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An Empirical Pilot Study of a Domestic Ventilation System For The Control of Moisture in New Zealand Housing

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Abstract: New Zealand is a country with a humid climate and frequent rainfall. These climatic conditions are a contributing factor in damp buildings. Also low levels of ventilation, insufficient insulation and heating, can cause unacceptable levels of dampness. Damp housing is strongly implicated in causing asthma and allergies, providing a ripe environment for fungi and dustmites to propagate. This is of considerable concern as New Zealand has the second highest rate of asthma in the world.

A ventilation system which may suit the New Zealand climate and construction systems is a domestic ventilation system which draws air from the roof space to trickle ventilate other parts of the house.

A Massey University research team assessed the effectiveness of the domestic ventilation system in the winters of 2000 and 2001. This paper presents the findings of moisture within houses comparing the previous study and a further inspection carried out one year following the installation of a domestic ventilation system in the Manawatu region of New Zealand.

The study contained three components, an exterior and interior inspection, an occupant's questionnaire and indoor air quality measurements. Results indicate that the participants perception of condensation and health symptoms improved throughout the study. Indoor air quality measurements including viable fungi, relative humidity and carbon dioxide levels in the majority of houses studied also improved.

1. Introduction and background

Moisture levels of up to 70 litres per day can be generated in a medium sized residential dwelling. Moisture comes from the environment (ground and air), the building materials, the occupants and the occupant's activities.

Ventilation is an effective method of removing moisture from a house.

Ventilation can occur via:

- Infiltration of outdoor air through small penetrations around windows, chimneys, walls etc;
- Natural ventilation through open windows or doors;
- Stack effect;
- Mechanical ventilation.

The Domestic Ventilation System (DVS®) is a 'mechanical air-handling system to assist with the control of condensation in a room' (BRANZ, 1999). The system makes use of the dry and warm air that usually exists in the ceiling cavity. This air is filtered before being transferred into the home by a variable speed fan.

A Massey University research team originally assessed the effectiveness of the DVS® for reducing moisture in 2001 by monitoring the indoor environment before and after the DVS® was installed. This paper reports on a follow up study which was conducted one year following the installation of the DVS®.

Moisture is a significant problem in New Zealand (NZ) housing. Moisture problems, including excessive condensation, mildew and dampness affect 45% of NZ houses, and more than 20% of houses have repeated prolonged mildew attacks (BRANZ, 1990). Most NZ homes have condensation during the winter months.

Excessive moisture contributes to the premature deterioration of building materials and household contents, with dampness rated as the most common cause of building failure, representing nearly two thirds of the failures in NZ dwellings (BRANZ, 1999). Sources of moisture inside houses include dampness rising from the ground, humid outdoor air, building materials, occupants and their activities such as showering and cooking, with up to 70 litres of moisture a day typically entering a house.

Phipps & Fortes (2002) state that dampness in houses is also a serious health concern. Moisture can provide a ripe environment for fungi and dustmites to propagate. This is of serious concern, as allergens produced by fungi and dust mites have been highlighted as leading causes of asthma and triggers for asthma attacks. New Zealand has the second highest rate of asthma in the world.

Miller (1992) reported that fungi growth occurs in warm damp conditions, with microscopic moulds and yeasts predominating in housing. Flannigan & Morey (1996) state that relative humidity greater than 70% is optimum for fungi growth, however most species can tolerate lower water availability at warmer temperatures. Flannigan & Morey (1996) also state that indoor air contains spores of many fungi, with the most common being *Cladosporium*, *Penicillium*, *Aspergillus* and *Eurotium.* There are sufficient nutrients present in most indoor environments for spores to propagate. The moisture required to support mould growth occurs via two mechanisms, either by direct wetting of surfaces from aerosols, droplets or splashing, or from condensation on cold surfaces such as uninsulated walls.

Fungi are recognised as significant biocontaminants of indoor air. Research conducted by Samson (1985), Rylander (1993) and Miller (1998) found that mycotoxins and microbial volatile organic compounds produced by fungi have been shown to cause acute respiratory symptoms, nasal congestion, skin redness and headaches. Miller (1992) stated that fungi allergies are common, typically affecting between six and fifteen percent of the population. Atopic allergic dermatitis and respiratory disease are associated with fungi commonly found in housing (Flannigan & Morey, 1996). While a variety of fungi are usually present in houses that do not experience moisture problems, often only one or two species dominate in houses with moisture problems. *Penicillium* in particular is reported to be more abundant in houses

where occupants report respiratory health symptoms (Flannigan & Morey, 1996). Yeast's are less dominant indoors and are most commonly associated with growths on wet, mould colonised surfaces such as inside shower cubicles (Flannigan & Morey, 1996).

Humidity can also present problems in the domestic dwelling. High humidity levels can result in condensation within the building structure and on interior and exterior surfaces and the subsequent development of moulds and fungi. The American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) specifies a relative humidity range of between 25% and 60% (Flannigan and Morey, 1996).

Reducing or controlling the level of moisture within a home can be carried out at the source. Methods such as effective subfloor ventilation, properly dried construction materials being installed, appliances that create moisture being ventilated effectively, limiting the number of pot plants, and/or an adequate ventilation system to provide approximately 10 litres per second per person of air are recommended.

2. Objective

The objective of the pilot study reported in this paper, is a one year follow up evaluation on the effectiveness of the DVS® domestic ventilation system for removing moisture and improving air quality in houses which had been installed with DVS® units in the Manawatu Region of New Zealand in 2001.

