not qualified to offer health specific solutions and refer to an Environment consultant or do not include client health assessment in product or service delivery.

[3] Product and general service providers tend to focus on generic solution provision where specific client health issue is not addressed.

Consumer marketed indoor air quality products include: portable and fixed, room and whole house air purification systems; low VOC construction products; non-lead based products; and non-organic, non-toxic, biodegradable cleaning products. IAQ products are sold in stores, by mail, and over the internet. As the marketplace for IAQ products is not generally regulated, unsubstantiated claims can be made. Chemical cleaners may be marketed as “mold killers” for example. Biodegradable and chemical free cleaners (labelled as green) and chlorofluorocarbon (CFC) free aerosols (regulated) are now readily available in stores. Along with these environmentally regulated products are chemically enhanced, VOC based “deodorants” and cleaners. Products purporting to be “earth friendly” and “IAQ” specific require further scrutiny to ensure accuracy of product claims. The claim of earth-friendly, ecological, natural, and non-toxic implies no harm to the environment. However no standard exists; moreover, the Federal Trade Commission cautions against use of such terms (Consumer Reports 2014).

Scented consumer products and air freshener/masking agents are found in homes that can directly or indirectly mask mold and otherwise obvious odours that could indicate an active biological environment. The efficacy of the use of home air fresheners and scented laundry products was examined by a University of Washington study and found to be potentially health affecting at best and toxic or hazardous by US federal law at worst (Caress 2004). A study by the National Resource Defense Council (NRDC) added to the public debate. In testing 14 different air fresheners sold at a drug store, the study concluded that many contained chemicals that could cause developmental and reproductive problems, especially for infants (NRDC 2007). The University of California at Berkeley performed a study on air fresheners and household cleaners that discovered ethylene-based glycol ethers, classified by the U.S. EPA as hazardous air pollutants (Science Daily 2006). These are but a few examples of the IAQ product industry purporting to solve indoor air quality problems by odour masking techniques. These methods can result in the continuance of mold proliferation and ill-health in residences.

Product and service providers have found an increased consumer awareness of indoor environmental issues that could be leveraged into product sales utilizing terms such as: IAQ; clean air; mold and VOC removal; environmental cleaning; and a variety of IAQ specialist services. Regularly, house and carpet cleaners, duct cleaners, and heating and ventilation contractors now include these terms in marketing their existing products or they add product lines deemed to contain indoor air quality benefits but are generic in nature. Those practicing the necessary care and attention commensurate with demonstrable customer indoor air quality requirements deserve the opportunity to offer services within the context of their profession. However some practitioners may have expanded into indoor air quality services without the necessary expertise or awareness. This scenario is played out in households that include environmentally sensitive occupants where a contractor's premise for IAQ-based renovation work was found to be exaggerated or irrelevant due to lack of building science and indoor environmental knowledge. This supports a buyer beware concern with IAQ products and services.

Web accessible businesses have the opportunity to cater to simplified consumer focussed IAQ-based requirements through industry specific products and services. However the adverse effects of IAQ are not a simple or generic problem–solution couplet. In fact, determining IAQ solutions is a complex process (Cabral 2010); that requires an approach that exposes the cause, researches the specific effects, and engineers a solution that endures. This usually requires house specific professional IAQ input for accurate validation of indoor environmental cause and effect. Understanding environments accurately requires rigor and a thorough assessment using the scientific method. IAQ solutions necessarily include the understanding of all aspects of the building's indoor air quality both by visual assessment and, as required, by lab based sampling methods. This appears to be missing in products and product-oriented services that are not based on specific home environment and occupant conditions. Field experience and data collection consistently reveals that products and services obtained without professional advice likely do not address the underlying problems associated with environmental impacts.

Economics plays an important if not central part in the occupant's decision to determine the cause and effect of health issues that may pertain to their home environment (Wu et al. 2007, Cabral 2010). Anecdotal evidence gathered from personal professional experience between 2002 and 2012 suggests that more than one quarter of health-related callers could not afford services at any cost; most others had a fiscal or psychological threshold of less than $200 - $600. The cost of various IAQ related services is provided in Table 5-3 based on general trade information gathered from the Okanagan region of British Columbia in 2014.

Table 5-3 Cost of IAQ industry services

SERVICE	Low end cost	High end cost	Mid-range
Duct Cleaning with anti-fungal agent	$ 200	$ 500	$ 350
Carpet Cleaning with anti-fungal agent	$ 250	$ 450	$ 350
Air Purification equipment- central	$ 1,000	$ 5,000	$ 3,000
Air purification equipment- portable	$ 500	$ 2,000	$ 1,250
Major mold abatement (2000 sf house)	$ 5,000	$ 25,000	$ 8k – 15k
Light mold abatement (2000 sf house)	$ 1,500	$ 10,000	$ 4,000
Basic mold testing	$ 300	$ 600	$ 450
IAQ Consult. w/ written site assessment	$ 200	$ 600	$ 400
IAQ consultant incl. testing for molds	$ 500	$ 1,200	$ 850

The majority of those who could not afford an IAQ service at any cost were tenants/renters, not home owners. With no regulatory authority over the IAQ sufficiency of tenanted residential indoor spaces, unhealthy indoor environments with health consequences are more likely. Those living in substandard rental housing that are less able to make repairs are three times as likely to have indoor mold and dampness issues that become the source of physical impairment (Wu *et al*. 2007). Researchers suggest that mold and dampness-related environmental issues tend to happen more often in inner-city low income households (CDC 2009, U.S. EPA 2011). For this group, resolution of health impacts is limited to affordable (reactive) medical treatment with no professional attention to potential indoor environmental causes. There is a cost to society when indoor environments are left in a hazardous toxic state. The broader cost in terms of impact on the U.S. economy has been measured in the billions of dollars ($2B to $40B) from the loss of workplace productivity alone due to building related ill health (Fisk 2001, Kosonen and Tan 2004). In Canada, the major cause of the increase in respiratory-related sicknesses is due to asthma from inadequate indoor air quality, and health care costs have been estimated at over $700 million per year in direct costs and over $800 million per year in indirect costs (PHAC 2007). In terms of reduced life and loss of well-being, as well as overall social impact, there are consequences that are difficult to fully and reliably quantify.

5.1.4 The environmental consulting industry

While there are knowledgeable experts in the environmental service industry such as the environmental consulting engineer (ECE) and the industrial hygienist (IH), unfortunately they are not commonly engaged in the residential sector, for several reasons. First, as the name suggests, the IH is trained for and typically employed by industry and industry regulators (e.g. WorkSafe BC). Second, the ECE is highly trained in complex issues and is significantly regulated to provide extensive reporting and analytical services that are essentially impractical at a single household residential level. For example, the ECE is trained (and constrained) to consider a broad range of conditions and determine the extent of environmental impact from a regulatory perspective, risk, and prescribe comprehensive remedial clean-up methods based on industry regulations, oversee the cleanup, and certify environmental compliance (STATSCAN 2014). Such, regulation-based professional indoor air quality reporting can be extensive and therefore expensive. Hence, ECE's and IH's have generally not been present in the evaluation, assessment, and prescription of indoor air quality issues in single family residences to any great extent as the required level of professional thoroughness and detail predisposes the assessment to be economically non-viable to the average homeowner. With a charge out rate of $175 - $350 per consultant hour, site visits, testing, and reporting can run into several thousand dollars for baseline services, and much more for specialized analysis. So while there may be a willingness and need of homeowners for their services, there is not generally an economic ability to assess residential indoor environments (Wellington *et al.* 2005). This is a significant barrier to be overcome by homeowners; even more so with residential tenants. As such, the ECE and IH have historically not been involved in residential mold related issues unless the projects were of a larger more comprehensive scale (e.g. an entire multi-unit residential apartment complex or entire production plants, processes or industries) or driven by regulatory fiat.

A more appropriate alternative may be a certified Indoor Air Quality (IAQ) consultant who typically focuses on residential and small building assessment, with solution provisions within a limited suite of services (www.IAQA.org). However, IAQ consultants are not regulated and have limited outside professional criteria to conform to. They can deliver uncertified professional services or be certified through an indoor air quality association such as the IAQA (2014) and are considered an independent third party if not associated with a remediation firm or IAQ product supplier. The IAQ consultant is expected to be guided by professional protocol required by their profession that can be defined as:

> *"The goal of a building investigation is to identify and solve indoor air quality complaints in a way that prevents them from recurring and which avoids the creation of other problems. To achieve this goal, it is necessary for the investigator(s) to discover whether a complaint is actually related to indoor air quality, identify the cause of the complaint, and determine the most appropriate corrective actions"* (U.S. EPA 2011).

Site delivered third party professional assessments by certified IAQ consultants endeavor to validate a hypothesis statement whether an indoor environmental hazard exists or not through site assessment and specific field testing (as required). Environmental hazard issues that exceed the IAQ consultant skillset are generally referred to an ECE or IH consultant. The Canadian Mortgage and Housing Corporation (CMHC) developed a program in the mid-90's called the "Residential Indoor Air Quality Investigator Program" that introduced the issues surrounding IAQ in homes to professionals (builders, architects, engineers and other residential specialists) and provided a general overview program for the assessment of indoor environments and solutions (CMHC 2011). CMHC facilitated the training of IAQ consultants in science-based assessments and solutions for home IAQ problems to provide exclusively visual site assessments in the range of $500 - $800. Testing would add $450 - $600 to the cost of assessment per residence for simple air and bulk mold testing. These costs tend to be acceptable to all but the lowest income demographic.

Healthy Indoor Partnership (HIP 2014) took over CMHC's IAQ training program in 2012. The resulting IAQ Investigator certification courses are accessed by not only IAQ consultants, but IAQ product service providers, insurance companies, and government of Canada personnel. HIP is expanding the CMHC protocol and updating the courses to ensure relevance in this emerging industry. This is important to note as there are a limited number of IAQ consultants who conduct residential assessments in North America. In Canada, HIP's "Certified IAQ Investigator Program" adds a few more trained third party investigators each year from those who take the course. As of

2010, more than a decade after its inception, 46 certified IAQ consultants trained by CMHC practised in Canada, including only 12 outside of BC, Ontario, and Quebec. Currently of 34 noted Certified IAQ investigators, less than 17 are independent consultants not employed by suppliers, contractors, or laboratories. There is a large US association for IAQ consultants, but with only an estimated 600 members who aren't also contractors, suppliers, or laboratories (IAQA 2014). This lack of independent IAQ consultants in Canada and the US, together with unaffordable IH/ECE consultants, suggests that at present little is being done to properly assess and remediate mold and dampness problems in homes in North America.

Compounding this lack of affordable and available residential IAQ expertise, opinions vary widely on what investigative and testing methods are necessary, as well as what constitutes an unhealthy mold level in a home. The perspective of CMHC (2014) that a visual only assessment is sufficient to determine IAQ related health issues in a home differs from research indicating that air and bulk testing for mold is a good indicator of indoor air quality in building environments (Cabral 2010). The EPA (2014c) recently tempered their visual only assessment statement with a further statement that "surface sampling may be useful to determine if an area has been adequately cleaned or remediated. Sampling for mold should be conducted by professionals who have specific experience in designing mold sampling protocols, sampling methods, and interpreting results. Sample analysis should follow analytical methods recommended by the American Industrial Hygiene Association (AIHA), the American Conference of Governmental Industrial Hygienists (ACGIH), or other professional organizations". There is no specific accepted value that defines either safe or unsafe mold exposure levels. Some experts have proposed airborne mold guidelines; however none of these have been adopted by regulatory agencies. Suggested means and methods that take into account the health and well-being of the occupant do exist and are prescribed in reference documents such as the NYC IAQ protocol (NYC 2008), U.S. EPA IAQ protocol (U.S. EPA 2012), and Canadian Construction Association document CCA 82 (CCA 2004). These documents outline the cause of mold proliferation, the possible and probable health effects, and describe remedial solutions to reduce or abate health consequences qualitatively or partially, but suggest no acceptable concentration levels.

Over the last decade many inspectors trained to collect mold samples have come from the home inspection field. However, these inspectors are usually associated with a remediation contractor or testing lab not trained in hypothesis testing or environmental or mold assessment, and therefore not qualified to provide an unbiased independent IAQ home assessment. This level of service for the homeowner costs between $ 300 - $600 (Table 5-3) for generic air testing and lab results. The limitation of this methodology is that the lab results are not interpreted. Air test results typically contain significant variability and testing methods not grounded in a hypothesis test may misrepresent actual conditions. The initial intent is towards a consumer-based IAQ solution not a customer-based health focussed result. Specific (value added) consulting work to help the homeowner understand the results would be in addition to this service. Industry oversight organizations state that testing without independent professional site assessment is not an accurate or recommended method for IAQ assessment (CMHC 2013a, Health Canada 2007, U.S. EPA 2014c).

5.2 Regulation-based IAQ solutions

Federal government legislation regulated through the Canadian Department of Justice and Provincial workplace legislation, Occupational Health and Safety (OH&S), and the US Department of Labor Occupational Safety and Health Administration (OSHA) make employers responsible for the health and safety of their workers in public and workplace environments.

However, there is no government legislation to regulate the residential indoor environment. For example, WorkSafe BC manages regulations affecting indoor workers by charging employers with this responsibility, including workplace audits and incident assessments to ensure solutions have been applied and remedies proven. In the workplace, it is accepted that mold, perceived or visible, can cause sickness; hence, regulations require thorough professional assessment and remediation upon complaint to meet WorkSafe BC (2014) criteria in commercial and public spaces. The response and recourse for a worker who potentially develops environmental sickness on the job is overseen by a certified occupational health specialist, who takes into consideration the materials of the trade and the worker's environment. In contrast, residential environments have no such criteria. This disjoint in the regulatory system to protect residents is exacerbated by lack of science-based information and research available to building owners, as well as Privacy Legislation that can restrict landlord, municipal, and regulator access to private residences for verification and assessment purposes. For example, in 2011 over five million homes transferred ownership in North America (CREA 2012, NAR 2012), with many of those accessed by professional home inspectors; yet mold identification and assessment is not listed in home inspection and real estate disclosure statement protocols given to prospective purchasers and new residents (ASHI 2014, CAHPI 2014). This may be due to lack of awareness or due to liability reduction protocol.

5.3 IAQ and mold information derived from government and NGO involvement

Apart from formal research and public libraries, individuals can consult the internet and find resources such as government agencies on-line including CMHC, Health Canada, U.S. HUD, U.S. EPA, state and provincial government websites, and non-government organizations (NGOs). These sites would be considered by the general public to be credible to deliver "how to" knowledge on various defined indoor air quality subjects that provide guidance towards addressing hazards and achieving better IAQ in the home. If location on a website indicates prominence, mold is the first focus under the IAQ section of the Health Canada website (Health Canada 2014); and second after asthma on the U.S. EPA website (U.S. EPA 2014d) providing detailed guidelines and information support. Yet from personal professional experience, most residential clients with mold related health concerns have little knowledge as to how their “mold problem” was caused or how it could be remedied. From this, it appears there is concern but little science-based knowledge. This may indicate that consumer awareness programs have been effective in creating awareness to the point of concern, but ineffective in transferring relevant, science-based, knowledge to those affected to allow them the confidence to develop solutions without professional help. Although governmental agencies and authorities recognize dampness derived mold in indoor environments as a possible to likely biohazard they consider it a less significant or insignificant issue compared to other more prominent environmental stressors in indoor environments; such as, radon, lead, asbestos, VOCs, dioxides, particulate matter (PM), and formaldehyde (Shaw *et al.* 1997, Williams and Wilkins 1998, Lawrence and Martin 2001, Laquatra *et al.* 2005, Wu and Jacobs 2007). This has been exacerbated by focusing on homeowner remediation techniques and downplaying professional bioremediation and biohazard verification sampling (U.S. EPA 2014 a,c,d).

Further, since mold and its impact on health have not yet been systematically measured, authorities have begun to bypass mold as a central issue, preferring to refer to the eradication of dampness in homes as a primary focus (U. S. HUD 2013, CMHC 2013, U.S. EPA 2014c) There have been breakthroughs in the focus, as healthy homes initiatives are promoted in a broader U.S. Federal Healthy Homes program that includes exposing the effects of mold and asthma triggers has shown some effectiveness in modifying individuals’ traits towards internalizing IAQ initiatives

(Brown *et al.* 2010). As well, the U.S. HUD, the U.S. EPA, and state legislators appear to be set to codify the environmental mold aspect of IAQ (Indoor Environment, 2012). States, such as Florida and Virginia have recently enacted (and then repealed due to short term cost cutting measures) laws regulating mold assessors that may ultimately require the setting of maximum specific fungal count levels as the regulations get tested legally. Note that these regulations were not for the overall IAQ of a home; but only pertained to mold testing assessment. Regulation, even to a limited extent, may require indoor environments meet a standard that can be measured, which can then be part of a sustainable initiative for better IAQ and mold and dampness management in homes. In 2008, the Government of Alberta instituted a regulation of residential tenancies that included identifying and directing the remedy of poor IAQ environments specifically due to visible mold growth. From direct discussions with the Health Officer in charge of the program, the initiative had no punitive force behind it and recently has been reduced to providing recommendations only. Moreover, no assessments or studies have been conducted to verify whether prescribed remedies were undertaken or whether tenants were better off after the intervention.

In addition to federal, state/provincial IAQ regulations, the ideal of IAQ residential building assessment for the public good can be found in a few municipal-level initiatives and studies. One such program is outlined in U.S. HUD's *Healthy Homes – Assessing Your Indoor Environment,* which introduced a program in New York State through the "Cooperative Extension Office" (U.S. HUD 2007). Within this outreach, educators respond to resident indoor air quality concerns by visiting the home, conducting a visual assessment with the homeowner, advising them of health and safety hazards, and making specific recommendations to correct described IAQ issues. Further research on the costs associated with the initiative should assist in developing an overall NPV for the program. This would add more experience to assist in developing a sustainable community based IAQ resource program.

These types of home-visit based consumer education programs are available and are being utilized primarily throughout the U.S., but with limited capability as many regions, municipalities, and districts cannot enforce regulatory control over home intervention. Government regulations and intervention programs to correct residential hazards have long been rebuked by civil liberties groups, private citizens, landowners, and the courts. The main objections are not on privacy invasion grounds, but on economic impact concerns, to the detriment of the disenfranchised building tenants, and, to society at large which financially underpins the PCHS. There have been numerous Government-funded pilot projects and studies throughout the years that have introduced homeowners to indoor environmental issues and how to economically improve their indoor environments (U.S. EPA 2007). Unfortunately, pilot projects have limited funding and a built-in short term focus with little to no monitoring, assessment, or follow-up primarily due to budget constraints.

5.4 Integrated approach utilizing asthma in industry and PHCS

An integrated approach to asthma prevention by bridging the gap between the patient's medical requirements, medical and industry support methods, and the home indoor environment realities has not been found in the literature. But the core principles on which an integrated, system-oriented, prevention program would be planned and sustainably operated have been researched and generally relate to: education, prevention, and sustainability.

5.4.1 Education

Decision-making initiatives to implement changes in how society addresses issues can take many forms. With a preventable disease, this may take the form of general and specifically targeted population education in health promotion, lifestyle changes, enhanced medical training and measures, improved hospital procedures, protocols and screening and prevention treatment (Prevention Institute 2008, Katz and Ali, 2009). These methods, in part, have not been successful though if the high incidence (60%) of uncontrolled asthma or the controllable 21,000 radon caused lung cancer deaths in 2014 are considered (U.S. EPA 2014). The cause, solution, and repercussion of respiratory disease are known. The solution of cessation or occupant initiated remediation is simple and economical, except for chronic cases of addiction. However, the lack of action by asthma patients suggests that education campaigns alone will not reverse ingrained mannerisms or convictions to any great extent (WHO 1993, 2009b). Other methods should be considered to change status quo habits.

5.4.2 Prevention

The focus of this thesis is to address the root cause of environment induced respiratory disease proactively. A means to this end is to consider redress under the umbrella of prevention. Primary disease prevention is a systematic process that promotes healthy environments and behaviors before the onset of symptoms, reducing the likelihood of illness (Prevention Institute 2007, Katz and Ali, 2009). Currently, 96% of health care funding goes to medical care, and only 4% to prevention in the form of research, planning, education and environmental change, yet disease prevention is known to better support health care sustainability, reduce health care costs, and improve the population’s health status (Prevention Institute 2007). The use of a prevention model that benefits the patient, the health care system, and government based on socio-economic modeling valuation for health care initiative decision-making has gained success in other sectors as exemplified by the Insurance Corporation of British Columbia (ICBC) Road Improvement Program. It improves hazardous locations based on economic payback valuation of reduced crashes and injuries. (Sayed and Leur 2009). The ICBC model prioritizes projects based on a B/C > 2 and a three year capital payback period (PP). Its sustainability is based on a20 year track record to date. Municipalities utilize prevention models to develop and rehabilitate infrastructure, such as pavement and bridge maintenance programs. Building health care cost prevention analyses have been shown to be based on B/C, PP, NPV, and IRR (City of Hamilton 2014, MOI 2014). This suggests that appropriate economic justification tools to employ in proposing a health care prevention program would include these financial tools.

Remediation of the indoor environment of hazards is a prevention method that reduces or eliminates conditions that generate poor health in society, and cost savings in an overburdened PHCS (Prevention Institute 2008, WHO 2009a). By taking a proactive approach to identifying occupants that may be environmentally affected and undertaking on-site prescriptive measures that reduce health impacts from validating their indoor environments of mold and dampness, the cost of health care may be significantly reduced. Prevention measures could include a framework that would focus the medical profession on an indoor home environment data capture diagnosis approach and the IAQ service industry on a health-based medical support approach, with both based on good science (population health and epidemiological data) and regulation to enhance results. A standard environmental assessment tool for site condition determination and for test results assessment would be critical in the prevention approach. Importantly, though, accurate medical evaluation is required to establish the validity of site assessment protocols (Lawrence and Martin 2001). Overarching all of these process considerations, a successful prevention program would necessarily be self-sustaining.

