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Indoor Environment Quality

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About This Report

Title
Indoor Environment Quality

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Abstract
World Health Organisation has found a large body of evidence that housing conditions affect health status. Internationally there are many large projects underway to research factors affecting healthy homes and initiatives to improve housing conditions. The pollutants that have been identified as requiring attention are volatile organic compounds and other gaseous pollutants such as nitrogen dioxide, fungi, bacteria and dustmites, respirable particulates and noise.

The environment inside New Zealand homes has received remarkably little attention other than research and promotion of the benefits from retrofitting insulation and non-polluting heaters. The quality of the home environment affects health as a Time Use study has found that on average New Zealanders spend 75% or more of their time at home. Further International studies have found the air inside homes is much more polluted than outdoor air and that pollutants inside a home are 1000 times more likely to be inhaled than ambient pollutants. New Zealand homes are too cold and damp and about 40% are mouldy. While some species of mould can be benign, others can cause health problems especially respiratory effects.

There have been only two comprehensive field studies connecting the home environment and the health of the occupants. The first found that every dollar spent insulating homes constructed pre-1979 had a four-fold return in health savings in addition to the energy conserved on heating. The results from this study have provided evidence of the financial benefits of insulating homes. There are currently subsidies and programmes operating to insulate low income housing, however health benefits are applicable to all socioeconomic groups. Preliminary results from the second large study which was an investigation of five types of domestic heaters and health showed high levels of indoor pollutants from unflued gas heaters and statistically significant health benefits from changing domestic heating types. Other studies conducted in New Zealand have shown interesting results on various aspects such as research by BRANZ on psychometric control of dustmites and a Massey University study on endotoxins levels in homes.

Little research has been conducted on chemical pollutants, particulates or noise in homes and these areas are amongst the topics that have been identified as requiring research. Further research is also recommended on increasing warm in homes and reducing humidity.

High Standards of Sustainability with a component for Indoor Environmental Quality were developed following a review of existing literature. These standards are easily measurable features for homes to control pollutants at source and provide a warm and dry environment that will minimise the growth of fungi and bacteria, or dustmites; have low levels of volatile organic compounds and other gaseous pollutants especially those from combustion processes, as well as low levels of respirable particulates and noise.

Reference

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1 Executive Summary

This report backgrounds the issues of healthy and unhealthy home environments and provides evidence that the home environment and health are intrinsically linked. Pollutants that are of concern in new and existing homes include;

- volatile and semi-volatile organic compounds, such as formaldehyde, and benzene,
- other gaseous pollutants such as nitrogen dioxide and carbon monoxide,
- microbiological pollutants such as fungi, bacteria and dustmites and fragments of these,
- particulates,
- and noise.

Concentrations in the homes of these pollutants can be exacerbated by an indoor climate that is too cold and damp, or hot and humid, and has inadequate ventilation to dilute the pollutants, moisture and heat from inside the home. International IEQ research has focused on volatile and gaseous pollutants, microbiological pollutants and particulates, with noise in homes being an emerging issue. Key international project are summarised in Section 3 of this report.

A review was conducted of researchers who are or have recently been active in conducting healthy homes research or initiatives which are implementing research findings to ascertain the current knowledge and research base in New Zealand. This review found that few comprehensive studies have been conducted in New Zealand and found some large knowledge gaps. There have been several studies conducted or are currently being conducted investigating fungi in homes, however research to date shows over 40% of New Zealand homes have excessive levels of fungal activity. There has been almost no research conducted on the levels of VOCs, particulates or noise found in New Zealand homes. Several eminent New Zealand researchers expressed an interest in this area but have had difficulty in attracting research funding for topics that fall on the cusp of health and infrastructure. New Zealand research projects and initiatives to promote healthy IEQ in homes are summarised in Section 4 of this report.

International data is required to fill the gaps until New Zealand specific data is available. However there is currently sufficient evidence of where improvements can be made to advance the IEQ in homes.

One study that has been successfully completed in this area was the Insulation, Housing and Health study which was conducted by the University of Otago led Healthy Homes Research team. This study found every dollar spent on insulation gave a four-fold return in health savings, in addition to the energy conserved in home heating. This result is of importance for the one million privately owned or rented homes constructed pre-1979, and has provided the evidence for various agencies to invest in initiatives to improve the level of insulation in ceiling cavities and under floor spaces. Whilst making considerable improvements to low income housing, these initiatives are not bringing low income homes up to a high standard of insulation, nor are they addressing the large number of middle or high income houses. Further improvements are possible for many homes constructed pre -1978.

The Housing, Heating and Health study which is a New Zealand study of five types of domestic heaters and health effects found homes heated with unflued gas heaters had levels of nitrogen dioxide up to three times higher than allowed by health based standards and significant health improvements were found when old heaters were replaced with modern low polluting heaters. Preliminary results show savings in health costs exceed capital investment and could provide sufficient evidence for financial incentives to upgrade to heaters that do not emit pollutants into the indoor air and have a higher heating capacity.

This research and many other reviewed studies were used for the development of Indoor Environmental (IEQ) component of the High Standards of Sustainability (HSS), which identify housing features and occupant behaviors where improvements can be made to the healthiness of new and existing housing. The approach focuses on control of pollutants at source, with secondary reliance with mitigation measures such as mechanical ventilation. A home constructed to meet the IEQ component of a HSS would include features relating to the siting of the home in a low pollution environment with minimal risk of flooding, or the ingress of water, noise and ambient pollution. The building envelope would focus on the functions of keeping moisture and noise out, optimizing free passive solar heating in winter and have a high level of insulation, shading and ventilation to reduce summer over heating, and provision for adequate ventilation. The construction and interior materials used in the home should be selected for low VOC emissions and where emissions are unknown or unavoidable pre-airing of materials or ventilation with higher than normal air change rates should be provided for the first year of the new construction. Materials and systems should be specified to have low water availability /and should be easily maintained and cleaned. Control of combustion emissions in the home from heating, cooking, garaging of cars and tobacco smoking should be undertaken. The control of moisture from occupant activities and other diffuse sources in the home is an important consideration which requires a combination of warmth and ventilation. These features and the justifications for them are explained in more detail in sections 8 and 11 of this report.

The last section of this report addresses research gaps and studies that could be conducted. While comprehensive, this list is not exhaustive. A key project that is recommended is a comprehensive large study of health and pollutants in homes, including particulates, fungi, bacteria, dustmites, VOCs, nitrogen dioxide and carbon monoxide, moisture, and temperature in a large cross section of homes. This large study would underpin other more targeted studies, provide benchmarks to measure improvements and provide the foundations for future research and potential changes to the Building Code. Other projects recommended include a cost benefit analysis of the effectiveness of "healthy" interventions. The benefits would include reduced hospital admissions or medication, days absent from school and work. It is recommended that interventions focus on improved housing for vulnerable populations such as infants, elderly, people with pre-existing impairments to their health, and households with overcrowding as these groups could show the largest benefits. It also recommends research on materials to reduce VOC's and moisture availability in homes.

2 Background

Beacon Pathway Ltd's overarching goal is: that 90% of New Zealand homes will be sustainable to a high standard in 2012. IEQ is one of the five key performance indicators that have been prioritised by Beacon Pathway Ltd for the definition of a High Standard of Sustainability (HSS). This document refers specifically to IEQ of New Zealand homes and links to health of the population.

The quality of the indoor environment is critically important. There is a growing body of evidence that improving the IEQ of homes has substantial health benefits that include fewer hospital admissions, fewer visits to the doctor, reduced dependence on medication, fewer days of work for people in the work force and fewer days of school for children. The health benefits can be several times in excess of any additional cost of constructing a healthier home. While the health benefits have been determined for retrofitting insulation to uninsulated homes, this level of analysis has not been undertaken for most IEQ improvements.

A study conducted by EECA found that the desire to improve the healthiness of the home is a more powerful consumer driver than the desire for energy efficiency or reduced global warming [1]. Where health benefits are synonymous with other sustainability features it could be easier driver to use to gain consumer approval.

The New Zealand Time Use Survey and the New Zealand Travel Survey found that we spend more than 75% of our lives at home, mostly indoors [2]. A similar figure for hours spent at home has been found in other countries [3]. Populations, whose health is most vulnerable, such as the infirm, infants, children, elderly and disabled persons, tend to spend longest in the home environment with those over 65 years of age spending 90% of their time at home, mostly indoors. Infants and children are an important demographic group to study as there is evidence that damage sustained to developing airways in the first five years of life from air pollution can have life long consequences on health (Ginsberg, 2004) [4].

There are also significant opportunities for creating sustainable and healthy housing of people in the retirement age group. The ageing population is growing both in size and increasing numbers in this segment will face issues of poor health, such as chronic obstructive pulmonary disease (COPD), which is a debilitating disease that is forecasted for New Zealanders to increase significantly in prevalence, peaking around 2020 [5]. The severity of this respiratory disease is affected by inhaled respiratory irritants, such as cold air or pollutants. Consequently measures to improve IEQ could equate to reduced hospitalisation rates and savings in primary health care. Also as elderly people become less active they are more sensitive to cold temperatures and dampness.

Elderly people, solo parents and singles could well perceive they are physically vulnerable to home invasion and keep doors and windows closed for their personal security. The act of not opening windows will deprive their home environment of natural ventilation and dilution of indoor pollutants. This will increase the reliance for alternative means of no or low energy ventilation or risk increased levels of pollutants and moisture and moisture by-products (dustmites and mould) within the home.

IEQ is an area that has received little attention from government, compared to the large amount of resources devoted to researching, monitoring and regulating outdoor air quality. Despite regulation in the Building Code for minimum-sized openable window area etc, New Zealand homes still have a very high level of dampness and nearly half of New Zealand homes have been found to have excessive mould growth. This is discussed in more detail in section 8 of this report. Most homes constructed pre-1979 have no or limited insulation and are too cold. Several New Zealand studies [6, 7] have found indoor temperatures can frequently be 6 ^{o}C or more below the WHO recommended minimum indoor temperature of 18 ^{o}C to avoid adverse health. A pre-1979 home without an insulation retrofit is typically in winter only 1 ^{o}C warmer than outside temperatures (Howden Chapman, 2007). Indoor temperatures below 18 ^{o}C will lead to dampness and condensation, which in turn contributes fungi and dustmites, as well as increased susceptibility to infectious disease. The WHO have also determined that temperatures below 18 ^{o}C also cause respiratory, cardiac and circulation problems.

Homeowners are reacting to the marketing activities of companies offering so-called healthy home solutions. This has lead to a prolific multi-million dollar industry of energy consuming appliances, such as dehumidifiers, domestic mechanical ventilation systems, home air filtration units, air ionisers and odour masking devices that are sold as “solutions” to IEQ problems. These appliances seldom address the source of the problem, and as is the case of air fresheners and air ionisers may add to the pollutant load. Appliances such as dehumidifiers can not always remove the amount of moisture from within a home especially if the home has a problem with sub-floor moisture [8] There is currently at least one company planning to import biocides to routinely “fog” homes with fungi problems. This will only introduce an irritant to “treat” fungi and will do nothing to remove fungi fragments which can be very allergenic even when dead or to control moisture which is the primary factor that will limit the growth of fungi. Unbiased educational material is seldom available for consumers to make informed decisions on the effectiveness of these “solutions”.

Indoor air quality (IAQ) is one of the US Environmental Protection Agency’s (EPA) top five priorities for improving health in developed countries. The World Health Organisation (WHO) has also listed Indoor Air Quality as a high priority ranked within the top four environmental problems within the USA. The Asthma and Respiratory Foundation of New Zealand have identified the risk of substandard and overcrowded housing on respiratory health and have recommended tightening of the New Zealand Housing Strategy [9]. The initiatives that these agencies are undertaking is discussed in Section 3 of this report. It is timely that New Zealand policy makers, the building industry and researchers give their attention to issues that can improve the IEQ of homes.

Indoor air contains both pollutants that have originated outdoors and have migrated into the home, such as vehicle emissions and community noise, as well as pollutants that have originated indoors, such as emissions from building materials and mould. Indoor air is usually more polluted than outdoor air. A five year US EPA study found indoor VOC concentrations to be 100 times higher in new homes than outdoor air [10] and a study of Australian existing homes found indoor VOCs concentrations to be seven times higher than outdoor air [11]. Further, pollutant found indoors can be around 1000 times more likely to reach a person’s lungs than an outdoor pollutant, due to longer periods of exposure and higher concentrations [12-14]. In addition to inhalation, pollutants can affect an occupant's health via ingestion or contact with skin and eyes. This exposure mechanism is a common pathway for infants.

The definition of what constitutes good environmental quality raises two questions which are discussed, but the answers are beyond the scope of this report. The first question is; how healthy is healthy – how high to set the standard? and healthy for whom - which populations should the IEQ component of the High Standards of Sustainability be established for? How high to set the boundaries of a healthy home is a large philosophical question with economic, social and political aspects in addition to the technical feasibility of IEQ. Some of the issues are raised below in the next section. Healthy for whom raises the issues of healthy for the majority of the population or vulnerable sub-groups. While this report does not seek to resolve these difficult questions which are common too many standards in many topics, it is necessary to mindful that mainstream standards could exclude adequate protection for some sections of society.

2.1 How healthy is healthy?

In 1948 the World Health Organisation (WHO) published the definition of health, which is still upheld by WHO as "health is a state of physical, mental and social wellbeing, not merely the absence of disease or infirmity".

Housing designed to this health definition would include a home with very low levels of pollutants and allergenic substances. It would also have materials and a structure that throughout the homes entire lifecycle of installation, general cleaning, maintenance, renovation, and redecoration would need be free from noxious chemicals, including those used for cleaning and decorative surfaces; and well ventilated. It would feature an absence of chemicals and compounds which are odoriferous or sensory irritants as well as those with defined toxicity. It would always be warm and free of mould and dust mites. It would have no open sources of combustion including candles; nor dust, pollen, or respirable particulates. This definition would include mitigation of unwanted noise from neighbours and traffic to avoid mental stress and annoyance. It would include opportunities for social interactions with the wider community to avoid loneliness or social isolation, including views outside of the home and a sheltered sunny outdoor space.

2.1.1 Deprivation

At the opposite end of the spectrum there are currently some low income houses in New Zealand which are challenged with overcrowding, fuel poverty, lacking in basic sanitation and weather tightness.

People with low disposable income often have the least access to adequate healthcare, live in lower quality rental or private accommodation and lack the financial means to alter their living conditions or affect housing maintenance. Coincidentally occupants of the poorest quality housing often have the highest exposure to tobacco smoke, are over represented in hospital admissions for respiratory and preventable illnesses and have other predisposition to health problems [15]. There is a significant compounding effect of poor living environment and poor healthcare [15].

Fuel poverty is defined as a household needing to spend more than 10% of the household income on total household energy in order to maintain a satisfactory heating regime [16]. Fuel poverty leads homes to be under heated by many degrees below the WHO minimum temperature guideline for health of 18 ^{o}C [17]. The decision not to have any household heating is currently growing more rapidly in New Zealand than the decision to purchase any new type of heater. It is most prevalent for solo parents.

During every winter around 1600 more New Zealanders die than in other seasons. This excess winter mortality isn't experienced in other OECD countries, such as Canada or the UK. Cold and damp housing is most probably an important contributing factor in this phenomena [18].

There are also some New Zealand households who lack running hot and cold water or a fully functioning sewage disposal system that doesn't overflow in periods of heavy rain. Decent sanitation would have a greater positive impact on the health of occupants of these homes than dustmite control.

2.1.2 Overcrowding

Overcrowding is well established as a risk factor for the communication of infectious diseases. A New Zealand study [19, 20] on overcrowded housing found higher rates of tuberculosis and meningitis, as well as parasitic diseases and respiratory diseases presumably as living with more physical contact and closer proximity to each other increases the chance of communication of infectious disease. Occupants of overcrowded households have significantly higher levels of hospitalisation, including bacterial infections, shingles, acute bronchiolitis [9] and most forms of skin infection as well as higher rates of acute myocardial infarction and heart failure.

Overcrowding also means that there are more people in the indoor environment generating moisture from ablutions, laundry and cooking and pollutants associated with their activities, such as smoking or hobbies, bioeffluents, as well as noise. It is conceivable that in overcrowded homes, passive ventilation (openable windows) and infiltration of outdoor air provides insufficient air exchange for dilution of indoor pollutants and moisture [20]. However, there have been no studies conducted in New Zealand that measure indoor pollutants including fungi and bacteria in overcrowded homes.

The preliminary results from a study conducted by Baker et al [19] on the impacts of resolving overcrowding and poor condition housing on health outcomes found that applicants and tenants for HNZC housing had significantly higher hospitalisation rates than the New Zealand population at large for all major disease categories, except congenital diseases. Many of these diseases are preventable. Hospitalisation rates were very high among HNZC tenants during their first year of tenancy (277 per 1,000 per year). Hospitalisation rates declined in the subsequent 1-3 years , but plateaued for those who are tenants for 4 or more years (about 182 per 1,000 per years). This hospitalisation rate remains significantly higher than that seen for the general New

Zealand population (about 127 per 1,000 per year). Some mental health conditions and infectious diseases have a very pronounced decline in hospitalisation rates with duration of HNZC tenancy [21]. This study showed that social housing had positive health outcomes compared to private housing for this socioeconomic group and suggests that private low income housing may be of a lower standard than public housing.

Increasing numbers of New Zealanders' live in rental housing or apartments, and it is not uncommon for the occupants' quality of life to be affected by noise, poor ventilation, poor air quality, poorly moderated temperatures, and affordability. There can be a large disparity between a landlord's motivation to invest in improving the quality of housing and the needs of tenants for safe and healthy conditions. There is a need for a survey of IEQ in rental accommodation to ascertain if tighter controls or building warrant of fitness scheme for rental housing are necessary.

2.1.3 Health guidelines for healthy homes

However, in between these extremes lie the vast majority of homes. This report and the IEQ component of the HSS are aimed at the majority of the housing stock. Some of the HSS only constitute behavioural changes and incur no additional or minimal expense and are therefore applicable to all households regardless of income or tenure. While the HSS will be of some relevance to households with occupants who are very sensitive to environmental pollutants and allergens, these households may need to take additional measures, such as air filtration and more stringent materials selection. Filtration and ventilation are discussed in more detail in Section 9 of this report.

New Zealand does have regulations embedded within the Building Code for minimum-sized openable window area, Clause E3 of the Building Code for the control of internal moisture etc, however, these regulations only apply to new homes and homes/parts of homes that have undergone consented additions or some renovated. There is anecdotal evidence that new homes have sufficient available moisture to grow fungi, and are equally represented in the 40% of all New Zealand homes that have a very high level of dampness and mould. Validation of the effectiveness of ventilation, such as window frames with trickle vents, for controlling indoor moisture and diluting indoor pollutants is worthy of research and will inform a proposed revision of Clause G3 of the New Zealand Building Code.

Mark Bassett from BRANZ has developed BRANZVENT which is a guidance document for the passive venting of new and existing houses. This document defines ventilation requirements for rapid ventilation such as for summer cooling and to meet high ventilation requirements; background ventilation for general contaminant removal and extract ventilation for source control of moisture and odours in kitchens, toilets and bathrooms [22]. This document is discussed in more detail in Section 9 of this report.

Indoor air quality guidelines are primarily set by international agencies such WHO, US-EPA or Californian Air Board. Guidelines established in overseas research are derived either from, large epidemiology studies, animal studies or chamber tests on healthy adults. Occupational pollutant standards have both pros and cons for use in assessing pollutants within the home. The main advantage is occupational levels have been well defined and are regularly reviewed for a number of chemicals, and in the absence of better limits these are a reasonable benchmark. However, the limitation of occupation levels is that they are set for healthy adults and they assume a period of exposure of 8 hour out of 24 hours, five days per week followed by a recuperative period without exposure. It is also typically assumed in occupation settings there will be a predominance of a few compounds rather than a cocktail of 100s of chemicals at low levels, as can often be found in homes[23]. Occupational standards are usually determined by exposing subjects to a known concentration of a single pollutant for a short time. Volunteers for chamber tests are typically medical students or military personnel and in particular the later of these groups has a bias towards being healthy (that is they have minor predispositions to illnesses), are fit (high metabolic rate), with a lean body mass. This is not a reflection of the general population and in particular the test population is not a reflection of vulnerable sub-groups who spend the longest hours in the home environment such as infants, children, the elderly, and those with chronic illnesses. Health based guidelines are also not tested on foetuses for obvious ethical reasons, however it is well established that developing foetuses are particularly susceptible to exposure to pollutants [24].

Two problems have been identified with establishing safe levels of indoor pollutants and these are difficulties isolating health risks for a single chemical from a cocktail of indoor pollutants and lower levels of effects observed for epidemiological assessments compared to chamber studies.

Risk assessments are mostly conducted on single chemicals. There is seldom relevant data for evaluation of mixture effects. The air indoor environments is typically characterised by complex mixtures of chemicals from various sources and exposures can be highly variable with time. The difficulties in assessing the combined toxicity of mixtures of chemicals and chemicals in combination with particulates or biological pollutants has lead the SCHER project on risk assessment of indoor pollutants to conclude that "a risk assessment that takes into account the combined exposure and cumulative effects of pollutants in indoor environments is seldom possible. Mostly there is not enough relevant data and the available methods may not fit the case" [25].

Further, it has been established that large epidemiological studies show much lower levels of health effects than chamber studies and research on health based exposure standards are now using epidemiological studies (considered as the Gold standard) with evidence from chambers studies as confirmation and explanation of the effect mechanisms [26]. This may see many threshold values adjusted to lower levels in coming years.

Another approach has been developed by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) which is the ASHRAE Standard 62.2: 2004 [27]. This standard is not surprisingly ventilation based and uses mechanical ventilation as the solution to pollution, and has less emphasis on source control of pollutants.

The approach advocated in this report places highest priority on source control measures, such as preventing the ingress of subfloor moisture. Source control measures are generally passive and permanent solution and these are a preferred strategy for achieving sustainable solutions, compared to use of dehumidification or ventilation to dry out the moisture once it is in the home. Mechanical ventilation can be used successfully for improving indoor air quality. However when mechanical ventilation is poorly installed or maintained it can allow fungi and bacteria to grow on damp components and the ventilation system has a direct pathway to effectively distribute these into the home. Mechanical ventilation also consumes electricity for operation and is therefore generally not the highest ranked approach for IEQ HSS in New Zealand.   This is discussed in more detail in Section 9.

The next and possibly most feasible approach is the development of an indoor environmental standard specifically for homes. Several OECD countries, such as Australia, are considering or in the process of developing such a standard, however, these are in their infancy and it will be several years before they are available and the guidelines will probably relate more to new rather than the existing housing stock. To date there is no agenda for such a standard in New Zealand however there are early discussion for a joint Australia New Zealand Standard [28, 29]. The development of the guideline is expected to take two to three years, and it is recommended that WHO guidelines should be used until this work is completed.   This standard will only cover the toxicity of single pollutants rather than mixed pollutants. While acknowledging that mixed chemical pollutants are an issue there is currently insufficient science to untangle the complex mechanisms and combined toxicities.

After reviewing a vast body of research it is apparent that few studies have focused on systematic approaches to address healthy homes. Two projects [30, 31] have proposed systems for healthy office buildings and the concepts are largely applicable to homes although there are obviously wide differences in the specific building features between offices and homes. This approach is also followed by Mark Bassett in the ventilation tool BRANZVENT[22]. Both these approaches are based around the concept of ranking control of pollutants in the following order of priority;

- source control, such as specification of building systems to prevent the ingress of water
- reduction by specify materials that have lower concentrations of pollutants such as low VOC paints or using a smaller quantity of emitting materials or dilution ventilation to reduce exposure to pollutants
- followed by solutions such as filtration.