3. Methodology

A field study was originally conducted in the winter of 2000 utilising sixteen residential single storey houses in the Manawatu and Wanganui regions of New Zealand. Due to a natural attrition rate, only fourteen houses remained in the final study, one year following the installation of the DVS® in 2001.

This study compares and contrasts the findings based on three visits to each of the houses. Visit one(V1) prior to the installation in 2001, visit two(V2) approximately 8 weeks after the installation in 2001, and visit three(V3) approximately one year after installation of the DVS® in 2002.

In each of the houses, the trickle ventilation system drew air without additional heating from the ceiling cavity at a constant rate of one air change per hour (ACH). Either one or two outlets were installed depending upon the floor area of the house and the home owners preference. In houses with only one outlet, this was installed in the main hallway and where more than one outlet was present the second was located in the main living area.

As with the earlier study, field measurements were taken during the winter period to maximise weather conditions when condensation and moisture problems would be greatest. Each house was inspected in the early evening. The appraisal comprised of three sections, an exterior and interior inspection, an occupant's questionnaire and indoor air quality measurements.

The exterior and interior inspections carried out on the first visit to the property identified building defects, signs of moisture or moisture damage and the house construction materials, including the presence of insulation, poor site drainage or inadequate subfloor ventilation, in order to classify house types in which moisture problems were more prevalent.

The occupants' questionnaire identified sources and quantities of moisture generated inside the home from the occupants and their use of the house including cooking, heating, showering and clothes drying habits, plus other occupancy generated moisture sources such as plants and

pets. The questionnaire was also used to identify health symptoms experienced by occupants that may be affected or result from moisture, mould or dust mite populations. Finally, participants were asked a number of questions regarding their perception of moisture in their home and their perception of the systems performance (post installation).

A number of parameters relating to aspects of indoor air quality and thermal conditions were measured to determine if the installation of the trickle ventilation system affected the quality of the indoor environment. Viable airborne fungi and carbon dioxide were measured to evaluate indoor air quality, with temperature and humidity measured to give an indication of thermal conditions within the house.

All air quality measurements were taken in the following locations at a height of approximately one metre:

- The southern most bedroom, as this bedroom experiences the least sun and typically has the greatest moisture problems
- An area close to where the DVS® outlet was installed, as this area would be most affected by the system
- The main living area, as it has the highest occupancy rates and often experiences moisture problems associated with this;
- Outside the house, to act as a benchmark for the three interior measurement locations.

All air quality measurements were conducted in the early evening between the hours of 1730 and 2030 and were one-off spot measurements at the date of inspection.

An air sampler (PBI) was used to measure viable microbial spores. The sampler drew 100 litres of air over a petri dish containing a media (potato dextrose agar) that had been treated with antibiotics (penicillin and streptomycin) to inhibit bacterial growth. Bacteria multiply more rapidly than fungi, often overgrowing fungi colonies and are not typically associated with moisture generated by condensation. The samples were incubated at 25^{o}C for five days prior to identification. In visit three four samples were taken at each house at each of the locations discussed above.

An IAQ monitor (TSI Q-trak) measured carbon dioxide (CO_2) levels, temperature and relative humidity in all the sites given above. CO_2 levels provide a measure of the ventilation rates and hence bioeffluent concentrations within the spaces. Temperature and relative humidity give an indication of the air mixing within the house and across the exterior.

The velocity of air being supplied by the DVS® diffuser was checked in visit three at the DVS® vent site using a TSI flowhood to assess the air supply to each house.

4. Results & Discussion of Results

The results of this study reports on any change in indoor air quality or thermal conditions following the installation of the DVS®. Changes in each of the following are reported.

- The occupant's perception of the house environment;
- Changes in temperature or humidity gradients;
- CO_2 levels;
- Velocity of air being supplied by the DVS®.
- Number of viable fungi colony forming units (cfu/m²) and the types of fungi or yeast colonies present in the houses;
- Symptoms which may be attributable to moisture, fungi or dust mite populations;

The houses surveyed were a mixture of owner-occupiers and rental properties, in the Manawatu and Wanganui regions. All were single dwelling, detached low-rise structures. Sixteen houses were initially surveyed for the first visit, just in case any properties were lost due to attrition. One house was withdrawn from stage one of the study, as the occupants vacated the property before the second appraisal visit and the house remained empty. A further house (H6) was not included in the second stage at the request of the owners.

4.1 House Construction and Moisture Loads

Table One shows the different types of house construction methods, moisture loads within the houses and the perception of moisture within the houses by the occupants.

The sources of moisture most commonly found included unvented gas heaters, houseplants, drying clothes indoors on clothes racks or unvented clothes driers. While most householders were aware of the importance of ensuring that bathrooms had open windows to allow ventilation, in more than half of the households, occupants left the internal bathroom door open after a shower or bath, allowing the moist air to disperse through the house.

At the conclusion of visits two and three, without exception, all participants felt that condensation within their houses was either significantly reduced or had disappeared entirely.

Table One. House construction, moisture loads and perception of moisture on visits one, two and three.

	Date of Const-ruction	**Sub-floor cavity**	**Moisture Loads**	**Moisture Perception Visit One**	**Moisture Perception Visit Two**	**Moisture Perception Visit Three**
H1	1935	Yes	gas heater, subfloor wet, bathroom door open.	Morning condensation Damp Musty Mildew in all rooms	Condensation rare Less damp Musty in south bedroom only	Less condensation and dampness No mildew Fresher air in summer.
H2	1975	No	2 unflued gas heaters.	Morning condensation Minimal mildew	No condensation Air felt drier DVS® felt cold	No condensation Lowered setting to reduce coldness 1 outlet would have been sufficient. Can be warm in summer.
H3	1958	Yes	Dehumidifier.	Window condensation Ceiling mildew	No condensation House felt colder	No condensation House felt colder No mildew Turned off DVS® in summer.
H4	1974	Yes	2 unflued gas heaters, bathroom door open.	Condensation in south bedroom damp, musty	No condensation South bedroom no worse	Less condensation House felt warmer at night in summer.
H5	1950	Yes	2 unflued gas heaters, subfloor wet, bathroom door open.	Heavy condensation, South bedroom severe condensation	Less condensation House warmer Gaps in w/boards	Less condensation House feels ‘fresh’ after being closed in summer.