5.4.3 Sustainability

Review of literature on the subject of sustainability in health care revealed two primary models. The first, proposed by the Conference Board of Canada, comprised of six pillars on four foundation levels as shown in Figure 5-1. Lapelle *et al.* (2006) contends that sustainability also requires an improvement loop which supports and measures innovation in aligning services with organizational goals.

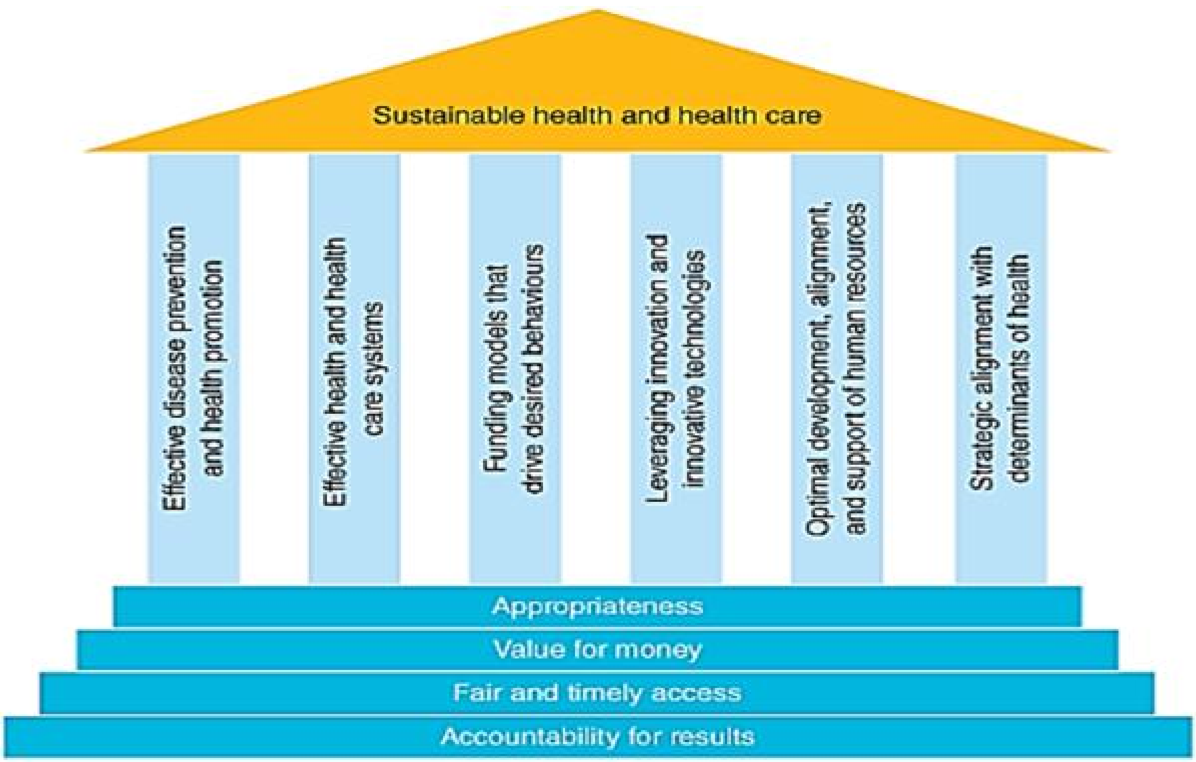


Figure 5-1 Pillars of Sustainability
*Conference Board 2012

Together, this suggests that a sustainable health care program requires:

1) Optimal health outcomes such as effective disease prevention and health promotion;

2) Meeting the health care needs of individuals;

3) Effective health care systems that can measure outcomes and efficiently deliver health care;

4) An effective funding model that supports and sustains effective health care systems;

5) Driving desired behaviours to facilitate change in how health care is done and better health is accomplished;

6) Innovative thinking and technologies that support change in how health care systems are run and measured;

7) Supporting adaptive organizational alignment that is flexible to patient needs and demands on the health care system;

8) Flexibility to adapt to cultural, social and economic conditions that are part of the day to day nuance of human interaction;

9) Delivery without compromising the outcomes and ability of future generations; and,

10) A sustainability loop that addresses shortcoming, failures, and builds on prior successes.

Given these 10 elements, the following expected outcomes were developed to integrate health care sustainability into a prevention program.

a) A health recovery focus that delivers greater than 50% measurable health recovery/ reversal in candidates;

b) A sustainable prevention PSHC program using a systems implementation approach with an open learning component;

c) A funding model that returns and measures financial benefits to the PHCS after cost recovery;

d) no program subsidy requirements;

e) Indoor environments that remain free of consequential molds and dampness;

f) An onus on the patient to maintain and monitor their indoor environment;

g) Ongoing monitoring and adaptive management for innovation; and,

h) The development of methodologies that transcend this program and support new prevention programs.

Sustainability is both a financial-based goal and an organizational-based goal. In whole, these outcomes would be intended to be achieved through a sustainability model.

5.5 Health care prevention program and implementation strategy

5.5.1 Program overview

It is proposed that a sustainable mold and dampness prevention program could enhance the existing methods undertaken by the PHCS to reduce asthma risk levels and increase the functional life of an environmentally affected asthma patient. The sustainability principles and assumption behind this program are based on:

1) The PHCS continuing to move towards more proactive, prevention-based medical solutions;
2) Proactive, prevention-focused decision-making based on risk assessment benefit costing;
3) Measured reduction in reactive treatment-focused decision-making over the longer term;
4) Prevention strategies and sustainability are cornerstone requirements of a successful prevention program;
5) Program success depends entirely on people; and,
6) The primary motivating factor for program sustainability, beyond altruism, is economic benefit.

It is proposed that the “Sustainable IAQ Residential Asthma Prevention Program” (SIRAPP) be administered by and through the Ministry of Health. There are other administrative manager options, such as through private insurance, or a for-profit health care manager; however, the PHCS is arguably a good choice, for the following reasons:

1) The proposed SIRAPP may provide the PHCS with significant economic benefits (reallocation opportunities) in short order;
2) The SIRAPP is designed to integrate with the necessary administrative oversight and infrastructure of the PHCS already in place for the most part;
3) SIRAPP would bolster of the image of the PHCS as a health leader; and,
4) If not delivered within the PHCS, some of that infrastructure would likely have to be shifted to a provincial or private body or created to administer the SIRAPP, which might produce significant angst among relocated unionized employees and additional unneeded infrastructure costs.

For these reasons, it is proposed that the SIRAPP be administered through the PHCS. One-time start-up funding for SIRAPP implementation has been assumed through the Ministry of Health with operations funding from internal cost reallocation such that no external funding would be required beyond start-up with start-up costs recovered within one year of implementation. It is suggested that the specific details of SIRAPP implementation would be determined by regional health authorities and individual hospitals, based on policies and procedures set by the Ministry of Health. Ongoing monitoring of SIRAPP costs and benefits through patient recovery and their associated reduced PHCS use would be tracked and analysed. Historic pre-SIRAPP patterns of hospitalization would be used as a baseline for economic benefit determinations, based on individual patient assessment.

Policy support for the SIRAPP already exists via the BC disease prevention and health promotion policy pillar, and the PHCS would leverage the HEALTH[2] tool as a health care innovation technology; however, the SIRAPP funding model is the key to its sustainability. With few examples of net positive funding models existing for the SIRAPP to follow in BC, the program details will require further research and policy analysis to refine, including a possible pilot program. A prevention program in BC that was reviewed is the BC Ministry of Health fall-prevention program called "Falls and Related Injuries in Residential Care: A Framework & Toolkit for Prevention**"** (MoH 2014). The program was initiated after medical practitioners and researchers confirmed that seniors' injuries due to falls were over-represented, and found science-based prevention measures to reduce fall risk. Available on-line web-based sources outline the problem, impacts, outcomes, goals, and strategies to accomplish the goals. Information was lacking on program funding strategies. The ICBC road improvement model previously discussed is also an excellent reference in program development.

The proposed SIRAPP program would identify patient candidates, verify that their asthma condition and home environment falls within program applicability, remediate the problem source, and monitor patient health and PHCS utilization. From initial discussions with medical practitioners, it appears that SIRAPP could be carried out within existing staff complements and coordination capacities; however, some reallocation would likely occur, for example, of personnel who treated high-use patients in the ED and hospital wards, to other PHCS priority areas.

Subsequent to a home environmental audit, remediation and repair, the home would be maintained by the patient to prescribed SIRAPP healthy-home criteria. Partnering with the patient is a consideration via social contract, as a way of moving forward to preclude personal privacy concerns and obtain legitimate buy in. Under social contract, the patient would maintain their health, home health, and hygiene levels and self-report on-line or through already existing channels, thus allowing for feedback and educational input from SIRAPP staff, including addressing any hazard potential promptly as part of normal residential maintenance. As such, ongoing costs for maintenance of home healthiness have not been proposed in SIRAPP budgets, although funding for building environment inspections and site follow-ups may become appropriate.

The benefits of reduced PHCS utilization by the patient would be measured and resources reallocated to other PHCS areas as the SIRAPP program reduces ED and hospital bed demand, with reduction measured and validated on an ongoing basis. Lack of demand reduction would require prompt attention. Post-remediation PHCS patient use would be compared to their historical records. The PHCS expected direct benefits would include: reduced reactive medical provision; reduced health care costs; and more sustainable, proactive medical services (Prevention Institute 2014).

To define SIRAPP success, specific program objectives are recommended. These objectives are a minimum based on research and results in chapter four, and would be refined after the initial pilot project and/or the first year of SIRAPP operation, as follows:

1) Full payback of SIRAPP start-up costs within one fiscal year;

2) Benefit to cost ratio of >>1 (2:1 per ICBC);

3) Overall positive NPV per identified high-use asthmatic patient; and,

4) Initial program subscription rates (and remediated homes) increase by a specified percentage per year, based on reported SIRAPP capture success to date.

5.5.2 Implementation Strategy to Shift to an Outreach Prevention Program

Long-term SIRAPP success will depend on ongoing cycles of identification, remediation, monitoring, evaluation, and refinement. The process would shift healthcare workload from reactive, ED-centric measures to proactive, outreach, patient home-centric measures. The reallocation of savings could be directed into an extension of the prevention program, outreach, using the following measures of effectiveness measured continuously: 1) decrease in the number of ED and doctor visits, and severity of cases; 2) decrease in the costs of associated emergency care; and, 3) decrease in patient-doctor contact hours.

The proposed sustainable IAQ residential asthma prevention program (SIRAPP) would use a systematic approach undertaken by the PHCS, the Ministry of Health, and /or the Health Regions in accordance with generally accepted ED medical process such as defined in EDACP (March 2013) *Medical Guidance Document and terminology* and Vancouver Coastal Health Emergency Department protocol initiative acute asthma management toolkit *Probable diagnosis of asthma – moderate to severe uncontrolled scope* (VHPHC March 2006). These are accepted medical protocols and procedures for the emergency room asthma care pathway in British Columbia.

A proposed process flow chart is provided in Figure 5.2. The chart indicates how the patient would transition from the traditional ED process to the SIRAPP program. The SIRAPP process flow chart outlines the suggested steps to be taken in the emergency department (ED) beyond the traditional ED process flow. Should a candidate be considered from the healthcare field, such as their physician's office, the modified approach is noted in the process steps.

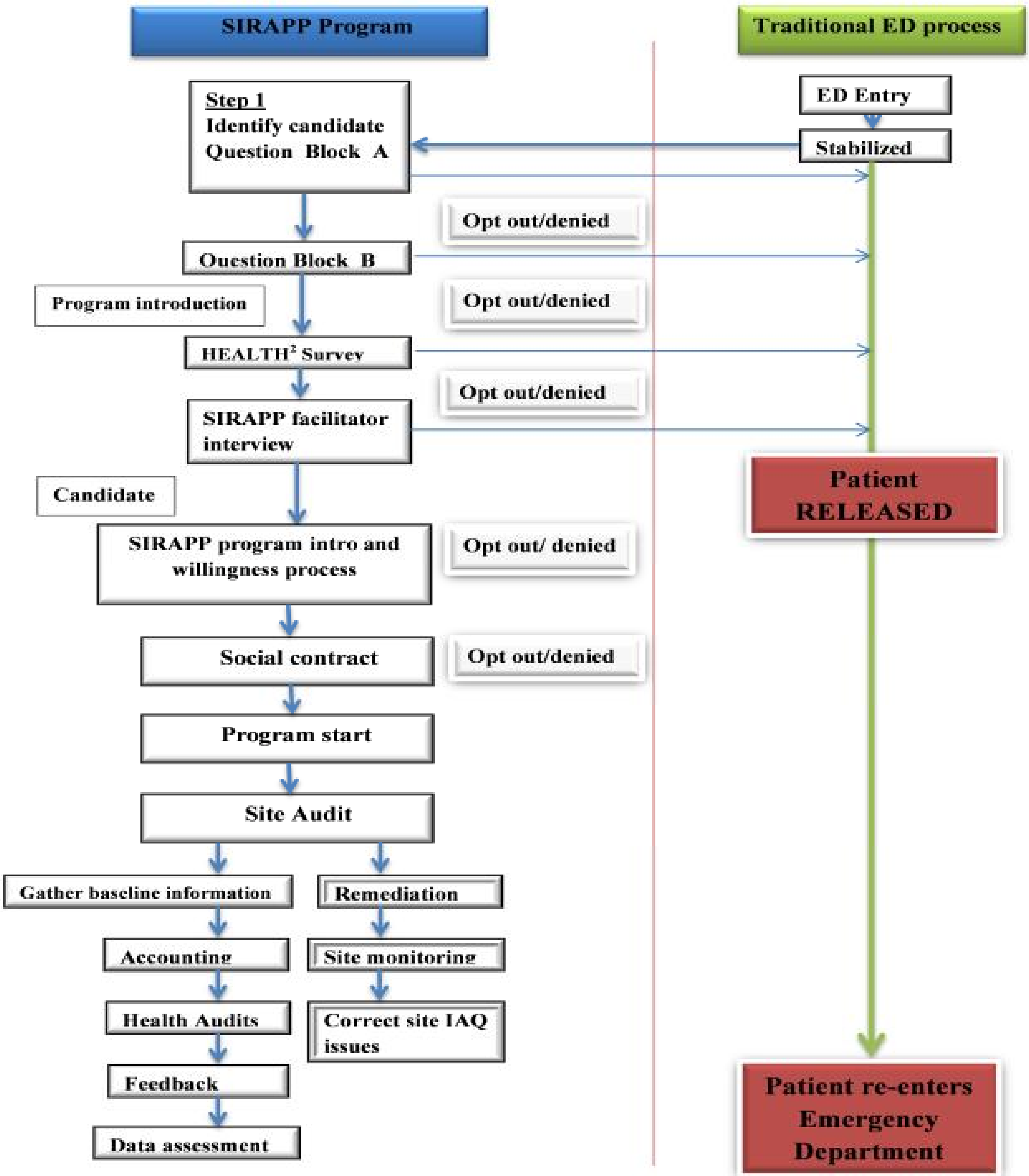


Figure 5-2 SIRAPP Flow chart
* see Table 5-4 for description of question blocks A & B.

Program development and the SIRAPP process flow chart shown in Figure 5-2 includes the following possible components and steps:

1. Identify possible candidate. The acceptable candidate will have moderate to severe uncontrolled asthma confirmed by a medical practitioner that may be environmentally induced (other exacerbation triggers ruled out). The candidate is considered for the program in the ED or physician office by referral from healthcare professionals to the SIRAPP representative. The move forward criteria is based on two sets of question blocks noted in Figure 5-2 that would eliminate other triggers or conditions and give the staff a methodology to confirm or deny an environmental trigger condition. Question block A is a health check for applicability. If the criterion is met, then the health care worker will undertake question block B, environmental site questions. Refer to Table 5-4 for details of the question blocks.

Table 5-4 Question blocks A and B

Question Block A

- History of respiratory issues
- Significant function reduction
- Numerous debilitating attacks
- Health history

Question Block B

- Issues specific to patient's residence
- Previous home history
- Residing > 3 mos.
- Okay away from home
- General Environment Question

Step one is designed to screen all patients and identify candidates with the highest likelihood of being indoor environment mold and dampness affected and to minimize the impact on the traditional ED process. At step one acceptance, after the patient has been stabilized and is medical professional approved to do so, they are introduced to a SIRAPP facilitator at step 2 of the process. The role of the SIRAPP facilitator is summarized in Table 5-5 after the process step summary.

2. Program introduction. Upon determination by a medical professional that the patient met candidate health criteria, pertinent information about their home environment would be gathered from the candidate in person at the ED, by phone or mailed-in survey, and inputted in the $HEALTH^2$ tool. The potential candidate is introduced to the program benefits and process, including patient responsibilities under the SIRAPP (sustainable IAQ residential asthma prevention program). Upon initial acceptance, the stabilized patient will be helped with completing the $HEALTH^2$ occupant survey to ensure accurate results. If the house health score is 32 or higher (concerning), the patient will be then interviewed by a SIRAPP facilitator to verify the information provided and to further evaluate the occupant’s health condition and the residence state.

3. Candidacy: With steps one and two complete, the patient becomes a candidate for the program and is introduced to the program and their willingness to participate is gauged. If amenable, the candidate is introduced to the social contract for acceptance. Otherwise, opted out of the program. After the social contract is signed the process becomes formal and the SIRAPP investigator begins the program start.

4. Social contract. A social contract will be necessary to protect the rights of the individual and time and fiscal commitment of the PHCS. The contract will define the parameters of the program, roles and responsibilities of the health region and patient, allow access to the

home, and provide for ongoing and future research. When the social contract is signed the candidate is indicating willingness and engagement with the program.

5. Program Start. Administrative staff will present the necessary forms and ensure their accurate completion. Refer to Table 5-5 for the summary of SIRAPP facilitator's roles and responsibilities. The following will then occur:
    1. The candidate is registered with the program and given a management toolkit. The tool kit will include the necessary forms the Client and the program manager are required to complete at onset through the duration of the program. These can include medical records, medical tasks, physician orders, incidence reports, and feedback forms.
    2. The SIRAPP facilitator in concert with the physician of record will develop the program timeline and set the date for site audit and remediation program.
    3. The home is physically remediated and the candidate is educated on the process and their responsibilities after the site audit is completed. The candidate's medical history will be important. The starting phase of the program would benefit from a candidate with a long detailed applicable medical history of high medical system usage to best expose and highlight the benefits of the program.
6. Site audit. A formal audit of the home environment for dampness and mold is conducted and matched to the $HEALTH^2$ occupancy survey. The exclusively visual site assessment will be conducted by a SIRAPP pre-approved IAQ professional and a report will be written using the $HEALTH^2$ tool to validate the candidate's indoor environment. The home healthiness index (HHI) and resident health score (RHS) are then compared to the candidate survey and the hospital emergency department (ED) or asthma care centre

assessment. The (HHI) output value from the HEALTH^2 tool would be compared to the RHS to determine a match between occupant health issues and home environment. An HHI score of 32 or higher with an environmentally sensitive high-use asthmatic resident, for example, would constitute a fit with the program. If the results correlate to a medically diagnosed mold and dampness environmental trigger and significant health effect, then proceed to step 7 - remediation. If the site audit or assessment process fails at any point along the way, the candidate will be informed and opted out of the program.

7. Remediation. Upon approval of the home for environmental remediation, a professional remediation firm is chosen from a SIRAPP list of pre-approved contractors. The work will be overseen by applied microbial remediation technicians (AMRT) or equivalent, certified to remediate damp and moldy indoor environments to IICRC 500/520; CCA 82 (2004); and/or New York Dept. of Health "Guidelines on Assessment and Remediation of Fungi in Indoor Environments". Final assessment of a health safe environment will be conducted by a third party environmental professional (professional Engineer or Industrial Hygienist with demonstrable expertise) visually and by limited air and bulk sampling as required.
8. Baseline: Gathering health data and monitoring. A medical team approach will be applied to gather and manage the health data of the candidate and measure their progress and document the cycles of health care interaction going forward. The resulting data will be integrated with accounting records to identify hospital utilization variations for the purpose of measuring financial impact.
9. Medical system indenture. In concert with baseline data gathering, the approval process will include formal medical acknowledgement and verification from the traditional ED

process for asthmatics that the health effects are environmental induced (as opposed to other triggers, such as, genetics, gender, age, ETS, etc.).

10. Validation. Ongoing data gathering on the candidate's health and PHCS utilization will be compiled. Verified benefits and resource savings will be drawn from the health care budget for use to either expand SIRAPP and the acquisition of more candidates, or allow the Ministry to reallocate resources.

Table 5-5 SIRAPP Facilitator Roles and responsibilities

- HEALTH[2] Survey score >32 required
- Stage 2 interview
- Program introduction
- Confirms willingness to participate
    - Parental/guardian consent
- Social contract
    - Parental/guardian consent
- Coordinates site audit w/ Qualified professional
- Initiates file, initial data entry
- Manages file
    - Direct contact w/ accounting/ health care staff/ doctor
- Oversees site/ health audits
    - Home repairs
    - Patient compliance

Program insertion through the PHCS is considered at the ED or otherwise through the physician's office. Within the ED, several points of insertion have been considered, from the admitting nurse, to the emergency health care provider or physician in charge to identify the potential candidate. More practically, other possible insertion points would include: 1) pre-ED through pre-screening of administrative data, or reaching out to the higher probability demographics such as aboriginals and low income families; 2) nurse practitioner through home care or asthma care outreach and education programs; and 3), through private corporation internal health care programs. For the

PHCS option, significant assessment and discussion is required to ascertain the best model due to overcrowding and high stress levels already in place. Another consideration for further assessment is outsourcing the SIRAPP as a specialist support program that is referred to by family physicians and hospitalists as asthma care is generally conducted. Irrespective, the patient must remain in the care of their physician.

