EFFECTS ON INDOOR ENVIRONMENT IN 30 AUCKLAND HOMES FROM THE INSTALLATION OF A POSITIVE PRESSURE VENTILATION UNIT

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ABSTRACT

A two year study was designed to assess the efficiency of a positive pressure ventilation system during winter, in 30 houses located in the west Auckland area. These households were randomly divided into two groups: the intervention group consisting of 20 households who received the ventilation unit following the first week of the first year monitoring, and 10 control households who received the unit after the completion of the study. Temperature, relative humidity (RH), carbon dioxide (CO_2) and formaldehyde level were measured every two minutes in the living room and master bedroom for a two week period in late winter/beginning spring 2008 and in winter 2009. Other parameters like mould level from floor dust, general health (self report questionnaire) and air flow coming to the living area from the roof space were also measured but the results are not presented in this paper. The 2008 winter results showed a statistically significant decrease in the weekly average level for both gases in the intervention homes whereas no significant difference were detected in the control group homes when comparing the first week and second week results. For instance, the CO_2 level, which is a surrogate measure for ventilation, dropped by 24.5% in the living rooms and 31% in bedrooms of the intervention homes. RH levels also significantly decreased in the intervention homes (- 4% in the living rooms, - 4.8% in the bedrooms) but were not statistically different in either rooms for the control homes. Both groups showed a second week temperature higher than the first week. Coming results from winter 2009, not presented in this paper, will validate the 2008 findings.

KEYWORDS

Positive pressure ventilation; indoor pollutants; temperature; moisture

INTRODUCTION

Recently New Zealand (NZ) studies have reported that homes are on average too cold and damp compared to the guidelines for health (Boulic *et al.*, 2008, Lloyd *et al.*, 2008). Isaacs *et al* (2006) reported that only 18% of the 386 living rooms monitored had temperature in excess of 20˚C. Furthermore, Butler *et al* (2003) reported 37% of the pacific island families interviewed had home dampness problems and subsequent mould problem. Moisture in buildings comes from a diverse range of indoor and outdoor sources. Water leakages, air infiltration and moisture migration from soil are among the major outdoor sources of moisture (Christian, 1994), which can be controlled with good construction and maintenance. Indoor sources of moisture include occupant respiration and perspiration (which contributes daily to about three litres of water vapour per person during light activity at 20°C (Harriman, 1990)); plant respiration; and activities like washing, drying clothes inside, bathing, showering and cooking. Potential indoor sources of moisture and pollutants can be controlled at the source by using methods such as an extractor fan when showering, not drying clothes inside, using outside vented range hoods when cooking or using a flued heating system, alongside with adequate house ventilation. The NZ Building code requires homes to have an adequate combination of thermal resistance and ventilation in spaces where moisture could be generated but does not recommend to achieve any minimum moisture level (Department of Building and Housing, 2006).

The predominant reason for ventilation is to dilute the concentration of bioeffluents and odours, and other indoor pollutants which could issue from combustion sources (unflued gas heater, toasting, cooking) and product releasing solvent (carpet, furniture…). In Japan, Sakai *et al* (2004) found a positive correlation between the formaldehyde (HCHO) concentration decrease and the furniture age. This can be explained by the fact that 76% of the Japanese houses had HCHO based adhesive furniture. The adverse effects of indoor air pollutants on health are exposure time dependant, concentration dependant, health and age of the person exposed to the pollutant. Whereas carbon dioxide (CO_2) is not an indoor pollutant that gives concern for health, but is an approximate surrogate measure for ventilation, HCHO require specific attention in the development of the WHO guidelines (World Health Organisation, 2006)

Since the 1970's, positive pressure ventilation systems have been used in UK homes to overcome condensation problems (Stephen, 1998). In recent years, these mechanical ventilation systems using as input the roof space air, which is generally warmer than outside, have became very popular in NZ and might bring some "free heat" in the living area. New Zealand Surveys reported a significant increase of mechanical ventilation installation from 1% of the houses surveyed in 1999 to about 6% of the houses surveyed in 2005 (Clark *et al.*, 2005).