H6	1999	No	Unflued gas heater, bathroom door open.	Bedroom condensation	Less condensation	Didn't take part in 3rd visit.
H7	1961	Yes	Unflued gas heater, bathroom extract fan.	Bedroom, lounge condensation. Some mildew	No condensation House a lot drier	No condensation No mildew Warmer on cold days. Gets hot in summer – have to turn the DVS® off at times.
H8	1992	No	10+ plants, Air Cond, Dehumidifier	Condensation Mildew on curtains & in bathroom	Reduced condensation	Reduced condensation.
H9	1960	Yes	Unflued gas heater, bathroom door open.	Condensation Curtain mildew	Less condensation Air feels better Feel better in morning	No mildew No coldness or dampness
H 10	1993	No	Fish tank, garden built up to floor level, bathroom door open.	Severe condensation in bathroom, bedroom mildew	Less condensation Drier house Bathroom problem still	'New tenants' can't comment.
H 11	1960	Yes	10+ plants, bathroom door open.	Condensation Mildew on curtains.	Less condensation Feels warmer	Less condensation Feels warmer in winter – cooler in summer.
H 12	1921	Yes	Unflued gas heater, base of hill.	Mildew in front rooms, Severe condensation	Significantly reduced condensation. House warms faster Feels cleaner/fresh	Minor condensation in lounge.
H 13	1970	Yes	Unflued gas heater, indoor clothes rack.	Severe condensation Damp air Mildew in bathroom, south bedroom, localised areas	Less condensation House warms faster	Drier, less condensation. Keeps house fresh when closed up in summer. Had to turn it off in summer.
H 14	1970	Yes	Unflued gas heater, Unvented clothes drier, Leaks, bathroom window closed, bathroom door open.	Severe condensation Mildew on curtains, & in south bedroom walls & ceiling,	Less condensation	Less condensation
H 15	1970	Mixed	2 unflued gas heaters, unvented clothes drier.	Mildew most spaces condensation – all day	Less condensation Feels warmer	Less condensation, minor mildew. Warmer in winter

Notes
* House 1 Batts were installed in the ceiling in June 2001. Also carried out some building works during the 12 month period.

*House 4 installed larger flued gas fireplace

4.2 Health of Occupants

The occupants were asked to complete a questionnaire at each visit on the frequency with which they experienced health symptoms that may be associated with increased moisture including mould, dampness and dust mites. Table two summarises the results.

Overall, the incidence of symptoms experienced by participants decreased by more than 50% after the installation of the DVS®, suggesting that the level of pollutants present in the indoor air were reduced. Prior to the installation of the DVS® 31 respondents reported health symptoms such as headaches, sneezing, eye irritation, nasal irritation and asthma. One year following installation of the DVS® 24 respondents reported that these symptoms had decreased, while 6 reported that their symptoms had increased.

Table Two. Incidence of health symptoms per participants before and after installation of the DVS®.

Symptom	**Before installation**	**1 year After installation**		
		increased incidence	no change	decreased incidence
Headaches	11	3	2	6
Sneezing	13	1	3	9
Eye Irritation	3	1	-	2
Nasal Irritation	6	-	2	4
Asthma	5	1	1	3

Although the number of participants evaluated in the study was not large enough to draw definite conclusions on the cause and effect of symptoms, the results appear to show that installation of the DVS® improved the health of the occupants.

4.3 Temperature

The World Health Organisation recommends that indoor temperature should be kept above 12°C to avoid health problems. However, higher temperatures are required for comfort, and internationally agreed Standards recommend indoor temperatures should be maintained between 20 – 23.6°C in winter and 22.8 - 26.1°C in summer. Maintaining indoor temperatures above 20°C is an important component in the control of interior humidity levels. House four was the only home to meet the thermal comfort criteria on visit three.

Appendix 1 (Table Four) provides a summary of both indoor and outdoor temperatures. The temperatures within the houses ranged from 14.6°C to 19.3°C for visit one, 14.3°C to 21.2°C for visit two and 13.1 to 20.8°C for visit three. These low indoor temperatures are probably a reflection on the low levels of insulation and heating, and would have impacted on the indoor Relative Humidity (RH) levels shown in 5.5 herein and Appendix 1 (Table Three).

At the time of day that the measurements were taken, the indoor temperatures exceeded the World Health Organisation's recommendation of an indoor temperature higher than 12°C. However, it is possible that indoor temperatures during the night could fall below this level, which would contribute to the formation of condensation and high indoor relative humidities, even in a relatively dry environment.

The corresponding outdoor temperatures ranged from 10.8°C to 18.5°C, 11.2°C to 23.6°C and 10.6 to 18.8°C for visit one to three respectively (Appendix 1, Table Four). Temperatures were only approximately 2 °C warmer inside than outside than for visits one and two and 2.4°C for visit three. The installation of the DVS® did not appear to have a consistent effect on the internal temperature, with some houses being warmer and others cooler, relative to the outdoor temperature. Appendix 1 (Table Four) provides a summary of the change in indoor temperature relative to the outdoor temperatures.