5.5.3 Program next steps

1. Feedback: the patient, candidate, physician, IAQ specialist and contractor feedback process with come into play to check the system accuracy, timeliness, and flow. Errors will be corrected.
2. Program expansion: a successful asthma prevention program would expand to 1) consider the moderate to mild uncontrolled environmental mold and dampness affected asthmatics; and 2) address those affected by other potentially reversible environmentally induced respiratory diseases as long as the program goals and criteria are met. It is expected that the level of productivity gain and cost benefit will drop as the most severe cases are addressed. By expanding the program to a broader outreach, by anticipating the laws of efficiency, and developing higher cost effectiveness in the systems as those systems used to facilitate the program become familiar, it is possible that the program can function with a lower level unit benefit.

The timeline to progress through the various steps and stages of the program will be dependent on the patient, availability of candidate slots, and degree of rigor of the process. It is left to the PHCS administrators, based on their expertise with other program monitoring, to determine the level of rigor required to verify the facts that validate success of the sustainable IAQ residential asthma prevention program (SIRAPP). Preparation for the introduction of the SIRAPP initiative would include training ED staff as well as general practitioners to identify candidates through a medical decision tree protocol adapted from emergency department asthma care pathway or ED protocol for environmentally affected acute asthma patients will be produced prior to implementation of the program.

To validate the patient's home residence as the probable cause of asthma exacerbation, the HEALTH^2 home survey would be conducted in the ED or physician's office from a web access portal. The program survey would be introduced to the potential candidate by trained health care staff with web-accessible tablets. Introductory information provides the outline for data gathering after the welcome page, as shown in Figure 5-3 below. A detailed template layout is provided in appendix G.

Figure 5-3 HEALTH^2 Software interface

The candidate would be guided through the survey step by step by the SIRAPP facilitator to answer the survey questionnaire and be prompted to provide additional input as required. The first step, outlined in Figure 5-4, is to provide general information about the patient's home residence. This helps the SIRAPP facilitator at a later stage to determine the level of health and environment connection.

Figure 5-4 Home information input page

The candidate then proceeds into a series of yes or no questions that assists in determining the home environmental condition with respect to the patient's respiratory condition. If the final screen output shown in Figure 5-5 identifies that the candidate is in a home that is very likely to be conducive to respiratory sickness (house score of 32+), then they proceed to the next step in the SIRAPP program.

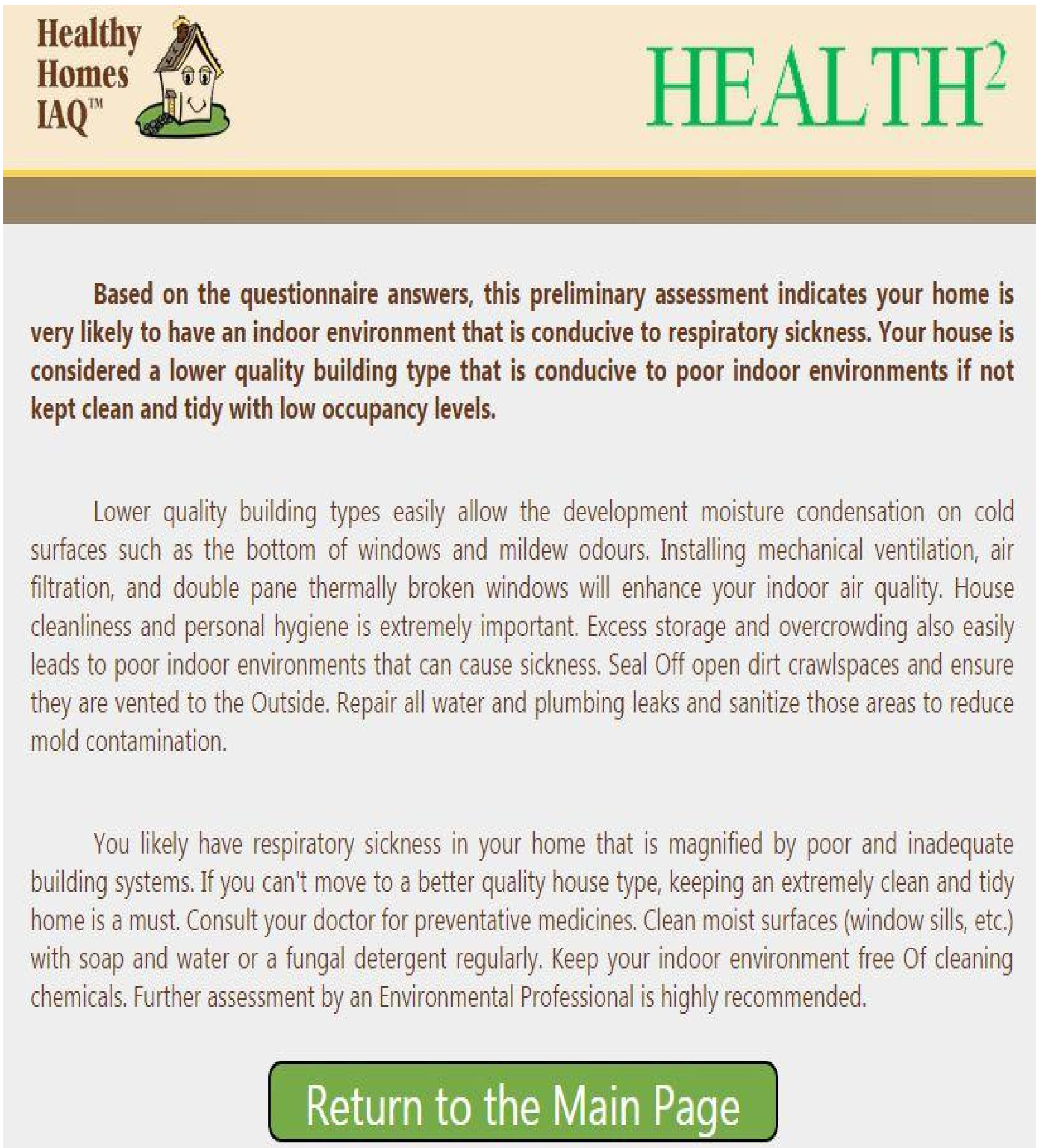


Figure 5-5 HEALTH^2 output page

The HEALTH^2 tool can also be used as an education platform to instruct the candidate on appropriate indoor environments and the means to accomplish simple improvements to maintain or improve their indoor environment. The details become more relevant and are addressed after the candidate is formally approved for the program and is in the process of signing the social contract, but the instruction may also be a means of introducing the SIRAPP program and the candidate's necessary day to day involvement in the process.

5.5.4 SWOT analysis

Along with the expected benefits, the proposed SIRAPP, like any new program, would likely face challenges. The key conditions that can be predicted at this preliminary stage have been outlined below, based on a SWOT analysis of SIRAPP. SWOT is an acronym for Strength, Weakness, Opportunity, and Threat. It is a strategic planning technique used to ensure all factors are considered before launching a project or business venture (Humphrey 2005). It will be necessary for the program to address all these elements in its development and outreach to optimize success.

A) Strengths

a. Lower health care and societal costs.
b. Healthier public through disease reduction.
c. Greater individual and societal wellbeing.
d. Stable program structure.
e. Dovetails with existing hospital processes.
f. Resource reallocation to other diseases/ impact centres.
g. Meets current Government of BC health care review process requirements to find and implement ways and means to cut health care costs for system sustainability.

h. Helps to move this segment of healthcare further towards prevention methods and to reduce the need for reactive measures.

B) Weaknesses

a. Although many PHCS professionals associate mold as a possible factor in ill health, its causal level impact on health has not been established by researchers, due to many other possible confounding factors. Therefore, the consideration of IAQ and therefore indoor environments in diagnosis has traditionally not been considered, and has to date precluded the opportunity for advancement in the existing medical system.

b. The PHCS culture is reactive by nature and process. This can impede systems adjustment and personnel refocusing.

c. Homes are private domiciles authorities can't enter without permission.

d. Candidates historically require significant motivation to participate.

e. Candidate involvement is time consuming and routine altering.

f. Patients can become accustomed to and rely on emergency medical support.

g. Candidates may not meet or accept the ongoing requirements of the social contract.

h. Validation of cause and effect of the program may include hitherto unknown complicating factors and reporting bias.

i. A decision tree for ED staff to identify potential for environmental mold and dampness cause in respiratory distress has not been developed.

j. Environmental and medical confounding factors are numerous and bias relating to humans in the environment cannot be fully verified by existing studies.

k. It is human nature to oppose changes in the workplace (Kanter 2012).

C) Opportunities

a. Long term, repetitive sustainable health care cost reduction.

b. Increase in patient well-being.

c. Program expansion into other possible reversible environmental respiratory diseases and health impacts.

d. Assists in modifying reactive medical culture into a proactive culture.

e. BC MoH are currently seeking innovative technologies and research to reduce over-burdened provincial health budgets.

D) Threats

a. The public have little appetite contracting with patients (private citizen vs. Public domain responsibilities), to remedy private property.

b. The candidates have little interest in adapting lifestyles.

c. The window of time to attract the BC MoH attention with this proposed SIRAPP is limited.

5.5.5 Monitoring the program

An appropriate method of program success measurement will be essential to ensure accurate and useful results. To ensure effectiveness, the variation in effects on the patient must be rigorously monitored for accuracy of results. Second, the quality and thoroughness of health authority assessment, record keeping, outcomes, and reported results are essential for program sustainability. The following program outputs must be measurable and be measured to ensure sustainability. Monitoring results would be in the form of feedback documentation and measurable conclusions. The following is a general outline with some detail on what might be expected for monitoring requirements. The initial program development phase would flesh out the operational details and expected outcomes, based on three required areas:

A) Financial

Based on social cost benefit analysis and achievement of the prime goals:

1) The program net present value (NPV) remains positive;
2) Initial cost payback in 1 year, and;
3) Benefit cost ratio >>1.

Statistical information on program and PHCS cost allocation, specifically cost reductions or variations, utilization and ED candidate capture rates, etc. is to be retrieved and analysed monthly during the first year of operation, and then perhaps reduced to bi-monthly or quarterly as the systems and expected results become commonly understood.

B) Program champion: corporate lead

Ministry of Health (MoH). It is proposed that the Ministry be responsible as champion and corporate lead to implement an efficient and thoroughly thought through program with a motivated team to ensure the start-up is free of setbacks and then adjust the program in the short term for optimal results. As noted earlier, there are alternative corporate lead models but this seems to be the most strategic and practical. This is a complicated and intricate process and requires a champion to ensure it gets off the ground well enough to develop towards its expectations. That requires clear process and program development. The internal corporate program development for the SIRAPP consists of:

1) Management reorganization and systems development including medical decision trees and reporting methods.

2) Methods to affect cultural change.

3) Workforce buy-in/transition/ reorganization and implementation.

4) Systems development, integration, and accounting.

5) A dedicated defined decision making process.

6) Consultation & approval process – Ministry, Health region, hospital, patients.

7) Improvements loop to support and measure innovation in aligning services with organizational goals.

Success will also be measured in part, by calculating the variation of conditions from baseline for actionable items, timelines, and deliverables using time study methods. A good project accounting system will address the various outputs designed to isolate the variables required to measure that success. The following are key output variables that require measuring.

C) Measurement methods and implementation and accounting for results.

1. The candidate level cost accounting method specifically broken down into the following categories is required for accurate cost accounting and output measurement:

   a. Patient / candidate effects

      1) Direct health care costs (per candidate)

         i. Doctor/ emergency room visits

         ii. Critical care and regular bed stay

         iii. Drugs

2. The business level cost accounting method is broken down into the following categories:

   a. Health region effects (per candidate)

      1) Program costs

2) Extent of reduction of patient health care demand (cost and utilization savings)

3) Cost benefit analysis results

4) Staff and physician impact

i. Work regimen

ii. Income

iii. Well-being

5) Systems impact

6) Efficiencies

7) Effectiveness

3. The following components of SCBA can be isolated and calculated through further research:

a. Societal effects

1) Patient impact (per candidate)

i. Lost productivity

ii. Time off

iii. Early retirement/ welfare

iv. Special needs – community delivered

v. Disability impact on patient service to community

vi. Wellbeing translated into community involvement

vii. Wellbeing translated into reduction of service requirements

viii. Mortality

2) Family impact (per candidate)

i. Caregiver loss of income

ii. Patient disability impact on family

iii. Special needs

iv. Income impact (financial)

5.5.6 Securing program sustainability

The methods and measurables noted above to monitor the SIRAPP program are necessary to follow, but without sustainability the program may have a limited shelf life. Of the six pillars of sustainability introduced in section 5.3.3, securing an adequate funding model is essential. Sustainability for the SIRAPP is obtained through a continual positive NPV that is supported by the disease prevention and health promotion pillar that leverages the $HEALTH^2$ innovation technology. SIRAPP draws its vital resources from measuring and accounting for the benefits as part of the program. This is similar to the insurance corporation of British Columbia's (ICBC) road improvement program, which contributes to crash zone improvements to reduce accident payouts for an ongoing accountable net financial benefit to the Corporation (Sayed and Leur 2009). This sustainable funding model has a 20 year proven track record. Towards this end, program sustainability is built on validating and presenting cost savings as a cash flow to the PHCS although it is rightly validating reduction in cost of care. Presenting the reduction as an income stream would be facilitated by the transfer of funds from asthma care to a budget account that can be drawn on to support other health care needs.

5.5.7 Pilot project

In order to validate the theory, to assist decision makers, and to work out the details and address any unforeseen conditions, a pilot project is recommended at the health region authority level. The design of the project would be representative, non-biased and scalable, and include a partnership with the authority for the conducting of site assessments. SIRAPP candidates would be drawn from an existing database of high-use asthmatics, and led through the process outlined in section 5.2. The cost for a one to two year pilot program is to be determined with the appropriate funding agency and should include University partner funding within a grad studies program at UBC. Success at one level can help to drive the program across the Province, then across Canada. The pilot program can be extended to large corporations with significant health care liabilities and who tend to run their own programs. Private corporations typically have less organizational inertia and bias to overcome, so might be a good initial step to consider for a pilot versus a pilot via the PHCS. Success at a private corporate level would lend additional lessons and evidence to minimize the cost of its implementation by the PHCS.

5.6 Summary

This chapter presented a sustainable environmental asthma prevention program concept, SIRAPP, suggested to be undertaken by the PHCS utilizing a prevention-based PHCS program structure outline that utilizes proactive decision making based on engineering risk assessment. Refer to Figure 5-2 to view the contrast between the SIRAPP program and the traditional PHCS asthma patient treatment protocol. The SIRAPP program is intended to provide healthier patients, better balanced health care provision, less burdened Governments, and overall relief to society as a whole. A pilot project has been proposed to the Ministry of Health task force on sustainability as a starting point to assist in the organic growth of the program concept into cornerstone development of an overall prevention based healthcare initiative for mold and dampness affected respiratory patients with reversible environmental disease characteristics. Consideration towards promoting initial SIRAPP pilots via private corporations has been made.

Chapter 6 Conclusions and Future Research

This chapter summarizes the research along with thesis conclusions, contributions, and recommendations for future research. A summary of research objectives and methodology is given in section 6.1. A summary of results and conclusions for each thesis objective is given in section 6.2. Contributions of this research are discussed in section 6.3. Limitations of this research are provided in section 6.4. Recommended future research is provided in section 6.5.

6.1 Research objectives and methodology

The objectives of this research have been to:

1. Present literature that demonstrates that damp and moldy indoor environments is statistically associated with respiratory impact and that the impact is significant and reversible upon remediation;
2. Develop a quantitative tool to score the condition of an indoor environment and deduce the extent of impact that residential indoor mold and dampness may have on occupant well-being;
3. Provide economic justification for a prevention program based on the remediation of homes of environmentally affected high-use asthmatics; and,
4. Propose a sustainability-focused health care prevention program utilizing a systems-based implementation plan to facilitate healthy building environments within a health care policy framework, including a monitoring plan.

Research methodology involved a review of the literature on the: 1) burden of illness from indoor mold and dampness exposure; 2) connections between mold and dampness and patient onset and/or exacerbation of asthma; 3) quantification of indoor environment condition assessment; and, 4) economic assessment-based decision making and evaluation of the direct, indirect, external burden of asthma from indoor mold and dampness with reference to PHCS and occupant benefits from hazard removal.

6.2 Results and conclusions

Conclusions have been reached that are related to each research objective, as follows:

1. **Mold and dampness is consequentially linked to significant reversible respiratory impact.** Recent meta-studies conclude that an increase in dampness and mold in homes is significantly associated with a consequential increase in respiratory impact with occupants. The accepted study results (9/14) from Sahakian *et al.* (2008) associate indoor mold and asthma and asthma-like symptoms with an average of the average odds ratio of 2.5 (CI 95%: 1.1 to 4.7), or 2.25 including the other 5 studies. Other studies ranged from 1.3 to 7.1 OR. Almost 60% of PHCS costs spent to treat asthmatics have been attributed to a small cohort comprising 1.4% of the asthma population which is estimated in North America to be 395,000 high-use environmentally affected asthmatics. The 65-70% estimate of reversible health effects by indoor home remediation methods provided in research is key to the SIRAPP program.

2. **Environmental assessment can be quantitatively deduced with the HEALTH^2 home IAQ assessment and health risk tool.** The Holistic Environmental Assessment Lay Tool for Home Healthiness (HEALTH^2) is the first comprehensive residential indoor environmental assessment tool that provides science-based, reliable, empirical assessments of indoor environment and a link to health risk impact based on building envelope and building systems type and their capabilities, maintenance, nutrient and occupant load, and hygiene levels from damp and moldy environments. This new technology employs a holistic view of indoor environments, and closes the knowledge gap through validated quantitative analysis.

Application of the model in this thesis demonstrates it's potential. Results from the HEALTH^2 model development, calibration, and tool validation tests suggest a statistically significant association between specific building components, maintenance levels, home IAQ indoor environments pertaining to mold and dampness, lifestyle conditions, and resident respiratory health risk outcome. The HEALTH^2 model and tool was validated using a 99% significance test, suggesting that its use can assist in reliably evaluating residential IAQ pertaining to mold and dampness and predict the level of respiratory health risk for home occupants.

3. **Economic verification of mold and dampness impact on the PHCS, patient, and society**. The cost of not addressing the source of environmental asthma exacerbation from mold and dampness in North American homes includes: 1) significant health care costs; 2) reduced occupant quality of life; 3) increased occupant burden on family and society; and, 4) side effects from drug taking. A North American SCBA found an estimated $15.2 billion dollars per year in impacts, with $8.8 billion dollars in potential benefits from the implementation of a sustainable IAQ residential asthma prevention program (SIRAPP). The North American PHCS cost impact component (i.e. direct costs) for non-action is $5.4 billion with $2.8 billion yearly in potential savings from program implementation that may be reallocated to other over-burdened PHCS sectors. For the province of B.C., the direct benefits alone, all of which accrue to the PHCS, are forecast at $31 million after the first year. The total SCBA benefits – direct, indirect, and external – in BC are forecasted to be $97 million dollars after the first year. The predicted payback period of PHCS investments to implement the SIRAPP is less than one year.

4. **Impact on patients and society.** The impact on patient and society of not addressing consequential mold and dampness in homes is enormous and includes: personal stigma from

loss of earning power and productivity, increased morbidity and mortality; and broader impact, such as, general loss of well-being and increased mental health issues, the increased emotional impact on self and family, higher demand on the welfare system, increased reliance on family and society for support, as well as the ever rising costs to society from an over-burdened health care system and increased demand on municipal services.

5. **Sustainable asthma prevention program**. A sustainable home environmental asthma prevention program (SIRAPP) is proposed and summarized in this thesis, based on prevention policy by, and through, the Ministry of Health. SIRAPP is a means to reverse the home-related environmental aspects of mold and dampness, to provide overall health benefits to high-use (severe) asthmatics, and to annually reallocate PHCS resources potentially valued at $31 million dollars in British Columbia and $2.8 billion dollars in North America after the first year. SIRAPP is also a means to direct more health care resources towards prevention.

6.3 Contributions

The main purpose of this research was to expose the extent of impact and provide a means to reduce consequential indoor mold and dampness effects on occupants observed over 20 years in the IAQ profession, and thereby promote proactive occupant health and reduce the effects of an overburdened PHCS. In the course of this research, the following contributions have been made from the conclusions noted above:

1. The link between a patient’s residence indoor mold and dampness level and their well-being was reinforced by identifying the importance of directly including the home indoor environment in health diagnoses. The direct benefits include: ensuring timely and accurate assessments in medical offices and emergency rooms; more effective long-term treatments;

and the opportunity for the development of a method to assess indoor environments quantitatively for a proposed asthma care prevention program.

2. This research resulted in development of the $HEALTH^2$ science-based building and occupant health assessment tool, developed and applied in this research, as the first of its kind to reliably predict residential indoor environment conditions quantitatively and the health risk associated with indoor mold and dampness in homes on occupants. The benefits of a useful indoor environmental assessment tool include: 1) supporting the development and enactment of public policy on indoor home improvement initiatives; 2) providing a basis for compliance monitoring and verification; 3) supporting research into the quality of new and existing housing stock as a basis for the development of more healthy environments; 4) extending the model to public and commercial environments for empirical analysis and validation; and 5) setting more defined boundaries and limits on extent of remediation required to regain health safe indoor environments.

3. This research provides a SCBA-based economic justification method that employs the $HEALTH^2$ assessment tool to support a health care sustainable prevention program utilizing a system-based implementation strategy. This was accomplished by pulling together from literature and research a comprehensive database on direct, indirect, and external costs and benefits to the PHCS for high-use asthmatics using a novel process flow methodology.

4. A sustainable indoor residential asthma prevention program, SIRAPP, is presented using $HEALTH^2$ as a quantitative measuring tool to test the candidate's indoor environment against program criteria. This asthma prevention program integrates patient home environment into PHCS diagnosis protocols. The SIRAPP discussion includes detailed implementation

strategy considerations, as well as a process flow chart to promote an economically sustainable health care policy.