A six month Canadian study comparing Inuit houses equipped with heat exchange ventilation unit with placebo houses showed a decrease of CO_2 level and relative humidity (RH) of 33% and 17% respectively. The same study did not find any statistically significant difference relating to the temperature (Kovesi *et al.*, 2009). In NZ, Phipps *et al* (2005) undertook monitoring in 14 houses before and after the installation of a positive pressure ventilation unit, and reported a significant decrease in CO_2 level and RH. However, the same authors did not find any significant changes in the temperature. Another NZ study was carried out in two Dunedin homes in summer time. The authors used the winter like days (low solar irradiance) of this summer season to predict the heat transfer from the roof space to the living area. They concluded that the roof space will not reach a sufficient temperature to increase the living area temperature whilst experiencing external winter temperatures (Smith *et al.*, 2008).

The objectives of this two year intervention study were to investigate the indoor climate change in term of RH, temperature and pollutants (CO_2 and HCHO), when a positive pressure ventilation system was installed and to compare these levels with the current health guidelines. This study was performed through two winter periods (2008 and 2009) in the same houses using the same monitoring instrumentation in order to obtain comparable data. In addition, temperatures have also been monitored over the summer (Dec 08/ Jan 09) and autumn (April/May 09). However, this paper presents only some results from the winter of 2008.

METHOD

This first year monitoring session was carried out in 30 homes (20 intervention homes + 10 control homes) in West Auckland from the 28th of July to 24th of October 2008. The ventilation unit was installed in the 20 randomly selected intervention homes at the end of the first week. Each house was monitored for a two week period; the active homes were monitored for one week prior and one week following the installation of the ventilation unit and the control homes (without a ventilation unit) were surveyed for two weeks. Results of temperature, RH, CO_2 and HCHO for the intervention group and the control group in two locations (living room and master bedroom) will be presented here.

Temperature and relative humidity measurement

For each house, measurements of room temperature and RH were carried out in the living room and the master bedroom, using a Gas Probe IAQ-4-DL sensor (BW® Technologies Ltd, Calgary, Canada). The loggers were set to monitor the temperature continuously every two minutes for up to two weeks. The sensors were placed in a custom made support structure which kept the probe at the desired height (1.10 m high from the floor) and prevented the instrument from being tampered with

(Illustration 1 a). Outdoor temperatures and RH measurements were downloaded from the online NIWA database (NIWA Climate Data Base).

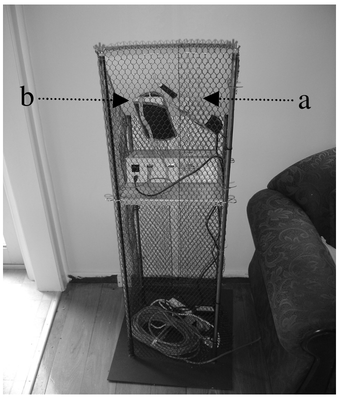

Illustration 1: Temperature /RH/ CO_2 sensors (a) and HCHO sensor (b) in the protective structure.

Carbon dioxide measurement

For each house, measurements of CO_2 were carried out in the living room and the master bedroom, using the same equipment than for temperature and RH measurement i.e. the Gas Probe IAQ-4-DL sensor (BW® Technologies Ltd, Calgary, Canada). The logger was set to monitor CO_2 continuously every two minutes for up to two weeks (Illustration 1 a).

Formaldehyde measurement

For each house, measurements of HCHO were undertaken using an AMS-2 Aldehyde Monitoring Station (PPM Technology Ltd, Gwynedd, Wales, United Kingdom). This instrument was also located in the sampling structure with the sampling probe located at 1.1 m about the floor and the logger was set to monitor HCHO continuously every two minutes for up to two weeks (Illustration 1 b).

Statistical analysis

The data were analysed using the statistical package R version 2.7.1 (R Development Core Team, 2005). Wilcoxon's rank tests were used to test the difference between the intervention and control group homes (living room and master bedroom) and outside temperatures (week 1 and week 2).

RESULTS

1) Temperature measurement.