4.4 Carbon Dioxide

Carbon dioxide (CO_2) is a widely accepted indicator of ventilation efficiency, and high concentrations of CO_2 frequently indicate there are also high levels of other gaseous pollutants. CO_2 is an important constituent of normal air and is exhaled as mammals breathe. Fresh outdoor air has a concentration of 325 to 400 parts per million (ppm) and buildings with adequate ventilation will have an indoor concentration between 400 to 800ppm. Although CO_2 is not considered a health risk until a concentration of 4000ppm, it can induce drowsiness and headaches at 1200ppm.

Appendix 1 (Table Three) provides a range of CO_2 levels taken at each visit. Prior to the installation of the DVS®, carbon dioxide levels in six of the fifteen houses were in excess of 800ppm (parts per million), suggesting that the building ventilation was inadequate with one house recording a CO_2 concentration over 3.5 times the recommended value.

The first post installation inspection (Visit two) found a large improvement in CO_2 levels. All but two of the houses had CO_2 concentrations comfortably within acceptable limits. One of these two properties (House 12) had produced an abnormal result due to a meeting of ten people coinciding with our visit. The other (House 13) was only marginally over 800ppm and had several visitors in the house at the time of the sampling. The other thirteen houses had CO_2 levels near the level found in fresh outdoor air, and it can be concluded that these homes were receiving sufficient ventilation to remove the bioeffluents emitted from people.

The CO_2 measurements were not as conclusive for the third visit. Half the houses (houses 1, 2, 4, 8, 9, 10, 11, and 14) had levels that showed there was sufficient ventilation to dilute the bioeffluents generated within the space. Five of the remaining houses had CO_2 measurements that were above 1000ppm. The reasons for this level are not clear, given that the DVS® was supplying one or more air changes per hour (ACH) for these houses.

The CO_2 measurements showed that fresh air was being introduced into other parts of the home, not just the room with a DVS® diffuser. Therefore, the average of the three indoor CO_2 measurements taken are an acceptable representation of the entire house and these are shown in Appendix 1 (Table Three). Outdoor concentrations were predictably stable between 350 to 400ppm.

4.5 Relative Humidity

Humidity can present problems in the domestic dwelling. High humidity levels can result in condensation within the building structure and on interior and exterior surfaces and the subsequent development of moulds and fungi. ASHRAE specifies a range between 25% and 60% (Flannigan and Morey, 1996).

The results (Appendix 1, Table Five) suggest that the indoor relative humidity (RH) levels were dominated by outdoor humidity. This effect appeared to be more pronounced in the third visit when outdoor moisture levels were high due to a wet winter. Twelve of the fourteen houses evaluated in stage two had RH levels that were below or very close to the acceptable upper limit of 70%. Houses H12 and H15 had indoor RH levels of 78% and 77%, respectively during visit three, however the outdoor humidity was also above 70% for these two houses. Six of the houses had indoor RH levels that were similar or below the levels measured on the second visit.

It appears that the additional ventilation assisted in the removal of moisture generated within the homes. A comparison of the RH between the visits one and two showed that the indoor RH readings reduced in ten of the houses, despite the outdoor RH being higher for nine of the visit two readings. Three of the houses experienced a difference between the change in indoor and change in outdoor readings in excess of 12% reduction, with the average being a 3.5% reduction.

Similar RH results (Appendix 1, Table Three) were found during the third visit. It appears that most of the achievable reduction in RH had occurred within the first eight weeks post installation of the DVS®, which is a logical result. Further changes in RH were not as pronounced for the third visit, possibly due to the above affect and the damp weather conditions that prevailed during the study period. The net change in indoor RH between visit one and three after adjustment for the change in outdoor humidity ranged from an impressive decrease of over 21% to an increase of 10%, however, on average the adjusted indoor RH had reduced by 1.4%. Interestingly, two homes had indoor RH levels that were more than 20% lower than the corresponding outdoor level.

None of the houses showed evidence of the air being too dry. RH below 40% can lead to drying of skin and mucus membranes in the eyes and respiratory tract, which can lead eye irritation and increased susceptibility to dust particles and bacteria entering the body's airways. Fortunately, this is seldom a problem in New Zealand buildings that are ventilated with fresh outdoor air.

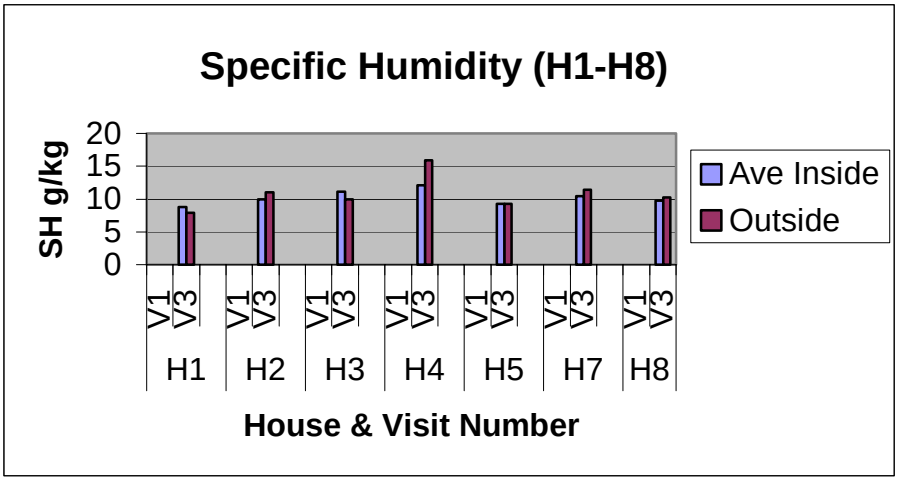
In this study, the effectiveness of the DVS® on reducing moisture was assessed with spot RH measurements made in the early evening. It is anticipated that the indoor RH levels might have increased overnight prior to the installation of the DVS®, as lower night indoor temperatures would have reduced the indoor air's ability to hold moisture. Condensation on windows is evidence of this.