The source control approach is expanded upon and shown how it can be applied to achieve the HSS in Section 11,

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2.2 Healthy for whom?

When defining what is a healthy house it is also important to consider healthy for whom? As mentioned previously occupational standards are established for adults who are healthy enough to be in the workforce and have fully developed lungs and immune systems. Other vulnerable populations may need special consideration and possibly lower levels of exposure as they are more susceptible to poor health. These groups include foetuses, infants and children, the infirm and elderly. These group combined make up a large percentage of society. Whilst it is known that one in four New Zealanders from all walks of life have asthma [15], it is difficult to quantify the numbers of people with other health conditions that are vulnerable to environmental conditions. It is difficult to quantify the numbers of people with diseases such as COPD due to the way are difficult to hospital discharges are coded. These vulnerable sub-populations need particular attention as physiology and toxicokinetics (such as reduced renal elimination in elderly) vary with age, and the elderly are more susceptible to pollutants as they may have pre-existing conditions that could impair their respiratory or cardiac health.

An ethical question is: should a healthy house be built with the anticipation that it will be occupied by one of these sub-populations or should the environment be a healthy environment for a healthy adult?

2.2.1 Vulnerable populations

Foetuses, infants and children are considered as vulnerable populations as their immune systems are under developed, their lungs are under developed until about the age of six, and their body mass is very different to that of an adult [32]. Therefore pollutants will have a greater effect at lower levels than for healthy adults.

Vulnerability to low levels of chemical toxicity may be highest within the first six months after birth and can continue for years until maturity [25] . Exposure to pollutants can adversely affect foetal and infant lung development, cause infant mortality, due to respiratory disease [33]. Children are more susceptible to environmental exposures than adults, due to their underdeveloped systems. They also breathe in 50 percent more air per kilo of body weight than adults and spend more time close to flooring which can be a potent source of VOCs, as well as being a reservoir of dustmites and fungi. They are also establishing susceptibilities to disease, such as asthma, that will affect them for much of their lives.

A study on 3600 children found that the development of a child’s lungs can be chronically damaged by air pollution and this can lead to a higher risk of respiratory infection and lung function for the child’s entire life [4]. Adverse health effects have been seen in children at lower levels than the level at which no effect would be observed for adults for particulate matter, nitrogen dioxide, and ozone [34] lead and tobacco smoke and there is some concern expressed for organophosphate pesticides [25].

There is a concern that the nesting instinct causes “soon to be parents” to remodel or decorate a nursery before the arrival of a baby. This consequently loads the nursery with high concentrations of VOCs from new paint, floorings and bedding and then they settle their infant in this space for up to 18 hours a day with minimal ventilation. The baby's room is often the only room in the house other than the living room that is heated. Increasing the room temperature will accelerate the off gassing of volatile organic pollutants from materials. Some brands of disposable nappies and infant furniture are strong emitters of VOCs which will add to the pollutant load in the infant's room [35]. The windows and doors can often be closed to keep the room warm or the nursery quiet which will reduce dilution of pollutants. There are currently no guidelines or educational material for new parents on how to create a healthy bedroom for infants. Research is required on the pollutant exposure of infants, possibly in conjunction with an infant cohort study that tracks exposure in early life and health outcomes as the child develops.

However, it is difficult to determine appropriate health based standards for youth due to restrictions on exposure studies on youth on ethical grounds. Large infant cohort studies such as those currently being led by Julian Crane of Wellington School of Medicine and Public Health and Jeroen Douwes from Massey University will no doubt provide useful information in the future.

Also people with impaired lung function, such as asthma or Chronic Obstructive Pulmonary Disease (COPD) are most susceptible to indoor pollutants [15]. Asthma affects one in four New Zealanders and New Zealand has one of the highest rates of asthma in the world. There is a large body of evidence of the role of environmental pollutants such as exposure to fungi and fungal fragments and dustmites in triggering an asthmatic episode. The indoor environments is also implicated in the onset of asthma [9]. The Housing Heating and Health study showed removing unflued gas heaters had an improvement in asthma symptoms that exceeded the results expected from a "successful" clinical trial of a new pharmaceutical [36].

COPD is a debilitating condition that is seen mostly in people over 60 years of age with increasing frequency and is predicted to become very prevalent as the percentage of the NZ population over the age of 60 increases to 25% by 2025 [9]. A new study is currently being prepared by the Otago-led Healthy Housing Research team that will investigate the health benefits on a sample of over 60's with COPD when given a subsidy for heating.

It is well established that mouldy homes can cause adverse health outcomes, there are concerns that homes that are too clean can also be detrimental. There have been several large studies research into the hygiene hypothesis, with some results suggesting that some endotoxin exposure in the first three years of life is good for stimulating a young child's immune system, however this is not yet conclusive [37].

People with multiple chemical sensitivities (MCS) are also a growing subgroup of society and their prevalence in North America is currently being studied by the US EPA. The current thinking on MCS is these people have had an exposure to pollutants that has overloaded their body to the extent that they can react to even small exposures to substances, such as fragrances, mould or VOCs that would be considered benign to others.

3 Healthy Homes Initiatives Internationally

Internationally there have been a large number of small studies on IEQ that look at different elements of pollutants in homes, source concentrations, health risks and mitigation methods. These are too numerous to review in this report.

There are also reasonable numbers of large multinational or international studies that seek to draw collective expertise on IEQ and indoor air issues. Some recent studies are summarised below. All projects that were reviewed consistently showed chemical pollutants namely formaldehyde, carbon monoxide, nitrogen dioxide, and benzene as high priority pollutants. Other studies have also included naphthalene, ozone, sulphur dioxide, and particulate matter as pollutants of concern. Indoor temperature and moisture and the resulting fungi have been identified frequently in International studies. Dampness and the resulting by products of fungi and fungal components and dustmites were also consistently shown to be a concern in housing. Fungi contamination in housing is a multi billion dollar issue in the USA and Canada and many other countries and this has been intensively but not conclusively researched [38, 39]. Environmental tobacco smoke has also been consistently identified as a strong pollutants source in homes.

It is a reasonable assumption that the findings from the studies reviewed below have some relevance to New Zealand housing. From the current knowledge on IEQ in New Zealand homes many of the pollutants of concern are similar however it is not yet known if concentrations found overseas are also found to the same degree in new Zealand homes,.

While there are some obvious differences between New Zealand housing and European or North American housing especially in climatic conditions, housing constructions systems, and reliance on mechanical ventilation etc, there are also some findings that can translate to New Zealand conditions. Several of the large studies are reviewed in the following pages to illustrate the main findings from international studies and to give an overview of the depth and breadth of research conducted in other counties.

An exception to the relevance of international research is radon. Radon has been investigated in many European and American studies but is excluded from this report as an investigation conducted by the National Radiation Laboratory found very low levels in New Zealand [Robertson, 1988] .

The following section summarises some of the international studies being conducted on IEQ. While Section 4 of this report summarises the Healthy Homes research that has been conducted in New Zealand. Some further information is presented on specific pollutants in Sections 5-10 and attempts are made in these sections to draw connections between international and New Zealand conditions..

Few IEQ studies seek to draw in lighting, radiation or vibration as environmental factors of concern. Noise is an emerging issue, which can confound indoor air quality in that closing windows to keep ambient noise out of the home may reduce ventilation of the house and reduce dilution of moisture and pollutants generated inside the home. A trade off high density housing where the neighbourhood can have ambient noise above 40dBA may be an increased reliance on mechanical ventilation to bring in fresh air without needing to open windows.

The Scottish Housing Executive have developed a healthy housing index called the Scottish decent homes standard. The Scottish Housing Executive has also conducted research on the adverse health outcomes from cold housing and have recognised the health, economic and social benefits from warm housing and provides free insulation and heating subsidies for all elderly people. The Scottish Housing Executive have found it is less expensive in the long term to provide all elderly with subsidised heating than pay for the health effects from cold housing.

The World Health Organisation (WHO) has had a panel of international experts working on IAQ for over thirty years. The first report prepared by this panel was a review of literature and was published in 1982 [40]. The WHO panel assigned high priority to three research topics. The first of which is the characterisation of emissions including VOCs and radon from building materials. The development and validation of biological monitoring methods, and inter-laboratory comparisons were also viewed as high priority. The panel advocated large field studies of sufficient size to compare sub populations, with simultaneous measurement of as many indoor pollutants as possible as well as recording of health outcomes.

The World Health Organisation has also published a series of air quality guidelines; the 1995 global update and 1996 report are the latest documents in this series. The 1995 global update focuses on the primary pollutants of particulate matter, ozone, nitrogen dioxide and sulphur dioxide [33]. Although this document sets guideline values for these pollutants based on extensive scientific evidence, it cautions that adverse health effects can occur at levels even lower than the guidelines and predicts some countries may elect to set even lower limits.

The pan European project titled Large Analysis and Review of European Housing and Health Status (LARES) is a large WHO initiative that has surveyed housing and health across eight European cities [41]. The aims of the study were to;

- “improve the knowledge of the impacts of existing housing conditions on health and mental and physical wellbeing;
- to assess the quality of the housing stock in a holistic way and identify the housing priorities in each of the surveyed cities, and possibly common trends;
- to develop an easy to use tool to assess the impact of housing on health in any city or region in Europe’’

The method involved a housing questionnaire, inspection form and health questionnaire. This study found a tight relationship with housing and health irrespective of individual or sectarian issues. A decrease in housing quality was also associated with a decrease in health. The relationship between housing quality and health was less pronounced but still apparent even in higher socioeconomic groups. The study found that housing and health are tightly related and have a number of complex interactions that encompassed more health related housing factors than had been previously considered in many studies . The researchers found the main housing features that impact on health are thermal comfort, indoor air quality, (dampness, moulds, indoor air emissions, infestations etc.) noise and sleep disturbance, environmental barriers, home safety and the social and physical quality of the housing as well as the immediate environment. The researchers concluded these factors need consideration in public health and housing policies. This multi year study is still in progress however preliminary results and more information on the project is available on http://www.euro.who.int/housing/activities and http://www.euro.who.int/Document/HOH/lares_result.pdf.

The UK Institute for Environment and Health published in 1996 the second of two assessments on indoor air quality in the home. The 381 page report focuses solely on nitrogen dioxide, formaldehyde, volatile organic compounds, house dust mites, fungi and bacteria [42].

The Towards Healthy Air in Dwellings in Europe (THADE) [43] project has summarised indoor air pollution in homes in European countries, and include policies and actions taken by the various countries. The report shows large differences between countries and highlights a lack of relevant data to inform policy. This study found lack of heating, dampness, inadequate ventilation VOCs and combustion products to be pollutants needing to be addressed in homes

The INDEX project [44] is another large study coordinated by the European Commission that focuses on the classical pollutants of carbon monoxide, nitrogen oxides, radon, asbestos, organic compounds including formaldehyde and other VOCs. This study conducted a step-wise analysis of pollutants of known health risk to the European population and detailed risk assessments were considered for 14 compounds. The five highest priority chemicals were formaldehyde, carbon monoxide, nitrogen dioxide, benzene and naphthalene. The effects are known and strategies to mitigate most of these pollutants can be created. However this study has found new sources of old pollutants such as VOCs from air fresheners and lead in candle wicks. It has also identified that some reactive pollutants, for example terpenes, which can react with ozone to form secondary products that can have poorly understood effects.

The ENVIE project is a European collective investigating the Health Effects from Indoor Pollutants [45]. This is a major initiative encompassing 17 European research organisations representing a wide range of disciplines and areas of expertise. The draft reports on results from this EU funded project are currently only available to members of the consortium. However, the project team has identified five compounds as having a priority due to their health effects and prevalence in indoor environments. The five highest priority compounds are formaldehyde, carbon monoxide, nitrogen dioxide, benzene and naphthalene. This project will be completed later in 2007, with preliminary results will be presented at a workshop attached to the Clima 2007 conference to be held in Helsinki, Finland.

The European Commission's Scientific Committee on Health and Environmental Risks (SCHER) [25] has prepared a study to identify a risk assessment strategy to support policy on indoor air quality levels that do not result in unacceptable risks to human health, especially vulnerable populations. The submissions of the international experts can be found on http://ec.europa.eu/health/ph.risk/risk_en.htm . The preliminary report addresses indoor air pollution in homes, offices, schools and transportation systems. The report focuses on specific chemicals compounds from indoor and outdoor sources, including consumer products (decorating materials, cleaners etc.), particles and building dampness. This study has identified the following indoor pollutants as of particular concern; formaldehyde, carbon monoxide, nitrogen dioxide, benzene, naphthalene, environmental tobacco smoke (ETS), radon, lead, and organophosphate pesticides. Benzene is emitted from some plastics, rubber solvents and paint. It is also one of the many compounds from tobacco smoke. Naphthalene is a compound found in some solvent based products and is used in mothballs and other indoor insecticide products.

ANSI/ASHRAE Standard 62.2-2007 [27], Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, is the only nationally recognised indoor air quality standard developed solely for residences. It defines the roles of,, and minimum requirements for, mechanical and natural ventilation systems and the building envelope intended to provide acceptable indoor air quality in low-rise residential buildings.

The Australian Healthy Habitat programme has a focus of improving the health via the housing conditions of aboriginal communities. This programme has prioritised the needs as adequate facilities for washing people, clothes and bedding; sanitation and waste removal; improving nutrition via adequate kitchen facilities; reducing overcrowding; reducing the impact of animals, vermin and insects; reducing dust; controlling temperature via insulation and passive design.

4 Healthy Homes Initiatives within New Zealand

In New Zealand, the indoor environment in has received remarkably little attention, compared to research efforts conducted overseas and efforts on ambient pollution. Much of the research that has been undertaken in New Zealand has had a slant towards low income housing, as low income housing undoubtedly has the greatest need and housing improvements can have a significant impact of health including mortality and hospitalisations. Research has been prioritised on low socio economic homes with lesser research conducted on middle socio economic status homes. Middle income homes could be an area where a significant improvement could be multiplied over the majority of the housing stock.

New Zealand has many high calibre researchers with experience, ability and motivation to conduct research into healthy homes. There is also a reasonable level of capacity of environmental monitoring equipment and laboratory facilities, some of which are under utilised. However, most researchers commented their activities in this field were restricted by availability of funding and the level of research activity that has been witnessed in the last six years is unlikely to continue in the short term due to difficulties in attracting funding..

4.1 Healthy Housing Research in New Zealand

The He Kainga Oranga Healthy Housing research programme led by Professor Philippa Howden-Chapman from the University of Otago is the most significant team working in this area. The research group with members from four universities and BRANZ consists of a multidisciplinary team with experts in respiratory health, social scientists, building physics, indoor air quality, biostatistics and economics. This team has completed or has work in progress on a number of significant studies on healthy housing including the Insulation and Health study, the Healthy Housing Index, the Housing, Heating and Health study and Overcrowding study.

The Insulation, Housing and Health study was conducted in the winters of 2001 and 2002 and involved insulating the underfloor cavity and ceilings of 1400 New Zealand homes to the standard EECA package. The occupants of the households completed daily records of how warm they felt in their home and their health. They also permitted the research team to measure temperature, humidity, dust and fungi in their homes. Data was also collected on the number of hospital and doctor visits made by the participants, as well as information on energy usage. Analysis of the data is ongoing, however, results have shown a small, but significant drop in energy usage when houses were insulated. The insulated homes were drier and 1 ^{o}C warmer and people felt warmer. Occupants (and the fungi and dustmites trying to co-share the home) were exposed to relative humidity above 70% for several hours less every day. There was a significant improvement in the self-reported health of adults and children, with fewer GP visits and admissions to hospital for respiratory conditions per winter season. Adults living in the insulated homes had fewer days sick leave off work and children had fewer days away from school due to illness. Insulated homes had less visible mould [6]. This study found that home owners took a mix of both warmer indoor temperatures and savings in purchased heat. This study is also discussed in Section 9 of this report.

The Insulation, Housing and Health study was an important milestone in the study of healthy housing. This study demonstrated the real and cost efficient benefits that can be achieved from modest improvements in housing insulation. Although the homes were still several degrees below of the WHO's recommendation of 18 ^{o}C minimum, the health benefits were significant. The cost of the additional insulation is equivalent to one night stay in hospital and the study found that houses with the insulation had on average one less night hospital admission per year. This alone paid for the capital cost in one year, with ongoing health benefits accruing. An as yet unpublished cost-benefit analysis of this data suggests returns of $4 in health savings for every dollar spent on insulation. This study has provided the evidence of substantial health and economic benefits from insulating homes and consequently provided other agencies with the arguments for insulating thousands of other public and private homes. Some of these other projects are discussed in section 4.2 of this report.

A Healthy Housing Index, also conducted by the University of Otago lead He Kainga Oranga Healthy Housing Research Group, and involving Michael Keall, Professor Julian Crane, Michael Baker, and Malcolm Cunningham, (BRANZ), is a study that attempts to index housing factors that indicate the 'healthiness' or the likelihood that occupants have adverse health or accidents attributable to the indoor environment. A pilot study has been conducted on 100 homes in the Hutt region to investigate the method of surveying and calculation of the Healthy Housing Index. The Index was adapted from the British Housing Health and Safety Rating System and includes factors such as: insulation, mould, sewerage, heating, temperature of water, ventilation, and safety on stairs (interior/exterior). Household behaviour, such as opening windows, is excluded from the Index. This research is on going and more funding is required to complete the project. It is possible that it will be aligned with the Department of Building and Housing's projects on Building Quality Targets. Target values will not be released until the development phase of this project is further advanced.

Following the positive health benefits derived from increasing home insulation, the next obvious research question was to investigate the health benefits from moving from heaters which emitted pollutants and/or only heated a small area of the house to more effective and non polluting heaters. The Housing, Heating and Health Study, was lead by Philippa Howden-Chapman of the He Kainga Oranga Healthy Housing research programme with other researchers being Professor Julian Crane, Michael Baker, Sarah Nicholls, Helen Vickers, Julie Gillespie, Neville Pierce and Associate Professor Bob Lloyd (all from University of Otago); Malcolm Cunningham, (BRANZ) Ralph Chapman (Victoria University); Robyn Phipps, Professor Chris Cunningham, Mikael Boulic and Par Fjällström (Massey University).

The objective of the Heating, Housing and Health study was to investigate the benefits from insulating a home and moving from a small portable heater either unflued gas or small plug in electrical heater, to a higher heater output and more effective heat pump, wood pellet burner or flued gas heater. 412 homes from Hutt Valley, Porirua, Christchurch, Dunedin and Bluff with an asthmatic child and where their main heat source was an unflued gas heater or small electric heater were enrolled in the study. The results showed dramatic improvement in health with children living in a house with a new non-polluting heater having three less days per winter off school from illness, less night coughing and wheezing, less respiratory inflammation and for shorter periods. The improvements shown in health from replacing an unflued gas heater with a non polluting heater exceed an improvement in health that is expected from a clinical trial of a new "successful" pharmaceutical drug. The houses were also warmer with less visible mould and less condensation. Nitrogen dioxide were reduced to acceptable levels in homes were the unflued gas heaters was replaced with a non polluting heater..

These results give further evidence of the interactions between health and the indoor environment. Preliminary results of this project have been reported, however analysis of the data, including a cost benefit analysis and a study of the consumer drivers and behaviours will continue for another year [46].

Intensive monitoring of a number of environmental parameters was conducted in nearly 70 homes drawn from the Housing, Heater and Health study. The Intensive Monitoring nested study was led by Dr Robyn Phipps, Massey University, and Dr Malcolm Cunningham from BRANZ with Mikael Boulic and Par Fjällström, both from Massey University, conducting the field work. Continuous measurements were made of nitrogen dioxide, carbon monoxide, formaldehyde, humidity, temperature and carbon dioxide. Results showed some homes with unflued gas heaters had peak nitrogen dioxide levels five and a half times the recommended maximum WHO levels and long residence times of this gas in the homes. Carbon monoxide also had many periods where the WHO guidelines were exceeded. The detection of both these pollutants and the operation of the unflued gas heater were highly synchronised. Formaldehyde levels were also too high in several homes, however the coincidence of formaldehyde and operation of the unflued gas heater was not always tightly correlated as there are many sources of formaldehyde in homes. Homes heated with wood pellet burners, heat pumps and all but one of the flued gas heaters had no emissions of the measured pollutants. Preliminary results have been reported [47] with full results due later in 2007. Results from fungi and dustmites samples are still be analysed and will be reported in 2008. A conclusion from this study is that unflued gas heaters are incompatible with HSS.

The He Kainga Oranga research group are currently conducting a pilot of a research study on health benefits for elderly people with COPD from increased heating in their home. If further funding can be secured, this project will be extended as a randomised control trial to people with COPD in five centres New Zealand.

Professor Julian Crane has been very active in research for several decades into allergens in the home environment. Professor Crane is a Co-director of the He Kainga Oranga Healthy Housing Research programme and also leads the asthma and respiratory health research team at Wellington School of Medicine and Health. Other researchers in Asthma and Respiratory

Health Research team include Kristen Wickens, Tristram Ingham, Rob Seibers, and P Fitzharris. The research of this team includes dustmites in homes and the relationship between housing characteristics and dust mite allergen concentrations, mouse allergen in homes, cat allergens, geographical variations in the prevalence of asthma symptoms in New Zealand, endotoxins and (1-3)-ß-D-Glucans levels in homes, controlled case studies for risk factors for asthma, risk factors for mould in New Zealand housing. The effectiveness of smoking cessation programmes to reduce the exposure of environmental tobacco smoke in homes is also being researched at the Wellington School of Medicine and Public Health.

Professor Crane is also leading a longitudinal birth cohort study to investigate wheeze and asthma in infants. This is study that will be conducted over many years.

Mikael Baker from the University of Otago is also a Director of He Kainga Oranga and in addition to the projects conducted by this research team outlined above, he has conducted research on overcrowding and the relationship with communicable disease such as meningitis.

Dr Malcolm Cunningham from BRANZ has been active in indoor air quality research in homes for several decades. In addition to being a Director and investigator on the projects conducted by the He Kainga Oranga Healthy Housing Research programme, Dr Cunningham has conducted research on dustmites, fungi and performance of dehumidifiers. Projects have included a Verification Method for mould and condensation for the New Zealand Building Code Section E3. This has included modelling and field validation of a tool for mould control. A key finding of this project was mould will germinate after only 6 hours of available moisture and the results reinforce the need for providing means for rapid drying of wetted materials and preventing leaks and condensation

Dr Cunningham has also conducted research projects on the measurement of microclimates in which mould and dustmites live. For this work he developed a new and very small relative humidity sensor that was used to explore the conditions in microhabitats such as carpets, bedding and soft furnishings in which biocontaminants (mould and dustmites) live. In a subsequent study on microclimates, these were modelled and the model was validated against experimental data. This research found that keeping carpet very dry by placing a heating pad in the backing of the carpet was effective for killing dustmites. More work is required to verify that seeding with dustmites from other sources such as bedding doesn't repopulate the carpet.

Another study conducted by Dr Cunningham and Adrian Pike, P Lester, J Andrews from Victoria University of Wellington was a detailed investigation of the population dynamics for dust-mites under a range of steady and fluctuating temperature & relative humidity conditions. Following from their earlier work this team are currently conducting a study that uses molecular genetic techniques to identify distinct strains of dust-mites and then to use these strains to explore dust-mite cross infection between dust-mite reservoirs such as carpets, bedding and soft furnishing.