Table 1 shows the average weekly outside temperatures and the average weekly temperatures for both rooms of the intervention and the control groups. For both groups and for both locations (living, bedroom), the second week was significantly warmer than the first week (Table 1). In average, the intervention group second week temperatures were 0.6˚C and 0.7˚C warmer for the living and the bedroom respectively. Similar results were found for the control group houses (0.7˚C and 0.6˚C warmer for the living and the bedroom respectively). For both groups, the outside temperatures were warmer on week 2, but not statistically significant. Furthermore, for both weeks, at the control home locations, the outside temperatures were warmer but not statistically significant ($P_{week\ 1} = 0.61$, $P_{week\ 2} = 0.22$). Due to technical constraints, the monitoring intervention/control was not well balanced, and consequently five out of ten control houses were monitored in the last month when ambient temperature started to be warmer.

	Week 1 outside temp. (˚C)	Week 2 outside temp. (˚C)	*P*	Week 1 living temp. (˚C)	Week 2 living temp. (˚C)	*P*	Week 1 bedroom temp. (˚C)	Week 2 bedroom temp. (˚C)	*P*
Intervention homes (N=20)	11.3	11.8	*0.18*	17.8	18.4	*0.07*	17.3	18.0	*0.04*
Control homes (N=10)	11.7	12.3	*0.11*	17.5	18.2	*0.02*	17.6	18.2	*0.02*

Table 1: week 1 and week 2 average temperatures

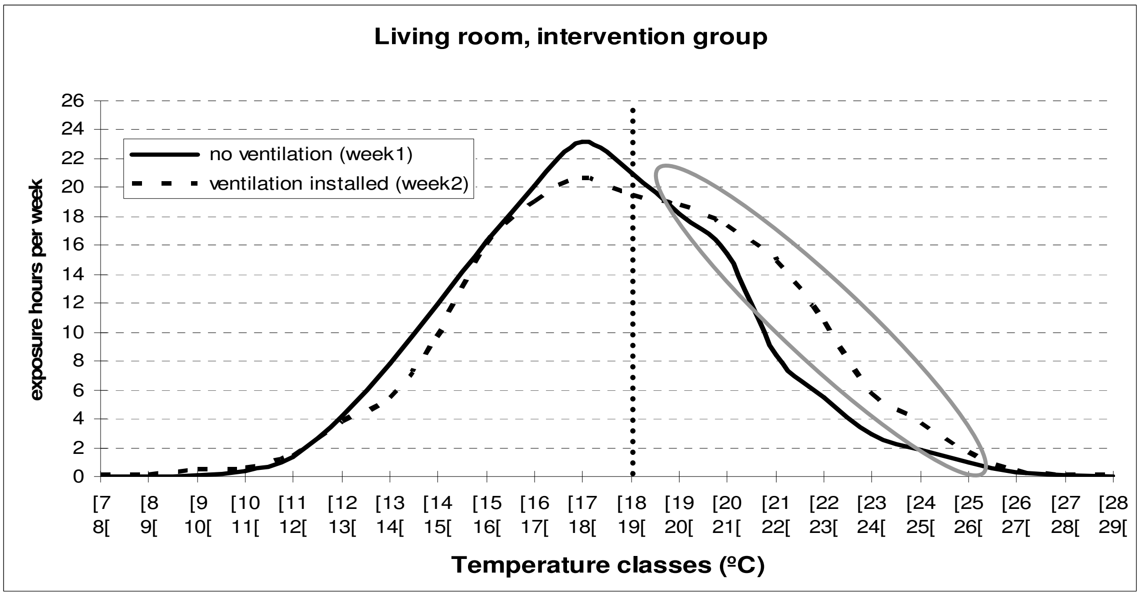

Figure 1: weekly temperature exposure for the intervention group homes

Figure 1 shows, that the living rooms of the intervention homes, experienced longer exposure to temperatures above the 18 ºC minimum recommended level (World Health Organisation, 1987). During the first week, the intervention living rooms were for 47% of the time above 18 ºC. Following the ventilation unit installation, the intervention living rooms were for 55% of the time above 18 ºC. The difference was even greater for in the bedroom with 35% and 47% for the first and the second week respectively. Similar results were found for the control group homes. However, it should be noted that the WHO recommendations are based on occupied periods only, whereas this study measured data for both occupied and unoccupied periods. Future analysis will look at the exposure above 18 ºC between 5 pm and 9 am when people are at home.

2) Relative humidity measurement.

Figure 2 shows the two week RH level in the living room and master bedroom for both groups of houses.