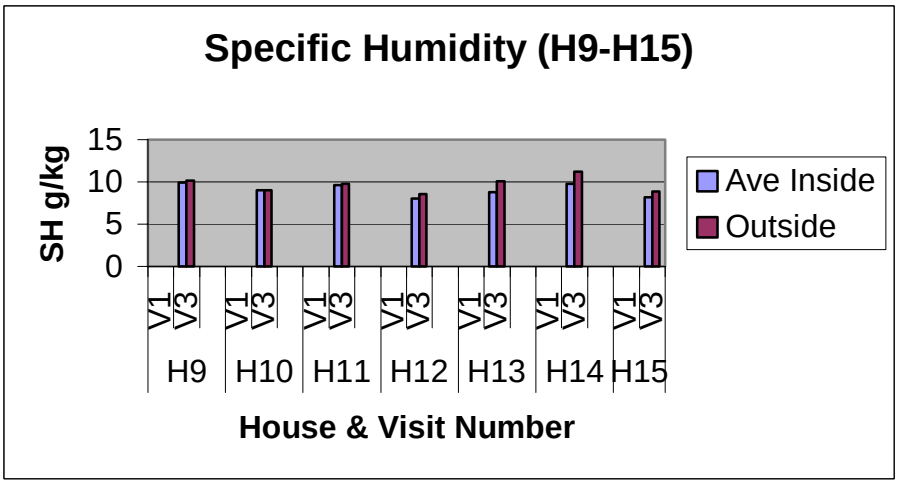
However, we can speculate that homes that are ventilated with the DVS® through the night with air drawn from outside, will have a sustained lower RH. This is due to lower night temperatures naturally dehumidifying the air by condensing surplus moisture before it enters the dwelling. The formation of dew is part of this process. By ventilating the house overnight, via the DVS®, with dryer night air could show marked decreases in indoor RH and condensation. This effect would be most pronounced if continuous background heating were also incorporated. Further experimental work would need to be conducted to confirm this hypothesis.

4.6 Specific Humidity

As with the relative humidity, the interior readings for specific humidity are similar enough to take the average without losing too much information.

The graphs below show the average inside specific humidity and outside specific humidity or mixing ratio in grams per kilogram (g/kg) for visits one and three.





There is a strong relationship between inside and outside absolute humidity.

The specific humidity provides a mixing ratio of grams of water per kg of dry air. A range of specific humidity of between 7 and 12 would be considered normal for New Zealand (Marsden, 2003).

The results (Appendix 1, Table Six) for specific humidity (SH) indicate that 11 of the houses showed the indoor and outdoor SH had reduced between visit one and visit three. In visit one all of the houses had SH readings within the range considered normal for New Zealand. In visit three only one house had a SH reading both indoor and outdoor greater that 12. This could be attributable to the very wet and cold weather conditions at time of inspection.

The results indicate little or no change in SH before and after the installation of the DVS®. The DVS® units installed in the subject houses did not have additional heating elements. Should any of the units be supplied with a heating or cooling units the results would likely be different. Again, further experimental work would need to be conducted to confirm this hypothesis.

4.7 Ventilation Rates

A TSI flowhood was used to measure the rate of air supplied to each home either via one or two diffusers on the third visit. To have an air change rate of approximately 1 air change per hour (ACH) the ventilation rates should be approximately 0.44 l/s/m².

The average ventilation rate was 0.36 l/s/m² with a range of ventilation rates between 0.23 and 0.64 l/s/m² as shown in Appendix 1 (Table Three). Four of the homes had a ventilation rate close to the desired rate of 1ACH, eight homes were below this figure and one home was above it. The units were designed to automatically reduce the fan speed (air supply) to .6 ACH when the ceiling air temperature dropped below 19°C. The occupants of the homes had reported to the researchers that they sometimes turned the fan speed up during periods of cold weather when conditions were favourable for forming condensation. The occupants of H2 had turned the fan speed on their DVS® unit down as they perceived the incoming air was too cold.

Some houses were supplied with more than one ACH per person and other houses less. In visit three 6 of the houses reported spot CO_2 readings greater than 800ppm. This may indicate that ventilation rates did not have a direct relationship with carbon dioxide levels suggesting the importance of controlling indoor sources of carbon dioxide and possibly poor room air mixing.

4.8 Fungi

The fungi results from the third visit were very positive, with most houses, which had previously had high fungal counts, showing a marked reduction. Outdoor fungal concentrations during the latest study period were very high due to a wet winter, which naturally had some influence on internal conditions. Individual fungi counts (CFU/m²) are attached in Appendix 1 (Table Seven).

Eleven of the fourteen houses studied in the one-year follow-up evaluation had extremely low to acceptable levels of fungi. Most of the houses had shown a reduction, with some houses having a large reduction in viable fungi from the previous visit, which suggests that moisture was being drawn out of the building structures. Houses 2, 14 and 15 had concentrations that were at the lowest range that could be expected for a naturally ventilated building, suggesting these houses had very dry indoor environments. Houses 9, 10 and 16 were still slightly higher or higher than desirable, but the range of species present suggested that the fungi concentration were not of immediate concern. Several of the house inspections showed extremely high outdoor fungi concentrations, however, the corresponding indoor concentrations were very low, showing that supply air was being drawn from a clean source.