A project on the performance of domestic dehumidifiers in cool indoor climates far from their design climates was also conducted by Malcolm Cunningham, BRANZ, and Professor Gerry Carrington from University of Otago

Dr Cunningham and Mark Bassett also from BRANZ are involved in the development of the latest generation of ALF version 4. ALF 4 will include content on home energy rating schemes, ventilation, mould, biocontaminants, heating, energy, energy conservation, insulation. Mark Basset has a wealth of knowledge and research on infiltration and ventilation of homes, but will not be researching in this area in the foreseeable future. Mark Bassett has developed BRANZVENT a tool for the evaluation of ventilation requirements in homes. This tool is currently only paper based and not very user friendly, however it will be incorporated into a future version of ALF. BRANZVENT is useful for assessing the ventilation requirements of new and existing homes for the control of moisture and indoor pollutants. However, it is not designed to assess ventilation requirements when there are high indoor sources such as post new construction or refurbishment.

Associate Professor Ralph Chapman, from Victoria University of Wellington, is a Director and investigator on the projects conducted by the He Kainga Oranga Healthy Housing Research programme. His research interest is the economic benefits and formulation of the value case of healthy housing interventions like increasing insulation and non polluting heating.

Associate Professor Bob Lloyd, From University of Otago has conducted research on fuel poverty in New Zealand, and was involved in the Housing, Heating and Health Study. He has conducted an in depth study of the thermal efficiency of houses in cold climates following insulation retrofits. He has also conducted research on the efficiency of heat pumps and solar water heaters.

Dr Robyn Phipps, from Massey University, is a Director of the He Kainga Oranga and has conducted research on the effectiveness of domestic ventilation systems for the control of moisture and fungi. A study of 15 homes found an improvement in ventilation rates and warmth in homes and reduced levels of airborne fungi after the installation of domestic ventilation systems that draw air from the ceiling cavity. Raewyn Fortes (Massey University) and Dr Marie Fleming (ex Massey University), were involved with this study. Further work will soon be conducted in this area that will look at a larger sample of homes and in more detail.

Professor Jeroen Doewes and Professor Nevil Pearce, both from Massey University, Wellington Campus, have been involved in large studies investigating the effect of fungi and fragments of fungi such as endotoxins and (1-3)-ß-D-Glucans and bacteria and the associated risk of childhood asthma and wheeze. Much of Professor Doewes work has been conducted outside of New Zealand.

Kate Henderson, from Massey University Albany campus is commencing a study of fungi and bacteria in water damaged Auckland homes. Robyn Phipps and Professor Ian Maddox will be involved with this study.

Caroline Shorter, from AgResearch, is currently undertaking a PhD thesis on the distribution, aerodynamic characteristics and clinical relevance of fungi found in NZ homes. Dr Simon Causer, Professor Julian Crane, Malcolm Cunningham and Nick Wiapara are the supervisors of this research.

AgResearch is also has a strong interest in particulate and gaseous pollutant interactions with textile materials - especially carpets and furnishings. Simon Causer has lead much of this work; however he has recently left AgResearch and research on indoor environments.

Three researchers at Victoria University of Wellington, School of Architecture have interest close to healthy homes. Jackie MacIntosh has investigated fungi and bacteria in primary schools and has a secondary interest in environmental quality in homes. Mike Donn has supervised several Masters and Honours students in projects investigating day lighting, energy use, thermal comfort and ventilation in homes and apartments. John Gray has experience with tools for assessing building performance but has primarily had a focus on commercial buildings. John Gray has been involved in the design of the Tokelaun housing in New Zealand to address overcrowding. This later project was a collaborative study with the He Kainga Oranga Healthy Housing Research Group.

Professor Jim Johnston and Dr Thomas Borrmann, both from Victoria University have conducted several projects investigating innovative building materials. Projects have included indoor temperature control via phase change materials imbedded in building materials; proprietary technology allows the incorporation of resins into porous structures and the containment of resins even in a liquid state; the use of a nano-porous support to control the slow release of disinfecting agents from coatings for walls, wood; use of nano-particulate silver, magnesium oxide and zinc oxide. Proprietary calcium silicate regulates moisture level in room, keeping the room at a constant 75 %RH, releasing water if required, taking up to 175 % its own weight of water if needed; the same material can absorb irreversibly sulphurous and noxious gases which can in turn improve indoor climate. This work is currently laboratory based and more work is required to bring it to actual building materials.

Dr Bin Su from Unitec has conducted a study on fungi in Auckland houses and natural ventilation in humid climates.

Guy Coulson and Jeff Bluett from NIWA have conducted a large number of studies on ambient exposure of pollutants, especially nitrogen dioxide, carbon monoxide and respirable particulates. They have developed some inexpensive pollutant loggers however are seeking funding to undertake field work of indoor air quality and comparative projects with the United Kingdom.

Gavin Fisher, ex NIWA, has been the lead researcher of a large health and ambient air pollution study (HAPINZ) that found 1079 people are dying prematurely from air pollution each year, 705 hospital admissions and 1.92 million restricted days activity are also caused by ambient air pollution which is estimated to cost New Zealand $1.333 billion per year. The main causes for the pollution were combustion by-products from vehicles and low efficiency wood fires. This study did not investigate infiltration of ambient pollution into the indoor air. The study authors have reiterated the need for Councils to work towards national air quality standards by 2013.

Dr Simon Kingham from Canterbury University has conducted three studies related to nitrogen dioxide and particulates levels in homes and outdoors. Dr Kingham lead a study where indoor and outdoor measurements of very fine respirable particulate matter ($PM_{2..5}$) particulates were taken in three houses, using four different fuel types (wood, coal, gas and electricity) for a week each in each home. Indoor emissions were measured and revealed indoor pollutants levels were dependent on fuel type, outdoor particulate levels and the age of the home.

A further study conducted by Dr Kingham on particulates examined the health effects of ambient particulate air pollution from wood burning on school-age students in Christchurch, and to explore the utility of urine and exhaled breath condensate biomarkers of exposure in this population. A panel study of 93 male students (26 with asthma) living in the boarding house of a metropolitan school was undertaken in the winter of 2004 with continuously monitored indoor and outdoor PM. There was no significant effect of ambient wood-smoke particulate air pollution on lung function of school-aged students, but a small effect on respiratory symptoms. Relationships between indoor and outdoor pollution varied according to level of outdoor pollution.

A study by Dr Kingham on personal exposure to nitrogen dioxide was undertaken with university students wearing NO_2 passive sampling tubes. Levels of NO_2 were measured personally as well as in and out (at a variety of locations) of homes from a sample of University students. The most important factor for the variability of NO_2 within a house was the distance from a gas heater. The time spent in different environments (with or without combustion appliances) was not significantly correlated with personal exposure.

Dr Nick Waipara, Peter Buchanan & Eric McKenzie, from Landcare Research have undertaken building research as it relates to microbial contamination, and the biodiversity of wood decay fungi. Landcare houses both the New Zealand Fungal & Bacterial Culture Collections which are the reference cultures. Dr Waipara has conducted a research project "investigating the microbial populations associated with "leaky buildings" and other indoor living environments and possible links with air quality, biodeterioration, human health issues and the mycotoxins produced by New Zealand fungi".

Almost no research has been undertaken on noise levels in New Zealand homes. Stuart Mclaren, and Professor Philip Dickenson from Massey University, Wellington campus, have a research interest in the health effects from noise, however this has not been conducted in the home setting due to lack of funding. Professor Philippa Gander, leads a team at Massey University that has been conducting research on the health effects from sleep disturbance. Although not a primary focus, community noise and noise transmission between rooms and apartments is a significant contributing factor in sleep disturbance. Similar research is necessary in New Zealand.

Three small studies conducted by Dr Ken Morsley (retired DSIR engineer), Dr David Bennett (Chairman of Trans-Orient Petroleum Ltd) and Tailor Baines and one study of over 600 people (Dr Robyn Phipps) have found that noise disturbance is an issue for resident living close to wind farms in New Zealand.

There has been almost no research on VOC or particulates levels in homes in New Zealand, nor the ingress of pollutants from sites previously used for industrial activities.

While the above listing of research projects shows a good level of activity has been achieved in recent years. There have been several large projects that have provided strong evidence of the link between IEQ and health. However funding has not been extended for three of these larger programmes and current predictions are for a reduced level of activity.

4.2 Healthy Housing Applications

There are a number of healthy or warm housing initiatives that are not research based occurring through out New Zealand. These are generally based around an insulation retrofit and may also include education of householders about energy efficiency, or access to other health or social services. Most of these programmes focus on low income households. Universally all these insulation programmes have found a very high level of appreciation from occupants of their warmer home and dramatically improved health of household members.

EECA have assisted in the insulation of 35,000 low income homes. They are soon to be offering 55% subsidies for insulation of rental properties in order to reach a larger pool of the housing stock. They aim to have insulation in most of the pre-1978 homes by 2012.

The Healthy Housing programme lead by Housing New Zealand Corporation (HNZC) and several District Health Boards is one large example of an insulation retrofit programme. This programme targets regions with high health needs, low income, and with more than 20% houses in the region owned by HNZC. The intention is to assist families with high rates of hospital admissions for preventable infectious diseases. Since 2001 the programme has completed insulation and other upgrades in over 4000 HNZC homes in Northland, Central and South Auckland. Additional funding has recently been secured to extend the programme to 1700 HNZC homes in the Hutt Valley over the next three years.

HNZC staff work directly with health professionals to identify families that are living in conditions that may affect their health and suggest mitigation measures including educating families about health risks and referring households to local health providers, installing insulation, or enlarging overcrowded homes. While the emphasis is on the intervention rather than collecting research evidence, evaluations have found improvements in self-rated health, self-esteem, use of primary and secondary health care. Hospital acute admissions for respiratory infections, tuberculosis, gastroenteritis, ear, nose and throat infections, meningococcal meningitis, asthma and COPD were reduced by 37% or 127 admissions per year in houses that had undergone some form of modification, compared to homes without any modification. The largest decrease was seen in respiratory conditions, particularly in children. Households that had had interventions to reduce overcrowding (e.g. additions of bedrooms) had a slightly larger fall than those that had insulation/ventilation modifications only. The draft report of the year three results show an increase in social wellbeing and anecdotally residents are reporting less family tensions, children performing better at school, and families have the mental space to get involved with other health programmes such as healthy eating. Tracey Moore, Housing New Zealand Corporation, (09 261 5580) is the Project Manager for the Healthy Housing Programme,

A healthy homes pilot initiative is about to be piloted in the Hutt Valley focusing on older people. This project is a multi agency initiative (HNZC, EECA, Hutt Mana Charitable Trust, Energy Smart, ACC, etc) for low income older people, (50+ years old for Mäori and 65+ for other ethnic groups) and will consist of an insulation retrofit, some basic household maintenance, accident prevention measures, as well as education on energy efficiency use of the home, and a health and social assessment. If further funding can be secured this study will be rolled out for more low income homes in the Hutt. A contact for this project is Barry Gaull, from the Hutt Valley Regional Health Service (04 570 9311)

The Department of Housing and Building have an ongoing project called the New Zealand Housing Quality Standards project. This project started as a HNZC project of substandard public sector housing but was transferred to DBH in March 2005 and the brief broadened to encompass all existing buildings. The project is long term and has the ongoing objective of "reducing the number of substandard buildings being occupied or used in New Zealand by 2010. The quality targets for existing housing are still being established and are as yet confidential until Ministerial and local government approval has been received. The contacts for this project are Rob Murray and Sian Smith (04 494 5356) from the Department of Building and Housing.

The objective of the DHB study is to coordinate the efforts of organisations with an interest in housing quality and measurement of housing quality. Housing quality, in this instance, is considered to encompass health gain and environmental sustainability in both private and public sector housing. One objective of the study is the development of a common instrument and method for comparing housing quality that is useful, informative and widely used. As this tool gathers more data that can link the investment in remedial work with actual health and sustainability outcomes, then this will help to justify further investment in the housing improvements.

There is still debate on whether quality targets will be mandatory or voluntary or will be used for regulation, education or raising awareness. They will deal with the following aspects of buildings; structure, ventilation, insulation, heating, water, waste/sewage, sanitary facilities, food preparation facilities, lighting, safety from falling and fire safety. Progress to date includes a review of international studies on housing quality and draws heavily from the UK "decent homes standards". Researchers from the He Kainga Oranga research group are currently working on a review of this project. Local government will be involved in the next stage of consultation on the quality targets, with public consultation expected to occur in mid 2009.

The He Kainga Oranga Healthy Housing research team leaders organised a meeting of organisations involved in Healthy Housing Schemes, which was held in September 2006 in Wellington. The list of participants invited to attend this workshop is appended in Appendix A. This workshop consisted of brief presentations from representatives from HNZC, Wellington City Council, Department of Building and Housing Christchurch City Council and EECA on their schemes to improve housing. In the following discussion it was agreed that many of the schemes were based on the Scottish Decent Housing Scheme and there were sufficient similarities between the schemes for efforts to be combined.

The Ministry for the Environment has initiated a Warm Homes programme that promotes tips for home insulation and clean heating such as wood pellet burners, low emission wood burners, flued gas heaters and heat pumps. They have a list of approved wood burners and pellet burners and tips to reduce the production of smoke from the operation of wood burners. They have completed two pilot studies in Tokorua and Timaru, with detailed results yet to be published.

ECan and Christchurch City Council have initiated a Clean Heat project, which has invested financial assistance to convert 6000 open fireplaces and inefficient wood burners to low polluting heaters such as wood pellet burners and heat pumps. A further 10,000 homes have undertaken the assessment process and 14,000 more homes have registered interest. The rate of conversions has been trimmed to match available funds drawn from rate payers. An educational programme has been adopted for 2006/7.

The central government in the 2007 Budget has promised to provide assistance to increase energy efficiency, and warmth in homes. These initiatives will have health as well as energy benefit. Some of the main elements in the package are an interest-free loans scheme to assist homeowners pay for energy efficiency and clean heating upgrades; financial assistance for the installation of clean forms of heating for low-income households in areas of poor air quality; financial grants for 12,000 energy efficiency retrofits per year for low-income households; and an information campaign to provide consumers with clear, practical advice on actions they can take to improve their homes. These financial incentives are not available to middle and high income households.

Public Health Service Midcentral Health has been running a series of free seminars. Topics covered include domestic insulation, heating condensation and mould and energy efficiency. The contact for these seminars is Sharon Vera, 3509110

Consumer Build and Beacon Pathway Ltd have developed web based information services for home owners and industry stake holders with the aim of providing advise on warmer dryer homes.

Winstone Wallboard's have lead a consortium of building supply companies to promote a healthy homes package which advocates good, better and best solutions for homes with improved insulation levels, ventilation and moisture management.

Contact Energy have lead a consortium of building companies and service providers to promote warmer dryer homes. Contact Energy is also a sponsor of Asthma Awareness week and has promoted methods to reduce allergens in the home.

5 Pollutants

Home occupants can be exposed to indoor pollutants via inhalation of gas phase compounds or fine particles, via ingestion of dust or via dermal contact. Ingestion is most common for young children who ingest dust due to their hand to mouth contact and mouthing of articles and toys. Semivolatile compounds, such as phthalates, flame retardants, polyaromatic hydrocarbons (PAHs), chlorophenols, pesticides, organotins, and metals may absorb to house dust [48]. These pollutants are outside the scope of this report but are well referenced in other publications.

5.1 Volatile Organic Compounds

Internal air/environment quality started to receive attention internationally in the 1970's as houses became better insulated, drafts minimised and rate of air changes reduced, whilst concurrently houses are built, decorated, heated, furnished and maintained with products that emitted volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) which are chemicals that can be harmful to human health. It has been found that homes can have between 200 – 2000 different chemicals each in very small concentration, and there is very limited information on the combined health effects [25]. Guideline values are available for a small fraction of these chemicals and these apply when the chemical is present in isolation. There are no guidelines values available for a cocktail of hundreds of chemicals [49]. Studies conducted in Australia, Europe and in the USA have found that pollutant levels inside homes can be two to seven times higher than outdoors for existing homes [11]. After some activities, and following new construction indoor air pollution levels can be 100 times higher than outdoors [10]. Pollutants in the indoor air are 1000 times more likely to be inhaled than pollutants in outdoor air due to the long resident times and room concentrations [12-14].

VOCs are widely considered to be causal agents of poor IAQ because of the following factors:

- Many are irritants and/or can cause central nervous system symptoms,
- They are found in stronger concentrations in indoor air than in outdoor air,
- As so many VOCs are simultaneously present they may react additively or synergistically to induce symptom responses. The cumulative health risk for combinations of VOCs found in indoor air is unknown,
- As people spend 75% or more of their time at home, mostly indoors, the home environments tend to expose the occupants to longer periods of more complex mixtures of chemicals than those which are found in industrial settings from where the standards have been derived,
- Exposure to VOCs can occur simultaneously with other risk factors, such as microbial contamination and particulates,
- A high temporal exposure dose, such as after the laying of new carpet, can cause some previously healthy individuals to become sensitised, and they will subsequently experience symptoms at substantially lower doses,

- Irritation effects, such as irritated mucous membranes, generally have steep dose–response relationships (Cometto-Muniz & Cain, 1992),

Emissions from building materials can be classified as primary pollutant sources which include emissions of free VOCs, or secondary emissions which include pollutants formed by chemical or physical reactions, hydrolytic decomposition, oxidative degradation and reemission of adsorbed VOCs (sink effect)(Wolkoff, 1995). Many laboratory studies and field investigations have measured emissions from building materials and the results differ between studies depending on the experimental method used. However, while there are differences in the reported emission concentrations, types of VOCs and decay rates there is general consensus on which types of new materials are sources of VOCs.

Most primary emissions occur from new construction and finishing materials within weeks to months of exposure to the air but can take over 12 months to decay to acceptable levels. The decay of emissions varies considerably with material type and environmental conditions, however, emissions from new construction and finishing materials routinely dominate the primary emissions for the first twelve months of the life of a new building.

The strength of the source is obtained by multiplying the area of the material with its emission rate. A material with a large surface area will have higher emissions than the same volume of the same product in a dense mass(Wolkoff, 1995). Therefore materials such as carpet can pose a strong source of VOC's.

Wet construction products such as paints, wall or floor material adhesive, sealants including silicone, wood stain, floor varnishes, water and solvent-based adhesives contribute significantly more to VOCs in homes than do dry products. However, dry products including - vinyl, rubber, many types of textile flooring, medium density and high density fibreboards, particleboards, plywood polyurethane foam, vinyl wallpaper, and plywood - have all been identified as sources of VOCs.

Total VOCs (TVOC) is a measure that is frequently reported in field studies as a total count of VOCs present in the space. This is a surrogate for expensive, difficult and time consuming separation of possibly hundreds of individual compounds. TVOCs are a useful screening measure. While there are attractions for using this measure there are also limitations in that an aggregated count can hide concentrations of particularly noxious compounds. There is also a lack of agreement in the research community on which compounds should be included in a count of TVOCs and which omitted.

TVOC concentrations found in existing homes range between 70 to 1,130μg-m^3 and mean TVOC concentrations found in building less than 3 months old were approximately 4000 μg-m^3, with some new homes reaching peaks of 18,000 μg-m^3 . The Australian maximum exposure criteria for TVOCs is 500 μg-m^3 [50]

Research that keeps up to date with new low emission formulations of construction materials and finishes is important as manufacturers make continuous product improvements. An example of this is new generation resin technologies (super E0) that when used for the manufacture of particle board products can give formaldehyde emission at the same or lower emission as solid wood [51]. Materials using this resin are not currently sold in New Zealand.

Also research that is conducted using New Zealand materials and in New Zealand homes is required to quantify the issues of VOCs in the New Zealand context. It could is possible that differences to products formulated and construction systems could vary the species or concentrations of VOCs found here compared to other countries.

5.1.1 Occupant Activity

VOCs can arise from the activities of the occupants, such as personal care products and fragrances and cleaning products. Environmental tobacco smoke is a strong point source of numerous VOCs, including aldehydes (formaldehyde and acrolein), benzene, styrene, aliphatic-hydrocarbons, 3-vinylpyridine, 2- and 3- picolines. Emissions from occupant activities tend to dominate the VOC profile of homes after the emissions from the new construction materials have decayed.

VOCs emitting from human activities are often point sources and are emitted close to the occupants. They also have large temporal fluctuations of the concentration patterns, which can temporarily increase the occupants' exposure and confound measurements(Rodes, Kamens, & Wiener, 1991). In field investigations, VOC levels have been found to fluctuate on an hourly and daily basis and occupant activities are thought to contribute largely to these fluctuations.

5.1.2 Outdoor Sources

Although a lesser contributor to the concentration of indoor VOCs than indoor sources, VOCs which originate outdoors have been found to infiltrate buildings, depending on geographic location. Geographic factors include adjacent traffic patterns, neighbouring activities, soil characteristics or prior contamination of the site. A prominent outdoor source is emissions from nearby passing traffic or idling vehicles. Their entry route is primarily via infiltration and open windows. Increasing the ventilation rate in the home will only serve to increase indoor pollutants if the outdoor air is also polluted. As outdoor air and indoor air can be considered as two interlinked compartments, outdoor air pollutants are also of concern to the indoor environment.

5.1.3 Sink Effect

VOCs are adsorbed onto other surfaces, such as fleecy materials such as carpet and dust particles and these can be reemitted at later stages when the boundary air concentration is lower than the concentration within the material. This phenomenon is called the sink effect and prolongs the residence of VOCs in indoor air considerably longer than the time required for primary emissions to decay. The adsorptive properties of fleecy materials such as textiles and open storage of paper can be a factor in prolonging the concentrations of VOCs in homes.

VOCs absorbed onto dust particles, which are subsequently either deposited on skin or inhaled, produce alternative exposure mechanisms which also has been considered and water soluble VOCs, such as formaldehyde, were readily carried on the surface of dust particles.

5.1.4 VOC Interactions and Dynamics

Temperature affects the vapour pressure and diffusion coefficients of the emitted VOCs and has a large impact on the rate of emissions of VOCs. Large temperature rises frequently occur during the course of a typical day from solar radiation on surfaces, especially dark surfaces, and from heating sources.

Urea formaldehyde resin, which is the base polymer for many wood panel adhesives, can degrade and emit gas phase formaldehyde, especially under the influence of heat and moisture. The emissions of formaldehyde doubled for every 7°C rise in temperature within the range of 14-35°C, and they will also double if the relative humidity increases from 30% to 70% at 22°C. While these results have been measured in laboratory conditions, the temperature and relatively humidity ranges are comparable to those found in homes.

Building characteristics, such as the ventilation rate, contribute to the variable nature of VOC emissions, due both to the infiltration of outdoor pollutants and to the effectiveness of the removal of indoor pollutants(Molhave, 1991). Wind is usually the major driving force for infiltration, so infiltration of many types of contaminants is a particular problem at windy sites or sites with localised air turbulence such as around medium rise apartment.

Many studies have found that total VOC (TVOC) levels increase as the air exchange rate is decreased(Nagda et al., 1991);, however, the converse is not always true if there are strong sources within the indoor spaces. Increased ventilation changes the vapour pressure around a source material, and this can cause emission rates of many VOCs to increase. A six-fold increase in ventilation can cause a two-fold rise in formaldehyde emissions and it is possible that the same phenomenon occurs for other gas-phase contaminants emitted by diffusion [52].