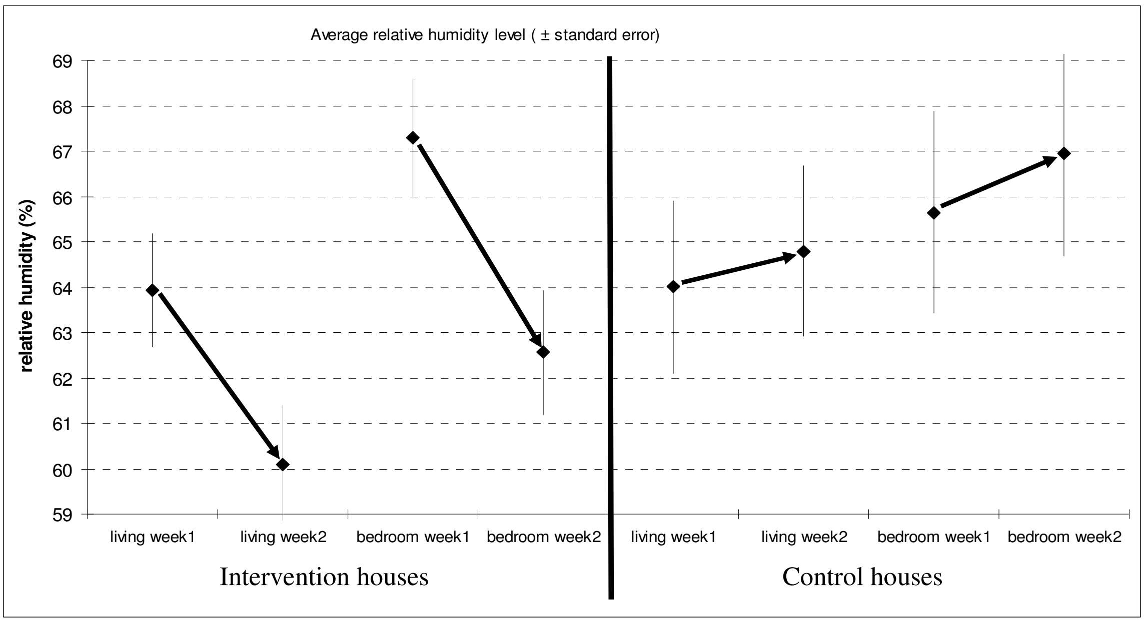

Figure 2: weekly average relative humidity for both groups with standard errors.

The arrows, on Figure 2 left part, represent a significant RH decrease (-4 % in average for the living and -4.8 % in average for the bedrooms) after the ventilation unit installed (p-value $_{\text{living room}}$ =0.002, p-value $_{\text{bedroom}}$ = 0.001). These findings are consistent with another NZ study which reported similar decrease in average RH after a ventilation unit was installed (Phipps *et al.*, 2005).
The control group homes showed no significant difference in the RH level between week 1 and week 2 for both living rooms and bedrooms (p-value $_{\text{living room}}$ =0.49, p-value $_{\text{bedroom}}$ = 0.44). In addition, for both groups, the bedroom RH level was always higher than the living room RH. Despite having a ventilation unit installed, 11 livings and 15 bedrooms out of 20 intervention homes showed a weekly average RH level above the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) recommended RH level of 40% - 60% for occupants comfort. This finding is mainly the consequence of the high outdoor RH level at this time of the year (hourly average outdoor RH level of 79.3% ($CI_{95\%}$ 78.8 - 79.8%)) (NIWA Climate Data Base).

3) Carbon dioxide measurement.

Figure 3 shows the two week CO_2 level in the living room and master bedroom for both groups.