5. This research has led to an on-line HEALTH^2 software program (health2.ok.ubc.ca) to assist IAQ professionals to more intricately and accurately assess in-situ residential conditions and occupant health effects, and formulate more comprehensive analytical assessment. The HEALTH^2 tool provided from an internet-based common software platform allows the environmental professional access and participation in a common logic and intelligent systems network from which to validate conditions and solutions in participation with other environmental professionals, thereby supporting their determination methods within the context of a quantitative model and providing additional quality data to the network. The software is in Beta testing stage. A free version for homeowners is provided as a starting point to assist the general assessment abilities of the home owner in determining whether their home environment may be conducive to respiratory health effects from dampness and mold and whether to take the next step to obtain professional assistance. Refer to appendix G for detailed input and output template details.

6.4 Limitations

This thesis relied on the results of previous research that focused on indoor health effects specifically from indoor mold and dampness to confirm association levels between mold and dampness and ill-health, particularly asthma and asthma-like conditions in indoor environments. While progress has been made, several limitations should be noted, including:

1. Factors other than mold and dampness contact may cause an ill-health response within the same environment in which molds and dampness exist at levels of concern. A direct disease pathway has yet to be defined. This reduces an association level to less than causal, which is

below the level of association required to be fully accepted by the medical research and health care professions. As such the thesis information should be used with caution, and its results tempered with proper professional judgment.

2. Difficulty exists in isolating, identifying, and measuring how mold and dampness alone may cause health problems. There is indication from research that the effects of the various indoor environment hazards may interplay, reducing the chance of a single condition causing a particular outcome. The impact of this is to qualify results that otherwise indicate a strong relationship or link that exists between mold and dampness and respiratory ill-health.

3. Current evidence does not support measuring specific indoor microbiological factors to guide health-protective actions. As such, a means to quantify indoor mold and dampness hazard levels accurately through biological measurement to support hazard level assessment is limited.

4. Accurately gathering data from national and regional asthma literature is limited by regional variations in identifying cost categories, different asthma conditions, along with direct and indirect scopes varying by study. The ramification is reduced data quality for analysis. Clearer definition for future studies and more studies that address the various scopes of study will assist future researchers in analysis.

5. Confounding factors such as genetics, age, ethnicity, environmental tobacco smoke environments (ETS), second hand smoke (SHS), obesity, degree of biodiversity in the environment, lifestyle, urban vs. rural environments, outdoor air pollution, and socio-economic levels can affect results. Further, outdoor air pollution overall is known to increase hospitalizations. These confounding factors reduce results accuracy and robustness of the data used in this thesis.

6. Limitations with the $HEALTH^2$ model and tool include the simplified approach it takes to indoor environments by eliminating environmental factors other than dampness and mold from the assessment. Factor relationships are region specific based on housing type and occupant use patterns. The model does not address specific health sensitivities and their reliance on certain environmental triggers although reverse engineering may provide insight. Some model factors are simplistic due to limited technical information and site gathered data to date. The model is specific to population health and cannot predict the individual health condition of occupants. Moreover, bias is introduced if occupant or site data were used from self-selection, mail in surveys or telephone interviews. Also, accuracy of professional site review assessment depends on and varies with expertise levels of the professional.

7. People with immune-compromised conditions, congenital respiratory problems, or acquired sensitivity to certain molds affected by their indoor environments are more severely affected than those without these conditions. Future study will adjust results for gender, age, ethnicity, ETS, SHS, and unique medical conditions to derive specialized or more specific results.

8. Both historical and e-survey data used to verify the $HEALTH^2$ tool were not intended to validate a causal association between indoor environments and health, but to undergird a quantitative engineering risk analysis approach to the association. Further data accumulation through a more thorough strictly epidemiological approach should be considered if the medical profession intends for the tool's use in medical diagnosis.

9. The development of the data used to validate the $HEALTH^2$ tool did not follow standard population health or epidemiological study procedures due to the process conducted and as such do not replicate the rigor required by such study procedures. Data used for the $HEALTH^2$ model and tool were gathered from reports and studies over years of professional

investigation that varied in thoroughness and scope and were not part of one study design or from a specific study design formulated for the expressed outcome derived. Data from a specifically designed methodology to validate the $HEALTH^2$ model may give differing results.

10. This research, thesis formulation, and outcomes are engineering risk assessment based and is not to be construed as a medical or epidemiological or population health based assessment or derived from a medical research program that would require more rigor.
11. Thesis results indicate a 44 - 89% (Tables 2-13 and 2-14) reduction rate in patient health effect by component after remediation of the home. The overall reduction value noted in this thesis of 65-70% is based on comparing the economic savings versus the cost impact calculated by MCS and SCBA median component valuation methods from risk assessment. Actual health reduction impacts will vary with indoor environments and specific condition of patient/ occupant.
12. The cost benefit may be no more than PHCS resource allocation without the tools for accurate measurement at this time.

6.5 Future Research

As a product of this research, contributions have been made, but gaps in knowledge remain, that include the foregoing which is presented as future research opportunities:

1. A knowledge gap exists in determining a quantitative means of setting permissible mold exposure limits (PEL) that regulatory bodies may rely on to set healthy indoor environment criteria. Further research can begin by looking at the mycotoxicity of mold and conducting a fate analysis in concert with medical trials on organ response to mycotoxicity through assay-based research. Further research can be conducted to define specific molds that

generate toxins at a specific concerning level. Quantitative studies on indoor environment nutrient levels, occupant storage levels, occupant levels, extent of ventilation and filtration correlated to moisture or visible mold levels can be conducted to assist in refining the HEALTH^2 model factors.

2. Isolating dampness and molds from other indoor environment hazards is critical in validating cause and effect from remediation of indoor environments for these components from the interaction effects of various hazard sources, and diversity versus exposure conditions. Study design would consider removal of consequential conditions by defining and filtering out confounding effects such as ETS, SHS, VOCs, and normalizing building envelope conditions, HVAC, filtration, and thermal variations.
3. Isolating and reliably quantifying all external costs and benefit components of not treating asthmatics for mold and dampness effects is needed. This research should begin by looking at the areas of impact that are lacking in research: such as, measuring loss of well-being or quality of life; loss of patient societal contributions through volunteering; special needs; community service requirements; and insurance impact. Studies specific to indoor environmental mold and dampness impact on patients should consider valuing the impact by tracking day to day activities versus the non-affected public and measuring variations for further research.
4. Developing a generally accepted quantitative sampling protocol for mold testing and analysis may assist the environmental consultant, health care professional, and the IAQ industry in determining the extent and specifics of indoor contamination to assist in designing environment specific remedial and medical processes to directly reduce health impact. This research can begin by looking at genus-specific moisture-based indoor molds

and the work conducted by Vesper (2011) on mold-specific quantitative polymerase chain reaction (MSQPCR), a highly specific DNA-based method for quantifying mold species. Studies should more closely research and, if possible, define a quantitative correlation between various levels of indoor mould and dampness contamination and respiratory health impacts.

5. Developing a decision tree to identify the potential of environmental cause in asthma treatment protocol would be primary in identifying environmental based respiratory distress in the ED for proactive treatment and focusing treatment towards a SIRAPP program.
6. Thesis results indicate a 44 - 89% (Tables 2-14 and 2-15) reduction rate in patient health effect by component after remediation of the home. The MCS and SCBA analysis conducted in this thesis projects a 65-70% health impact reduction overall based on cost estimation. Further research is required to validate population based health impact reductions. As well, the interplay between the various health effect components may play a part in overall health response from bio-remediation which requires further research to validate and quantify. Further, analysing resource allocation versus cost reduction will assist in validating the financial benefit of implementing the SIRAPP program.
7. Research indicates only a percentage of health affected occupants recover to some extent, but cannot confirm recovery method or extent specifically. Further, it is unknown which health component reduction has the best effect on health recovery and should be favoured over another if resources to assist are scarce. Further research in this area may expose benefits towards pinpointing health and environment components for remediation and possible sub-demographics of patients with specific health impacts beyond asthma levels.

This can help to refine the SIRAPP program towards better efficiencies or capture methods. The initial steps in this research process would be to monitor individual patients before and after remediation measures to gauge improvement in various categories including mobility, dexterity, medication levels, levels of malaise, activity levels, etc. Development and design of an ongoing study would be critical to validating the ideas presented in this thesis.

8. The SCBA results are based on the estimate of possible existing candidates. The projection of extent of future additions to the candidate population requires further research to predict demand for the SIRAPP going forward.
9. The NPV for a lifetime of program-based savings has not been calculated for two reasons: 1) the longevity of a mold and dampness induced high-use asthmatic has not been found in research; and 2) the increased longevity from removal of mold and dampness triggers from the high-use asthmatic's residential environment has not been researched. Further research will allow for a NPV evaluation for the purpose of more accurately predicting the overall value of implementing the asthma care program over a patient's lifetime.
10. Further research is required to determine applicability to expand the SIRAPP to other respiratory-based diseases that might be triggered by indoor environmental hazards and have a health reversibility component from bio-remediation.
11. Further research is required to address the effect of home remediation versus the effect of extended drug therapy in reducing the more extreme effects of asthma impact as the medical profession is showing success in extended drug therapy although drug therapy has health side effects.
12. The long term benefit-cost of home remediation versus drug therapy requires further research for best method determination.

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Appendices

Appendix A Residential Survey Results & Analysis

This appendix was developed from the Okanagan Residential Survey: Hostland 2012 study. The ethics approval was provided by the University of British Columbia. The study was conducted in 2012 as part of this thesis.

Final version obtained Sunday, May 06, 2012

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Executive Summary

This report contains a detailed statistical analysis of the results to the survey titled *Okanagan Residential Survey: Hostland 2012 study*. The results analysis includes answers from all respondents who took the survey in the 26 day period from Monday, April 09, 2012 to Saturday, May 05, 2012. 78 completed responses were received to the survey during this time.

Survey Results & Analysis

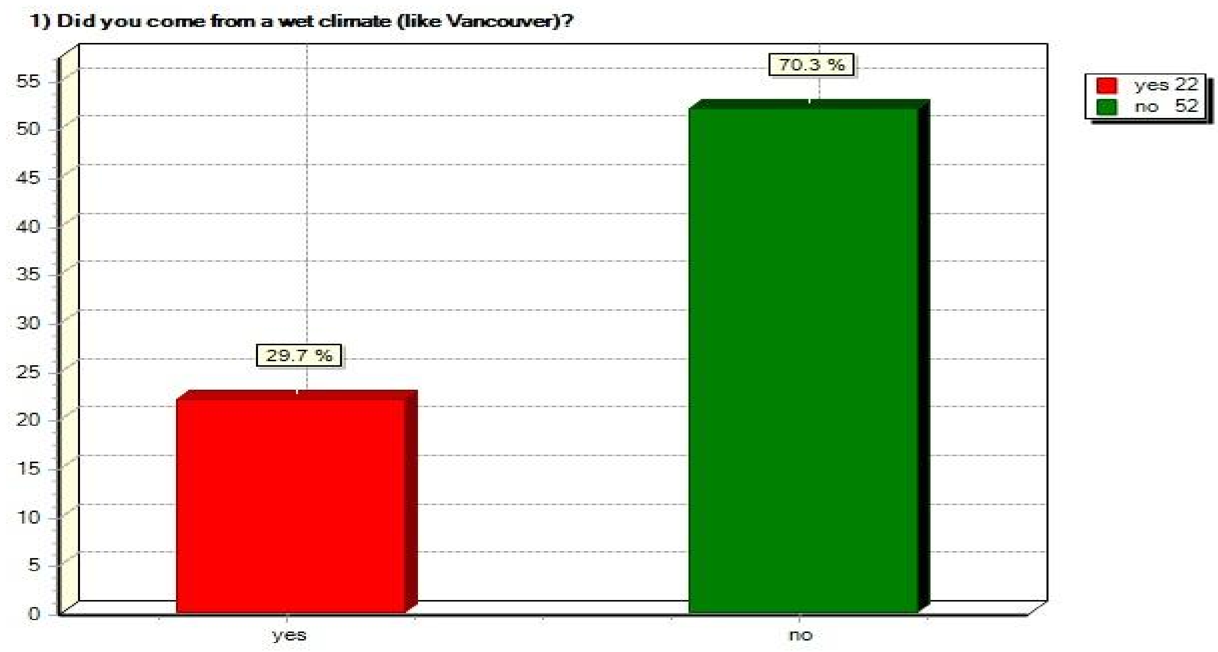
Survey: Okanagan Residential Survey: Hostland 2012 study

Author: Craig Hostland P. Eng. CIEC PhD C

Filter:

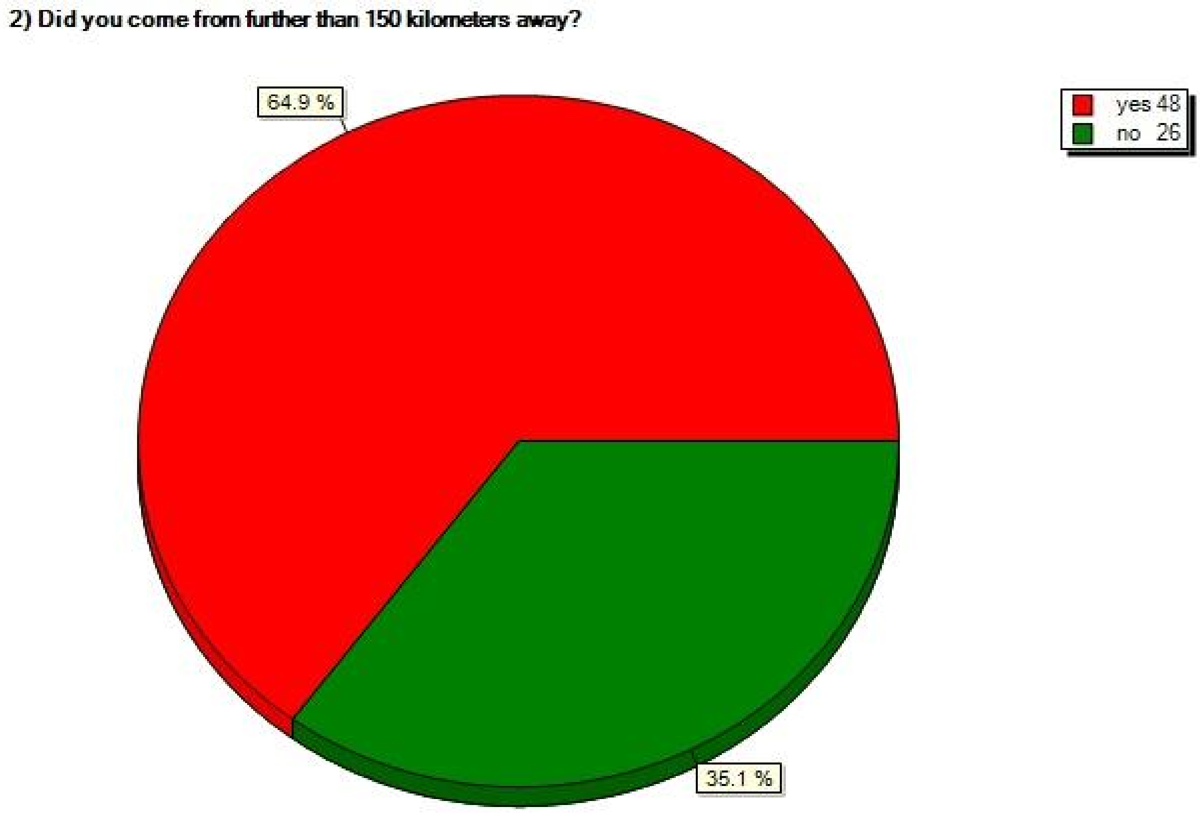
Responses Received: 78

The following are the specific questions, responses, and survey output.



Comment Responses:

lived on both east and west coasts
Toronto
Moist climate - SW Ontario
Burnaby / North Van
Edmonton
Left in 1974 when I was 8 years old
Also very high humidity
came from Port Alberni
Richmond
Local move
Local move
Holland west coast



Comment Responses:

Moved from Edmonton
See above
Moved from Vernon to Lumby in 2005
Calgary
live in Kelowna

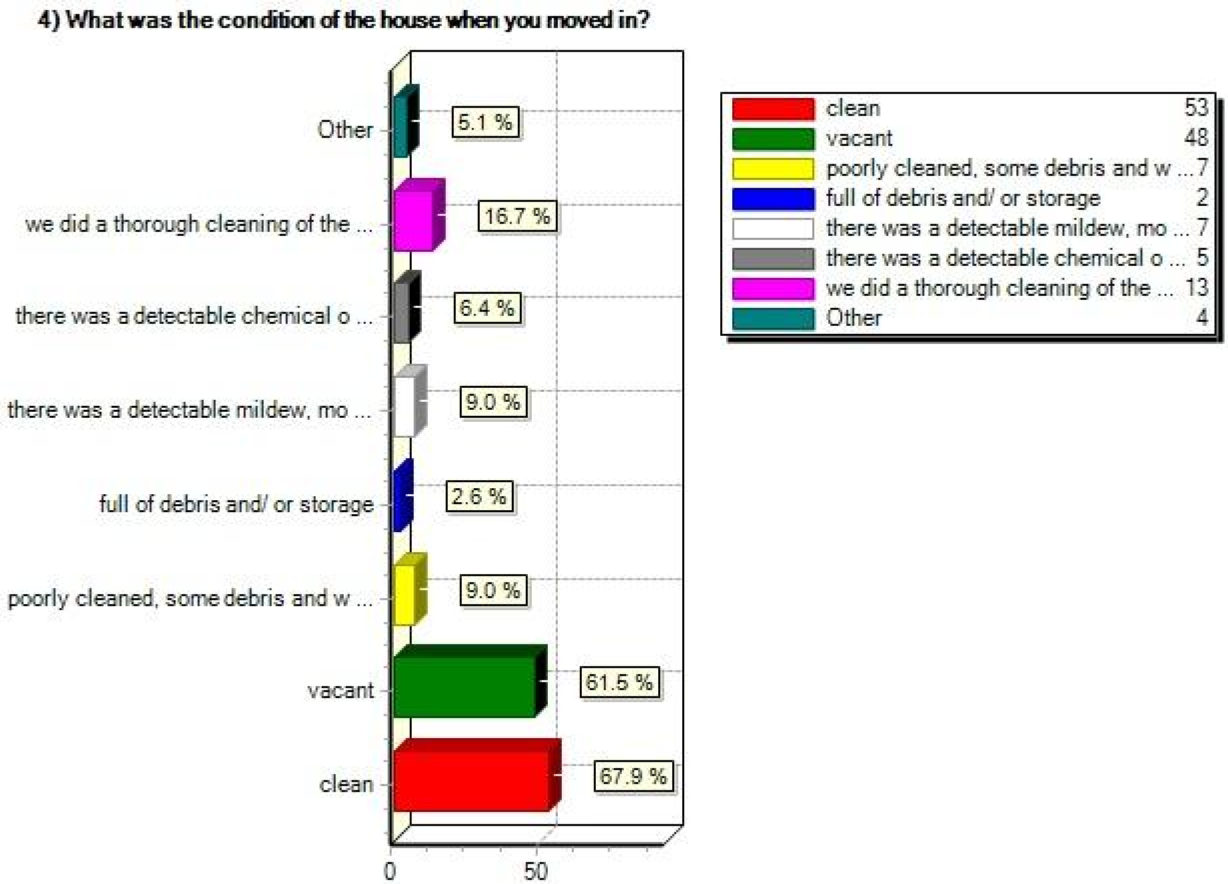
3) What was the condition of home on your last walk through prior to closing?