5.1.5 Source Control

Source control, that is the selection of materials to limit emissions of VOCs, is undoubtedly the best way to achieve low indoor levels of VOCs and care should be taken to avoid using construction materials that are likely to release quantities of VOCs [53]. Many studies have been conducted overseas to measure the vapour-phase emissions of common building products. Data from these have led to initiatives for labelling schemes for the "low emitting products". The Californian Air Board operates a scheme for the labelling of materials with low emissions, however such a scheme has not been developed for New Zealand materials.

The government of the state of Washington, USA has embarked on a programme for healthier new and renovated state buildings (usually commercial), where manufacturers of materials, furnishings and finishes are required to provide emission profile data with their tender price. Designers and builders of the State's buildings are required to develop and implement an indoor source control plan for all materials, furnishings and finishes. Emission standards for key pollutants are required to be met as follows - formaldehyde (below 61µgm^3), TVOCs (0.5 mg/m^3), 4-PC (1ppb), and particles (50µg/m^3). In addition, all emissions of regulated pollutants and chemicals with specified threshold limit values must be below the regulated criteria. The programme requires these criteria to be met within 30 days of installation. There has not been sufficient research on the levels of VOCs found in New Zealand homes to compare to these emission standards.

To minimise the sink effect, the Washington State Healthy Buildings programme allows only the least feasible amount of wet materials (paints, adhesives, sealants etc.) and prohibits the installation of adsorbent materials, such as carpets and furnishings, until all wet materials have been allowed to dry. All dry products must be air-out or preconditioned prior to installation. This approach has shown improved indoor air quality and reduced health complaints from occupants in these buildings.

Measures include:

- Selection of low VOC emitting materials
- Isolation of construction in occupied homes when renovations or decorating occurs
- Scheduling of construction and furniture installation to minimise VOC concentrations prior to occupants moving into a new home
- Delaying installation of adsorptive materials until after drying of wet materials and processes
- Using low emitting housekeeping and maintenance materials,

The Danish Ministry of Housing has made advancements in protocols for assessing the IAQ impact of materials. Consideration is given to chemical emission over time, and modelling the health impact, with the principal objective being to determine the number of months necessary for a product to reach an acceptable concentration to avoid mucous membrane irritation and odour detection.

Since hundreds of products are used in most construction projects, priority should be given when selecting materials with a large surface area, such as floor coverings [11].

5.1.6 Reduction in VOC concentrations

In addition to careful selection of materials, special ventilation should provide large quantities of full fresh air via doors and windows after installation of wet or VOC emitting processes or products. This will minimise the sink effect and help prevent a cycle of adsorption and re-release of VOCs. Potential "sink" materials, such as the upholstered furniture, should not be installed in the home until VOC emissions have diminished to acceptable levels. This special ventilation is additional to the general ventilation that can be calculated with tools such as BRANZVENT [22].

Pre-installation conditioning of materials has been cited as a beneficial control technique. Prior to installation, components such as carpet should preferably be unrolled and aired off-site, and not wrapped in a plastic bag from the time of manufacture to allow free VOCs to be released outside of the new home or renovated home. Further new construction materials can be aired in situ to allow VOC emissions to reduce to acceptable levels before the space is occupied. However this can run contrary to human nature to want to move into a new home as soon as it is completed and financial constraints to afford alternative accommodation while the house airs out.

The ventilation characteristics and adsorption/desorption characteristics of materials determine the removal of VOCs. General ventilation is not a panacea for strong VOC sources in homes(Liddament, 2000). It is possible to have a building with an excess of 4 air changes per hour (ACH) of outdoor air and still have air quality problems if there are strong indoor sources [52]. Obviously homes with 4 ACH would be considered excessively draughty in winter and be very difficult to keep warm.

5.1.7 General Dilution Ventilation

General dilution ventilation is the most common, and frequently the only, contaminant removal measure employed in homes. The general ventilation theory states that under static or constant emissions of contaminants, a 50% decrease in the concentration can be achieved from doubling the ventilation rate. A further 25% reduction of the original value can be achieved by a further doubling of the air volume. The theory states that the converse should also be true [30, 52].

However, it has been found that general dilution ventilation is not as effective as the theory predicts [52]. As discussed previously, emissions of VOCs vary in response to environmental conditions such as temperature, relative humidity and ventilation rates, and this confounds the applicability of dilution theory to the removal of VOCs.

Depending on the conditions, VOCs may continue to be emitted from building materials until the vapour pressure from solvents and other chemicals in the materials has reached equilibrium.

This can take up to two years from the time of construction, and ventilation rates should be held at high levels until the chemical concentrations have receded [30](Levin, 1996; Levin & Hodgson, 1996).

If only one part of a building has been fitted with VOC-emitting materials, as would be the case with renovations or redecoration of one part of the home, care needs to be taken to prevent air cross-contamination from this area to other parts of the building or other sink materials. Windows should be opened in this area and internal doors closed until VOC levels have reduced. This is an important consideration from renovation of existing homes.

5.1.8 Building Bake Out

Building bake out has been suggested to accelerate the emission of VOCs [54]. Building bake out is the practice of raising the indoor air temperature of a newly completed building for several weeks prior to occupation. This is very energy intensive, and the high temperatures can cause damage to some building materials. Experience has also shown that bake out simply tends to drive VOCs from one material to another, rather than permanently eliminating them from the building [54]. Levin found that although VOC levels were initially significantly reduced, they rose again when the vapour pressure of the VOC in the sink material altered. Controlling contaminants by bake out is no longer considered to be an effective remedy for removing the emissions from high VOC materials

5.1.9 Air Cleaners

Air cleaners can be used to reduce VOCs from the indoor air [55]. Activated charcoal filters are the most commonly used. Charcoal filters can be designed to remove most VOCs or specific chemicals. Filter specification is a problem as there are no standard methods for testing and ranking chemical filter performance. The weight of the charcoal or carbon filter gives a very rough assessment of the capacity for the filter to absorb VOCs. The maximum absorbency is approximately 20%, that is, 100g of charcoal can remove only 20g of VOCs from the air. There are currently no standard approval methods for testing the performance or replacement requirements of activated charcoal air cleaners.

Some species of plants are able to absorb quantities of VOCs from the air and lock them into their root structure. However, to rely entirely on plants for air cleaning would require a large quantity of plants. Depending on the maintenance regime, living plants may also be a source of contamination either through the application of pesticides or by microbial propagation in wet soil and surrounding materials caused by incorrect watering.

Although a multitude of VOCs maybe present in the home environment, for the sake of brevity only the main VOCs are discussed in this report. Formaldehyde and benzene are VOC’s that has been identified very frequently as compounds of concern both for the health effects and the frequency that they are found in homes [56] .

5.2 Formaldehyde

Extensive reviews of formaldehyde emissions sources have been published by the several agencies [32, 43, 55, 57-61].

Research from Europe, Australia and Canada have identified formaldehyde as a indoor pollutant of significant concern [58, 60]. It is both ubiquitous in homes and a toxic compound. Results from studies carried out in Canada since the early 1990s consistently indicate that formaldehyde concentrations in Canadian homes range between 2.5 and 88 $\mu g/m^3$ with an average between 30 and 40 $\mu g/m^3$ [62]. ENVIE, which is a major European collaborative research consortium on indoor air quality has identified formaldehyde as one of the top five indoor pollutants both for frequency found and adverse health effects [45].

Australia recently released the Formaldehyde Priority Existing Chemical Assessment Report 28 [56] which has found formaldehyde a chemical of concern on health grounds and as it is frequently found at concentrations of concern in homes, especially new homes and mobile homes.

Canada has also classed formaldehyde as a "toxic" substance that is "entering the Canadian environment in a quantity or concentration that constitutes or may constitute a danger for the environment on which life depends and a danger in Canada to human life or health" [62]. Health Canada recently revised its indoor air quality guideline for formaldehyde, based on the most recent scientific evidence. A short-term exposure limit has been set at 123 µg/m3 (0.1 ppm) in order to provide protection from irritation, and a long-term exposure limit has been set at 50 µg/m3 (0.04 ppm) to prevent chronic respiratory symptoms [63].

No comprehensive research has been conducted on formaldehyde levels in New Zealand homes, however it was one of the compounds that was measured in the Housing, Heating and Health field trial and formaldehyde was found in some homes at concentrations in excess of the WHO guidelines. It appeared the source was new (that is less than 2 years) construction materials, and unflued gas heaters. However, more research is required to apportion the sources and typical concentrations in New Zealand homes.

Formaldehyde is a frequent component of carpet, foam insulation, furniture, upholstery, and as a binder in plywood and wood particle products. It is also a by-product of combustion such as tobacco smoke and unflued gas heaters or cookers. It can be emitted by some high heat cooking methods such as frying and many personal care products such as hair spray. The major sources of formaldehyde in homes include furniture, and joinery made from particle board products (medium density fibreboard, particleboard, and plywood).Formaldehyde can also be released from acid cured finishes on wood and some paints(Godish, 1995).

Formaldehyde can have health effects that vary depending on exposure and an individual's sensitivities from acute nausea, eye irritation, skin irritation, and respiratory impairment. Longer term effects can include voice loss, and it is potentially carcinogenic.

Concentrations in the home can be reduced by careful selection of material, airing new materials in a warm dry warehouse prior to installation in the home and ventilation with clean outdoor air.

Table 1: Health Canada residential indoor air quality guideline values for formaldehyde;

Guideline value	Time period
123 µg/m3 (0.1 ppm)	short term mean exposure
50 µg/m3 (0.04 ppm)	long term mean exposure

5.3 Benzene

A longitudinal New Zealand study found that urban concentrations of ambient benzene were well within guideline values, except in areas with traffic congestion [64]. However it is produced inside homes from environmental tobacco smoke (ETS) and unflued gas heaters. Abnormally high concentrations of formaldehyde and benzene have been found during the burning of incense [25].

6 Other gas phase pollutants

Gaseous pollutants, such as nitrogen dioxide and carbon monoxide, are also found in many New Zealand homes at concentrations in excess of health guidelines, and are caused by incomplete or unflued combustion from heaters, tobacco smoke and vehicles. Combustion processes also can produce halogenated dioxins especially at low burning temperatures. Halogenated dioxins have received much less research attention than other combustion products.

6.1 Carbon Monoxide

High levels of carbon monoxide are poisonous to humans, as it binds with haemoglobins in blood 1.8 times more readily than oxygen and therefore reduces the amount of oxygen carried by haemoglobin around the body in red blood cells. Increased levels of carbon monoxide. The result is that vital organs, such as the brain, nervous tissues and the heart, do not receive enough oxygen to work properly. High levels can lead to asphyxiation. Carbon monoxide affects both healthy and unhealthy people.

No more than 2.5% of haemoglobin can be bound to carbon monoxide before some health effects become noticeable. At very high concentrations of carbon monoxide, up to 40% of the haemoglobin can be bound to carbon monoxide in this way. This level will almost certainly kill humans.

For healthy people, the most likely impact of a small increase in the level of carbon monoxide is that they will have trouble concentrating. Some people might become a bit clumsy as their coordination is affected, and they could get tired more easily. It is now known that headache and nausea as a result of exposure to concentrations of carbon monoxide can be long lasting effects; this is contrary to previous medical theory [26].

People with heart problems are likely to suffer from more frequent and longer angina attacks, and they would be at greater risk of heart attack. Children and fetuses are particularly at risk because they are smaller and their bodies are still growing and developing [24].

It cannot be detected by humans as it has no taste or smell and cannot be seen, however sensors similar to smoke detectors are mandatory in some States of America.

The natural concentration of carbon monoxide in air is around 0.2 parts per million (ppm), which is not harmful to humans. Natural sources of carbon monoxide include volcanoes and forest fires. The main sources of additional carbon monoxide are motor vehicle exhaust and industrial activities involving combustion such as smelters. Tobacco smoke is one of the main indoor sources of carbon monoxide in homes [65]. The use of unflued gas appliances, open fireplaces and operation of cars inside internal garages are also indoor sources of carbon monoxide.

In most New Zealand towns and cities, the levels of carbon monoxide in ambient air are below levels that are hazardous for human health. A few neighboorhoods have the potential to have harmful levels of carbon monoxide. The New Zealand Government has recently brought in National Environmental Protection Measures for carbon monoxide and efforts to reduce carbon monoxide from ambient air include:

- Implementing national fuel quality standards;
- Promoting alternative fuels; and
- Supporting the implementation of tighter vehicle emission standards.

One of the aims of the National Air Quality Strategy is to keep the concentration of carbon monoxide in the ambient air to less than 9 ppm (measured over eight hours) by the year 2008. This aim was largely achieved ahead of the 2008 goal, demonstrating that the steps taken to limit sources of carbon monoxide have been successful. Despite extensive monitoring few exceedences of CO are measured in ambient air, however there are many exceedences of this standard inside New Zealand homes [47].

Table 2: WHO guideline values for carbon monoxide

Guideline value	Time period
100 $\mu g/m^3$	15 min mean
60 $\mu g/m^3$	30 min mean
30 $\mu g/m^3$	1-hour mean
10 $\mu g/m^3$	8-hour mean

6.2 Nitrogen dioxide

Nitrogen dioxide is a nasty-smelling gas. Some nitrogen dioxide is formed naturally in the atmosphere by lightning and some is produced by plants, soil and water. However, only about 1% of the total amount of nitrogen dioxide found in our cities' air is formed this way. Nitrogen dioxide is an important air pollutant because it contributes to the formation of photochemical smog, which can have significant impacts on human health.

A major source of nitrogen dioxide is the burning of fossil fuels: coal, oil and gas. Most of the nitrogen dioxide in cities comes from motor vehicle exhaust (about 80%). Other sources of nitrogen dioxide are petrol and metal refining, electricity generation from coal-fired power stations, other manufacturing industries and food processing. Indoor levels of nitrogen dioxide can be elevated in houses located near major roads even when there are no indoor sources.

The main effect of breathing in raised levels of nitrogen dioxide is the increased likelihood of respiratory problems. Nitrogen dioxide inflames the lining of the lungs, and it can reduce immunity to lung infections. This can cause problems such as wheezing, coughing, colds, flu and bronchitis. It can increase the severity and duration of a flu episode. Recent indoor studies have found adverse respiratory effects for infants even at levels below 40 $\mu g/m^3$ [33].

Increased levels of nitrogen dioxide can have significant impacts on people with asthma because it can cause more frequent and more intense attacks. Children with asthma and older people with heart disease are most at risk. Nitrogen dioxide is also a modifier on the health effects from particulates. It appears that where nitrogen dioxide concentrations are high as would occur from emissions produced by unflued gas appliances, then the health effects from particles are greater than would be expected if nitrogen dioxide was not present [26]. The mechanism for this effect modification is as yet unknown.

Unflued gas space heaters, cookers and unflued gas water heaters are the major sources of nitrogen dioxide in homes. It is estimated that there are approximately 300,000 New Zealand homes with an unflued gas space heater. The age and condition of these heaters is highly variable, and a recent study, conducted by He Kainga Oranga Healthy Homes Research Group, which is in the process of being published, found peak levels of nitrogen dioxide in homes using an unflued gas heater to be up to five and a half times higher than WHO guidelines. These peaks were found to occur within an hour of turning the heater on and every time the heater was operated. Of equal concern was that although the nitrogen dioxide concentration quickly decayed, the minimum background level was still elevated above the annual mean guideline value suggesting there a sink and re-emission process was occurring. There were also significant health benefits achieved from switching to a non polluting heater. Estimates suggest that only 50,000 unflued gas heaters are serviced per annum and a lack of servicing could exacerbate the production of combustion by-products. Few users of unflued gas heaters will open a window for ventilation when they operate their unflued gas heater (which is usually the manufacturers instructions) as this is counter intuitive to space heating.

Table 3: WHO guideline values for nitrogen dioxide

Guideline value	Time period
200 μg/m^3	1-hour mean
150 μg/m^3	24-hour mean
40 μg/m^3	annual mean

6.3 Sulphur Dioxide

Sulphur dioxide irritates the eyes, nose, and the respiratory tract at low levels of exposure. At high levels, it causes the lung airways to narrow. This results in chest tightness, wheezing, or breathing problems. Chamber studies have found that exercising asthmatics have experienced lowered lung function and chest tightness in 10 minutes of exposure to sulphur dioxide.

Table 4: WHO guideline values for sulphur dioxide;

Guideline value	Timer period
500 μg/m^3	10 minute mean.
350 μg/m^3	1 hour mean
20 μg/m^3	24-hour mean

6.4 Ozone

Ozone in the ambient air is rarely found in New Zealand at concentrations of concern. Ozone is formed in the presence of sunlight with precursor pollutants such as oxides of nitrogen and volatile organic compounds. Measures to control precursors pollutants are often also be effective in controlling ozone. Ozone has a short half life and will rapidly decay.

Ozone will cause air way inflammation and reduced lung function in healthy adults and asthmatics. There are concerns about increased respiratory morbidity in children exposed to ozone.

Several air cleaners, such as ionisers, marketed for domestic use can generate ozone as a byproduct or primary agent. There are no legislative restrictions on the sale of these appliances. Some mould remediation companies in Australia routinely use ozone fogging, which can be useful as part of a full mould remediation process to eradicate fungi in hard to reach places of a home, however it is important that ozone levels have decayed to below acceptable levels before the home is re-entered.

The WHO guideline level for ozone is 100 μg/m^3 8-hour mean

7 Particles and Ultra-fine Particles

Particles are formed by incomplete combustion by-products, vehicle emissions, especially diesel vehicles, as well as fragments of biological origin (fungi and fungal fragments), cellulose fibreglass and asbestos. Particles of diameter of less than 10 micrometers (µm) are called PM_{10}. These are considered as respirable as they are sufficiently small to bypass hairs in the human airways. They can be deposited in the nose, throat or lungs. They are fine enough to penetrate buildings and many filtration systems. These typically originate from construction activities, tobacco smoking, resuspended road dust, and wind erosion. Even finer particles are called $PM_{2.5}$ and consist of particles less than 2.5 micrometers. These are produced by combustion processes such as vehicle exhausts. $PM_{2.5}$ can bypass filtration by the airways and lung and travel directly into the blood stream.

Recently a new class of particles, 'ultra fine particles', has become the focus of research interest through the world. Ultra fine particles are generally considered to have a diameter less than 0.1micrometer (µm). They are found both in outdoor and indoor environment and are giving rise to growing concern. In the ambient environment they are generated from primary sources such as combustion processes – power stations and vehicle exhausts, or are formed by nucleation and condensation processes known as secondary reactions. In homes, ultra fine particles are thought to be generated by processes such as gas cooking.

Particulates can cause eye, nose, throat, and lung irritation, and can increase respiratory problems, especially in people with pre-existing medical conditions, such as cardiovascular illness and immune system diseases. There is extensive evidence linking PM_{10} with premature death and increased levels of hospitalisation due to a wide range of health effects including coughing, wheezing, reduced lung function, asthma, chronic obstructive pulmonary disease (COPD) lung cancer, heart attacks, strokes and high blood pressure. Long term chronic health effects are up to 15 times more consequential than short term acute effects [66].

Certain chemicals attached to the particles may cause lung cancer if they are inhaled. The risk of lung cancer increases with the length and amount of exposure. The health effects from inhaling particles depend on many factors, including the chemical makeup and size of the particles. People with cardiovascular disease are more vulnerable to particulates [34].

Studies have found high concentration of ambient particulates originating from traffic can extend 500m from a major road way [67]. These ambient particles could well penetrate housing, however, this hasn't been studied in New Zealand. New (to New Zealand) land use patterns are seeing high rise buildings of apartments being developed near major roadways. The Auckland Regional Council has concerns that this will lead to pockets of particulates generated by traffic and a canyon effect concentrating particles outside and potentially inside apartments.

There are no threshold levels for particulates below which adverse health effects are avoided [34]. The WHO have stressed that the guideline values given in the 1995 global update are not sufficient to fully protect human health.

Several studies have found adverse health effects in environments with both particulates and other gas phase pollutants with the health effects observable at exposure levels lower than would be predicted if only one class of pollutants was present. This suggests that particles, which have very large surface areas relative to their total mass can absorb gas phase pollutants on to their surface and behave as carriers of gaseous pollutants into the lungs, where the residence time of the pollutant may be longer than if it was just inhaled and exhaled as a gas. This may cause airway sensitisation in susceptible individuals. Due to their large surface area they readily adsorb other compounds on their surface. It has been estimated that particles that have originated from combustion process may have 18,000 different combustion products attached to a carbon core (Auckland Regional Council, 2007). These products can include polyaromatics, nitroaromatics, and aliphatic hydrocarbons as well as heavy metals such as chromium copper and nickel.

Exposure to particles has been associated with both acute and chronic health effects. Concerns about these effects have been derived primarily from epidemiological studies showing an association between increases in particle concentration and an increase in daily mortality. Although there have been numerous epidemiology studies into the health implications of particulate matter, there is little evidence to assess the long term exposure and the particle characteristics associated with the health effects.

Very limited data exists on the levels of particulate generation in indoor environment and there is a growing need for such information in order to establish possible links that may exist between indoor activities and consequent health effects.

Particles may also abrade from building materials and furnishings, which can be of concern if the source material is a compound with some toxicity risk. This can include phthalates from PVC IScher, 2007) . House dust can be a long term sink, however particles are typically too large for respiration, apart from a small fraction [48, 68, 69] . A strong source of particles in the home is residues of laundry detergents that have broken off laundered clothes and bedding. These particles can represent a health risk as they frequently contain florescent compounds and enzymes that can be irritants [44].

Table 5: Guideline values established for PM10 and PM 2.5 by the WHO [34]

Guideline values	Time period
$PM_{2.5}$	10 μg/m^3 annual mean
$PM_{2.5}$	25 μg/m^3 24-hour mean
PM_{10}	20 μg/m^3 annual mean
PM_{10}	50 μg/m^3 24-hour mean
ultrafine particulate matter	No guidelines are currently available

7.2 Combustion products

All unflued combustion process will release particulates into the indoor environment. Unvented combustion in the home, from heaters, gas cookers, tobacco smoke, attached garages and the burning of incense has been repeatedly found to be the dominant sources of combustion products.

Unvented space and water heaters and gas cookers will be the dominant source of nitrogen dioxide and carbon monoxide in the home. These emissions can be at concentrations more than two fold in excess of health based guidelines. Unflued gas heaters can also produce benzene, sulphur dioxide, carbon dioxide, butadiene,, PAH's, fine particulates and formaldehyde at lower concentrations.

Nitrogen dioxide is often used as a surrogate for other combustion products as it is one of the easier to measure. However, frequently nitrogen dioxide is accompanied by fine and ultrafine particles, and ozone and other photochemically generated oxidants [33]. A reduction in nitrogen dioxide to levels below 110ppb will also give a reduction in other combustion products, consequently the health benefit is greater than would be expected from a reduction in toxicity of nitrogen dioxide alone.

Gas cookers produce lower emissions of chemical compounds than unflued heaters but the emissions are produced very close to the cook's breathing zone. This will give a high personal exposure unless a range hood is used. The effectiveness of rangehoods is a topic worthy of further research. Unvented space heaters also produce copious quantities of moisture which will feed the growth of fungi, dustmites and insects. These biological contaminants will produce a range of odours and substances which are discussed in the following section.