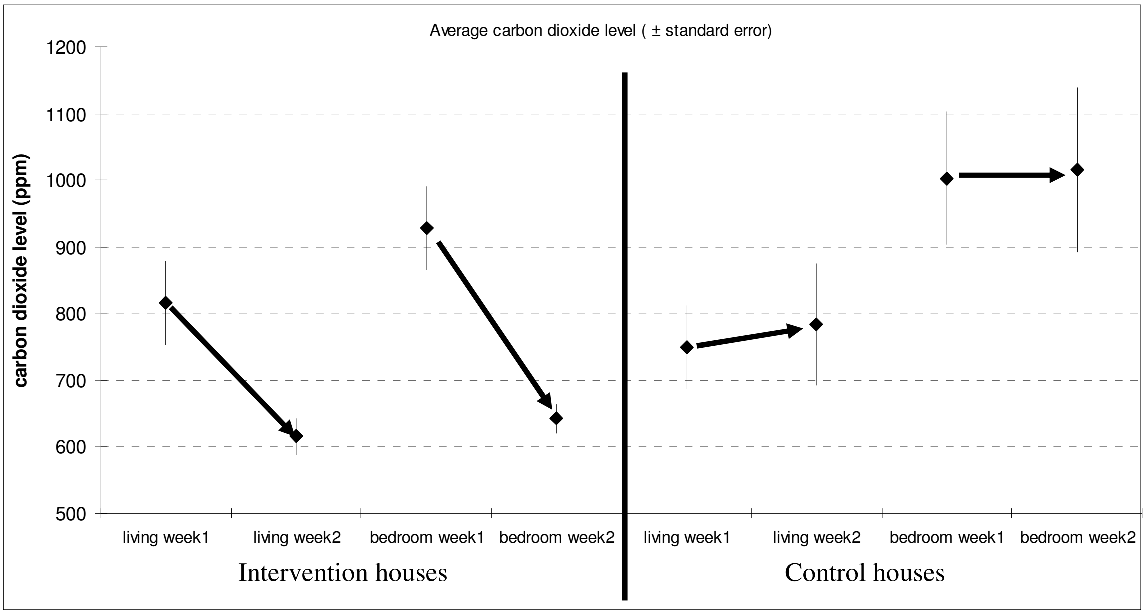

Figure 3: weekly average carbon dioxide level from both groups with standard errors.

The arrows, on Figure 3 left part, show a significant CO_2 level decrease (200 ppm decrease in living rooms and 286 ppm decrease in master bedrooms) after a ventilation unit installed (p-value $_{\text{living room}}$ < 0.001, p-value $_{\text{bedroom}}$< 0.001). In the control group homes, there were no significant difference in the CO_2 level between week 1 and week 2 for both rooms (p-value $_{\text{living room}}$ =0.49, p-value $_{\text{bedroom}}$ = 0.62). These results are consistent with a recent Canadian study which authors reported a 33% CO_2 decrease when a ventilation system installed (Kovesi *et al.*, 2009). As outdoor CO_2 concentration is quite stable between 350 and 400 ppm, the indoor CO_2 concentration is increased with combustion sources (unflued heating system, unflued cooking) and the number of people living in the house. However a typical indoor CO_2 concentration should be between 500 ppm and 1500ppm (Seppanen *et al.*, 2004). In this way, CO_2 concentration is often use as a surrogate indicator of the home ventilation level.

To date there is no World Health Organisation (WHO) guideline relating to CO_2 indoor concentration and this pollutant is, so far, classified as "current evidence uncertain or not sufficient for guidelines" in the in development WHO Guidelines for Indoor Air Quality (World Health Organisation, 2006). However, some countries like Canada set a recommended concentration to be less than 3500 ppm. In NZ, the standard for ventilation for acceptable indoor air quality (NZS 4303:1990) mentions that "Comfort (odour) criteria are likely to be satisfied if the ventilation rate is set so that 1000 ppm CO_2

is not exceeded" (New Zealand Standard, 1990). Figure 4 shows the percentage of time exposure above 1000 ppm (comfort threshold) for the living rooms. In Figure 4, the 20 intervention group houses are numbered from 1 to 20 and the 10 control houses from 1 to 10.