Other Responses:

house was new
The condition of the walls was fair but the carpets and appliances had to be removed. One bath had a leak (as did the washing machine tap as we later discovered but no mould was located when we remove
AND WATER INTRUSION ON MAIN LEVEL
condo
30 year old panelling, carpets, etc that were well worn

Comment Responses:

Evidence of treated mould in attic
75-year-old home, odors expected somewha
d the offensive items
New renovation
The house was empty for 3mons. new paint



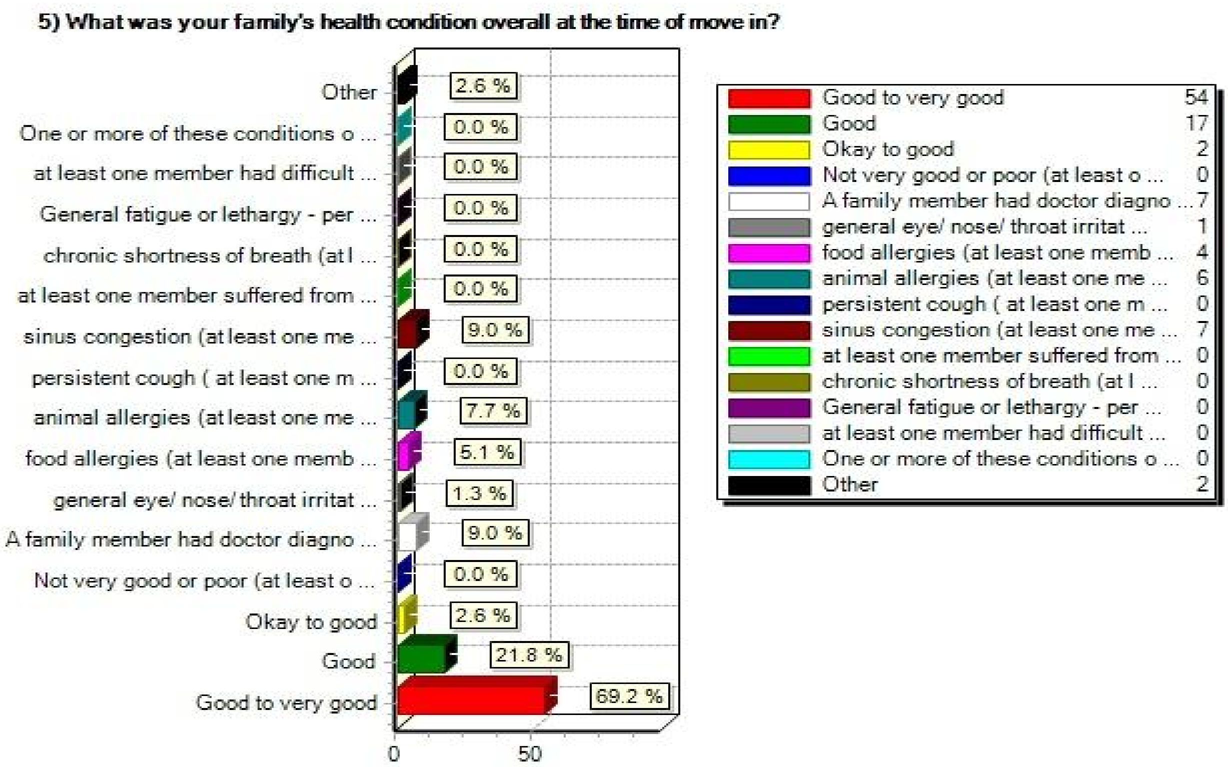
Other Responses:

odour of animal urine in bedroom
BLACK DEPOSITS ON CRAWL SPACE BEAMS

There was material in garage and workshop, as per arrangement.
carpets poorly cleaned - residue left behind?
purchased home from older family members, they left all possessions they did not want in new place including old rancid canning jars in crawl space under stairs, 30 year old couches

Comment Responses:

post-construction cleaning not adequate
house occupied by tenants
we moved in 6 weeks into huge renovation



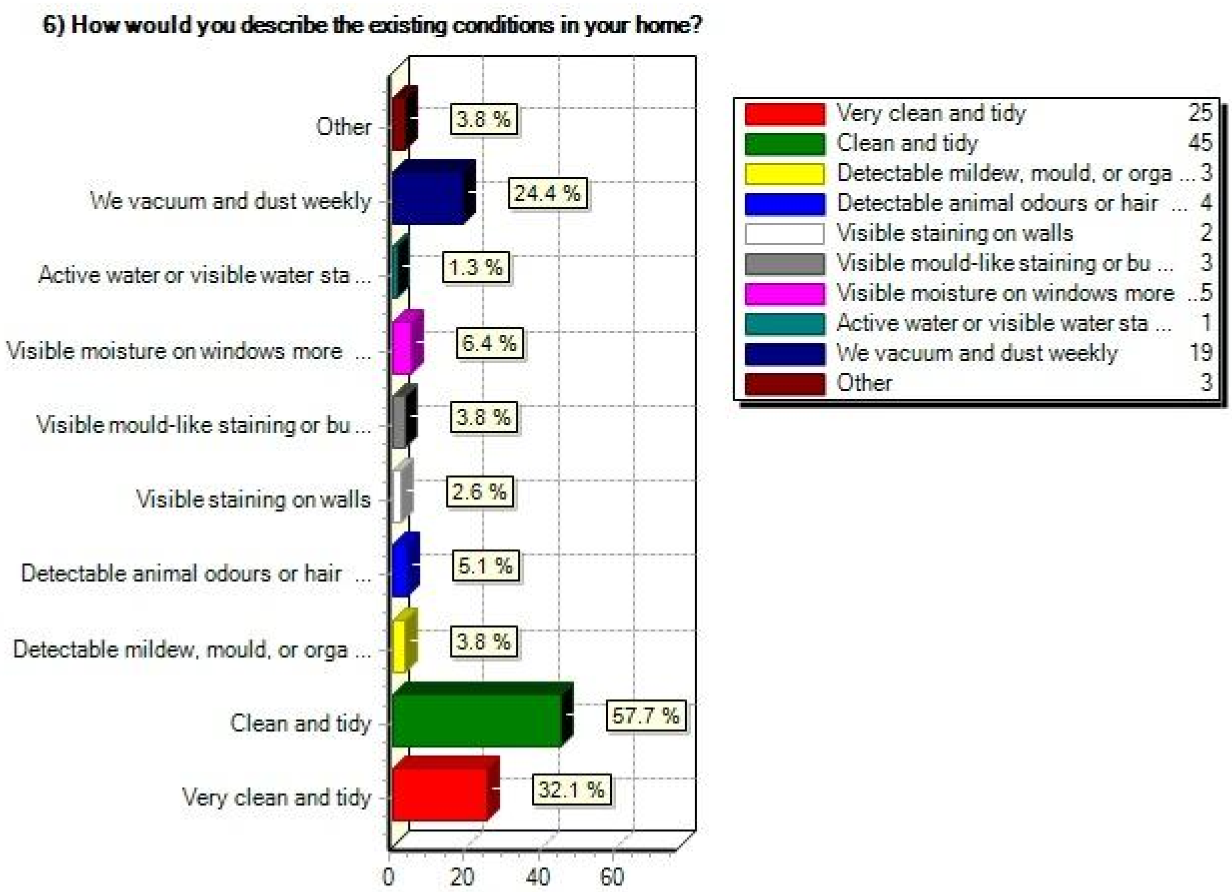
Other Responses:

a chronic condition

chronic rhinitis
Pain. Moving overstrain. Fatigue.
electronic air filter on furnace

Comment Responses:

plantar's faschitis from old house tile.
house occupied by tenants
we have a heat pump, all ducting new changed from electric base board heat to forced air as a part of reno, replaced basement windows

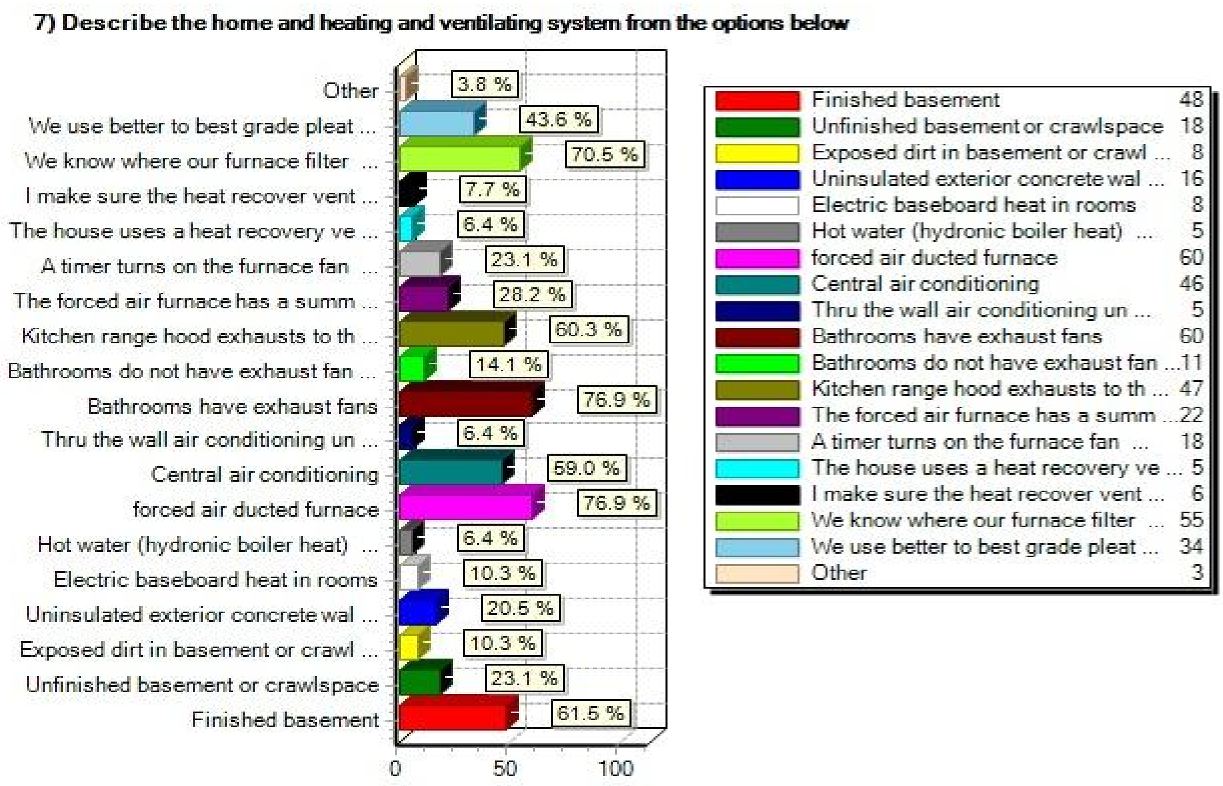


Other Responses:

there is still off gassing from the laminate
It is a farm and we are renovating a lot.
SWEEP & MOP WEEKLY WOOD FLOORS OR LINO

Comment Responses:

laminate floor. Windows need to be open for part of each day
The house had mold problems that are now fixed,
NO CARPET DUE TO ASTHMA
house occupied by tenants
No vent in bathroom creating moisture problems.

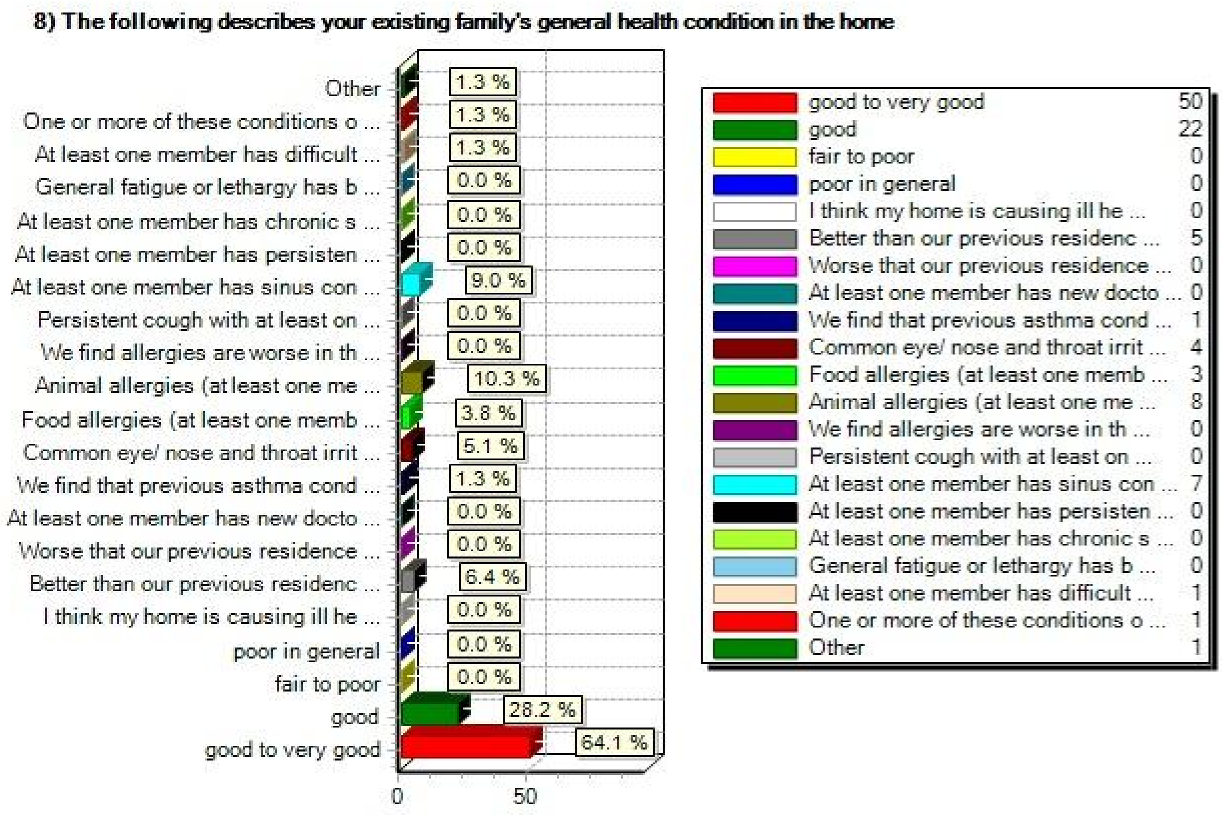


Other Responses:

ceiling fan also moves air about
Have only been in home since Oct 2011
dehumidifier used in winter
Replace the furnace filter every months
Our furnace guy recommends fibre filters
gas fireplace, wood fireplace

Comment Responses:

Replaced the 20 year old furnace with a high velocity furnace with air filtering system and humidifier
asbestos and old ductwork/furnace replaced
Two furnaces, one has an electronic filter
Change fibre filters every month, other filters make furnace work too hard to pull air thru pleated filters.
We use regular fibre filters but replace them monthly. Still cheaper than best grade pleated filters quarterly.
Only two of three bathrooms are exhausted
house occupied by tenants
partially finished basement. concrete floor seems to be deteriorating though. not sure if its moisture causing it.

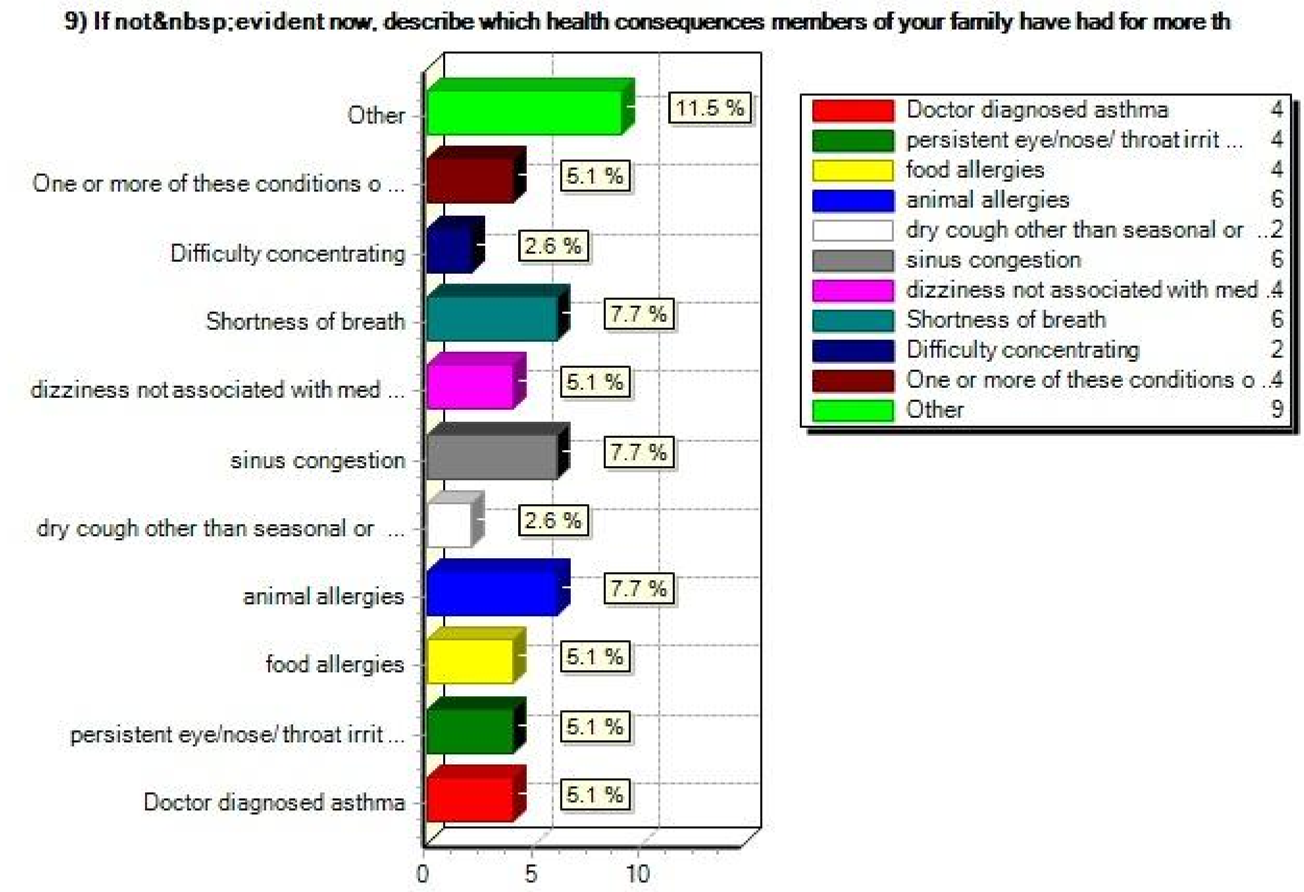


Other Responses:

No different than last home (log home)
Once mold was removed, much better
plantar's faschitis gone gone gone

Comment Responses:

We have nasal congestion (i.e. stuffy noses) on waking that seems to diminish or disappear if we're away for extended periods.
Haven't actively lived in home as it is a summer seasonal residence
Allergies lessened as well, cleaner air in Lumby
Pain gone. Peace and joy.
house occupied by tenants



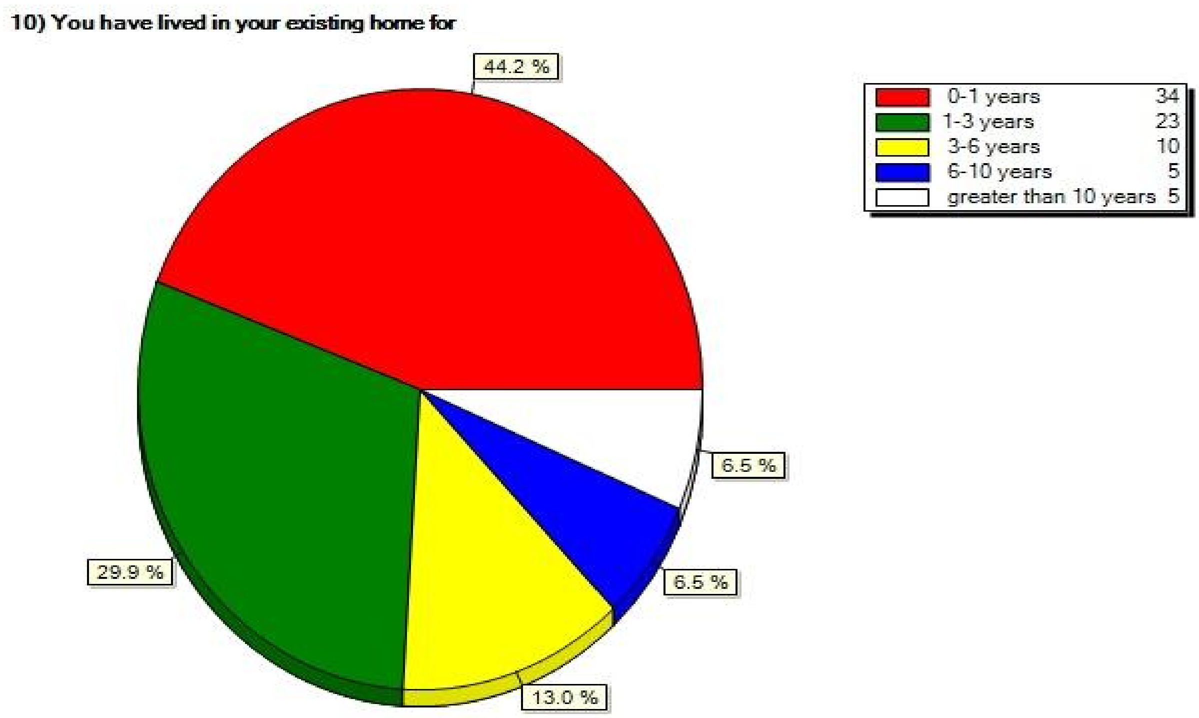
Other Responses:

Nil
anemia
no issues
The ongoing stress of mold and fixing it
None

Comment Responses:

none of the above
Stuffy noses on waking.
none

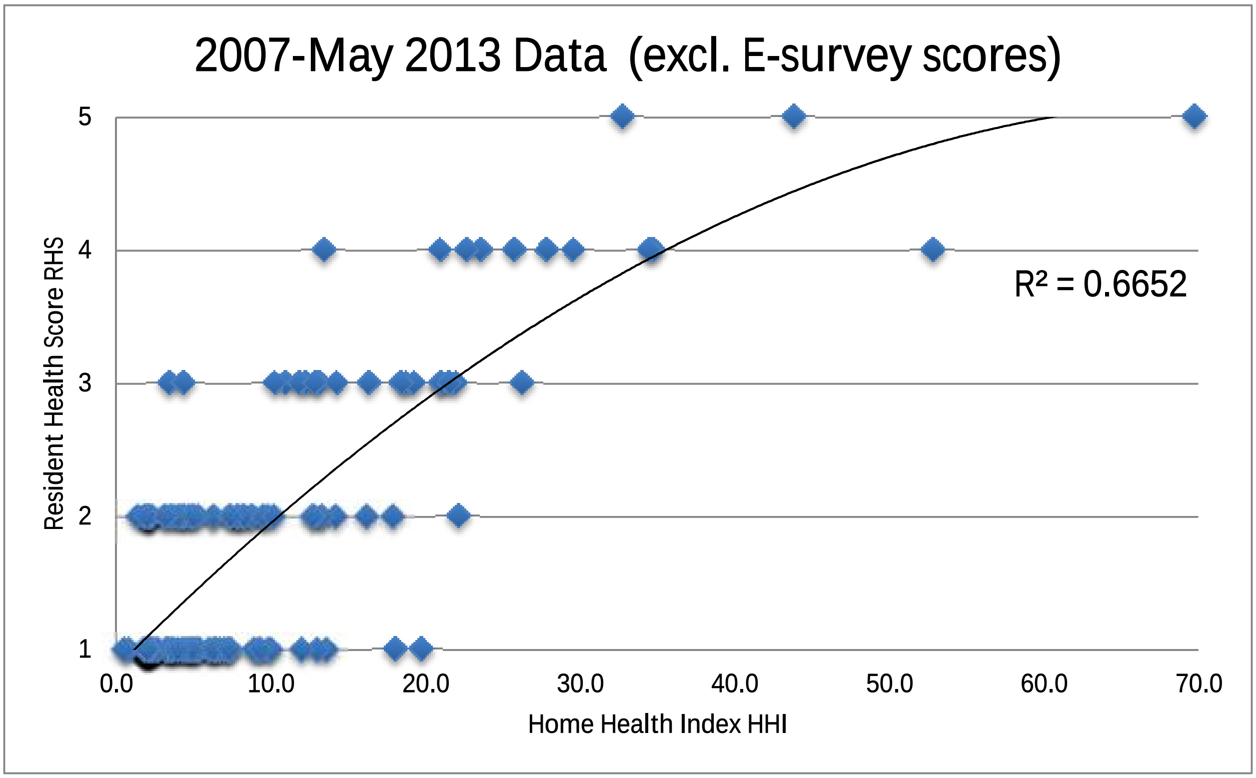
No noted health consequences
One member of family was even able to stop using Dristan after everything was fixed.
none
house occupied by tenants
seasonal allergies to grasses, pollens are my worst trigger of asthma/ congestion symptoms, have had skin contact rash when outdoors in months of may/june that improves with showering, not from house



Appendix B-1 Historic data

HHI vs RHS Data May 2013 updated

2007 - 2013 HHIAQ reports + 2003 HHIAQ add-on reports (excl. E-survey)



<u>HISTORIC DATA</u>

HHI	RHS
2.2	1
2.3	1
2.2	1
2.0	1
2.0	1

<u>Health Values from data</u>

1= no respiratory health issues
2= minimal respir. health issues (not hindering)
3= light respir. issues (hindrance)
4=moderate respir. issues (function affecting)
5=severe respir. issues (hosp.)