Environmental tobacco smoke (ETS) is the primary source of benzene, fine and ultrafine particles in homes with smoking indoors. ETS also contains formaldehyde in addition to several hundred other compounds, many of which are toxic. Although it is not possible or politically correct to regulate the home environment, initiatives that lead to smoking cessation or at least avoidance of smoking in the home environment will be of considerable benefit to the indoor environment. ETS or passive smoking has been associated with coronary disease, sensory irritation and respiratory symptoms including asthma [65]. Children exposed to ETS have a higher incidence of sudden infant death syndrome and middle ear infections than children without exposure to ETS.

Vehicle emissions can be communicated to other parts of the house from attached garages. These emissions can include nitrogen dioxide, carbon monoxide, and particulates. One study found that vehicle emissions resided in the home for around eight hours and concentrations had typically only just decayed to acceptable levels when another vehicle event redosed the house. The effectiveness of extract fans or passive vents for removing vehicle emissions is a topic deserving further study.

8 Biological contaminants

Biological contaminants are alive or once were living organisms. They can cause poor indoor air quality and some can deteriorate the building's surfaces and structure. These contaminants have evolved to readily travel through the air and are often invisible to the naked eye and difficult to detect, identify or quantify.

Common indoor biological contaminants include bacteria, fungi, viruses, animal dander and cat saliva, house dust mites, cockroaches, rodent excrement and pollen. There are many sources of these pollutants:

- Bacteria are carried by people, animals, and soil and plant debris.
- Fungi are readily airborne and can carried by air currents, people and animals
- Viruses are transmitted by people and animals.
- Pollens originate from plants and can be carried by air currents.
- Dustmites are commonly found and it is thought that even new mattresses and bedding can be inoculated with parent material prior to purchase.

High levels of microbiological contaminants, such as fungi and dustmites are found in nearly half of New Zealand homes. There are always sufficient nutrients for fungi, dustmites and bacteria to grow even in the cleanest homes. Further, suitable parent material for inoculation is a natural part of ecology and these organisms like the temperatures that are typically found in homes. Consequently the only factor that will limit their germination and growth is moisture availability. Homes with a leaky envelope or that are cold and damp will inevitably be host to fungi and dustmites and possibly bacteria.

Sufficient available moisture can be found in many locations, such as bathrooms, damp or flooded basements, wet appliances (drainage trays from dehumidifiers and air conditioners), and some carpets and furniture. Fungi and bacteria can grow in contaminated central air handling systems. These systems can directly distribute the contaminants through the home and need regular maintenance.

The health effects experienced will depend on an individual's sensitivities, exposure and the species of the microbial contaminant but can range from allergy, asthma and some fungi species are toxic or carcinogenic.

Many health effects are associated with biological contaminants:

- Some may trigger allergic reactions, including hypersensitivity pneumonitis, allergic rhinitis, and some types of asthma. Allergic reactions occur only after repeated exposure to a specific biological allergen. However, that reaction may occur immediately upon re-exposure or after multiple exposures over time. As a result, people who have noticed only mild allergic reactions, or none at all, may suddenly find themselves very sensitive to particular allergens.

- Infectious diseases, such as influenza, measles, tuberculosis, and chicken pox, are transmitted through the air.
- Symptoms of exposure to biological contaminants include sneezing, watery eyes, coughing, and shortness of breath, dizziness, lethargy, fever, and digestive problems. Children, elderly people, and people with breathing problems, allergies, and lung diseases are particularly susceptible to disease-causing biological agents in the indoor air.

Correct remediation of past moisture and fungi events is a critical step in restoring a healthy indoor environment after a water event but this is not a service readily available in New Zealand. Control and remediation of fungi is a massive industry, in many parts of the world, especially America, however this industry is in its infancy in New Zealand.

Exposure can be reduced to biological contaminants in several ways:

- Install and use exhaust fans that are vented to the outdoors in kitchens and bathrooms. Vent clothes dryer air to the outdoors.
- Keep the relative humidity level of the house between 40 to 60 percent. Dry off wet surfaces such as wipe down shower walls after a shower and correct water problems.
- Thoroughly clean and dry water-damaged carpets and porous building materials (within 24 hours if possible) or consider removal and replacement.
- Dust mites, pollens, animal dander, and other allergy-causing agents can be reduced, although not eliminated, through regular cleaning. Thorough vacuuming with a vacuum cleaner fitted with a High Efficiency Particulate Arrestance (HEPA) rated filter will reduce recirculation of particles.
- Passive ventilate the ceiling cavity and subfloor to prevent moisture build up. Install site drainage to direct storm water away from the house and lay a vapour barrier on top of the ground in the subfloor crawl space.
- Take steps to minimize biological pollutants in basements. Regularly clean and disinfect any basement floor drain. If needed, use a dehumidifier to keep relative humidity levels between 40 to 60 percent.

8.1 Fungi

Fungi growth affects about 40% of New Zealand homes and this can pose a significant health risk to the occupants. Health risks depend on exposure and, for asthma symptoms, on allergic sensitization. A dose-response relationship has been found between the extent of fungi contamination and health effects. Adverse health effects are primarily associated with the respiratory system and can include irritation of the mucous membranes and respiratory symptoms. However, more general symptoms can also be observed such as fever, fatigue, headache and difficulties concentrating and infections. Permanent diseases such as asthma, allergy or aspergillosis are also possible [70]. New Zealand has one of the highest rates of asthma in the world and asthma triggers are of particular concern to this country. Some clusters of cases of sarcoidosis, rheumatoid diseases and pulmonary haemorrhage among infants have been reported [71].

However, the large number of mould species and strains growing in buildings and the large inter-individual variability in human response to mould exposure preclude the derivation of exposure limits. Currently there are no standards for mould, however, Health Canada has recently released an annex on Residential indoor air quality guideline for mould. This represents a significant advancement in control of mould in buildings [72].

Health Canada considers that mould growth in residential buildings may pose a health hazard. Therefore, Health Canada recommends: to control humidity and diligently repair any water damage in residences to prevent mould growth; and to clean thoroughly any visible or concealed mould growing in residential buildings. These recommendations apply regardless of the mould species found to be growing in the building. The Housing Insulation and Health study found that increasing the temperature in New Zealand homes by only 1 ^{o}C to 12.7 ^{o}C significantly reduced the number of hours that the indoor relative humidity was in excess of 75%. It is possibly that insulating and warming homes in winter to required 18 ^{o}C mean minimum could make reduce the incidence of dampness and fungi in New Zealand homes during winter and this is worthy of further study.

Fungi produce, airborne spores and fungal by-products; endotoxins, mycotoxins and microbially generated volatile organic compounds. Some moulds can release disease-causing toxins. These toxins can damage a variety of organs and tissues in the body, including the liver, central nervous system, digestive tract, and immune system. Some diseases, like humidifier fever, can be traced to microorganisms that grow in home heating and cooling systems, although it is not certain whether the disease is an allergic reaction or a toxic response.

Counts of fungal spores are frequently elevated inside homes air. As such, moulds and their antigens represent a major source of air contamination and potential human inhalation exposure. The health effects from fungi are of great consequence to IAQ. Fungi can produce toxic products and evoke symptom response through a number of physiological mechanisms [73].

Typically 6% - 15% of the population become sensitised to the antigens from the spores of fungi and develop allergic-type reactions [38](Miller, 1992). The likelihood of developing an allergy to fungi is related to the time and quantity of exposure. Allergy reactions - such as sore throats, coughs, bronchitis and wheezing - frequently affect the respiratory system, and can also cause eye and skin irritation, ear infections and headache. Once a person has sensitised they can react at relatively low exposure even across different species of moulds.

Fungi species typically found in homes include *Aspergillus, Penicillium, Alternaria* and *Cladosporium*. The *Aspergillus* genus of *A. fumigates, A. terrus* and *A. flavos* can cause a condition known as aspergillosis. Aspergillosis is a serious and invasive lung disease that is particularly difficult to treat. Personal characteristics and certain kinds of medication influence susceptibility to this pathogen [39, 74, 75].

Stachybotrys Chartarum is a fungi found in environments with a high water availability, such as leaky buildings. It is also difficult to detect with traditional viable sampling methods so if frequently underestimated in building assessments unless a non viable sampling method is also conducted. *S. chartarum* has been linked to building-related respiratory problems including pulmonary haemorrhage in infants. The macrocyclic trichothecenes produced by *S. chartarum* have been the primary focus of many investigations. However, in addition to trichothecenes this fungus is capable of producing other secondary metabolites and a number of protein factors that could potentially also have adverse health effects [94].

8.1.1 Conditions for Fungal Growth

Spore counts in non-contaminated buildings can vary between 0 - $10^4/m^3$ per species [71]. Fungal spore counts in buildings with natural ventilation often emulate the spore count in outdoor air. Fully air conditioned buildings, with well maintained systems can have viable mould counts that are lower than outdoor levels. However, there are many sites where amplification of fungi can occur within homes.

Any combination of moisture (including high relative humidity) and organic dust can provide an ideal site for fungi propagation. Humidity greater than 70% is optimum for fungi growth; however, most species can tolerate lower water availability if temperatures are warm. There can be sufficient water present in a substrate to support microbial growth even if the moisture is not visible or the relative humidity is low [71]. Fungi can grow at very low ambient relative humidity levels if there is moisture available within the host material. Therefore, sites with repeated or persistent condensation and leaks should be considered as being at risk of fungi colonisation.

Nutrients are not a limiting factor in homes, as there is always sufficient organic material to supply the nutrient requirements of fungi. To maintain a home to the level of cleanliness such that nutrients were a limiting factor in fungal growth, the home would need to be as clean as an industrial clean room which is clearly not possible. Treating fungi with biocides without the removal of the dead fungal material leaves an excellent nutrient source for subsequent colonies [74].

The optimum temperature for fungi propagation is 20-30 C°, however, some species can survive in a broader range of 10-40 C°. There is an overlap between the thermal conditions suitable for fungi and those found in homes. (Pasanen et al., 1991)[76] found that temperature was not a limiting factor on the growth of fungi on building materials as they could grow at temperatures below 10 C°. Lower indoor temperatures may limit germination of new fungal colonies (Boulic, 2007). Douwes et al studied β(1-3) – glucan levels in house dust and found no correlation with either room temperature or relative humidity [77]. Douwes and Boulic both concluded that environmental parameters measured in the centre of a room are poor indicators of the condensation potential on poorly insulated materials. They confirmed prior knowledge that the temperature of a surface, and hence its condensation potential, is a more critical factor.

The nutrient supply, water replenishment, temperature, and the presence of other organisms influence the growth of fungi and moulds in liquids, such as those found in humidifiers and condensate trays. Unless limited by the application of biocides, bacteria and yeasts have a faster growth rate than fungi, and will scavenge nutrients from the liquid medium. This will inhibit fungal growth, unless large amounts of complex organic matter are also present [38].

Many species of fungi are capable of producing very large quantities of spores in a short period. Most fungal spores are in the 2 - 100 micron range. They are readily airborne, making them cause significant reactions in the mucous membranes and respiratory system. Their wide variations in size and shape will cause a wide range in the length of time they will remain airborne following disturbance. Spores of *Aspergillus* and *Penicillium* can remain viable for more than twelve years in typical home conditions [38]. Consequently there are always viable spores present in a home, which can amplify when conditions, namely sufficient moisture, are present.

Some moulds have the physiological properties to grow on almost any material, provided there is sufficient water. This can include glass, petroleum products, paint, rubber, textiles and electrical equipment [38]. The presence of viable microbial spores on building substrates is normal and inevitable.

Limiting available moisture is widely considered as the best option for controlling fungi growth. Control of fungi with biocides is not recommended as this does not remove dead but still allergenic fragments from the environment. Biocides can also be harmful to the occupants.

8.1.2 Sources of Fungi and Dissemination

8.1.2.1 Outdoor Sources of Fungi

Most fungi produce spores that are designed to become airborne and transported on air currents. Consequently the outdoor air has an abundant source of fungal spores and outdoor air is the primary source of all microbial growth. The types and concentrations vary with seasonal, diurnal and geographic factors. These spores can freely penetrate through the building envelope through open windows and doors, and mechanical air intakes: they can also infiltrate through small penetrations as well as being carried into the home on clothing and footwear.

Outdoor levels are highest near ground level, where dense vegetation or piles of leaf litter are close to the building. Openings in the building envelope near these sources represent an increased risk of contamination within the building. Lakes, streams and wetlands in the immediate vicinity have not been found to be a risk factor for microbial contamination. However, birds roosting in areas close to any penetration of the building envelope can be a focus for fungi and other allergenic matter.

8.1.2.2 Indoor Sources of Fungi

Fungi can proliferate almost anywhere in and around the home environment where there is a source of moisture and nutrients. Frequently colonised sites include porous insulation and building materials that has become wet from leaks, condensation, or flooding. Areas where there is the potential for dampness, such as basements, kitchens and bathrooms or condensation-prone areas should be regarded as a potentially strong source of bioaerosol [39]. The current trend to install swimming pools and water features immediately adjacent to the home should be regarded as a potential risk factor.

The building dynamics which contribute to the formation of condensation are varied. Areas of the building envelope with thermal bridging, where warm air comes into contact with an uninsulated area of the building envelope, are common sites for fungi to colonise [39].

The stack effect also indirectly contributes to condensation during periods of cool weather. While the stack effect is not a significant driving force in low rise New Zealand housing, it is an issues with medium to high rise [22]. When warm indoor air exfiltrates through the construction at the upper levels, interstitial condensation can occur as the water vapour contained in the air cools below the dew point within the wall cavity. The extent of the condensation depends on the quantity and initial moisture of the airflow, and the temperature gradient within the construction. Condensation from exfiltrating air increases with building height, indoor air humidity and cooler winter temperatures.

There are no guideline values available for fungi.

8.2 Bacteria and viruses

Bacteria levels in New Zealand homes have received little research attention and it is impossible to draw conclusions on the extent of these as a problem. Baker et al [78] found higher levels of certain bacteria diseases were associated with overcrowding. Jackie McIntosh from Victoria University's School of Architecture has found bacteria level in Wellington primary schools are second only to levels found in sewage treatment plants. This study has not been published yet. While it is difficult to draw comparisons between the bacteria counts found in classroom and homes it could be surmised that there will be cross contamination between the school environment and home.

The SARS outbreak focused the attention of building designers and services engineers as it was found that certain building features facilitated the communication of the virus among apartment dwellers with no physical contact. In a Hong Kong apartment building the epidemic started when the viruses found their way through poorly constructed sewage systems with dry water traps and poor bathroom ventilation. According to the studies conducted afterwards the ventilation and sewage systems had had the water seal traps dried out which allowed air contaminated with the SARS virus to move between units. The effect on indoor quality and the people living in, and visiting the building, were fatal. Simple devices to prime the waste traps with water could have curtailed the spread of the virus.

Like fungi the best opportunity to control bacteria growth in a home is to control moisture, however bacteria require higher moisture contents than fungi to remain viable. Water traps, condensation trays in dehumidifiers, shower heads etc are wet places where bacteria can grow. These need regular cleaning and drying. Research conducted by ESR has found that bacteria can grow in hot water cylinders that are maintained at a temperature under 60 ^{o}C. To control bacteria it is recommended that the thermostat in hot water cylinders be set to 60 ^{o}C and a tempering valve installed in the hot water supply line to cool hot water to safe temperatures. Monitoring should be undertaken to insure that solar heated hot water cylinders are heated to 60 ^{o}C for some period of most days to control bacteria such as *Legionella*.

There are no guideline values available for bacteria.

8.3 Dustmites

Dustmites are another contaminate frequently found in NZ homes. Health effects from microbiological agents can include exacerbation of asthma and allergy, respiratory conditions, skin irritation, headache and other malaise. Dustmite faeces are highly allergenic and many people with asthma also test positive to dustmites skin prick tests.

There are on average 6 million dustmites in a double mattress and 20% of the weight of a ten year old pillow can be dustmite faeces [79]. They are also found in carpet, floor dust on hard flooring. They are difficult to control in New Zealand's moist climate as they only require an environment with 1 hour out 24 hours with a high relative humidity to be fully hydrated. Male dustmites will huddle around a breeding female dustmite to protect her from dehydration. It is postulated that they feed on fungal matter in addition to dead skin scales, which could mean the two populations have symbiotic affects. The psychometric properties of microenvironments that support the growth of fungi could also support dustmites and this is an area requiring further research. Some of this is currently being conducted at BRANZ.

Source control of moisture can also be assistance to reducing dustmites. Turning back bedding for an hour or two after getting up can allow moisture from bedding (which can have a RH up to 95%) to evaporate. Placing pillows in the freezer once per week will kill dustmite populations but not remove existing dustmite debris or allergenic material. Thorough vacuum cleaning with a powerful vacuum cleaner fitted with HEPA filtration or a central vacuum cleaner system will assist to remove live mites and debris. Reducing the moisture in microclimates is considered to be a key priority for controlling dustmites [80] Replacing carpets with hard flooring has been widely debated and there are advantages and disadvantages for both types of flooring. Dustmites can still survive in the dust found in accumulated dust such as under furniture in rooms with hard flooring surfaces.

There are no guideline values available for dustmites.

8.4 Invertebrates and rodents

The protein in urine from cockroaches, rats and mice is a potent allergen. When it dries, it can become airborne and fine fragments can reside in the indoor environment for prolonged periods. Containment of wastes and food will assist in the control of rodents and invertebrates.

Temperature Heating, Filtration and Ventilation

New Zealand homes are often under ventilated and tightly sealed trapping in moisture which creates favourable conditions for the growth of fungi and dustmites. [The Healthy, Wealthy and Wise report by Morgan Williams during his term as the Parliamentary Commissioner for the Environment, addressed these issues.] The findings of the report were welcomed by the Energy Minister, Hon David Parker, who agreed with Dr William's findings that "cold, damp and poorly insulated houses make people ill more often, and we could save money on hospital bills by making sure our houses are healthier."[81]

Recent New Zealand research on Housing Insulation and Health [6] has shown that internal air temperature below 12 ^{o}C can have a significantly detrimental impact on health. The research showed even a 1 ^{o}C increase in indoor temperatures and small reduction in the number of hours per day that homes are exposed to relative humidity above 75% can result in improved health including, reduced hospital admissions and visits to the GP and fewer days absent from work or school. The cost of retrofitting ceiling cavity and underfloor insulation to an existing home is roughly equivalent to one nights stay in hospital; consequently there is a good value case for insulating homes.

Low indoor temperatures are also associated with an excess winter mortality of approximately 1600 New Zealanders per year [18].

Temperatures in New Zealand homes are frequently found to be 6 ^{o}C below the WHO minimum guideline temperature of 18 -24 ^{o}C. Cold homes are found across all socioeconomic groups [7].

A subsequent study to the Housing and Insulation study called the Housing, Heating and Health study also conducted by the University of Otago led Healthy Housing research group that compared small electric and unflued gas heaters (control group) with more effective larger heaters namely a heatpump, flued gas heater or wood pellet burner (intervention group) [46]. Preliminary statistically significant results include the intervention group having;

- The average temperature increased one degree.
- People self reported they felt warmer, which is possibly due to occupants being exposed to fewer hours of very low temperatures and fewer hours of high RH.
- Condensation was reduced.
- There was less mould and mouldy smells.
- Indoor levels of nitrogen dioxide were halved.
- Nitrogen dioxide was associated with coughing in children with asthma.
- Children with asthma reported less coughing and wheezing during the night and on waking. (This is one of the major symptoms of asthma.)
- Children reported fewer episodes of cold and 'flu.
- Children had on average three days less off school.
- Children had on average fewer visits to the GP.

Heating and energy efficiency measures can improve the indoor environment and also alleviate fuel poverty. The combination of greater warmth, improved air quality and reduced household expenditure on purchased energy may have a compounding effect to reduce symptoms. Previous studies indicate that warmer and less humid living conditions may improve health, but they also suggest that the health benefits for low income families may disappear if household expenditure increases.

Several studies assessing the impact on health of heating improvements are now near completion, including a large quasi-experimental evaluation of the Scottish Executive's central heating programme. These and the New Zealand study suggest that heating improvements may hold most promise for the development of an evidence base to inform healthy housing policy.

A recent (2004) review of evidence conducted by the World Health Organisation acknowledges ‘there is considerable evidence that housing conditions do affect health status’. While domestic heating may impact on residents' health via a number of routes, research on the physiological effects of cold environment suggests that low temperatures may be implicated in respiratory conditions and may be a risk factor for heart disease [82]http://eurpub.oxfordjournals.org/cgi/content/full/16/5/463?ijkey=e9256b31faffbb5948ab2714394404d5a9afe3a6 - B9#B9.

Low indoor temperatures may be caused by a number of factors, including poor thermal characteristics of the home and economic constraints on residents (low disposable household income and/or high fuel costs). Such constraints are now widely recognised and enshrined in the concept of fuel poverty[16]. The effects of fuel poverty on health in the United Kingdom are accepted in the Government's fuel poverty strategy. Evidence for an effect of fuel poverty on health within a European context has emerged from the WHO LARES study, initial findings from this project specifically identify fuel poverty as a factor associated with cardiovascular problems.

Filtration of indoor air is not routinely required or advocated, however there may be some circumstances when it is advisable to mitigate adverse air quality. There are two approaches to achieving filtered air which can both either be incorporated into new housing or retrofitted to existing. The first method uses in room filtration units which circulate the air inside the space through a filter or filters. These are readily available portable appliances. The second method is to positively pressurise the home with a supply of filtered air. The effectiveness of both these methods is dependent on the rating of the filter and many other properties. Filtration devices have the advantage of improving the quality indoor air in regions where the ambient air has a high level of contaminants. However the disadvantages include;

- Filters which haven’t been maintained can become a source of fungi and odour.
- Filtration systems require on going purchased energy, and the higher the efficiency of the filter the more energy is required to push the air thru the filter
- The effectiveness of filtration systems can be oversold and difficult to verify.

The airtightness for New Zealand homes has been measured and modelled by Mark Bassett from BRANZ who found that all homes constructed pre 1960's with strip timber floors and unsealed timber windows are defined as "draughty" and can have an hourly air change rate (ACH) of 0.9 ACH. Homes constructed post 1960's with complicated design and unsealed windows can have an ACH of 0.7 and are defined as air leaky. While post 1960's homes with a simpler design and sealed windows will have a lower infiltration rate of 0.5 ACH. Simple post 1960's rectangular, single storey homes, with airtight air sealed joinery can have air infiltration rates as low as 0.3 ACH. All these air change rates will be higher if the home has an open fire, and /or the home is constructed on an exposed site or high wind region. [Bassett, 2004]

From modelling ventilation rates in many homes for four city climates and measurement in a smaller number, Bassett concluded that for homes constructed in the two decades from 1962-1982;

- Approximately 90% of homes have sufficient ventilation to meet the air leakage area targets suggested by ASHRAE 119-1988 (RA94)
- Approximately 2% of homes constructed in this period would be sufficiently airtight to require full time mechanical ventilation
- The majority (87%) of homes would benefit from extract ventilation in wet areas
- The least air tight homes (11%) would have sufficient infiltration to not require any further ventilation. However the warmth of these leaky homes would be improved by increased airtightness.

Bassett found that for moisture control purposes extractor ventilators in kitchen and bathroom areas are more targeted and effective than house wide ventilation. He concluded that the most effective ventilation system in small New Zealand buildings (homes) will be a mix of mechanical and passive ventilation, each targeting a specific sources of contamination in the building. The strengths and weakness of this approach are summarised below.