A summarised interpretation of the fungal result for each house is shown in table five in Appendix 1 (Table Eight).

5. Conclusions

Moisture, condensation and fungi are significant problems in many New Zealand homes and can affect the health of the occupants. Low indoor temperatures, low ventilation rates and many indoor sources of moisture exacerbate these problems.

In the first of the post installation evaluations, the vast majority of the occupants reported significantly decreased condensation in their homes. This result was even stronger in the one-year re-evaluation with all participants reporting that their homes had significantly less or no

condensation. Many occupants also reported that the air was drier, warmer or easier to heat and felt fresher.

The results appeared to show that the installation of the DVS® significantly improved the health of the occupants of the houses studied. The reported incidence of headaches, asthma, sneezing, eye irritation and nasal irritation had all decreased since the installation of the DVS®. A health survey of a larger group of households would be necessary to confirm and add strength to this apparent relationship.

The results showed that the DVS® did reduce viable fungi, relative humidity and carbon dioxide levels in the majority of the houses studied. Carbon dioxide levels had been elevated in many of the homes prior to the installation of the DVS®, however, most homes were comfortably within the acceptable range post installation. CO_2 levels were improved in all areas of the house, not just the rooms with a DVS® diffuser, which showed that fresh air was being introduced into all parts of the house. CO_2 is an indicator of ventilation effectiveness and it is highly probable that other indoor contaminants that were not measured in the study were also reduced. This is supported by the decrease in health symptoms experienced by the occupants. The ventilation rates supplied by the DVS® unit, as measured at the diffuser showed some houses were being supplied with more than 1 air change per hour, and others less. This is most probably due to the home residence adjusting the fan speed to suit their ventilation needs and comfort. The units were also designed to automatically reduce the fan speed (air supply) to .6 ACH when the ceiling air temperature dropped below 19^{o}C.

The viable fungi concentrations measured during visit three showed significant changes from the first post installation visit. This result is not unexpected, as the moisture held in the materials where the fungi propagate (carpets, wall linings, furnishings etc.) can take some time to dry out. The fungi results from the third visit were very positive and even homes that had previously had high concentrations of fungi showed marked reductions of viable fungi spores. Further several homes had very low indoor concentrations of viable fungi, despite very high outdoor concentrations occurring at the same time. This suggests that there were no indoor fungi propagation sites and that the supply air was being drawn from a clean source. Some of the levels were much lower than the level normally expected from a non-air conditioned indoor environment.

The one-year results suggest that the drier indoor environment was drawing moisture from building materials, furnishings and other deeper sources of moisture. A separate study of the moisture content of building materials could confirm this result.

The indoor relative humidity levels showed a strong association with the outdoor relative humidity, although it appeared that the increased ventilation assisted in the removal of moisture generated within the home.

Indoor temperatures were below International comfort standards in all but one home during the third visit. All homes were above the World Health Organisations 12°C temperature level for health at the time of day that the measurements were taken, however it is possible that indoor temperatures could drop below this level over night. Where there are large indoor sources of moisture and low indoor temperatures, it is difficult for ventilation alone to maintain a dry house, consequently the heating option in the DVS® or another continuous background sources of heat is recommended.

The DVS® did not appear to have a consistent effect on the interior temperatures of the homes. The temperature measurements showed that some homes were warmer, while others were cooler relative, to outside temperatures. However, as mentioned previously, many homeowners reported that their homes were warmer and/or easier to warm.

The results from the first stage of the study illustrated that the DVS® was effective in significantly improving the indoor air quality in the homes studied. Repeating the evaluations after a further one year period has shown that the initial improvements were sustained and further reductions in condensation and viable fungi levels were achieved.

Acknowledgements

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APPENDIX 1

Table Three. Recordings of CO_2, RH and Ventilation Rates taken on visits one, two and three.

House No		CO2 (ppm)		Exterior RH %		Ventilation Rates l/s/m²
		Outdoor	Indoor	Out	Indoor	
1	V1	484	1319 – 1396	52.6	62.8 – 68.6	
	V2	448	510 – 574	59.4	54.9 – 58.5	
	V3	374	427 – 437	79.5	68.4 – 74.1	0.23
2	V1	447	900-919	48.7	55.2 – 58.4	
	V2	386	520 – 760	59.7	64.4 – 71.1	
	V3	387	698 – 720	57.4	60.9 – 65.7	0.33
3	V1	387	518 – 610	54.7	56.4 – 57.6	
	V2	412	513 – 647	38.6	50 – 56.4	
	V3	392	872 – 935	63.4	65 – 82.2	0.38
4	V1	400	600 – 636	62.1	66.1 – 73.6	
	V2	422	530 – 572	51	52.3 – 53.4	
	V3	400	463 – 536	40.1	50.1 – 54.5	0.47
5	V1	467	2472 – 3258	49.7	66.8 – 79.4	
	V2	398	596 – 660	53.9	60.3 – 62	
	V3	367	852 – 1179	68.1	61.1 – 78.3	0.48
6	V1	-	-	-	-	
	V2	-	-	-	-	
	V3	-	-		-	-
7	V1	409	743 – 820	52.9	55.3 – 61.1	
	V2	399	635 – 734	53.9	54.8 – 62.7	
	V3	406	1219 – 1630	55.6	56 – 68.3	0.32
8	V1	425	690 – 714	49.5	54 – 56.9	
	V2	389	459 – 612	51.3	58.6 – 61.6	
	V3	436	679 – 852	61.5	61.2 – 70.1	0.32
9	V1	379	783 – 876	65.9	62.9 –71.3	
	V2	396	492 – 525	76.1	64.2 – 64.8	
	V3	378	487 – 730	62.3	61.9 – 65.4	0.29
10	V1	380	-	-	-	
	V2	438	545 – 550	60.7	50.3 – 52.5	
	V3	380	543 –707	70.2	68.7 – 70.6	0.30
11	V1	376	770 – 2522	58.7	62.2 – 69.2	
	V2	391	443 – 543	55.9	64.9 – 65.3	
	V3	387	461 – 595	64.7	62.4 –70.2	0.35
12	V1	380	563 – 617	60.7	67.3 –69.6	
	V2	417	1060 – 1380	66.6	68.5 – 70.4	
	V3	359	1455 – 2631	73.9	74.6 – 80.9	-
13	V1	360	492 – 575	61.7	59.1 – 63.1	
	V2	380	850 – 916	62.8	64.1 – 67.6	
	V3	396	1121 – 1310	62.5	69.4 – 74	0.64
14	V1	393	1360 – 1368	62.4	60.6 – 65.2	
	V2	408	482 – 524	62.4	60.6 – 65.2	
	V3	400	638 – 827	56.4	60.3 – 70.1	0.28
15	V1	408	1088 – 1123	57.5	61 – 64.4	
	V2	427	530 – 560	51.7	56.3 – 58.4	
	V3	453	1259 – 1832	71.3	74.4 – 80.5	0.42