2.1	1
2.4	1
6.4	1
5.1	1
6.0	1
13.6	1
2.2	1
2.4	1
2.3	1
2.3	1
2.2	1
2.0	1
2.0	1
2.0	1
2.0	1
2.1	1
2.0	1
4.8	1
2.3	1
4.0	1
0.8	1
4.5	1
3.7	1
1.8	1
6.0	1
20.9	3
2.0	1
2.0	1
32.7	5
13.0	1
4.3	1
4.9	2
3.4	3
5.4	1
4.4	2
19.7	1
2.0	1
13.4	4
2.0	1
2.0	2
2.0	1
2.0	1

20.9	4
2.0	1
6.3	2
1.8	2
6.7	1
3.4	1
1.8	1
2.0	1
9.2	1
2.1	2
13.3	2
43.8	5
2.0	1
2.0	1
9.8	2
2.0	1
16.3	3
2.3	2
21.9	3
9.8	1
16.2	2
14.2	2
7.8	2
13.3	2
3.1	2
8.2	2
2.7	1
23.5	4
8.7	2
2.3	2
7.9	2
18.0	1
7.2	1
2	1
18.7	3
4.9	1
6.3	2
3.5	2
3.3	1
69.7	5
4.3	2
2.0	1

4.7	2
3.7	2
0.5	1
8.9	1
2.0	1
7.3	2
10.9	3
2.0	1
2.0	1
2.7	1
34.7	4
12.2	3
4.7	1
4.2	2
7.0	1
3.5	1
2.0	2
2.0	1
2.1	2
2.3	1
2.4	1
10.0	1
2.0	1
2.0	1
12.8	2
2.2	2
2.0	1
2.4	1
1.4	2
29.5	4
9.5	2
5.3	1
2.0	1
2.0	1
2.0	1
5.2	1
13.1	3
7.8	2
2.0	1
2.2	1
6.4	1
3.7	1

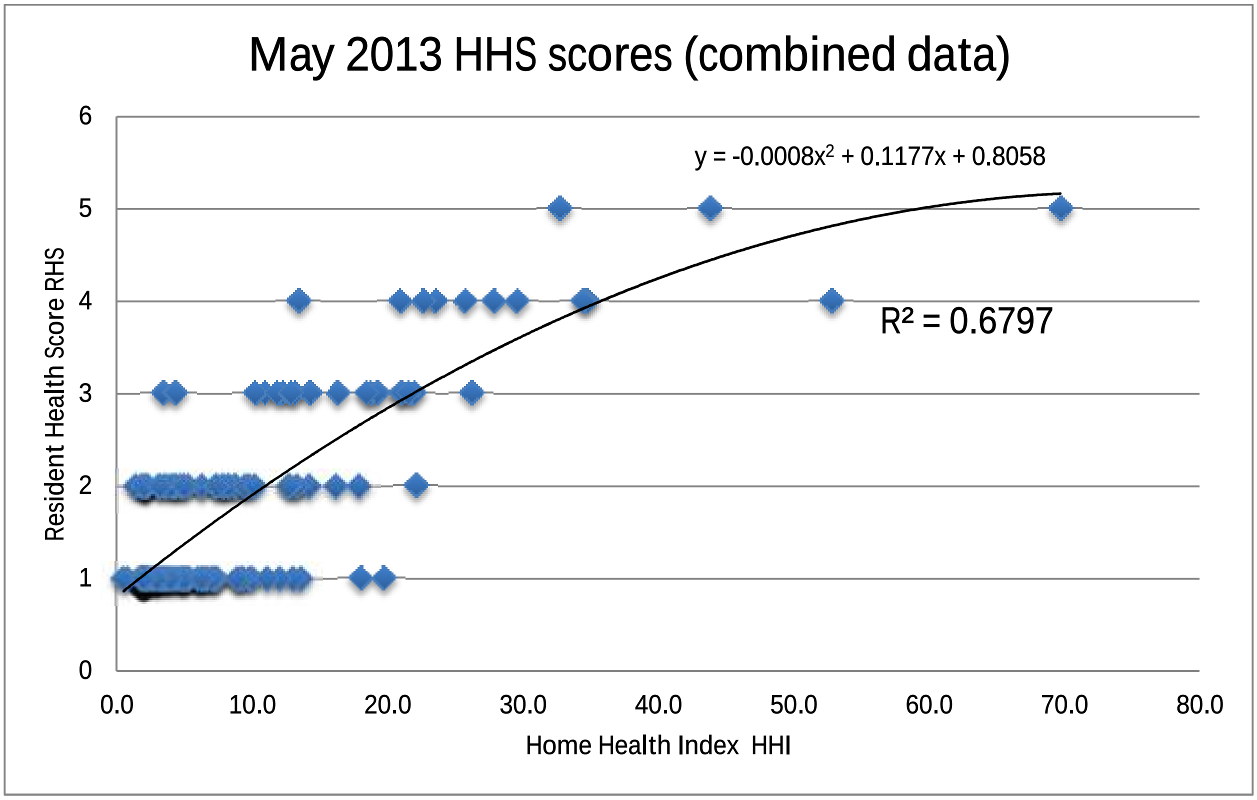
14.2	3
8.8	2
3.2	1
4.8	1
2.2	1
2.0	1
2.0	1
2.0	1
2.0	1
22.6	4
9.3	1
2.0	1
2	1
4.0	2
3.6	1
10.2	3
21.0	3
11.8	3
6.5	1
2.0	1
2.2	1
2.1	1
2.1	1
8.3	2
12.0	1
2.6	1
3.7	1
4.3	1
17.9	2
26.2	3
2.0	1
22.1	2
6.3	1
2.2	1
2.0	1
2.0	1
9.5	2
2.2	1
7.4	1
2.0	1
2.0	1
4.9	1

	7.4	2
	52.8	4
	2.0	1
	12.7	2
	5.3	2
	25.7	4
	19.2	3
	34.4	4
	7.3	1
	4.0	1
	21.5	3
	2.0	1
	27.8	4
	2.0	1
	2.0	1
	12.8	3
	4.3	3
	18.4	3
	5.0	2
	2.0	2
	3.2	2
	10.2	2
Total	**1472.5**	**318**
Mean	**7.55128**	**1.6307692**
n= 195		

Appendix B-2 Combined data set (Historic & E-survey)

HHI vs RHS Health Data May 2013 updated

2007 - 2013 HHIAQ reports + 2003 HHIAQ add-on reports



Historic + E-survey Data

HHI	RHS
2.2	1
2.3	1
2.2	1
2.0	1
2.0	1

<u>Health Values from Data</u>

1= no respiratory health issues
2= minimal respir. Health issues (not hindering)
3= light respir. issues (hindrance)

2.1	1	4=moderate respir. issues (function affecting)
2.4	1	5=severe respir. issues (hosp.)
6.4	1	
5.1	1	
6.0	1	
13.6	1	
2.2	1	
2.4	1	
2.3	1	
2.3	1	
2.2	1	
2.0	1	
2.0	1	
2.0	1	
2.0	1	
2.1	1	
2.0	1	
4.8	1	
2.3	1	
4.0	1	
0.8	1	
4.5	1	
3.7	1	
1.8	1	
6.0	1	
20.9	3	
2.0	1	
2.0	1	
32.7	5	
13.0	1	
4.3	1	
4.9	2	
3.4	3	
5.4	1	
4.4	2	
19.7	1	
2.0	1	
13.4	4	
2.0	1	
2.0	2	
2.0	1	
2.0	1	

20.9	4
2.0	1
6.3	2
1.8	2
6.7	1
3.4	1
1.8	1
2.0	1
9.2	1
2.1	2
13.3	2
43.8	5
2.0	1
2.0	1
9.8	2
2.0	1
16.3	3
2.3	2
21.9	3
9.8	1
16.2	2
14.2	2
7.8	2
13.3	2
3.1	2
8.2	2
2.7	1
23.5	4
8.7	2
2.3	2
7.9	2
18.0	1
7.2	1
2	1
18.7	3
4.9	1
6.3	2
3.5	2
3.3	1
69.7	5
4.3	2
2.0	1

4.7	2
3.7	2
0.5	1
8.9	1
2.0	1
7.3	2
10.9	3
2.0	1
2.0	1
2.7	1
34.7	4
12.2	3
4.7	1
4.2	2
7.0	1
3.5	1
2.0	2
2.0	1
2.1	2
2.3	1
2.4	1
10.0	1
2.0	1
2.0	1
12.8	2
2.2	2
2.0	1
2.4	1
1.4	2
29.5	4
9.5	2
5.3	1
2.0	1
2.0	1
2.0	1
5.2	1
13.1	3
7.8	2
2.0	1
2.2	1
6.4	1
3.7	1

14.2	3
8.8	2
3.2	1
4.8	1
2.2	1
2.0	1
2.0	1
2.0	1
2.0	1
22.6	4
9.3	1
2.0	1
2	1
4.0	2
3.6	1
10.2	3
21.0	3
11.8	3
6.5	1
2.0	1
2.2	1
2.1	1
2.1	1
8.3	2
12.0	1
2.6	1
3.7	1
4.3	1
17.9	2
26.2	3
2.0	1
22.1	2
6.3	1
2.2	1
2.0	1
2.0	1
9.5	2
2.2	1
7.4	1
2.0	1
2.0	1
4.9	1

7.4	2
52.8	4
2.0	1
12.7	2
5.3	2
25.7	4
19.2	3
34.4	4
7.3	1
4.0	1
21.5	3
2.0	1
27.8	4
2.0	1
2.0	1
12.8	3
4.3	3
18.4	3
5.0	2
2.0	2
3.2	2
10.2	2
2	1
2	1
2	1
2	1
4.1	1
2	1
2	1
2	1
8.9	1
2	1
2	1
2	1
6	1
2	1
6	1
7	1
2	1
5	1
2	1
2	1

2	1
2	1
5	1
2	1
3	1
2	1
2	1
3	1
3	1
2	1
2	1
2	1
2	1
2.8	1
3	1
3	1
3	1
2.8	1
3.8	1
2	1
2	1
2	1
5	1
2	1
2	1
2	1
2	1
3	1
2	1
2	1
2	1
2	1
2	1
2	1
11.1	1
3	1
2	1
2	1
3	1
6.3	1
2	1
2	1

	2	1
	2	1
	2	1
	2	1
	3	1
	4	1
	2	1
	2	1
	2	1
	3	1
	3	1
	2	1
Total	1682.3	392.0
Mean	6.253903	1.457249
n=269		

Appendix C AHP scoring scheme

Value scale comparing A to B

1/9 Extreme preference of B over A

1/7 Very strong

1/5 Strong

1/3 Moderate

1/1 Equal

3 Moderate preference of A over B

5 Strong

7 Very strong

9 Extreme

Matrix A Modifier - Indoor house hygiene levels (M_{31} – M_{34})

M31-M32 = 2 Moderate to equal preference of house hygiene over occupant/storage load

M31-M33 = 0.2 Strong preference of Mold growth over house hygiene levels

M31-M34 = 0.3 Moderate preference of Mold stain over house hygiene

M32-M33 = 0.14 Very strong preference of Mold growth over occupant/storage load

M32-M34 = 0.2 Strong preference of Mold stain to occupant / storage load

M33-M34 = 1 Equal preference Mold growth to mold stain

Matrix B Source – Moisture rating (S_{11} – S_{13})

S11-S12 = 4 Moderate to strong preference of active water to relative humidity

S11-S13 = 9 Extreme preference of active water over a past moisture event

S12-S13 = 5 Strong preference of relative humidity to past moisture event

Matrix C   Modifier - Ventilation/ Filtration/ house hygiene (M_1 – M_3)

M1-M2 = 3 Moderate preference of ventilation over filtration

M1-M3 = 7 Very strong preference of ventilation over house hygiene

M2-M3 = 5 Strong preference of filtration over house hygiene

Matrix D   Source - Nutrients   rating (S_{21}, S_{22})

S21-S22 = 9 Extreme preference of loose cellulose over dense wood products

Matrix E   Source - Moisture/ nutrient (S_1 – S_2)

S1-S2 = 5 Extreme preference of moisture over nutrient as without moisture, mold growth will not occur.

Matrix F   Modifier - O/I Ventilation (M_{11} – M_{12})

M11-M12 = 9 Extreme preference of outside air vs. indoor air circulation for Northern climates

Matrix G   Modifier - Outdoor air (M_{111} –M_{112})

M111-M112 = 5 Extreme preference of mechanical outdoor air over passive outdoor air

Notes: This supplemental page provides the comparative factor relationships for housing in the Okanagan, BC, Canada to determine relative weightings. This forms the basis for the accuracy of the regional HEALTH^2 model. The AHP scoring scheme will vary by region/ country based on specific characteristics of housing stock and quality of installation. Local environmental and building science expertise will be required to validate regional scoring schemes.

Appendix D HEALTH^2 model structure scoring input template

	Factor	Description	Maximum value	House value
1	S11	Active Moisture (SC)		
	a	> 48 hr water ponding	5	____
	b	roof/plumb leak < 48 hrs/ intermittent	1	____
	c	roof/plumb leak > 48 hrs/ reoccuring	3	____
	d	condensation on window glass	1	____
	e	Puddling water in window channel	3	____
	f	unvented operating clothes dryer	2	____
	g	moldy/ dirty humidifier	1-2	____
	h	blg surface SC 15-20%	1	____
	i	blg surface gt 1 sm SC 20-30%	2	____
	j	blg surface gt 1 sm SC gt 30%	4	____
	0 = best	TOTAL (max 10)*		[ ]
2	S12	Active moisture (RH - relative humidity)		
	a	ave blg RH < 50%	0	____
	b	ave blg RH 50-55%	2	____
	c	ave blg RH 56-60%	4	____
	d	ave blg RH 61 - 80%	8	____
	e	ave blg RH 81%+	10	____
	0 = best	TOTAL (max 10)		[ ]
3	S13	Past moisture history		
	a	Flood < 48 hrs	1	____
	b	Flood 48-96 hrs	5	____
	c	Flood 96 hrs +	10	____
	d	Repaired water leak <48 hrs	0	____
	e	Grow op not professionally cleaned	10	____
	f	History of roof leaks	5	____
	g	History of plumbing leaks	5	____
	0 = best	TOTAL (max 10)		[ ]

4	S21	Nutrient: paper/cardboard/dirt/dust		
	a	Drywall at potential moisture source	4	____
	b	Exposed in-house dirt crawlspace	2-5	____
	c	OSB/particle board flooring	1	____
	d	Window sill debris	1	____
	e	Cardboard/ paper storage - light to heavy	1-2	____
	f	Plants - light to numerous	1-2	____
	0=best	TOTAL (max 10)		

5	S22	Nutrient: wood		
	a	Dim lumber ground/concrete contact	4	____
	b	Manuf'd lumber ground/concrete contact	5	____
	c	Manuf'd lumber exposed in crawlspace	3	____
	d	Manuf'd lum at potential moisture source	5	____
	e	Dim lumber at potential moisture source	5	____
	0=best	TOTAL (max 10)		

6	M31	House Hygiene level		
	a	Very Clean - dust free	0	____
	b	Visible light dust on surfaces	2	____
	c	Poorly cleaned - very visible dust	6	____
	d	Very poor	10	____
	e	Use of tobacco in the house (ETS)	5	____
	f	Use of central vacuum system	-2	____
	0=best	TOTAL (max 10)		

7	M32	Storage/ occupant load		
	a	Vacant	0	____
	b	Light	1	____
	c	Moderate	3	____
	d	Cluttered	5	____
	e	Excessive clutter	8	____
	f	Hoarder	10	____
	0 = best	TOTAL (max 10)		

8	M33	Visible mold growth*, rot, odor, damp		
	a	Active mold growth < 1 m2	2	____
	b	Active mold growth < 10 m2	5	____
	c	Active mold growth > 10 m2	10	____
	d	Verified mold "odor"	5	____
	e	Active visible rot	3	____
	f	Activity and adjacent carpeting	2	____
	0 = best	TOTAL (max 10)		

9	M34	Fungal stain, no odor, dry		
	a	Fungal staining < 1 m2 total	1	____
	b	Fungal staining <10 m2 total	4	____
	c	Fungal staining totalling over 10 m2	8	____
	d	Carpeting adjacent to staining	2	____
	0 = best	TOTAL (max 10)		

10	M2	Filtration (10 = none)		
	a	None	10	____
	b	HEPA and or UV	0	____
	c	Pleated MERV 6+	2	____
	d	Spun fibreglas - basic	6	____
	e	Room HEPA/UV	1	____
	f	2 Room HEPA/UV	2	
	0 = best	TOTAL (max 10)		

11	M111	Passive outdoor air exchange (10 = none)		
	a	no fresh air duct to return plenum	4	____
	b	no min. 150mm open duct to exterior	4	____
	c	Majority of rooms have opening windows	0	____
	d	Few rooms have opening windows	2	____
	e	None	10	____
	0 = best	TOTAL (max 10)		

12	M112	Mechanical outdoor air exchange (10=none)		
	a	None	10	____
	b	HRV on continuous timer	0	____
	c	HRV on continuous timer - not functional	10	____
	d	HRV only on demand	3	____
	e	Washroom exhaust on switch	5	____
	f	Washroom exhausts connecting to light	2	____
	0 = best	TOTAL (max 10)		

13	M12	Internal mechanical air circulation - room		
	a	None	10	____
	b	F/A furnace on timer 4-6 hr a day	0	____
	c	Portable house fan - 1 room	9	____
	d	Portable house fan - 2 rooms	7	____
	e	F/A furnace - no timer	5	____
	0 = best	TOTAL (max 10)		

*48 hour fungal growth criteria per IICRC S-520, NYSTMTF (2010)

*Mold growth area criteria per WorkSafe BC guidelines part 4.79 (2012)

*Line item scores are additive to a maximum score of 10 for each factor

*Scoring values and range based on prof. experience

Appendix E Expert knowledge (cognitive) matrices

Matrices criteria: British Columbia single family residence, central BC/ lower mainland

Matrix A Modifier - Indoor house hygiene levels 0-9

	M31	M32	M33	M34	Relative wt	Normalized
M31	1	2	0.2	0.3	0.589	0.099
M32	0.5	1	0.14	0.2	0.344	0.058
M33	5	7.14	1	1	3.656	0.615
M34	3.33	5.00	1	1	1.351	0.228
					5.939	1.000

Matrix B Source - Moisture (0-9)

	S11	S12	S13	Relative wt	Normalized
S11	1	4	9	3.302	0.709
S12	0.25	1	5	1.077	0.231
S13	0.111	0.2	1	0.281	0.060
				4.660	1.000

Matrix C Modifier - Ventilation/Filtration/hygiene (0 - 9)

	M1	M2	M3
M1	1	3	7
M2	0.333	1	5
M3	0.143	0.2	1

Relative wt	Normalized
2.759	0.649
1.186	0.279
0.306	0.072
4.250	1.000

Matrix D Source - Nutrients (0-9)

	S21	S22
S21	1	9
S22	0.111	1

Relative wt	Normalized
3.000	0.900
0.333	0.100
3.333	1.000

Matrix E Source - Moisture/ nutrient (0-5)

	S1	S2
S1	1	5
S2	0.2	1

Relative wt	Normalized
2.236	0.833
0.447	0.167
2.683	1.000

Matrix F Modifier - O/I Ventilation (0-9)

	M11	M12
M11	1	9
M12	0.111	1

3.000	0.900
0.333	0.100
3.333	1.000

Matrix G Modifier - Outdoor air (0-5)

	M111	M112
M111	1	0.2
M112	5	1

2.236	0.167
0.447	0.833
2.683	1.000

AHP analysis: for each criterion (factor) the relative importance of the alternative for each pairwise comparison is assessed (See Table S1) in a matrix format. The criterion is given a value scale of 1-9 except for matrices E and G (1-5) representative of their relative importance to the other matrices based on local knowledge. The source matrices are B, D, and E. the other matrices are amplification types that magnify source impacts based on extent in the indoor environment (see Figure 5). The relative weightings are then normalized for HEALTH2 model input.