The author of this report has identified a few more strengths and weaknesses that could be added to the above table. A strength of mechanical ventilation in some situations is that neighbourhoods that have a high level of outdoor air or noise pollution could in particular benefit from mechanical ventilation. Mechanical ventilation is also useful for periods when pollutants levels inside the home are elevated such as following renovations, redecoration or new constructions or when rapid cooling is required. Such events were excluded from the scope of the Bassett reported cited above. Also mechanical ventilation can be operated during periods when openable windows may need to be closed for security reasons. A further weakness of mechanical ventilation is the opportunities that these systems can create for the amplification for fungi and bacteria which is of particular concern where the amplification occurs in the supply airstream

Table 6:Strengths and weaknesses of passive and active ventilation in small buildings

[Source Bassett 2004]

Passive ventilation	**Mechanical ventilation**
Strengths	
Good at providing un-targeted background ventilation	Easily controlled to target a particular contaminant
Low cost at construction stage	Relatively inexpensive and easy to retrofit to existing buildings
Easily integrated with window hardware	Hardware, design and installation supported by an established industry
Minimal maintenance	Easily integrated with filtration, heat recovery and space conditioning
Weaknesses	
Difficult to control for a particular contaminating event	Maintenance is essential, particularly of filters
Not compatible with filters and heat recovery	There is an ongoing operational costs
Some problems attenuating sound from outdoors	Fan noise must be addressed
	Wind pressure must be considered in fan specification

EECA and some electricity suppliers have expressed concerns that increased reliance on air conditioning for rapid cooling could contribute to the 4-6pm peak electricity load. The hottest temperatures inside homes coincidences with the peak electricity supply load especially for many people coming home to a house that closed up all day. Shading, insulation and orientation of windows for control of summer sun and ventilation are methods that would be prioritised for achieving a HSS ahead of air conditioning for cooling.

Temperature inside a home should be maintained within the range of mean minimum of 18 ^{o}C to a mean maximum of 24 ^{o}C.

Relative humidity should be maintained within the range of 40-60% RH [83].

9 Noise

Noise pollution is also of concern especially as homes are constructed in noisier environments, like next to major transportation routes and in higher density.

Research shows that the effect of noise is much more than auditory. Noise stimulates the brain sending neural impulses to the higher cortex and through out the nervous system. Noise can therefore influence perceptual, motor and cognitive behaviours and also triggers glandular, cardiovascular and gastrointestinal changes by the means of the autonomic nervous system [84].

Hearing has evolved from our survival instincts to respond to danger as well as to alert, warn and communicate; our hearing is operational even when people are asleep. As a result, both wanted and unwanted sound directly evokes reflexes, emotions and actions which are both stimulants and stressors. The auditory system has the fastest response rate in the human brain and processes information hundreds of times faster than other senses [85]. The extent to which noise is a stimulant or stressor is a factor of noise source, onset of the noise, duration and characteristics of the noise and whether the exposure is voluntary or involuntary [84].

Forty years ago the World Health Organisation (WHO,1966) concluded noise was an occupational hazard and public nuisance and identified that the level of annoyance involved more the characteristic of the noise than the intensity. Further it disturbed sleep and was a danger to physical and mental health.

More recently, WHO, the European Community members and numerous other high level health organisations have determined that there is a large body of evidence linking exposure to noise with many health effects and social consequences other than hearing loss. The WHO guidelines for community noise consider health effects as including;

…."hearing impairment, startle and defence reactions; aural pain; ear discomfort; speech interference; sleep disturbance; cardiovascular effects; performance reduction; and annoyance responses. These health effects in turn can lead to social handicap; reduced productivity; decreased performance in learning; absenteeism in the workplace and school; increased drug use; and accidents." [84]

Noise can't be blamed for initiating serious mental health problems but it is well established that people who are stressed or depressed are more affected by noise. Noise acting as a stressor and sleep disruptor has an impact on the cardiovascular system. Both stress reactions and sleep deprivation will evoke mechanism such as increased release of stress hormones, including adrenaline, noradrenalin and cortisol. These have a cascade of physiological effects and will increase blood pressure and vasoconstriction. Cortisol will increase blood pressure and suppress the immune system. A cross sectional study found an association between environmental noise annoyance and cardiovascular disease [86]. Disruption to the ability to learn, sleep disturbance, ischaemic heart disease and hypertension have been proven effects.

Further adverse health effects are caused by sleep disturbance and this is discussed in more detail later.

9.1 Low Frequency Noise

Low frequency noise is generated by mechanical equipment such as heat pumps, refrigerators, mechanical ventilation, some industrial activities and wind turbines.

"Low frequency noise (levels below 200 Hz) are perceived through both touch and hearing, which accounts for the greater level of annoyance from people exposed to low frequency noise. Recently greater attention has been given to the effects of low frequency noise because it is pervasive and many structural attempts at remedy are inadequate" [84]

The Report of the Noise Review Working Party 1990 published by the Department of the Environment [87] concluded that low frequency noise can have serious effect on the quality of life of those affected by it. The WHO are clearly concerned about low frequency noise and health.

Exposure to low frequency noise has been found to elicit stress reactions and in some instances resonance reactions in vocal chords and internal organs. Stress reactions in response to low frequency noise include bizarre auditory sensations such as pulsations or flutter in the ear. It increases the release of stress hormones like adrenaline, noradrenalin and cortisol. Cortisol extraction has a wide range of effects on the metabolism of proteins, carbohydrates and fats and will temporarily suppress the immune system and sharpen attention [84]. As with other noise, low frequency noise has been found to affect annoyance, stress, irritation, unease, fatigue, headache, nausea and disturbed sleep. A number of physiological (blood pressure and heart rate) and psychological effects were found in laboratory studies [88].

9.2 Noise and Sleep

It is well established that sleep is a fundamental for restoring biological function, body chemistry as well as mental outlook, behaviours and emotion. Adequate sleep is essential to our wellbeing and health and we are programmed to spend more than a third of our life in a semi conscious and unproductive state. Sleep quality and its effects on health is not only about duration but the ability to cycle undisturbed through the various sleep phases [89].

Noise interferes with sleep in a number of ways;

- Awakening – it causes the sleeper to awaken repeatedly resulting in poor sleep as well as other health impacts,
- Alter sleep pattern- noises may make the sleeper change from heavier to lighter sleep,
- Reduce the percentage and total time in REM sleep
- Increase body movement
- Change cardiovascular responses

- Cause effects on slow wave sleep

These changes can affect mood and performance the next day [84].

Sleep loss reduces cognitive function and can affect physiology, behaviour and subjective outcomes. Statistically significant variations occur in vigilance, memory, learning, hormone levels and sexual function. All stages of sleep are equally vulnerable to disturbance by noise and cardiovascular irregularities and increases in blood pressure can occur without the sleeper awakening [90].

Professor Philippa Gander, from Massey University, Public Health Research Centre, is a world expert of sleep. She has found that disturbed sleep, either due to disruptions of the REM cycles or duration lead to significant physiological changes including the release of two appetite hormones (which leads to over eating), headaches, blood pressure, impaired cognitive function and reactions, tinnitus, and type-2 diabetes.

Professor Gander's research centre has also demonstrated a sleep deprived driver will have their reaction time impaired similar to a driver under the influence of alcohol. Both sleep deprived drivers and drunk drivers place the driver, their passengers and other road users at high risk of accidents [91]. The NZ Police have determined from accident reports that fatigue can impact on a drivers reaction times, their concentration and general understanding of the road and traffic around them. In 2005 fatigue was a significant factor in 40 fatal traffic crashes, 162 serious injury crashes and 449 minor injury crashes. For every 100 drivers or motorcyclists killed in road crashes where fatigue was a factor, 45 passengers and another 27 road users were also killed. Driver fatigue is difficult to identify or recognise as contributing to a crash. This means it's likely that fatigue is under-recorded [92].

Measurable sleep disturbance has been observed as noise levels exceed 35dBA and the effects increase with increasing noise levels. These and other health effects have given sufficient evidence for WHO to recommend that the equivalent sound pressure level should not exceed 30dBA indoors, if the negative effects on sleep disturbance are to be avoided [93].

The guideline states that

> "to avoid sleep disturbance, indoor guideline values for bedrooms are 30 dB LAeq for continues noise and 45dB LA max for single loud events…. Lower noise levels maybe annoying depending on the nature of the noise source. If the noise includes a large proportion of low frequency components, values even lower than the guidelines values will be needed, because low frequency components in noise may increase the adverse effects considerably…"

and it goes on to recommend the use of dBC weighting rather than dBA, which is contrary to the noise criteria presented in most if not all the District Plans in New Zealand. This document also recognises the need to sleep with a window open for ventilation and for cooling in warm weather. The dBA weighting of noise is a measure developed for occupational settings where speech clarity is the primary concern. The dBA weighting filters out noise at lower frequencies. The dBC weighting includes a higher amount of low frequency noise than the dBA.

The Institute of Environmental Medicine at Stockholm University has undertaken extensive research on the impact of community noise and sleep. They found noise affects sleep in several ways including;

- Increasing the time needed to fall asleep
- Altering the cycle of sleep stages and
- Deceasing the quality of REM sleep

Any one of these problems over an extended period can lead to more serious health problems. Sleep disturbances have been linked to three characteristics of noise exposure, including:

- The total noise exposure (including daytime exposure)
- The peak noise volume
- For intermittent noise, the number of volume peaks

Sleep quality has been found to be eroded much more by a number of noise events that were roughly 5dBA above the threshold of the noisy event. Acceptable noise levels will vary depending on the situation, with noise being more obvious and annoying in quiet background conditions.

The ISO 1996 – 1971 Recommendations for community noise limits are summarised in table 7 below.

Table 7: Recommended levels for community noise

(Source ISO 1996 – 1971)

District type	Day time upper	7pm-11pm	11pm-7am
Rural	35dBA	30dBA	25dBA
Suburban	40dBA	35dBA	30dBA
Urban	45dBA	40dBA	35dBA

10 What are the Features of the Indoor Environmental Quality Component for High Standard of Sustainability?

10.1 The strategy for a home with a High Standard of Sustainability (IEQ)

Unfortunately all the linkages between building features and occupant behaviours that contribute to healthy or unhealthy conditions are not fully established. However there is sufficient evidence to move forward and some good sense recommendations are given in the standards below. Complying with the features in 11.2 - 11.8 below will make a significant improvement to the environmental quality of most homes. Features given in 11.2 – 11.8 are the expanded list for new and existing homes. A brief version of key features is given in section 11.9.

There are several tensions that are not easily resolved, such as, homes constructed in areas with high levels of community noise or pollutants will ideally have low levels of infiltration and natural ventilation to avoid ingress of ambient pollutants. This places reliance on mechanical ventilation and filtration which will have an energy consumption penalty. These will need to be addressed specifically for the subject properties. The other main tension is between ventilation rates and conservation of heat during cold weather. This is a tension that will affect all homes, however it can be partially addressed by having low levels of pollutants in the home and compensating with higher levels of ventilation during the warmer periods of the day.

The strategy for achieving a healthy home has five steps which are ranked in order of effectiveness. The stages are;

- Stage 1 Source control of pollutants
- Stage 2 Minimising the pollutants
- Stage 3 Removal of the pollutants as quickly and as close to the sources as possible
- Stage 4 General ventilation
- Stage 5 Remediation or provide a solution

The most effective step in the strategy is eliminating the pollutants at the source. Stage 1 is the foundation of the strategy for a healthy home. This strategy is most easily consciously achievable with new construction where the designers start with a clean slate. However, older homes could inherently have some aspects of the strategy in that the VOCs concentrations in most homes have decayed to acceptable levels within two years, therefore the source of VOCs has already decayed to acceptable levels; and homes constructed pre-1960's are usually sufficiently draughty to provide for adequate dilution (stage 4) of indoor pollutants.

Practical examples of source control of moisture include constructing the cladding with a water management drained and ventilated cavity to control water availability/microbiological pollutants; and source control of VOCs includes the selection of materials with low VOCs; and source control of combustion by-products includes banning smoking and unflued combustion inside homes.

Where it is not feasible to eliminate the contaminant at the source, then minimising the contaminant is recommended. An example of this would include pre-off gasing of VOCs from joinery constructed from medium density particle board and particle board or new carpet preferably outside the home prior to installation, or as the next best option prior to habitation of the home.

The next step down (stage 3) in the strategy is the removal of the contaminant as quickly or close to the source as possible. Targeted ventilation is difficult to achieve if the pollutants is diffused throughout the home such as would occur from VOC emitted from carpet or paint. However it is readily achieved for pollutants that are emitted from a concentrated source. Examples of this include extraction of moisture in a bathroom directly over the shower; and operation of range hoods above the stove or redecorating in summer when outdoor temperature are more conducive to copious natural ventilation to remove VOCs from paint etc and moisture from construction activities.

General ventilation (stage 4) is considered the least targeted but a necessary stage to dilute pollutants that are diffuse such as VOCs from occupant activities and bioeffluents from the occupants. Ventilation can often be compromised by other valid factors such as a desire to minimise heat loss during winter, or noise ingress when ambient noise levels are too high. Most New Zealand homes rely primarily on opening windows for natural ventilation and this can be thwarted by behavioural issues. There maybe justification to supplement natural ventilation with mechanical in some homes [22].

Remediation strategies and solutions (stage 5) are important when other strategies to control pollutants are not feasible. This could include filtration of ambient air for homes constructed close to major roadways, or dehumidifying air when other moisture management attempts haven't achieving desired results.

It is worth noting that the general the first stages of this strategy use the least consumed energy and purchased energy demands increase with subsequent stages.

To improve the quality of the indoor environment of New Zealand housing from the current standard priority could be given to reducing moisture and improving warmth via clean heating and insulation, as well as general ventilation to remove most pollutants and extraction ventilation in wet areas such as kitchens and bathrooms. These three variables are inter-related and can be visually represented as follows:

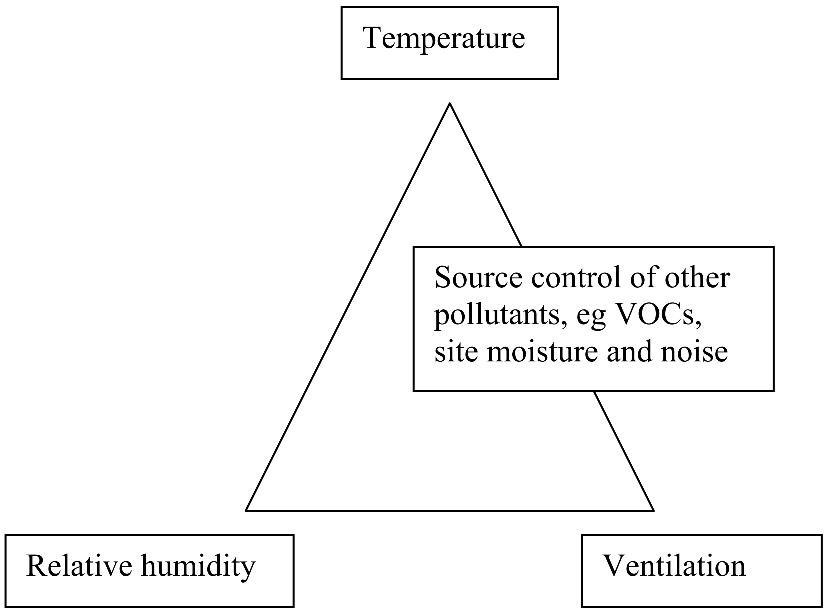

Figure 1: Inter-relationships between environmental parameters

Maintaining the parameters of ventilation, temperature and relative humidity within acceptable limits as detailed in Section 12, will in most case give a reasonable quality indoor environment. However, ventilation will not be sufficient to maintain IEQ where there are substantial sources of pollutants, such as site moisture, leaky claddings or VOC's. High levels of ventilation can be detrimental to IEQ in the minority of homes that are constructed near a source of noise or ambient pollutants, such as near airports or major roadways.

A more detailed listing of features required for good indoor environments in the home are given below in sections 11.2 to 11.8 with the key features given in Section 12.

10.2 Site features

10.2.1 Building features

- Low levels of outdoor pollutants. The indoor and outdoor environments are tightly interconnected. Ideally the selected site will be in an neighbourhood with low levels of ambient pollution, which is the case for most areas of New Zealand. There are other programmes lead by other agencies in place to reduce ambient pollution levels. If the outdoor environment is polluted then remediation such as filtration is required to reduce ambient pollutants. Filtration and ventilation are discussed in Section 9. As a general rule it is desirable to avoid houses located in valleys or basins where there is the potential for climatic inversions to trap winter smog and avoid house location within 500m of major roadways, or within proximity to airports or industrial areas. Ambient pollution can change more the better or worse during the life of the house as other land uses change.
  - New sites; selection of a site with low levels of ambient pollution can be a criteria for the selection of new construction sites.
  - Existing homes; it is not possible to alter the ambient pollution outside existing homes and if the ambient air is polluted then occupants will need to consider mitigation strategies such as air filtration to remove particulate matter. Monitoring for nitrogen dioxide could be useful, although this requires specialist and not very portable instrumentation. Relocating could be an option for people with compromised airways such as asthmatics.

- Low levels of ambient noise so natural ventilation can be provided. While the majority of neighbourhoods do not have ambient noise issues, there will be some homes sited in areas with noise issues. Houses constructed on very noisy sites require a tight envelope to reduce ingress of noise. This conflicts with natural ventilation to remove indoor pollutants and moisture. Ambient noise can change during the life of the house as other land uses change.
  - New sites; selection of a site with low levels of ambient noise especially at night can be a criteria for the selection of new construction sites.
  - Existing homes; it is not possible to alter the ambient noise levels outside existing homes and occupants will need to consider mitigation strategies such retrofitting double glazing and insulation of the house envelope. Closing single glazed windows can give a 5dBA noise reduction, however alternative means of ventilation will be required. Landscaping can assist to block out noise.

- Good site drainage – reduction in subfloor dampness. Natural ventilation alone is often insufficient to overcome dampness originating from the subfloor.
  - New sites; selection of a site with good drainage can be a criteria for the selection of new construction sites or site drainage can be installed.
  - Existing homes; additional field drains and landscaping can be installed to reduce site water. If the house has a subfloor, a vapour barrier can be installed over the soil. Installation of adequate subfloor ventilation is very important.

- Landscape the area around the house with permeable surfaces such as permeable paving rather than concrete to prevent standing water or water being directed towards the house. Slope driveways and landscaping to direct water from away from the house.
  - New sites; sloping hard surfaces away from the house and the use of permeable paving rather than non-permeable surfaces can be a criteria the landscape design. Note this has the added advantage of reducing run off of site storm water.
  - Existing homes; the above can be addressed when landscaping is being redone.

- Hard landscaping materials such as pavers, rough textured tiles or decking adjacent to the home will reduce the amount of soil particles walked into the home. Avoid walking directly off grass or vegetated areas.
  - New sites; this can be a criteria in the landscape design and can be attractively designed to encompass decking or paved areas.
  - Existing homes; this can be addressed when landscaping is being redone.

- Low levels of sub ground gases or contamination from previous site uses for the proposed and adjoining sites. For example avoid black field sites land used previously for timber treatment, old land fills, old underground fuel or gas tanks, old "P" labs etc. where contamination from previous uses could potentially enter the home.
  - New homes; this can be a criteria for the selection of the site.
  - Existing homes; this can be difficult to remediate and specialist case by case advice should be sort.

- Low risk of flooding – reduction in risk of post flood mould and bacteria contamination.
  - New homes; this can be a criteria for the selection of the site or alternatively the house can be elevated on piles or a raised slab above the flood line.
  - Existing homes; this can be difficult to remediate and specialist case by case advise should be sort.

10.2.2 Behavioural (new and existing houses)

- Avoid installing garden irrigation systems around the home that can soak the foundations or push water behind the cladding.
- Cut back vegetation close to the house to allow site moisture to evaporate.
- Keep subfloor vents clear and avoid the temptation to use the subfloor space as a storage area.
- Provide areas for the containment of rubbish prior to disposal or collection to deter rodents and invertebrates.

10.2.3 Performance (new and existing houses)

The above features and behaviours can be evaluated by visual inspection.

10.3 Building Envelope Features

10.3.1 Features

- Low or no risk of rain penetration. Windy or exposed sites with high rainfall have the highest risk of rain penetration and appropriate design of the envelope is essential.
  - New homes; complete a risk matrix assessment as per E2 of the Building Code to assess the leakage risk factor of the site, building design and cladding material and installation a water managed cavity system under the cladding where required. Regular maintenance of the cladding will be necessary to prevent or address water ingress issues. Avoid house designs with internal gutters and enclosed decks as there is a risk that these will fail and cause water ingress at some point in the life of the house.
  - Existing homes; complete a risk matrix assessment as per E2 of the Building Act to assess the leakage risk factor for the site, building design and existing cladding material. Installation of a water managed cavity system under the cladding is may be considered if the wall cladding ever requires replacement. Regular maintenance of the cladding and inspections for signs of leakage will be necessary.

- High insulation levels for thermal and noise control. Double glazing and high levels of floor, ceiling and wall insulation are required. Cold surfaces can cause condensation and this moisture will lead to mould growth. Homes with insulation are dryer, healthier and conserve solar and purchased heat. Select insulation materials with low emissions of VOCs.
  - New homes; install high levels of insulation to the building envelope and double glaze windows. Avoid cold microclimates.
  - Existing homes; install high levels of insulation to the ceiling cavity and subfloor cavity if it exists. Consider double glazing windows or install and use heavy curtains. Consider removing wall linings when it is time to redecorate and adding insulation to the walls. Avoid cold microclimates.

- Solar gain for passive heating. Windows should be orientated for solar gain and thermal mass materials should be installed for heat storage, such as polished concrete floors. Warm floor materials with high thermal mass are generally less hospitable to dustmites and fungi than carpet.
  - New homes; passive solar design principles can be incorporated into the new house design
  - Existing homes; passive solar design can be difficult to include into all existing homes and will require case by case design. It may be possible to replace carpets that have been laid over concrete in some north facing rooms with ceramic tiles or materials with thermal mass/thermal connection to concrete slab.

- Orientation and placement of windows for passive cooling and provision of shading to control of overheating thereby avoiding heat stress of the occupants. Over heated spaces will also increase the rate of emissions of VOC's from construction materials and household contents.

- New homes; passive cooling and shading can be incorporated with little additional cost at the design stage. Solar powered roof vents can assist to remove excess heat. Vents can be incorporated in window frames to allow some degree of ventilation without the need for open windows which can tempt home intruders. Roof vents and openable skylights can be orientated to catch breezes and drawn out warm air.
- Existing homes; shading in the form of deciduous trees, pergolas or verandahs can be added to many homes. Solar powered roof vents and openable skylights can be retrofitted to remove excess heat.

- Openable windows for dilution of indoor pollutants and moisture.
  - New homes; correct orientation and sizing is important to prevent overheating in summer or excessive heat loss in winter. Attention is required in the design of the windows to prevent thermal bridging and condensation, as well as water ingress around the frame.
  - Existing homes Conventional windows can still be used to provide dilution ventilation, however these may not be orientated or sized for optimum climate moderation.

- Passive ventilation to maintain a trickle of fresh outdoor air at all times. A ventilation rate of at least 0.35 ACH is required for general ventilation in rooms other than kitchen, bathrooms and en suite. This rate can be increased in periods of warm weather.
  - New homes passive ventilation is important to dilute pollutants, bioeffluents and moisture generated inside the home. Vents or hardware to allow frames to be securely fastened whilst ajar can assist with a constant trickle of ventilation.
  - Existing homes; vents and windows can be retrofitted as above.