V1 = Visit One prior to installation of the DVS®
V2 = Visit Two eight weeks following installation
V3 = Visit Three One year following installation.

Table Four. Indoor and outdoor temperatures °C for visits one, two, and three, and the change in indoor temperature relative to the outdoor temperature after the installation of the DVS®.

	Visit One		Visit Two		Visit Three		Change	Change
	Inside	Outside	Inside	Outside	Inside	Outside	Visit 3 to Visit 1	Visit 3 to Visit 2
H1	17	14.5	18.3	14.8	13.1	10.6	0.0	-1.0
H2	17	14.1	14.3	13	15.9	14.4	-1.4	0.2
H3	19.3	18.5	20.2	23.6	17.6	15.8	1.0	5.2
H4	18.3	17	20.3	16.1	20.8	18.9	0.6	-2.3
H5	18.5	16.3	18.5	16.3	18.1	13.0	2.9	2.9
H7	17.2	15.2	18.7	14.7	19.3	17.6	-0.3	-2.3
H8	16	13	18.2	16.4	15.5	14.2	-1.7	-0.5
H9	16.3	12.7	19	15.3	16.2	14.6	-2.0	-2.1
H10	16.7	10.8	20.5	14.9	18.4	15.8	-3.3	-3.0
H11	14.6	13.7	17.4	17.6	16.8	16.5	-0.6	0.5
H12	15.7	14.5	17.5	15.2	14.8	11.2	2.4	1.3
H13	15.7	12.8	15.4	11.2	16.5	12.9	0.7	-0.6
H14	16.8	13.6	18	17.2	17.5	14.9	-0.6	1.8
H15	17.1	12	21.2	17.4	18.0	16.7	-3.8	-2.5
Average	**16.8**	**14.2**	**18.4**	**16.1**	**17.0**	**14.8**	**-0.4**	**-0.1**

Table Five. Change in relative humidity between visit one and visit three adjusted for outdoor relative humidity.

House	Indoor Humidity			Outdoor Humidity			
	V1	V3	Change in indoor RH between V3 & V1 (RH1)	V1	V3	Change in outdoor RH between V3 & V1 (RH2)	RH1 – RH2
H1	66	71.7	5.4	52.6	79.5	26.9	-21.5
H2	57	63.5	6.7	48.7	57.4	8.7	-2.0
H3	57	71.0	14.0	54.7	63.4	8.7	5.3
H4	70	52.2	-17.8	62.1	40.1	-22	4.2
H5	72	68.2	-3.7	49.7	68.1	18.4	-22.1
H7	59	60.3	0.9	52.9	55.6	2.7	-1.8
H8	55	64.9	9.6	49.5	61.5	12	-2.4
H9	66	63.9	-2.2	65.9	62.3	-3.6	1.4
H10	58	69.9	11.9	68.5	70.2	1.7	10.2
H11	65	65.7	0.9	58.7	64.7	6	-5.1
H12	69	78.4	9.9	60.7	73.9	13.2	-3.3
H13	61	71.5	10.1	61.7	62.5	0.8	9.3
H14	63	64.4	1.3	62.4	56.4	-6	7.3
H15	63	76.7	14.2	57.5	71.3	13.8	0.4
Averages	**62.5**	**67**	**4.4**	**56.7**	**63.4**	**5.8**	**-1.4**

Table Six. Change in the mixing ratio (specific humidity) between visit one and visit three adjusted for outdoor specific humidity.