Appendix F ANOVA analysis and graph

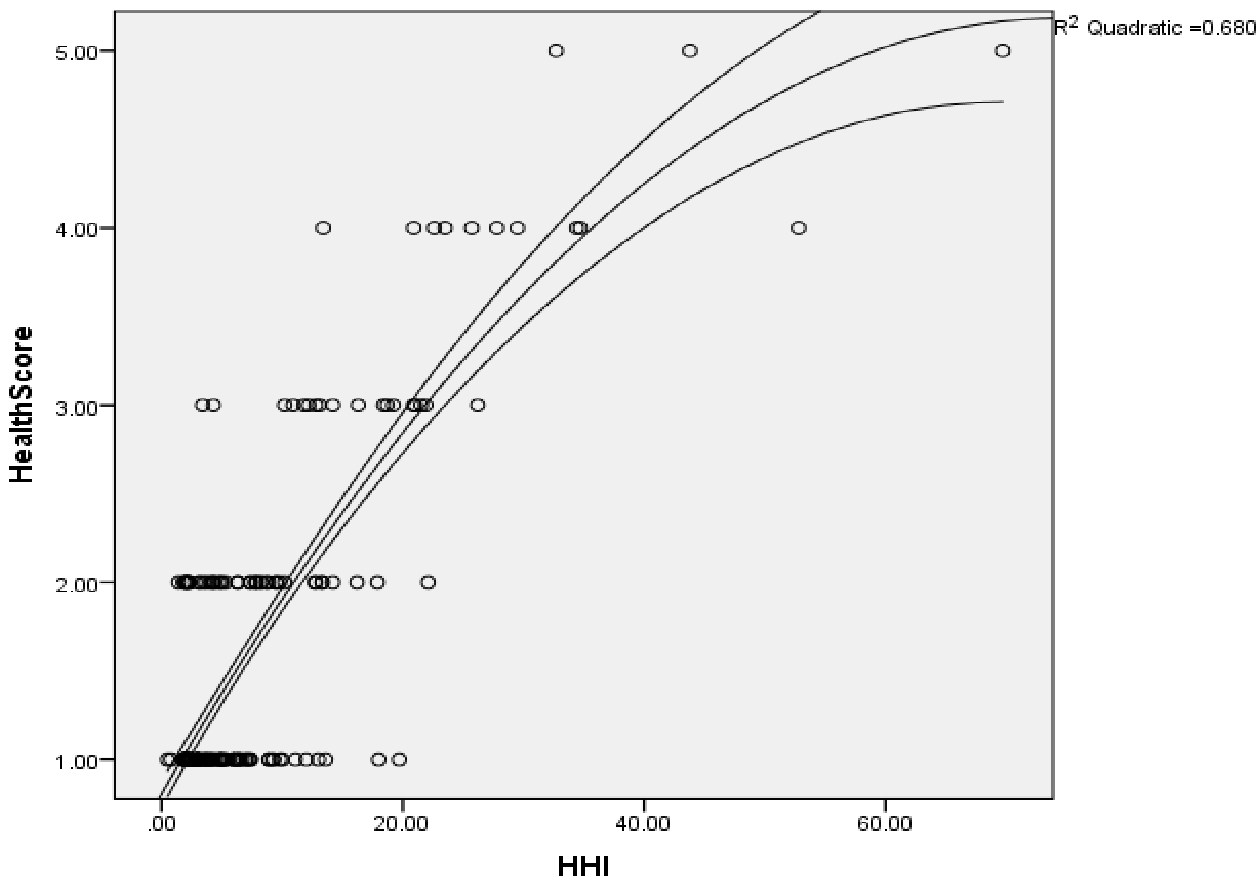
ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	135.093	2	67.547	282.217	.000
Residual	63.665	266	.239		
Total	198.758	268			

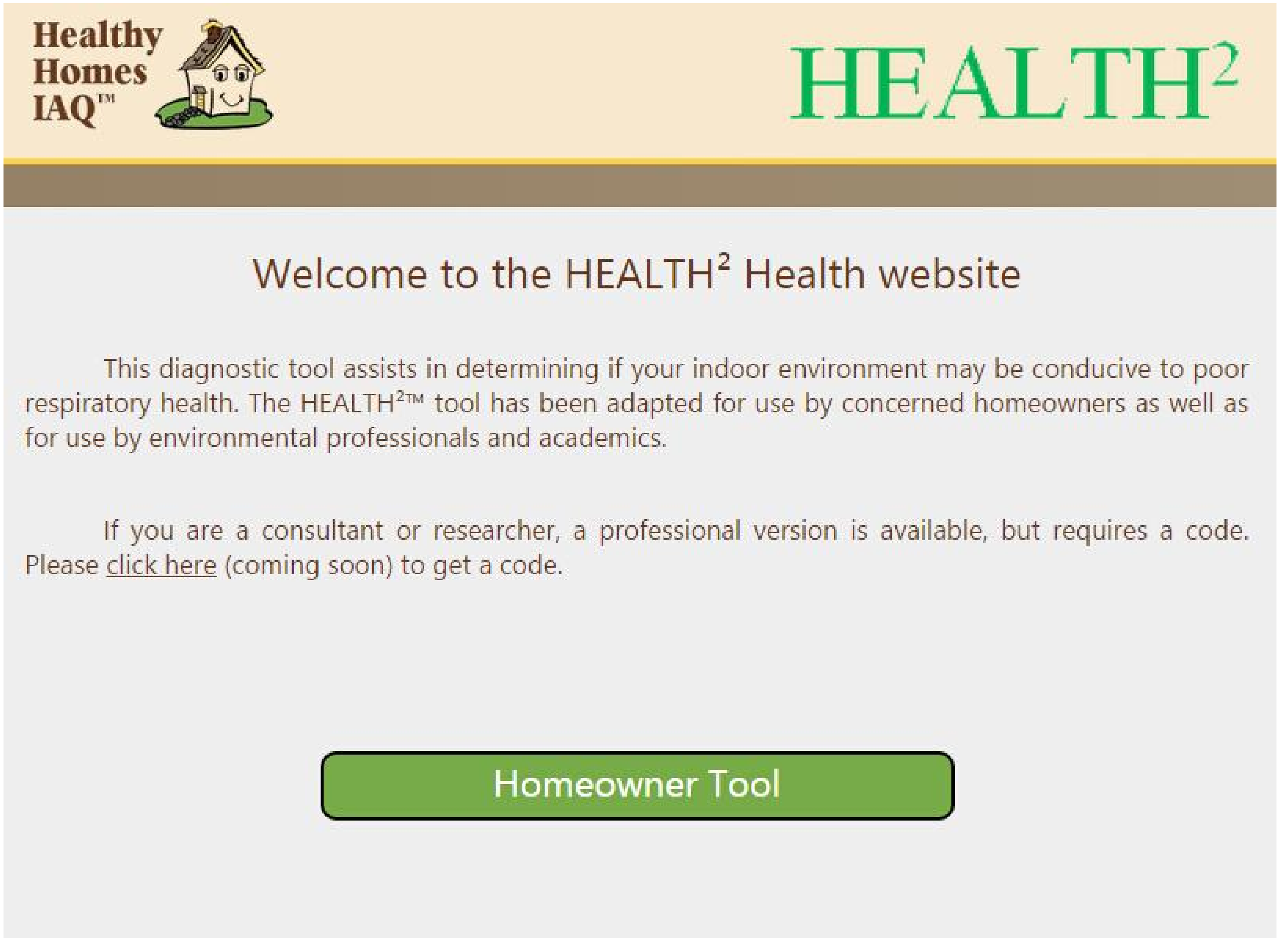
The independent variable is HHI.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
HHI	.118	.008	1.131	14.746	.000
HHI ** 2	-.001	.000	-.362	-4.719	.000
(Constant)	.806	.046		17.566	.000



Appendix G HEALTH^2 software input and output templates



Healthy Homes IAQ™

HEALTH²

Welcome

You have probably reached this point because you feel your home may contain harmful levels of mold or because you have a chronic respiratory illness that appears to be worse in your home. This tool has been designed to assist you in determining the general healthiness level of your home and what your next steps are towards understanding the environmental condition of your home pertaining to levels of mold and dampness.

Building Related Illness

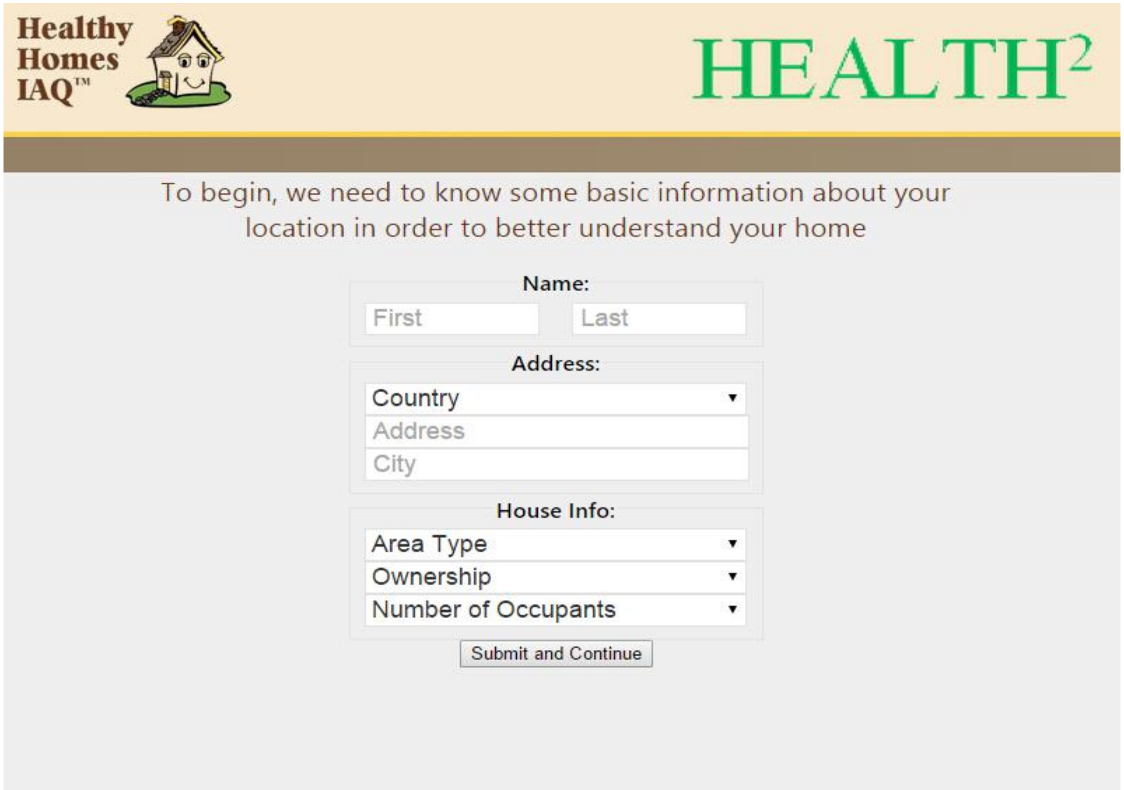
It is recognized that between 20 50% of North American homes have damp or moldy environments (Verhoeff & Burge 1997, Zock 2002). Poor maintenance and substandard construction practices lead to high levels of moisture and the proliferation of toxic molds (Singh 2010). Toxic mold development from dampness has been identified as a major contributor to poor health as evidenced by the improvement of health upon relocation (Lawrence & Martin 2001, Shaw et al. 1997), upon removal of molds and dampness (Bernstein et al. 2008, Kercsmar et al 2006), and by ultraviolet (UV) irradiation remediation (Burr et al 2007).

Molds are microscopic fungi that are highly adapted to grow and reproduce rapidly in damp to semi- damp environments. Fungal colonies produce spores and hyphae that generate allergens, microbial toxins (mycotoxins Or biotoxins), and microbial volatile organic compounds (MVOC) through the mold lifecycle. Specific molds cause allergenic reactions in some humans and pathogenic (a significant health concern) reactions in others. Strong evidence exists that indoor molds in buildings increase the risk and severity of asthma (Jaakkola & Jaakkola, 2004). High levels of airborne mold affect most Of the population to varying degrees (EPA 2012); but those who are more seriously affected are the environmentally sensitized, immune compromised, or those with underdeveloped immune systems, particularly the elderly and children (Antova et al. 2008, Tischer et al. 2011, Simoni et al. 2005). A higher level of exposure to living molds or a higher concentration of allergens on spores and mycelia results in a greater likelihood of illness, although levels and limits that cause illness are not known (Brandt et al. 2006).

In general, poor health from mold exposure Can include sore throat, nasal congestion or chronic runny nose, cough, wheezing, and increased asthmatic and allergic symptoms which can be misdiagnosed as flu-like effects (Bornehag et al. 2004 , Health Canada 2007, Mendell et al 2011, Palaty 2009, Wu et al. 2007). Inhalation of fungal spores or their toxins can also cause infections such as aspergillosis. MVOCs are capable of causing irritation to the eyes and upper respiratory tract, ABPA (allergic broncho-pulmonary spergillosis) and sinusitis. Colonizing fungi such as aspergillus fumigatus can cause bronchial inflammation and constant allergic response in asthmatics (Srikanth et al. 2008). Depending on the type and amount of mold present in a home, the amount and degree of exposure, and the health condition of the occupant, health effects can range from insignificant short term effects to significant allergic reaction and illness (CMHC 2011). Damp indoor environments and mold are associated with coughing, wheezing, and upper respiratory tract symptoms in Otherwise healthy people (Fisk et al 2007, IOM 2004, WHO 2009). Symptoms of asthma and rhinitis improved and medication use declined following removal of indoor mold in homes (Burr et al. 2007).

The process of evaluation requires not only a good understanding of your home conditions, but how they relate to your health concerns. Take this information to your doctor for the human health side of this analysis. You may or may not be environmentally sensitive to molds and dampness. In any event, knowing the type of home you live in and its level of indoor environmental quality will help you understand the opportunity to improve your indoor environment with helpful and sometimes easy solutions.

Continue


Healthy Homes IAQ™
HEALTH²
To begin, we need to know some basic information about your location in order to better understand your home
Name:
First
Last
Address:
Country
Address
City
House Info:
Area Type
Ownership
Number of Occupants
Submit and Continue


Healthy Homes IAQ™
HEALTH²
What health issues do one or more occupants suffer from?
Asthma:
None
Mild
Moderate and Controlled
Moderate and Uncontrolled
Severe and Controlled
Severe and Uncontrolled
Other:
Chronic Obstructive Pulmonary Disease
Emphysema
Ongoing Flu-like Symptoms
Other 1 (Please describe)
200 characters remaining
Other 2 (Please describe)
200 characters remaining
Submit and Continue

Healthy Homes IAQ™

HEALTH²

House Type

Check all that apply to your house

Windows:

- ○ Single pane windows
- ○ Double pane windows

Crawlspace:

- ○ No Crawlspace
- ○ Crawlspace has a dirt floor or is uninsulated
- ○ Crawlspace has plastic or concrete surfaces

Wall Construction:

- ○ 2x4 wall construction
- ○ 2x6 wall construction

Insulation:

- ○ Less than 6" insulation in attic
- ○ Less than 8" insulation in attic

Year Built:

- ○ Built in the 1970's or earlier
- ○ Built in the 1980's
- ○ Built in the 1990's
- ○ Built in 2000 or later

Furnace:

- ○ Electric baseboard heat
- ○ House has an old gas furnace
- ○ House has a high efficiency furnace

Bathroom Fans:

- ○ None
- ○ Piped to interior
- ○ Piped to exterior
- ○ House has a central heat recovery ventilator

Kitchen Fan:

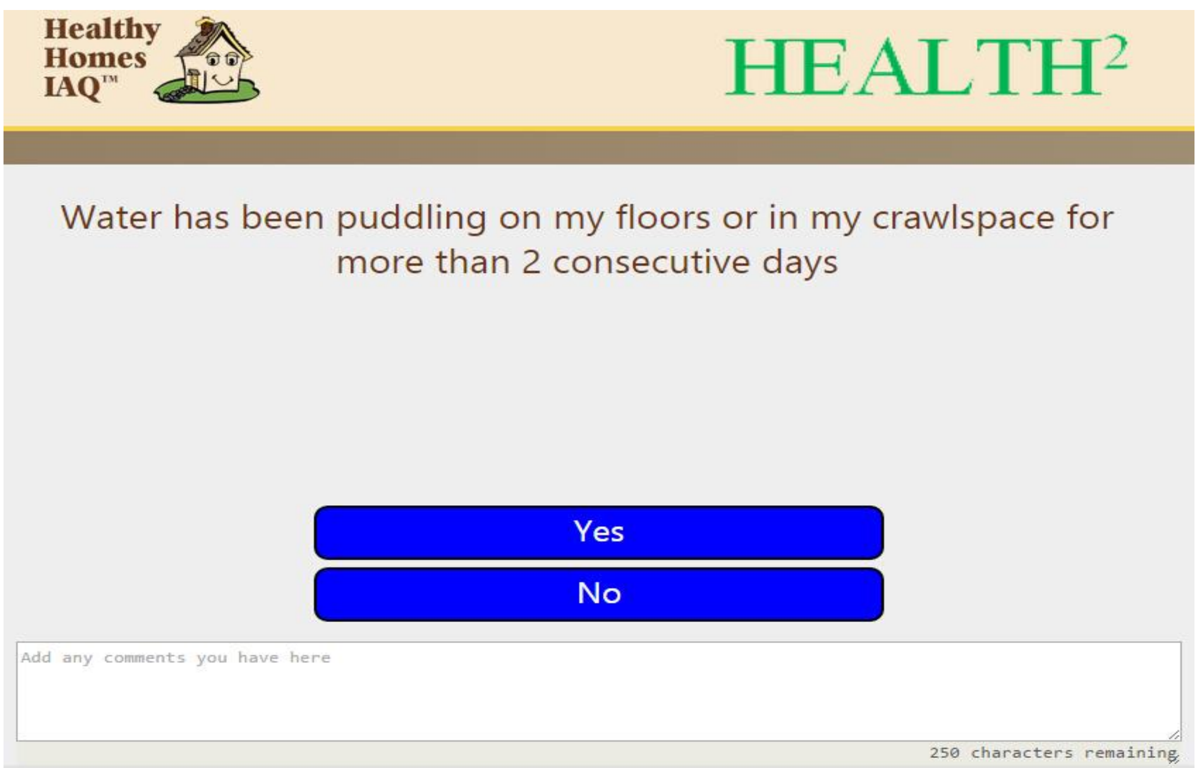
- ○ None
- ○ Piped to interior
- ○ Piped to exterior
- ○ House has a central heat recovery ventilator

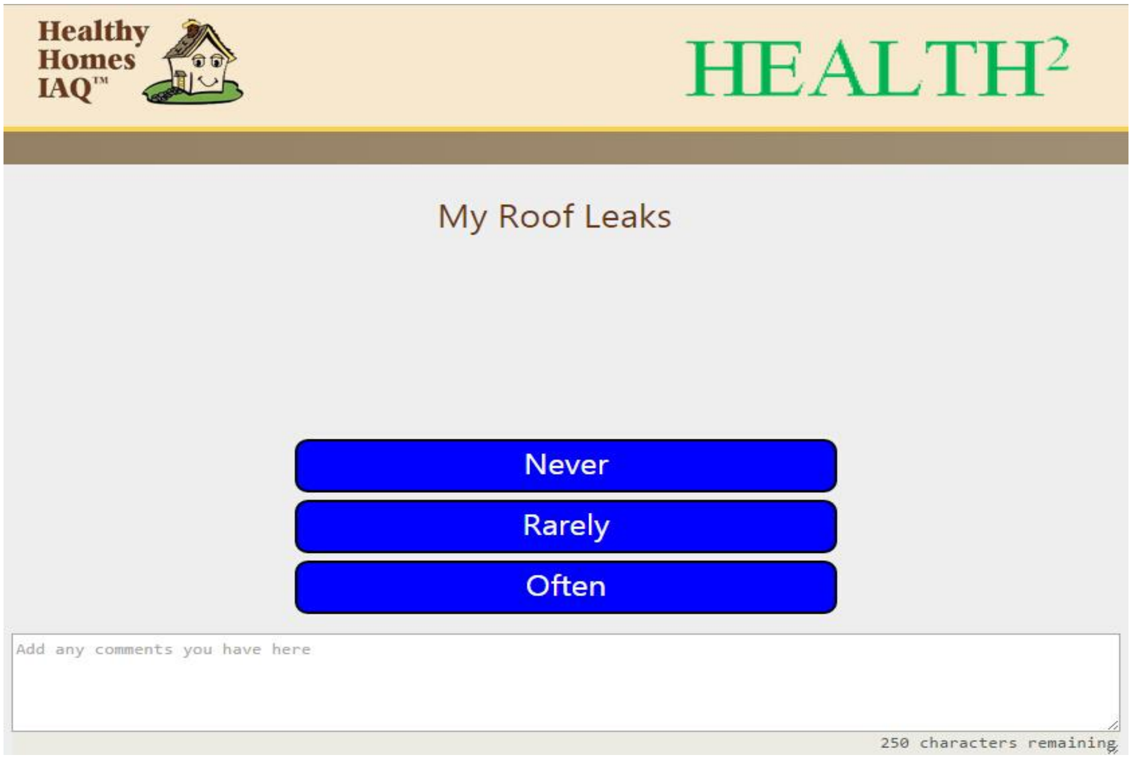
Air Filter:

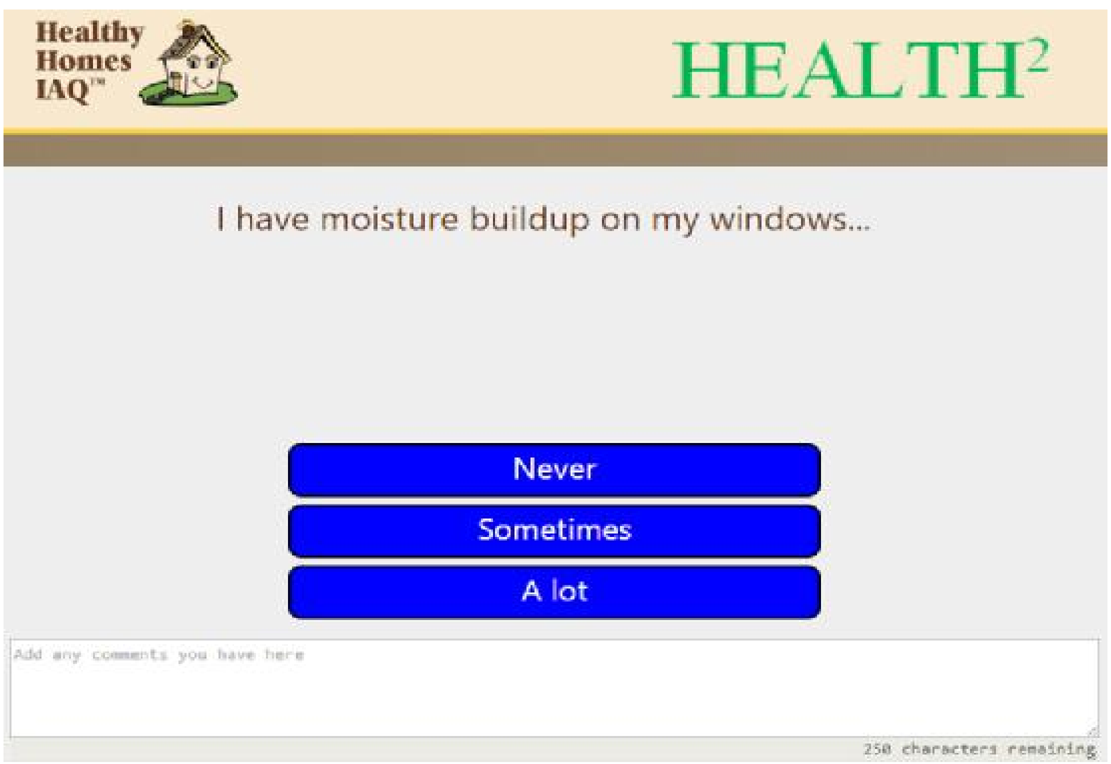
- ○ No filter
- ○ House has a basic fibreglass filter
- ○ House has a pleated or electric filter

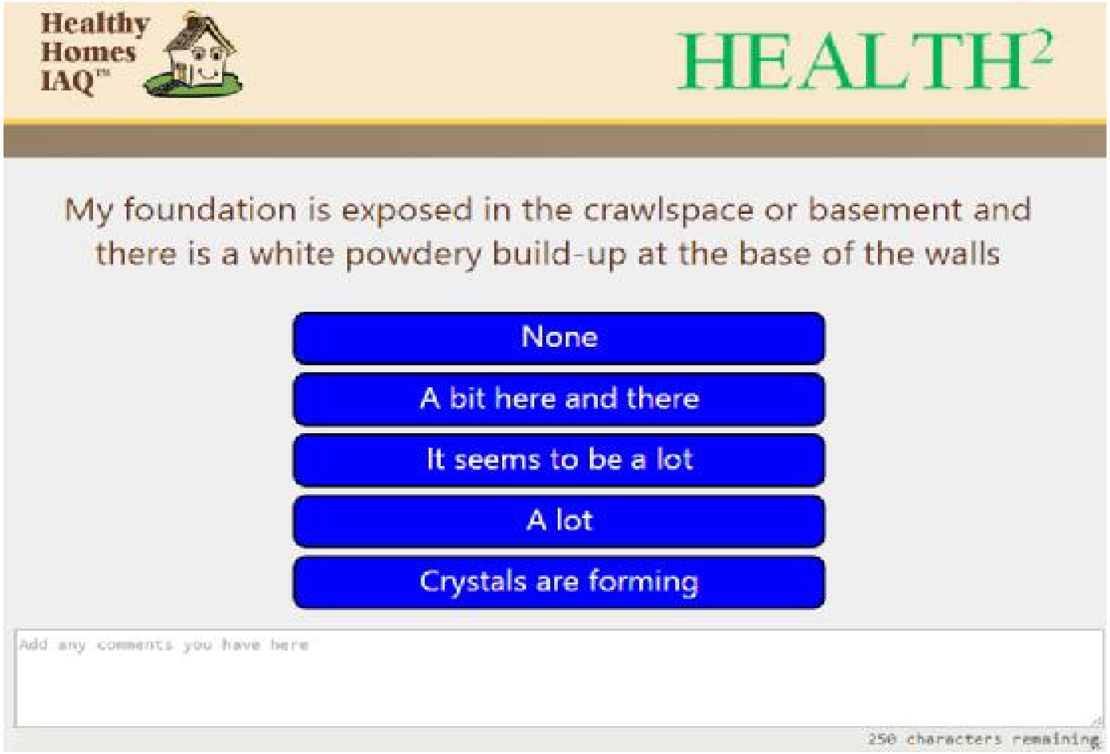
Submit and Continue


Healthy
Homes
IAQ™
HEALTH²
Homeowner Survey
Answer the questions to the best of your ability. Don't guess. Guessing reduces the accuracy of the assessment. This is a simplified version of the software to give you a general sense for the indoor environmental condition of your home. Refer to an Environmental Specialist for further information and a more defined process for obtaining results specific to your condition.
New Questionnaire
Continue


Healthy
Homes
IAQ™
HEALTH²
Water has been puddling on my floors or in my crawlspace for more than 2 consecutive days
Yes
No
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
My Roof Leaks
Never
Rarely
Often
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
I have moisture buildup on my windows...
Never
Sometimes
A lot
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
My foundation is exposed in the crawlspace or basement and there is a white powdery build-up at the base of the walls
None
A bit here and there
It seems to be a lot
A lot
Crystals are forming
Add any comments you have here
250 characters remaining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HEALTH²
My dryer does not exhaust to the outside
Yes
No
Add any comments you have here
250 characters remaining


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HEALTH²
The humidifier on my furnace is...
Clean and Operating
Not working at all
There is a foul odour
Add any comments you have here
250 characters remaining


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HEALTH²
Some wall surfaces look or feel wet
No
A small, toaster sized, area
A large, vanity sized area
Add any comments you have here
250 characters remaining


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Homes
IAQ™
HEALTH²
The inside of my home feels
Dry
Somewhat Damp
Damp
Very Damp
Extremely Damp
Add any comments you have here
250 characters remaining


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IAQ™
HEALTH²
I'm aware of flooding in the home
No
That lasted a day
That lasted 2 days
That lasted 4 days
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
I'm aware that the home had been a grow op that was never professionally cleaned
Yes
No
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
My house has a history of roof leaks
Yes
No
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
My house has a history of plumbing leaks
Yes
No
Add any comments you have here
250 characters remaining


Healthy
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IAQ™
HEALTH²
My house has a crawlspace with a dirt floor
No
Yes
Yes, and it is not vented
Yes, and it has an odour
Add any comments you have here
250 characters remaining


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IAQ™
HEALTH²
There is black debris build-up on my window sills
Yes
No
Add any comments you have here
250 characters remaining


Healthy
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IAQ™
HEALTH²
I keep watered plants in my house
None
A few
Many
Add any comments you have here
250 characters remaining


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I keep my house clean or very clean
Yes
No
Add any comments you have here
250 characters remaining


Healthy
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HEALTH²
I vacuum and dust weekly
No
Yes
Yes, with a HEPA vacuum
Add any comments you have here
250 characters remaining


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IAQ™
HEALTH²
I allow smoking in my home
Yes
No
Add any comments you have here
250 characters remaining


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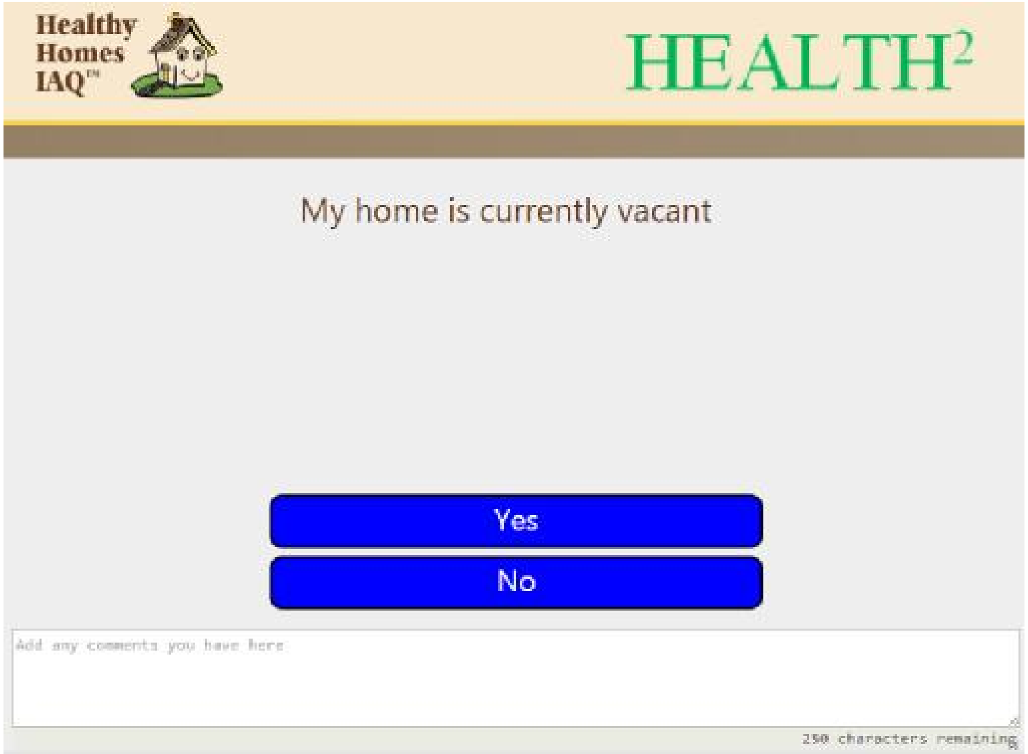
Homes
IAQ™
HEALTH²
I hate housework
Yes
No
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
My home is currently vacant
Yes
No
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
Regarding storage...
I keep little in my home
Most closets have some
I don't mind clutter
My house is full
I'm a bit of a hoarder
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
I see mould growth in my home
Nowhere
Over a small area
Over a vanity sized area
Over a wall sized area
Add any comments you have here
250 characters remaining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I smell a mould or mildew odour
No
Yes
Professionally confirmed
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
There is active visible rotten wood in my home
None
A little
Several small locations
A lot
Add any comments you have here
250 characters remaining


Healthy
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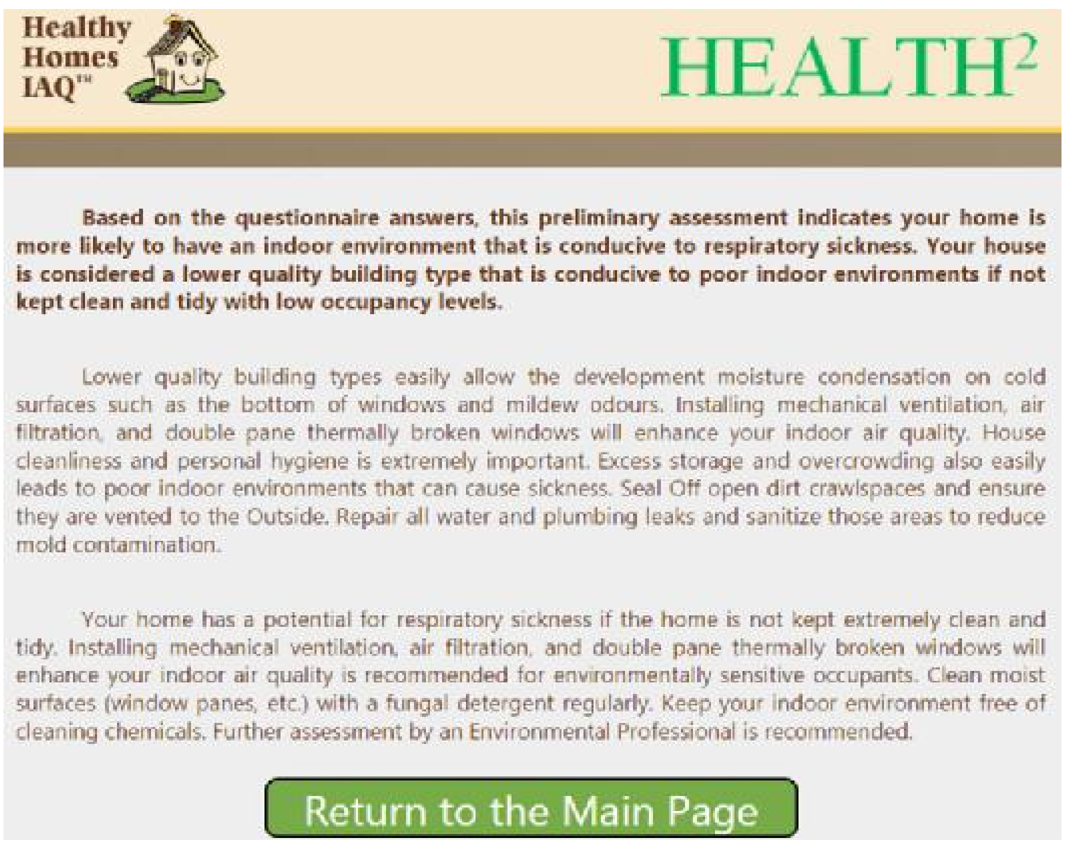
IAQ™
HEALTH²
There is carpeting next to mould or rot
Yes
No
Add any comments you have here
250 characters remaining


Healthy
Homes
IAQ™
HEALTH²
Home Questionnaire Submission
Submit


Healthy
Homes
IAQ™
HEALTH²
Based on the questionnaire answers, this preliminary assessment indicates your home is more likely to have an indoor environment that is conducive to respiratory sickness. Your house is considered a lower quality building type that is conducive to poor indoor environments if not kept clean and tidy with low occupancy levels.
Lower quality building types easily allow the development moisture condensation on cold surfaces such as the bottom of windows and mildew odours. Installing mechanical ventilation, air filtration, and double pane thermally broken windows will enhance your indoor air quality. House cleanliness and personal hygiene is extremely important. Excess storage and overcrowding also easily leads to poor indoor environments that can cause sickness. Seal Off open dirt crawlspaces and ensure they are vented to the Outside. Repair all water and plumbing leaks and sanitize those areas to reduce mold contamination.
Your home has a potential for respiratory sickness if the home is not kept extremely clean and tidy. Installing mechanical ventilation, air filtration, and double pane thermally broken windows will enhance your indoor air quality is recommended for environmentally sensitive occupants. Clean moist surfaces (window panes, etc.) with a fungal detergent regularly. Keep your indoor environment free of cleaning chemicals. Further assessment by an Environmental Professional is recommended.
Return to the Main Page


Healthy
Homes
IAQ™
HEALTH²
Home
User Management
Data Export
Welcome to the HEALTH² Health website
This diagnostic tool assists in determining if your indoor environment may be conducive to poor respiratory health. The HEALTH²™ tool has been adapted for use by concerned homeowners as well as for use by environmental professionals and academics.
Professional Version
Homeowner Tool

Healthy Homes IAQ™

HEALTH²

Home User Management Data Export

Expert Version

Description	Max Score	House Score
> 48 hour water ponding	5	0
intermittent roof/plumbing leak < 48 hours	1	0
reoccurring roof/plumbing leak > 48 hours	3	0
condensation on window glass or sill	3	0
efflor/moisture thru foundation	1 to 3	0
unvented clothes dryer	2	0
dirty/mouldy humidifier	1 to 2	0
building surface > 1m² SC 15-20%	1	0
building surface > 1m² SC 20-30%	2	0
building surface > 1m² SC > 30%	4	0

Description	Max Score	House Score
Average building RH < 50%	0	0
Average building RH 50-55	2	0
Average building RH 56-60%	4	0
Average building RH 61-80%	6	0
Average building RH > 81%	8	0

Description	Max Score	House Score
Flood < 48 hours	1	0
Flood 48+ hours	5	0
Minor to significant efflorescence	2 to 5	0
Repaired water leak < 48 hours	0	0
Grow op not professionally cleaned	10	0
History of roof/basement leaks	5	0
History of plumbing leaks	5	0
Uninsulated concrete exterior walls	3	0

Description	Max Score	House Score
Drywall at potential moisture source	4	0
Vented to non-vented exposed dirt crawl	2 to 5	0
OSB/particle board flooring	1	0
Window sill debris	1	0
Minimal Plants	1	0
Numerous Plants	2	0

Description	Max Score	House Score
Dim lumber ground/concrete contact	4	0
Manufactured lumber ground/concrete contact	5	0
Manufactured lumber exposed in crawlspace	3	0
Manufactured lumber at potential moisture source	5	0
Dim lumber at potential moisture source	4	0

Description	Max Score	House Score
None	10	0
F/A furnace on timer. 4-6 hours/day. Function = 0	0	0
Portable house fan - 1 room	9	0
Portable house fan - 2 rooms	7	0
F/A furnace. No timer or not functioning	5 to 10	0

Description	Max Score	House Score
Very Clean. Dust Free	0	0
Visible light dust on surfaces	2	0
Poorly cleaned. Very visible dusty	6	0
Very Poor	10	0
Use of tobacco in the house	5	0
Use of central vacuum system	-2	0
Regular (weekly) vacuuming house	5	0

Description	Max Score	House Score
Vacant	0	0
Light	1	0
Moderate	3	0
Cluttered	5	0
Excessive clutter	8	0
Hoarder	10	0

Description	Max Score	House Score
Active mould growth < $1m^2$	2	0
Active mould growth < $10m^2$	5	0
Active mould growth > $10m^2$	10	0
Mildew to verified mould odour	2 to 5	0
Active visible rot from minor to large	1 to 3	0
Activity and adjacent carpeting	2	0

Description	Max Score	House Score
Mould stain < $1m^2$	1	0
Mould stain < $10m^2$	4	0
Mould stain > $10m^2$	8	0
Carpeting adjacent to staining	2	0

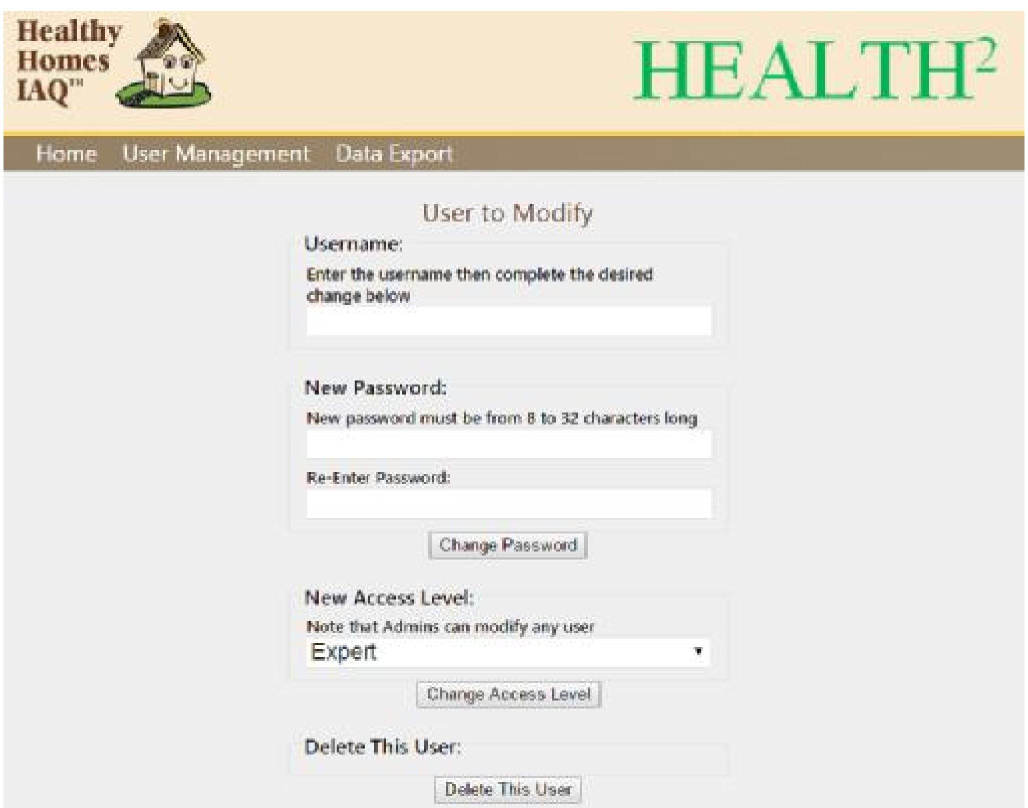
Description	Max Score	House Score
None	10	0
HEPA and/or UV	0	0
Pleated MERV 6+	2	0
Fibreglass - basic or poor fit	6 to 10	0
Room HEPA/UV	1	0
2 Room HEPA/UV	2	0

Description	Max Score	House Score
No fresh air duct to return plenum	4	0
No minimum 150mm open duct to exterior	4	0
Few to many rooms w/ opening windows	8 to 5	0
Dirty air vents	1 to 3	0
None	10	0

Description	Max Score	House Score
None	10	0
HRV on continuous timer	-2	0
No/poor washroom/kitchen extraction fans	4 to 8	0
Furnace fan on timer	-2	0
Washroom exhaust on switch	5	0
Washroom exhausts connecting to light	-3	0
Forced air furnace	2	0

submit


Healthy Homes IAQ™
HEALTH²
Home
User Management
Data Export
Create a New Account
Username:
Password:
Password must be from 8 to 32 characters long
Re-Enter Password:
Access Level:
Select the level of access you would like to give the user
Expert
Submit


Healthy Homes IAQ™
HEALTH²
Home
User Management
Data Export
User to Modify
Username:
Enter the username then complete the desired change below
New Password:
New password must be from 8 to 32 characters long
Re-Enter Password:
Change Password
New Access Level:
Note that Admins can modify any user
Expert
Change Access Level
Delete This User:
Delete This User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Home
User Management
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Download Survey Data by clicking below.
Expert Results
HO Quiz Info
HO Responses
HO Regional Info
HO Health Info
HO House Info
HO Results Summery