10.3.2 Behavioural (new and existing houses)

- Windows should be opened in periods of favourable weather to flush the home with large amounts of fresh air at regular intervals.
- Windows or some other means of ventilation should provide a trickle of ventilation at most times to dilute bioeffluents and indoor generated pollutants.
- Curtains should be drawn over single glazed windows to reduce heat loss in winter.
- Windows or other means of ventilation is required to be operated in all bathrooms, en suites and enclosed spa/pool rooms to remove moisture. Bathrooms and en suites should be vented with 1.5 ACH after used to remove moisture, automated operation of ventilation via a humidity sensor is recommended where occupants are not motivated to control their environment.

10.3.3 Performance (new and existing houses)

- Thermostats and relative humidity sensors are relatively inexpensive and can be installed in strategic locations in new and existing homes.   The indoor temperature should be maintained between 18 to 24 ^{o}C. Relative humidity should be maintained in the range of 40-70% (good solution) or 40-65% better solution or 40-60% (best solution).

- Carbon dioxide sensors are currently more expensive for permanent installation in homes but these can be installed for periods by an IEQ consultant to measure ventilation effectiveness. Carbon dioxide is a rough surrogate measure of the effectiveness of general dilution for the removal of indoor pollutants. It will however underestimate concentrations emitted from strong sources of pollutants. Carbon dioxide levels should be maintained under 1000ppm by the provision of ventilation, equivalent to 10L/s/person and avoidance of unflued combustion.
- Visual assessments can be made of installation of appropriate ventilation and passive solar principles.

10.4 Low Levels of Mould and Dustmites

10.4.1 Features

- Avoid porous materials in the areas of the home that could get wet especially the bathroom, laundry, kitchen and enclosed spa/pool rooms. This includes installing impervious flooring materials rather than carpet, and wall and ceiling surfaces that are vapour barriers.
  - New homes; these can be installed at the time of construction
  - Existing homes; these can be retrofitted at the time of redecoration.

- Install floor drains in bathrooms to catch any overflows from baths, basins etc are good insurance to contain floods from plumbing appliances or install basins, sinks and tubs with an overflow
  - New homes; these can be installed at the time of construction
  - Existing homes; floor drains can be retrofitted if there is an accessible cavity under the floor, basins sinks and tubs with overflows can be retrofitted.

- Install ventilation in bathrooms and indoor swimming pool rooms of adequate capacity to remove all moisture. Options for this can include an extract fan operated on a humidity sensor, a solar powered extract fan, or fixed vents.
  - New homes; these can be installed at the time of construction
  - Existing homes; these can be retrofitted.

- Install heating in bathrooms to avoid moisture condensing on cold surfaces and increase the moisture carrying capacity of the air
  - New homes; these can be installed at the time of construction
  - Existing homes; these can be retrofitted.

- Install sufficient insulation in external components of the home and avoid cold surface and damp microclimates. (refer to 11.3 above).

- Ban unflued gas heaters in the home and provide non emitting heating of sufficient capacity for the home such as passive solar space heating, wood pellet burners, low emission wood burners, heat pump or flued gas heater.

- New homes; these can be installed at the time of construction
- Existing homes; these can be retrofitted.

- Do not install swimming pools and water features directly against the side of a house, as any water leakage or seepage can enter the home. In the event that the containment of the water is breached at some point in the life time of the home then resulting fungal contamination could be significant and require major rebuilding.

- Design culverts and drains to accommodate 50 year or 100 year flood events. Anticipant where water could flow in a flood and install drains accordingly. Use landscaping to divert site and flood water away from the home, whist being respectful not to create a nuisance for neighbouring properties.

10.4.2 Behavioural (new and existing houses)

- Attend to maintenance, especially where this affects leaky cladding, overflowing stormwater or other plumbing and drainage system immediately.
- If the house has a subfloor crawl space, avoid storing materials in this area. Avoid blocking subfloor vents with landscaping and plants. Install a vapour barrier over the soil in the subfloor and provide adequate ventilation and sub floor insulation. Mechanical ventilation maybe required if the subfloor ventilation has been obstructed by extensive decking or landscaping around the house.
- Clean (or report to home owner if rental property) any major spills or leaks. All excess water events should be dried within 48 hours or wetted materials should be removed and replaced.
- Remediation of homes after a flood or serious leak should be undertaken by certified mould remediators. Just killing the mould and bacteria with biocide or bleach is usually more effective at removing the colour and visibility of mould than actually killing all colonies. Biocides will not remove the dead fragments which can still be allergenic or toxigenic. Remediation required proper cleaning and removal.
- Allow all new concrete floors to fully dry and test the moisture level in new concrete floors with a moisture meter prior to installing any flooring, especially carpet.
- Provide facilities for drying clothes outside the home and vent all clothes dryers directly to the outside. Avoid using heaters as an open vented clothes dryer system.
- Regularly clean shower heads, water traps and condensate trays in dehumidifiers
- Store water in hot water cylinders at 60 ^{o}C, and install a tempering valve so the temperature of the supply water is below 55 ^{o}C.

10.4.3 Performance (new and existing houses)

- Thermostats and relative humidity sensors are relatively inexpensive and can be installed in strategic locations in new and existing homes. The indoor temperature should be maintained between 18 to 24 ^{o}C. Relative humidity should be maintained in the range of 40-70% (good solution) or 40-65% better solution or 40-60% (best solution).
- Visual inspection can evaluate many of the above features.

- Hot water temperature can be checked with a thermostat to be above 60 ^{o}C.
- Visual mould or signs of water damage should not be apparent. These will indicate the need for a professional assessment and an IEQ consultant would be able to undertake measurements of fungi and bacteria.

10.5 Low Levels of Combustion Products and Clean Heating

10.5.1 Features (new and existing houses)

- Install only low NOx (as they are referred to by the appliance manufacturers) gas appliances which should be fully flued and tested annually.
- Solar heating is the preferred sustainable method of heating. Where additional heating is required, install low emission wood burners, wood pellet burners, heat pumps or low NOx flued gas heaters. Replace all open fires and old low efficiency wood burners.
- Heat transfer kits or ducted heating systems maybe required to distribute heat to all rooms.
- Ensure all gas- and oil-burning cooking, space and water heating appliances are properly vented to outdoor air, maintained and inspected annually by a qualified technician.
- Install door closers on doors between attached garages and the home. Install ventilation or extraction in attached garages to remove vehicle emissions.

10.5.2 Behavioural (new and existing houses)

- Never use an unvented combustion appliances such as unflued gas heater or any appliance designed for outdoor use, for example a kerosene space heater, LPG barbecue or patio heater in your home
- All wood and pellet burners and gas appliances should have an annual inspection and clean. Wood burners and pellet burners should have their flues cleaned at the beginning of the heating season.
- Operate heaters to provide a minimum of 18 ^{o}C in homes.
- Avoid over heating rooms above 24 ^{o}C.
- If you have a garage attached to your house, never start your car when the door between your garage and your home is open, or the garage door is closed.
- Never run petrol lawnmowers, or other garden tools inside an attached garage or enclosed area.
- Ban tobacco smoking inside the home.
- Install and always use a range hood vented directly to the outdoors above gas cookers. Automation of range hood operation with a heat detector could be an option.

10.5.3 Performance (new and existing houses)

- Thermostats and relative humidity sensors are relatively inexpensive and can be installed in strategic locations in new and existing homes. The indoor temperature should be maintained between 18 to 24 ^{o}C. The ideal temperature in the living area is considered to be 21 ^{o}C.

- Relative humidity should be maintained in the range of 40-70% (good solution) or 40-65% better solution or 40-60% (best solution).
- Carbon monoxide alarms can be installed if there is a risk of gases from open combustion
- Visual inspections can be made for the above features and behaviours. An IEQ consultant can advise on any air quality monitoring required.

10.6 Particles

10.6.1 Features (new buildings)

- Avoid constructing homes within 500m of a busy roadway. If this is unavoidable, consider filtration of the air.
- Avoid constructing tall apartment buildings alongside major roadways as this can create a canyon effect and increase the ingress of particles from traffic.
- Also refer to 11.2 and 11.4 above.

10.6.2 Behavioural (new and existing homes)

- Install extraction or ventilation in attached garages to remove particulate matter from vehicle exhausts
- Keep the home clean and dust-free. Dust furniture with a damp cloth rather than a duster that resuspends particles.
- Use a central ducted vacuum cleaner or vacuum cleaner with HEPA filtration to avoid resuspension of fine particles.
- Ban tobacco smoking inside the home.
- Take your shoes off when you enter the house. The soil outside your home can contain a number of substances you do not want inside. An area outside the homes with rough and hard landscaping surfaces will help to remove soil and particles from shoes.
- Always operate a range hood or open a window when cooking, especially with gas cookers. Automation of range hoods with a heat detector could be an option.
- Use the minimum amount of detergent required for washing clothes and ensure clothes are well rinsed.

10.6.3 Performance (new and existing houses)

- Visual inspections can be made for the above features and behaviours. An IEQ consultant can advise on any air quality monitoring required.

10.7 VOCs

10.7.1 Features (new and existing houses)

- Select low VOC paints and construction materials for new house construction and renovations. Look for materials with a low emission label.
- Avoid insulation products, such as sprayed foam insulation that uses urea formaldehyde binders.

- Replace VOCs emitting materials with VOC free materials if there is an option for example select ceramic floor tiles or polished concrete instead of PVC flooring or carpet.

10.7.2 Behavioural (new and existing houses)

- Off gas new furniture and carpeting in a well ventilated and dry area outside of the home before installation.
- Ventilate the home with more than 1 ACH for several months following redecoration or installation of new construction materials, such as pressed wood or carpeting or redecoration. Ideally renovations and redecoration should be conducted in summer to enable copious ventilation with outdoor air.
- If you are doing redecorating or a hobby that can produce VOCs then increase ventilation during and after the activity. Close doors to other parts of the home to avoid dispersing contaminants to other areas.
- Maintain ventilation rate of at least 0.35 at all times in living areas and 1.5 ACH (extracted) in kitchens, ensuite, laundry and bathrooms when these rooms ar in use. Use higher ventilation rates when outdoor air temperature is within the range of 16 ^{o}C – 25 ^{o}C and when emissions of VOCs and moisture are strongest, such as after redecorating.
- Avoid using cleaning products, such as floor polishes that can contribute to VOCs.

10.7.3 Performance

- Measurement of VOCs can be conducted by an IEQ consultant.
- Measurement of ventilation can be roughly monitored by injecting a source of CO2 into the home and monitoring the decay time.

10.8 Noise

10.8.1 Feature

- Select a site with low ambient noise.
  - New homes; this can be a criteria of the house site selection, however ambient noise can change as land uses around property change with time.

- Deflect and absorb ambient noise
  - New and exiting homes; plant dense trees and use landscaping features to reflect ambient noise.

- If the house is located near a major road, then orientate rooms within the home with bedrooms furthest from the road for new construction or major alterations.

- Install double glazing
  - new homes; double glazing can be installed at the time of construction
  - existing homes; double glazing can be retrofitted.

- Install heavy mass wall and roof construction/cladding for new construction or major alterations.
  - new homes; heavy mass claddings or construction, such as solid concrete walls can be installed at the time of construction
  - existing homes; heavy mass claddings can be installed during major house alterations.

- Install acoustic insulation, to be effective this needs to have as few breaks as possible
  - new homes; acoustic insulation can be installed at the time of construction
  - existing homes; acoustic insulation can be retrofitted during redecoration.

- An alternative ventilation system could be required such as mechanical ventilation with acoustical dampers. These can be installed at the time of construction or retrofitted.

- Avoid penetrations in envelope
  - New homes; avoid installing power points, flues, plumbing and other items that penetrate the wall on exterior walls facing the noise source, as these can form a noise bridge.

- Install absorbent surfaces in homes such as fleecy floor materials to absorb sound, however this needs to be done with consideration of passive solar heating, source control of VOCs and control of environments for dustmites and fungi.

- Separate quiet zones (bedrooms and study) and noisier zones (living areas) in the home. Use planning of the rooms/distance and install acoustical insulation to separate quiet and noisier zones.

10.8.2 Behaviour

- Be respectful of your neighbours and other occupants within your homes right to quiet times and turn down televisions, stereos, electronic games and toys etc. especially during the hours of 10 pm to 6:00am

10.8.3 Performance

- Noise monitoring can be conducted by an IEQ or acoustical consultant using a noise meter. Noise levels should not exceed 30dbA between the hours 10 pm to 6:00am.

11 Key features for IEQ component of HSS in homes

Table 8: Key criteria and surrogate measures for IEQ HSS

Absolute criteria	Surrogates	Monitoring	Solutions
Temperature	Temperature	16 ^{o}C mean minimum temperature in bedrooms, 18 ^{o}C mean minimum temperature in living areas 24^{o}C mean upper temperature	Non polluting heating, "best" standard of insulation
Relative humidity	Relative humidity	40-70% standard 40-65% better 40-60% best	Extraction of moist air from bathrooms, en suites, kitchens and laundries of 1.5 ACH when room in use. General ventilation of 0.35 ACH minimum at all times
Ventilation rate	Carbon dioxide Or air changes per hour	1000ppm max carbon dioxide. 0.4-0.6 ACH new homes, 0.0-0.75 ACH existing homes.	Minimum air changes as for relative humidity. Draught sealing of pre-1970's homes.
Biological	Visible mould and mould odour	Visible mould <0.5m2 in whole house	Air changes as for relative humidity no evidence of subfloor dampness or leakiness of building envelope or plumbing fittings

VOCs	Formaldehyde	Formaldehyde badge ($50/badge) as for relative humidity No new construction within last 12 months building works - need to ventilate	General ventilation of 0.35 minimum at all times Rapid ventilation following building works and redecoration
Combustion products	Nitrogen dioxide and carbon monoxide		No unflued gas heaters Door closer fitted on door between home and attached garage, Passive vents installed in garage House not sited next to major roadway
Noise	Noise	<30dBA in bedroom at night with window open. <40 dBA day time	Bedrooms located in quietest area of home or building envelope fitted with acoustic insulation window open/passive vents insulation House not located close to airport or other noisy activity
Particulates	Home not sited near major roadway or has attached No unflued combustion sources in home garage		Filtration and positive air pressure Door closer between garage and home and passive ventilation to garage
Asbestos fibres	Age of home Type of roof cladding, ceiling and floor vinyl		Certified asbestos removal contractor to check or remove asbestos if required
Fibre glass	No fibreglass insulation in mechanical ventilation ducts		

Sulphur dioxide	Live in geothermal area?		Mechanical ventilation to provide general ventilation and positive air pressure in home

12 Future Research

From a review of the international and New Zealand research and from interviews with researchers who have expressed an interest in this field, it is apparent that there are many areas where New Zealand specific research on IEQ is required. The list of topics below is not exhaustive and there are many relevant and very fruitful avenues for research that were discussed with other researchers that could not be mentioned in this report until funding has been secured. The potential projects listed below are not ranked in any specific order of importance. Although there is overlap between topics, they are roughly grouped into three topic areas of overview projects, protection of vulnerable populations, and new construction systems and materials.

12.1 Overview projects

- A comprehensive field investigation of the concentrations of health effects and pollutants found in New Zealand homes. A large study of sufficient magnitude to compare sub populations (vulnerable groups, socio-economic groups, types of housing etc) with simultaneous measurement of many indoor pollutants and recording of health outcomes. This would need to include factors, such as concentrations of pollutants in new or renovated homes as well as aged homes; seasonal influences to capture data in winter on pollutants generated from unflued heaters, originating from dampness, or increases in indoor concentrations from low ventilation levels in winter. This background data would inform regular monitoring and drive future research.
- A comprehensive investigation of the ingress into, and the concentrations that the home's occupants are exposed to inside the home, from ambient pollutants.
- Continuation of the development and validation of a Healthy Housing Index or a healthy housing rating tool to enable researchers to investigate the effectiveness of changes to the housing quality, designers select healthier options and home purchasers and renters make informed decisions. Ideally this would have a high degree of compatibility with the HSS given in Section 11.
- Development of detailed Indoor Air Quality Guidelines for key pollutants found in homes. A joint Australia New Zealand guideline is probably the most feasible option.
- A study of the health effects from long term exposure to combustion products such as nitrogen dioxide and carbon monoxide and lesser studied combustion products like halogenated dioxins and PAHs, found in homes that are close to major roads and with indoor combustion processes such as attached garages, environmental tobacco smoke and unflued heaters.
- A study of source apportionment of indoor pollutants, which would enable better targeted mitigation measures.

12.2 Protection of Vulnerable Populations

- A study to measure indoor pollutants, including fungi and bacteria, bioeffluents and VOC's from occupants activities in overcrowded New Zealand homes.
- Studies of environmental parameters found in infant's and children's bedrooms and the long term health consequences of early life exposure to pollutants.
- An investigation of the pollutants, fungi, dustmites and VOC's found in infants and children's bedrooms from the construction materials, furnishings and contents and means to reduce these pollutants. A survey of IEQ in rental accommodation to ascertain if tighter controls or a building warrant of fitness scheme for rental housing is necessary.
- Benefits from warm and dry homes on COPD symptoms.

12.3 Improved Construction Systems and Materials

- A study of costs and benefits including health benefits from passive solar heating of homes. This could show reduced levels of dampness, fungi and dustmites due to warmer surfaces and reduced moisture, in addition to better regulation of the thermal environment.
- An investigation of particulates in tall apartment buildings constructed near major roadways where the canyon effect may increase the concentration of vehicle pollutants in the vicinity of the building. The effectiveness of air filtration to remove particulate matter and other vehicle emissions should also be studied.
- An investigation of novel treatments of building materials to control moisture and microbial contaminants. This could include embedded physical properties for example hydrophobic or embedded heating for moisture control or treatments with non toxic fungicidal products, such as those approved for food or nutriceutical use.
- Redesign of resins and adhesives to reduce the emissions of VOCs especially formaldehyde.
- Development of a shower box that does not leak or support mould growth.
- A study of the health effects and ongoing fungi and microbial contamination from leaky or flooded homes.
- A study of the effectiveness of ventilation requirements in the New Zealand Building Code for the removal of volatile and semi-volatile compounds and construction moisture from new or remodelled homes.
- Utilisation of physical properties of materials, such as maintaining psychometric parameters within flooring and other construction materials, which are inhospitable to dustmites and fungi. This could permit the control of fungi and dustmites without the use of biocides.
- Sound insulation and absorption materials/systems in bedrooms for quiet sleep periods.
- Methods and low VOC materials to increase the insulation in the existing walls and windows that have been constructed with no or low levels of insulation.
- Effectiveness of air extracts and passive vents for removing moisture from bathrooms and vehicle emission from attached garages.
- Effectiveness of range hoods for removing cooking moisture and emissions from gas cookers.
- Development of inexpensive real time monitors that can give home users current feedback on the temperature, relative humidity, and ventilation efficiency of their home.

13 Future Initiatives

There are several initiatives where government or industry support will assist in the uptake of the HSS. These include but are not limited to the following programmes;

- Development and implementation of a Healthy Homes Index or rating tool. This is a practical way to measure the condition of the indoor environment, educate home users of features and help home users make informed decisions on their selection of a home and renovations they undertake.

- Incentives and a champion to promote the use of passive solar space heating to increase the uptake of free heating and warmer homes as other fuels become more expensive. If passive solar heating was a feature of low income housing it could help reduce the incidence of fuel poverty and dependence on unflued gas heaters.

- Broadening of the criteria for eligibility for insulation retrofits in existing homes to enable penetration into a larger number and all sectors of houses, as well as increasing the standards of insulation.

- Expanding the Clean Heat or a similar program to give incentives for the conversion of homes from polluting heaters to non-polluting heaters to all areas of New Zealand. This will need recognition that clean heating provides benefits for the indoor environment and health, as well as the ambient environment.

- Development and operation of a low VOC labelling scheme for construction materials and household contents that don't contribute to the VOC load within homes.

14 Conclusions

The home environment and health of the occupants are intrinsically linked. New Zealand has one of the highest rates of respiratory diseases, including asthma, in the world and it is imperative and feasible that we improve the quality of our homes to improve respiratory health and other symptoms.

The environment inside the home is directly affected by the ambient environment, so it is more difficult to create a healthy home in neighbourhoods with community noise, that are located close to major roadways or in industrial areas. The ambient environment has been well researched and regulated and there are initiatives in place to reduce ambient pollution. Except for certain geographic areas, there are relatively few times when the guideline values are exceeded.

However, the air inside homes is frequently more polluted than outdoor air; combustion by-products have been found to be at levels that are up to three times higher than WHO guideline values; and there can be a cocktail of 100's of chemicals for which the additive health effects are unknown. Over 40% of New Zealand homes have visible fungi and dustmites can also be a huge issue.

There is strong evidence that investing in healthier home environments can give significant financial and social benefits, in addition to savings in energy. The Housing, Insulation and Health study found a four-fold return on cost of insulating pre-1979 homes. The occupants of these homes were more productive with fewer days off school and work due to illness. This cost benefit analysis has provided an excellent value case to retrofit insulation in all homes that have no or low levels of insulation. The Housing, Heater and Health study found replacing unflued gas heaters and small electric heaters with non polluting heaters provided occupants the benefits of three days less per winter off school, fewer respiratory infections and less severe infections.

EECA have identified that health is a more persuasive driver for home owners to invest in upgrades to their home than compared to the desire to be reduce climate change or be more energy efficient. Fortunately, many features of a healthy home can save energy, such as high levels of insulation, or they are energy neutral. Some features of a healthy home are best instigated at the time of construction or major renovations as they involve selection of a healthy site or healthy materials. Other features only require the occupants to change their behaviours and will involve minimal costs, but will require the support from educational material and information transfer to assist behaviour change.

Pollutants that are of concern in new and existing homes include;

- Volatile and semi-volatile organic compounds, such as formaldehyde, and benzene
- Other gaseous pollutants such as nitrogen dioxide and carbon monoxide
- Microbiological pollutants such as fungi and bacteria and dustmites and fragments of these

- Particulates
- And noise.

Concentrations in the homes of these pollutants can be exacerbated by an indoor climate that is too cold and damp, or hot and humid, and has inadequate ventilation to dilute the pollutants, moisture and heat from inside the home. General ventilation of 0.35 to 0.6 air changes per hour in living rooms and 1.5 air changes per hour (extraction ventilation) in bathrooms and kitchens to remove background levels of indoor pollutants is considered to be sufficient to maintain healthy air quality unless there are strong sources of moisture, VOCs, gaseous pollutants or particulate matter. However, higher levels of ventilation will be required in warmer weather to remove excess heat or following the introduction of VOC or moisture rich construction materials.

Fungi, bacteria and dustmites can best be controlled with limiting available moisture. This requires holistic thinking of means to control moisture in the home from, site selections and drainage, design of the envelope, insulation and clean heating, to venting the bathroom after a shower and general ventilation. The landscaping around the home to direct water away from the structure can have an impact on moisture within the home.

VOCs can best be controlled by specification of low VOC emitting materials, pre-airing off site and copious ventilation for several months following installation of VOC producing materials. Occupant behaviour can also assist to reduce VOCs such as opening windows whilst they are undertaking hobbies that can produce VOCs and careful selection of cleaning and personal care products. General ventilation of 0.35 to 0.6 ACH per hour should be capable of removing low levels of VOCs once the initial free VOCs levels have decayed. However this needs to be confirmed for New Zealand homes as this situation has been outside the scope of research that informed BRANZVENT.

Gaseous pollutants such as carbon monoxide and nitrogen dioxide can be controlled with clean heat sources, and banning smoking in the home, and features to control exhaust gases from vehicles in internal garages from entering the home.