House	Indoor Mixing Ratio (g/kg)			Outdoor Mixing Ratio (g/kg)			
	V1	V3	Change in indoor RH between V3 and V1 (SH1)	V1	V3	Change in outdoor RH between V3 and V1 (SH2)	SH1 – SH2
	9.52	8.78	-0.74	12.05	7.93	-4.12	3.38
H2	11.15	9.95	-1.2	13.05	11.03	-2.02	0.82
H3	11.11	11.1	-0.01	11.58	9.97	-1.61	1.6
H4	9.02	12.14	3.12	10.18	15.91	5.73	-2.61
H5	8.77	9.26	0.49	12.78	9.28	-3.5	3.99
H7	10.65	10.48	-0.17	11.99	11.39	-0.6	0.43
H8	11.46	9.74	-1.72	12.83	10.29	-2.54	0.82
H9	9.56	9.89	0.33	9.59	10.15	0.56	-0.23
H10	10.91	9.03	-1.88	9.22	8.99	-0.23	-1.65
H11	9.76	9.62	-0.14	10.78	9.77	-1.01	0.87
H12	9.22	8.04	-1.18	10.42	8.53	-1.89	0.71
H13	10.3	8.82	-1.48	10.25	10.11	-0.14	-1.34
H14	10.01	9.79	-0.22	10.14	11.23	1.09	-1.31
H15	10.12	8.21	-1.91	11.02	8.85	-2.17	0.26
Averages	**10.11**	**9.63**	**-0.48**	**11.13**	**10.25**	**-0.89**	**0.41**

Table Seven. Fungi counts per house and room measured on visits one, two and three.

House	Location	Visit 1		Visit 2		Visit 3	
		Colonies	CFU/m^2	Colonies	CFU/m^2	Colonies	CFU/m^2
H1	Outside	9	45	23	120	30	310
	Sth Bed	21	110	25	130	11	110
	Living area	22	115	41	225	13	110
	Hall	-	-	41	225	23	210
H2	Outside	55	315	62	365	25	250
	Sth Bed	31	165	62	365	2	20
	Living area	31	165	80	495	10	100
	Hall	-	-	75	460	6	50
H3	Outside	24	125	32	170	49	460
	Sth Bed	9	45	19	100	42	340
	Living area	10	50	18	95	46	430
	Hall	21	110	18	95	39	330
H4	Outside	15	75	28	150	18	190
	Sth Bed	39	215	39	215	2	20
	Living area	40	220	21	110	23	150
	Hall	29	155	22	115	13	110
H5	Outside	13	65	57	330	44	480
	Sth Bed	98	545	29	155	20	170
	Living area	127	945	39	215	15	100
	Hall	92	595	42	230	22	230
H6	Outside	9	45	43	240		
	Sth Bed	10	50	21	110		
	Hall	19	100	15	75		
	Living area	26	140	19	100		
H7	Outside	14	70	51	290	57	500
	Sth Bed	25	130	20	105	8	80
	Hall	31	165	25	130	15	100
	Living area	28	150	21	110	22	230
H8	Outside	22	115	34	185	17	160
	Sth Bed	23	120	16	85	7	80
	Hall	7	35	14	70	15	150
	Living area	29	155	22	115	43	370
H9	Outside	67	335	85	535	17	150
	Sth Bed	31	165	85	535	19	190
	Hall	24	125	70	420	32	320
	Living area	21	110	72	435	31	310
H10	Outside	52	215	105	710	20	170
	Sth Bed	42	230	67	400	8	50
	Hall	39	150	69	415	10	100
	Living area	42	295	82	510	8	50

H11	Outside	32	170	57	330	121	1540
	Sth Bed	27	145	35	190	8	70
	Hall	8	40	65	385	21	200
	Living area	4	20	72	435	16	150
H12	Outside	15	75	37	200	86	840
	Sth Bed	8	40	30	160	12	110
	Hall	14	70	17	90	15	100
	Living area	15	75	24	125	20	140
H13	Outside	64	380	28	190	6	50
	Sth Bed	31	165	14	70	2	10
	Hall	36	195	16	85	4	20
	Living area	17	90	10	50	7	40
H14	Outside	39	215	37	200	165	3010
	Sth Bed	24	125	35	190	5	40
	Hall	17	90	32	170	13	120
	Living area	28	150	207	3135	10	90
H15	Outside	34	185	12	60	28	290
	Sth Bed	52	295	41	225	25	250
	Hall	44	245	10	50	28	300
	Living area	47	265	48	270	38	420

Table Eight. Summary interpretation of fungal results by house.

H1	Outdoor levels had increased while indoor levels had decreased. Improvement in research period
H2	Indoor concentrations much lower than outdoor and lower than previous visits. Well within acceptable range. Excellent result.
H3	Outdoor levels were very high. Indoor levels were lower than outdoor which suggest there are no indoor fungi amplification sites. Good result.
H4	Outdoor levels very high, however, indoor levels were lower than outdoor which suggest there are no indoor fungi amplification sites. Good result.
H5	Outdoor levels had increased, however, indoor levels were considerably lower than outdoor which strongly indicates there are no indoor fungi amplification sites. Very good result.
H7	Indoor levels in the south bedroom were substantially reduced, while levels in the hall were somewhat reduced. Although living area levels had increase, they are not of concern.
H8	Indoor levels in the south bedroom were very low. The hall levels were lower than outdoor levels and within the acceptable range. The fungi levels in the living area were higher than desirable.
H9	Indoor levels had reduced considerably from the previous visits, but were still higher than desirable.
H10	Indoor levels of fungi were extremely low and within the acceptable range. Levels had dropped considerably since the last visits.
H11	Outside levels were extremely high, possibly due to seasonal influences. However, indoor levels were well below the acceptable range. Indoor levels had reduced significantly since the previous visit.
H12	Outdoor levels were extremely high possibly due to seasonal influences. Indoor levels were well within the acceptable range.
H13	Both outdoor and indoor concentrations of fungi were extremely low. Indoor concentrations on this visit were much lower than on the previous visits and well within the acceptable range.
H14	Outside levels were extremely high, possibly due to seasonal influences. However, indoor levels were well within the acceptable range. Indoor levels had reduced significantly since the previous visit. The very low fungal count in the living area is a vast improvement on the level found at the previous visit.
H15	Levels within the house were slightly higher than desirable, however, the mix of species present were benign and not of concern.