Particulate matter can best be controlled by reducing fungi, banning open combustion including smoking and unflued gas appliances, and thorough cleaning of the home with a HEPA filtered vacuum cleaner. Selecting a site with low levels of ambient particulate matter will also have a big impact.

Noise from outside the homes is largely predicted by the site selection. Landscaping and design of the building envelope can reduce the ingress of community noise, however there is tension between sealing the home to prevent noise and the need for ventilation, preferably natural ventilation. Planning of rooms and acoustical insulation around quiet rooms can assist to maintain a quiet night time environment and protect undisturbed sleep.

While extensive research has been conducted overseas, there are many large gaps in the knowledge of the New Zealand conditions and housing stock. There are roughly three directions for research, namely overview projects, protection of vulnerable sub-populations and improvements in construction systems and materials. A significant project that needs to be undertaken to quantify the magnitude of unhealthy homes is a comprehensive field investigation of the health effects and concentrations of pollutants found in New Zealand homes. This study would be the baseline to measure progress, and drive future research and initiatives. Simultaneous measurement of health and key pollutants in a large number of homes across seasons, housing types, and sub-populations would be necessary.

Other overview research projects include monitoring of the ingress of ambient pollutants including noise; development of a Healthy Housing Index or rating tool to enable measurement of features and progress with achieving healthier homes; development of IEQ guideline values for key pollutants; studies of long term health effects from pollutants and source apportionment of indoor pollutants to enable better targeted control strategies.

There are several research projects recommended in the report that would result in more knowledge on effective ways to protect vulnerable populations. Vulnerable populations include infants and children, elderly, deprived and overcrowded households and people with health weakness such as asthma, and allergy, multiple chemical sensitivities, COPD etc. They can comprise a large proportion of the population. Infants and children are a subgroup worthy of significant research efforts due to their different and underdeveloped physiology and immune systems and because they are establishing predispositions to ill health that can effect them for the rest of their lives. Elderly are a growing demographic and also have many health complications. They are more sensitive to cold temperatures and draughts. Interventions to reduce specific diseases such as asthma, which affects a quarter of the New Zealand population, and COPD, which is predicted to increase in prevalence until 2020, are important and these debilitating diseases are closely linked with environmental factors and airborne pollution.

Research studies and initiatives that would be of benefit to vulnerable populations include research on pollutants within overcrowded homes and methods to reduce these, benefits and cost effective methods to maintain a warm and dry home, practical methods to reduce fungi and dustmites in homes, and longitudinal studies from exposure to pollutants in infancy and childhood and health.

There are a large number of research projects that could be undertaken to improve construction system and materials. Some of these include the health benefits from passive solar space heating; novel treatment methods for the control of fungi and moisture; new low VOC resins and adhesives; low VOC materials to insulate existing uninsulated walls; health effects and effectiveness of remediation in flooded and leaky homes; effectiveness of natural ventilation requirements in NZBC and attic mounted mechanical ventilators for the removal of indoor pollutants and noise protection in homes.

Education is also a very necessary component of assisting a high percentage of New Zealand's housing stock achieve a HSS of healthiness. There are a large number of basic behaviours that home occupants can do to improve their IEQ. Some are low cost, low energy and can give good results, such as turning back and airing bedding in the morning rather than making a bed. This can include information on healthy homes solutions, and low cost and low energy means to reduce moisture in their homes, such as installation of vapour barriers in sub floor cavities.

Beacon Pathway Ltd.'s has the goal of having 90% of New Zealand homes sustainable to a High Standard of Sustainability including an IEQ component by 2012. This goal is laudable, although the timeframe maybe slightly ambitious for healthy homes. There are two strong complimentary drivers that currently have momentum and will assist in moving towards achieving a HSS. The first is top - down and the second is from the consumer - up.

There is the growing evidence of returns in a health benefit that are well in excess of the investment. This will continue to give Treasury, EECA, DBH, HNZC, PHO's, energy companies and other corporations who can trade on this "great news", a compelling case to continue to regulate, promote, demonstrate and provide incentives for programmes such as improving insulation levels, HNZC upgrades and Clean Heat projects.

Current strategies have an emphasis on low income households. Unless the criteria are broadened it will be challenging to, for example, get 90% of New Zealand homes insulated to a high standard of insulation by 2012. However, the public health, social and marketing rewards for organisations whom are associated with these healthy homes initiatives that are produce tangible and immediate results will continue to fuel a momentum towards healthier homes.

The second driver comes from consumers' desires for an environment that is healthier for them and their families. Many home owners have demonstrated a "willingness to pay" several thousands of dollars for appliances that are promoted as healthy home solutions. Even some landlords and property developers will routinely install an attic ventilation system as they consider it assists the marketability of their houses. Companies selling healthy homes solutions report this is a rapidly growing and lucrative market. However the advice currently available to consumers can be subjected to bias which may not always direct them to the best solution. There is also a lack of champions actively promoting solutions such as passive solar design as there is no commodity to sell and this is an area where Beacon Pathway Ltd. could make a contribution.

There are opportunities too for Beacon Pathway Ltd. to leverage of both of these well established and powerful drivers for even greater results that would move homes to a HSS with regard to the IEQ component.

The three strands that are recommended to achieve this are increased research and development of healthy homes to provide the evidence and underpinning knowledge. 1. The research can be used to inform policy makers and other organisations of the compelling value case to make changes to the housing conditions. 2. The second strand is the implementation of initiatives and incentives to increase the rate of uptake of insulation retrofits, clean heat, passive solar design, low VOC labelling of materials and practical demonstration projects. 3. The third stand is the formation of linkages and sharing of quality information to other agencies with interests in healthier homes, such as DHB's, Ministry for the Environment and EECA.

15 References

1. Underhill, M. Energy Efficiency and directions for EECA. in First New Zealand Conference for Post Graduate Energy Researchers. 2007. Palmerston North.
2. Keall, M.D., Povey LJ., New Zealand Travel Survey Highlights 1997/98. 2000, Land Transport Safety Authority: Wellington, NZ.
3. Spengler, J. Indoor air quality issues in buildings. in Proceedings of the 10th Annual AIOH Conference. 1991. Bendigo.
4. Gauderman et al, Effects of exposure to traffic on lung development from 10 to 18 years of age: a cohort study. The Lancet, 2007.
5. Crane, J., COPD and indoor environments, R.A. Phipps, Editor. 2007: Wellington.
6. Howden-Chapman, P.M., A.; Crane, J.; Viggers, H.; Cunningham, M.; Blakely, T.; Cunningham, C.; Woodward, A.; Saville-Smith, K.; O'Dea, D.; Kennedy, M.; Baker, M.; Waipara, N.; Chapman, R.; Davie, G., Effect of insulating existing houses on health inequality: cluster randomised study in the community. British Medical Journal, 2007. **334**: p. 460-460.
7. Isaacs, N.C.M.F., L. ; Pollard, A.; Saville-Smith K.; Fraser. R.; Rossouw P.; Jowett, J., Energy use in New Zealand households - HEEP year 10 report. 2006, Building Research Association of New Zealand: Wellington.
8. Cunningham, M., Solutions for moisture control in homes. 2007: Wellington.
9. The Asthma and Respiratory Foundation of New Zealand, Trying to catch our breath; the burden of preventable breathing diseases in children and young people, I.B. Asher, Cass, Editor. 2006: Wellington.
10. Swankin, D., Washington letter. American Industrial Hygiene Journal, 1989. **50**: p. A6.
11. Brown, S.K., Volatile organic compounds in indoor air: sources and control. Chemistry Australia, 1997. **64**: p. 10-13.
12. Bennet, D., McKone, TE, Evans, JS, et al., Defining intake fraction. Environmental Science and Technology, 2002: p. 207A-211A.
13. Smith, K., Air pollution: assessing total exposure in the United States. Environment International, 1988. **30**(8): p. 10-38.
14. Lai, A., Thatcher, TL, Nazaroff, WW., Inhalation transfer factors for air pollution health risk assessment. J Air Waste Management Association, 2000(50): p. 1688-1699.
15. Asher, I., Byrnes, C, Trying to Catch Our Breath: the burden of preventable breathing disease in children and young people. 2006, The Asthma and Respiratory Foundation of New Zealand: Wellington.
16. DEFRA, Fuel Poverty in England: the Governments Plan for Action. 2004, DEFRA: London. p. 1-51.

17. Lloyd, C.R., Fuel Poverty in New Zealand. Social Policy Journal of New Zealand, 2006(27): p. 142-155.

18. Davie, G., The Seasons of "Six Feet Under": trends and determinants of excess winter mortality in New Zealand from 1980 to 2000 [Partial requirement for Masters]. 2004, University of Melbourne, .

19. Baker, M.M., J; Blakely, T; et al., Housing, crowding and health., in Housing and Health,, P.H.-C.a.P. Carroll, Editor. 2004, Department of Public Health, Wellington School of Medicine and Health Sciences: Wellington,.

20. Housing and Health: Research Policy and Innovation, ed. C. Howden-Chapman P, P. 2005, Wellington: Steele Roberts.

21. Baker, M.Z., Jane; Howden-Chapman, Philippa; Blakely, Tony; Saville-Smith, Kay; Crane, Julian, Housing, Crowding and Health Study: Characteristics of cohort members and their hospitalisations: Draft Report,, H.K.O.H.a.H.R. Programme, Editor. 2006, Wellington School of Medicine & Health Sciences: Wellington.

22. Bassett, M., BRANZVENT: A guide to passively venting houses Draft version 5. 2004, BRANZ: Wellington. p. 0-106.

23. Maroni, M.S., B., Lindvall, T., Indoor Air Quality; A comprehensive reference book. Air quality monographs - Vol 3, ed. M.S. Maroni, B., Lindvall, T. 1995, Amsterdam: Elsevier.

24. Paediatrics, The vulnerability, sensitivity, and resiliency of the developing embryo, infant, child and adolescent to the effects of environmental chemicals, drugs, and physical agents, as compared to adults, in S113, P. 2004, Editor. 2004.

25. Scientific Committee on health and environmental risks, Preliminary report on risk assessment on indoor air quality, E. Commission, Editor. 2007: Brussels. p. 1-28.

26. Maynard, R. Policies for indoor air pollutants. in Healthy Buildings 2006. 2006. Lisboa, Portugal.

27. ANSI/ASHRAE, ANSI/ASHRAE Standard 62.2-2004 ventilation and acceptable indoor air quality in low-rise residential buildings. 2004.

28. Reed, S.S., V. Indoor Air Quality Guidelines: Are there any air guidelines we can use? in Clean Air Society of Australia and New Zealand Special Interest group for indoor air quality workshop. 2007. Sydney.

29. Phipps, R.A.R., S.; Neumeister, H.; Wilkenson, S. Towards IAQ Guidelines in Australia and New Zealand: IAQ special Interest group workshop. in 14th IUAPPA World Congress and CASANZ conference. 2007. Brisbane.

30. Liddament, M., A review of ventilation and the quality of the ventilation air. Indoor Air, 2000. **10**(3): p. 193-199.

31. Phipps, R.A., Development of a Decision Support System for the Design of Good Indoor Air Quality in Office Buildings, in Institute of Technology and Engineering. 2001, Massey University: Palmerston North. p. Vol 1 1-200; Vol 2 1-358.

32. Schwartz, Air pollution and children's health. Journal of Paediatrics, 2004. **13**(4): p. 1037-1043.

33. WHO, Effects of air pollution on children's health and development, in Report on a WHO working group. 2005, European Centre for Environment and Health: Bonn office.

34. WHO, Health aspects of air pollution with particulate matter, ozone, and nitrogen dioxide., in Report on a WHO working group EUR/o4/5042688, W.R.O.f. Europe, Editor. 2003: Copenhagen.

35. Hasselaar, E.v.G., J.T. How healthy is the bedroom. in Healthy Buildings 2006. 2006. Lisboa, Portugal.

36. Howden-Chapman, P.P., N; Nicholls, S.; Cunningham, M.; Phipps, R.; Boulic, M.; Fjallstrom, P.; Bennett, J.;Free, S.; Chapman, R.; Lloyd, B.; Viggers, H.; Shields, D.; Baker, M.; Cunningham, C.; Woodward, A.; Wickens, K.; Bullen, C.; Crane, J., Reducing childhood asthma morbidity through housing intervention: main health results from the Housing, Heating and Health Study. submitted to Lancet, 2007.

37. Bornehag, C.G.S., J., Bonini, A.; Custovic, P.; Malmberg, S.; Skerfving, T.; Sigsgaard, A., Dampness in buildings as a risk factor for health effects, EUROEXPO: a multidisciplinary review of the literature(1998-2000) on dampness and mite exposure in buildings and health effects. Indoor Air, 2004. **14**(4): p. 243-257.

38. Miller, J.D., Fungi as contaminants in indoor air. Journal of Atmospherics Environments, 1992. **26A**(12): p. 2163-2172.

39. Morey, P. Mould Growth in Buildings: Removal and Prevention. in proceedings of the International Conference of Indoor Air Quality and Climate. 1996. Nagoya, Japan.

40. WHO, Indoor Pollutants: Exposure and Health Effects. Report on a World health Organisation meeting, 8-11 June, Norlington., WHO, Editor. 1982: Norlington.

41. WHO Europe, Large Analysis and review of European housing and health status -- Preliminary Overview, in European Centre for Environment and Health, W.R.O.f. Europe, Editor. 2005: Bonn. p. 1-41.

42. Humfrey, C.S., Linda; Harrison, Paul, IEH assessment on Indoor air quality in the home: nitrogen dioxide, formaldehyde, volatile organic compounds, house dust mites, fungi and bacteria, in Assessment A2, M.R.C. Institute for Environment and Health, Editor. 1996: Norwich. p. 1-381.

43. THADE, Toward healthy air in dwellings in Europe 2004. 2004.

44. INDEX project, Critical appraisal of the setting and implementation of indoor exposure limits in the EU, in EUR21590 EN, D.G. European Commission, Joint Research Centre, Editor. 2005.

45. EnVIE, I.A.a., 2002- 2006 frame work programme. 2006.

46. Chapman and Housing and Heating Research Team, Housing, Heating and Health Study: 2005/2006 Report Two. June 2006, He Kainga Oranga Healthy Housing Research programme: Wellington.

47. Phipps, R.P., ; Cunningham, M.; Fjällström, P.; Boulic, M.; Howden-Chapman, P.; Crane, J.; Baker, M.; Viggers, H.; Robinson, J.; Nicholls, S.; Lloyd, B.; Chapman, R.;. Intensive Monitoring of Emissions from Portable Domestic Heaters. in Healthy Buildings 2006. 2006. Lisboa, Portugal.

48. Butte, W.H., B., Pollutants in house dust as indicators of indoor contamination. Environmental Contaminant Toxicology, 2002. **175**: p. 1-46.

49. Ellacottt, M.R., Sue, Review: development of robust indoor air quality models for the estimation of volatile organic compounds concentrations in buildings. Indoor and Built Environment, 1999. **8**: p. 345-360.

50. National Health and Medical Research Council, National indoor air quality goal for volatile organic compounds. 1992, NHMR&C: Canberra.

51. Warnes, J., New resin technologies, R.A. Phipps, Editor. 2007.

52. Godish, T., Sick buildings: definitions, diagnosis and mitigation. 1995, Florida: Lewis Publishers.

53. Ellacott, M.R., Sue, Review: development of robust indoor air quality models for the estimation of volatile organic compounds concentrations in buildings. Indoor and Built Environment, 1999. **8**: p. 345-360.

54. Levin, H., Controlling sources of air pollution, in Chemical, microbiological, health and comfort aspects of indoor air quality - State of the Art in SBS, H.W. Knoppel, P, Editor. 1992, Kluwer Academic Publishers: Dordrecht. p. 321-341.

55. Department of Health and Aged Care, Indoor Air Quality: A report on health impacts and management options. 2000, Environmental Health Section: Canberra, Australia. p. 1-176.

56. Department of Health and Aged Care, N., Formaldehyde, P.E.C.A.R. 28, Editor. 2006, Australian Government: Sydney. p. 389.

57. United States Environmental Protection Agency, Healthy Buildings, Healthy People: A vision for 21st Century. 2000: Washington DC.

58. CIIT, Formaldehyde: hazard characterization and dose-response assessment for carcinogenicity by the route of inhalation., in Rev. ed. 1999, Chemical Industry Institute of Toxicology: Research Triangle Park, NC, USA.

59. Environment Canada, Priority Substance List Assessment Report: Formaldehyde., H. Canada, Editor. 2001, Minister of Public Works and Government Services.: Ottawa.

60. International Agency for Research on Cancer, Formaldehyde, I.M.o.t.E.o.C.R.t. Humans, Editor. 1995. p. 217-375. 62.

61. WHO, Formaldehyde. Environmental Health Criteria 89, in International Programme on Chemical Safety, W.H. Organization, Editor. 1989: Geneva.

62. Environment Canada, Priority Substance List Assessment Report: Formaldehyde., H. Canada, Editor. 2001:, Minister of Public Works and Government Services.: Ottawa.

63. Canada, H., Proposed residential indoor air quality guideline for formaldehyde. 2005. p. 31.

64. Fisher, G., Air Quality in New Zealand. Clean Air and Environmental Quality, 2000. **34**(2): p. 40-41.

65. IARC, Monographs on the Evaluation of Carcinogenic Risks to Humans: Tobacco smoke and involuntary smoking, V. 83, Editor. 2004.

66. Pope, D., Health effects of fine particulate air pollution: lines that connect. JAWMA, June 2006. **56**: p. 709-742.

67. Coulson, G., Ambient pollution and interactions with housing. 2007.

68. Isaacs, N.C.M.F., L. ; Pollard, A.; Saville-Smith K.; Fraser. R.; Rossouw P.; Jowett, J.

69. Pope, D., Health effects of fine particulate air pollution: lines that connect. JAWMA, 2006. **56**: p. 709-742.

70. Institute of Medicine, Damp Indoor spaces and health, N.A.o. Science, Editor. 2004, The National Academies Press,: Washington DC.

71. Nevalainen, A.S., M., Of microbes and men. Indoor Air, 2005. **15**: p. 58-64.

72. Canada, H., Residential indoor air quality guideline for moulds, in Canada Gazette Part I, Vol. 141 No. 13. 2007.

73. Samson, R.A.F., B.; Flannigan, M.E.; Verhoeff, A.P.; Adan, O.C.G.; Hoekstra, E.S.,, Health implications of fungi in indoor environments. Air Quality Monographs. Vol. 2. 1994, Amsterdam; New York: Elsevier.

74. Canada, H., Fungal Contamination in Public Buildings: Health Effects and Investigation Methods. 2004, Ottawa: Health Canada. 47.

75. Health Canada, Residential indoor air quality guideline for moulds, in Canada Gazette Part I, Vol. 141 No. 13. 2007.

76. Pasanen, A.-L., ; Kalliokoski, P; Pasanen, P.; Jantunen, M.J.; Nevalainen, A.;, Laboratory studies on the relationship between fungal growth and atmospheric temperature and humidity. Environment International, 1991. **17**: p. 225-228.

77. Douwes, J.D., G.; Heinrich, J.; Koch, A.; Wolfgang, B.; Brunekreef, B., Endotoxin and Beta (1-3) -Glucan in house dust and the relationship with house characteristics: a pilot study in 25 German homes. Indoor Air, 1998. **8**: p. 255-263.

78. Baker, M.M., A; Garrett, N, et al., Household crowding a major risk factor for epidemic meningococcal disease in Auckland children. Paediatric Infectious Disease Journal., 2000. **19**: p. 983-990.

79. Cunningham, M., Dusmites in homes, R.A. Phipps, Editor. 2006: Wellington.

80. International Society of Indoor Air Quality and Climate, Control of moisture problems affecting biological indoor air quality. ISIAQ Guidelines TFI-1996. 1996, Ottawa: ISIAQ. 1-70.

81. Parker, H.D.M.o.E., Press Statement, 'Report on healthy homes welcomed. 2006: Wellington.

82. Walker, J.M., R.;Platt, S.; Petticrew, M.P.; Hopton, J.;et al.,, Does usage of domestic heating influence internal environmental conditions and health? European Journal of Public Health, 2006. **16**: p. 463-469.

83. International Society for Indoor Air Quality and Climate, Control of moisture problems affecting biological indoor air quality. TF1-1996. 1996, Ottawa: ISIAQ. 1-70.

84. EnHealth, The Health Effects of Environmental Noise - Other than Hearing Loss. 2004, EnHealth Council, Department of health and Aging, Commonwealth of Australia: Canberra, Australia. p. 1-71.

85. Hudspeth, A.K., M, Auditory Neuroscience: Development , Transduction and Integration. National Academy of Sciences, 2000. **97**(22): p. 11690-11691.

86. Belojevic, G.S.-T., M., Prevalence of arterial hypertension and myocardial infraction in relation to traffic noise exposure. Noise and Health, 2002. **4**: p. 33-37.

87. Batho, W.J.S.C., Report of the Noise Review Working Party. 1990, Department of the Environment.

88. Chen, Y.H., S., An investigation on the physiological and psychological effects on infrasound on persons. Journal of Low Frequency Noise, Vibration and Active Control, 2004. **23**(1): p. 71-76.

89. Netherlands, H.C.o., Noise and Health. 1994: Hauge.

90. Carter, N.L., Ingham, P., Tran, K.,, Environmental noise and sleep - A study of arousals, cardiac arrhythmia and urinary catecholamines. Sleep, 1994. **17**: p. 49-55.

91. Gander, P.H.M., N. S.; Harris, R. B.; Reid, P., Sleep, sleepiness and motor vehicle accidents: a national survey. Australian and New Zealand Journal of Public Health, 2005. **29**(1): p. 16-21.

92. Landtransport, Factsheet 24 - Fatigue: Staying alert while you're driving. 2005, Landtransport.

93. Berglund, B.L., Thomas.; Schwela, D.H., Guidelines for Community Noise, in World Health Organisation. 1999: Geneva.

94. Yike I, Rand TG, Dearborn DG. Acute inflammatory responses to Stachybotrys chartarum in the lungs of infant rats: time course and possible mechanisms. Journal of Toxicology Science. 2005 Apr;84(2):408-17. Epub 2005 Jan 12.

16 Appendix A: Healthy Homes Scheme Workshop – 26 September 2006

The workshop was attended by the following people. Paul Bennett (HNZC), Vicki McLaren (WCC) Sian Smith (DBH) Anna Stevenson (CCC) Xanthe Howes (EECA), Rebecca Wells (Stats NZ), Jennifer Brown (ACC), Helen Topham (HVDHB), Victoria Owen (Local Government NZ), Neville Auton (DCC) Michael Gibbs (Office of Hon Chris Carter), Vanessa Selak and Cherry Morgan (Auckland Regional Public Health Board), Chris Cunningham and Robyn Phipps (Massey University), Malcolm Cunningham and Lynda Amitrano (BRANZ), Philippa Howden-Chapman, Michael Keall, Michael Baker, Sarah Nicolls (University of Otago)

At the meeting it was found there were large overlaps between the schemes being developed by several different organisations. It was agreed that there were sufficient overlaps that they could be combined. The DBH agreed to take the lead. There was some discussion around how the mechanisms of the Index such as when would it be triggered; on point of sale, change of tenancy or on application for a consent for further alterations? Would the results be entered on the properties LIM? There was also discussion on who was going to pay for the rating vs who will benefits? It was considered as the house last more than 80 years then the benefits extend beyond the current owner.