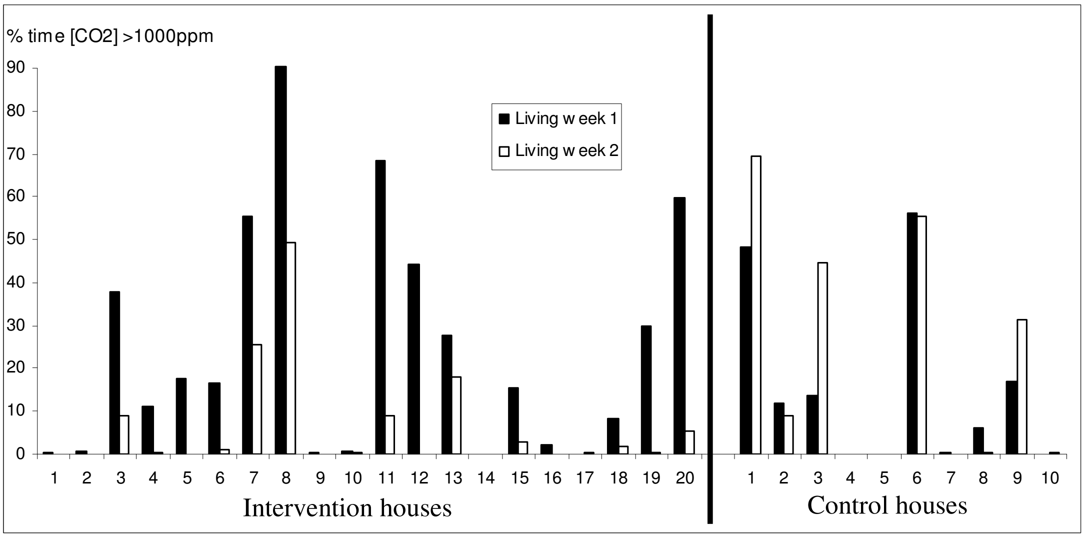

Figure 4: percentage of time with a CO_2 concentration above 1000 ppm in the living rooms.

Figure 4 shows that after installation of the ventilation unit, the exposure time to concentration of 1000 ppm and above decrease whereas the control homes show a similar exposure for both weeks.
The week 1 results for both groups show that around 50% of the houses have exposure time below 10% which means that according to the NZS 4303:1990, these houses have a satisfied natural ventilation rate. Furthermore, despite of having a ventilation unit installed three livings (ID No 7, ID No 8, ID No 13) still have more than 10% of the time with CO_2 level above 1000 ppm, which suggests high occupancy levels in the homes or important unflued combustion source (heating, cooking).

In the bedrooms, only 4 houses out of 30 showed sufficient natural ventilation (less than 10% of the time below 1000ppm) in the first week. Despite having a ventilation unit installed with an average 24.5% - 31% reduction in CO2 for livings and bedrooms respectively, eight master bedrooms still have a CO_2 level above 1000 ppm more than 10% of the time. In homes where there is no gas combustion process in the living room (unflued gas heater or gas cooking from an open plan kitchen), the CO_2 level was higher in the bedroom than in the living room, due to the occupants respiration during the night and usually smaller size of the bedroom.

4) Formaldehyde measurement.

Formaldehyde comes from diverse sources like combustion process (cooking, unflued heating…), off gassing from furniture and carpet (solvents, glues…), personal care products, etc...(NICNAS, 2006). At high concentration, HCHO is a colourless and pungent gas at room temperature. Amoore *et al* (1983) evaluated the human detection threshold at 0.83 ppm. However, HCHO is an irritant for eyes, nose and respiratory track at low concentration and around 0.05 ppm might exacerbate the risk of having asthma (Rumchev *et al.*, 2002). The Australian National Environment Protection and Heritage Council (NEPC) set a guideline value at 0.04 ppm for 24h averaging period (enHealth Council, 2007).

Figure 5 shows the percentage of time above 0.04 ppm (NEPC threshold) for both group living rooms. The houses are identified in Figure 4 and Figure 5 (1-20 intervention group houses; 1-10 control group houses). All intervention houses except for two (ID No 13 and ID No 17), showed decreased exposure to HCHO levels above 0.04 ppm after the installation of the ventilation unit, whereas the control homes show a similar exposure for both weeks.

The house ID No 17 shows a higher time exposure to HCHO concentration above 0.04 ppm during the second week despite of the ventilation system installed. A higher exposure time to HCHO was also found in the bedroom of this house. This house was located in the vicinity of an intensive construction site where solvent and paint were being applied during the monitoring period and it is possible that outdoor HCHO levels could have migrated indoors.
House No 13 bedroom showed a lower time exposure to HCHO concentration during the second week which does not support the living room result. This household had been operating an unflued gas heater intensively each evening, during this second week, with the ventilation unit fan set at low speed.

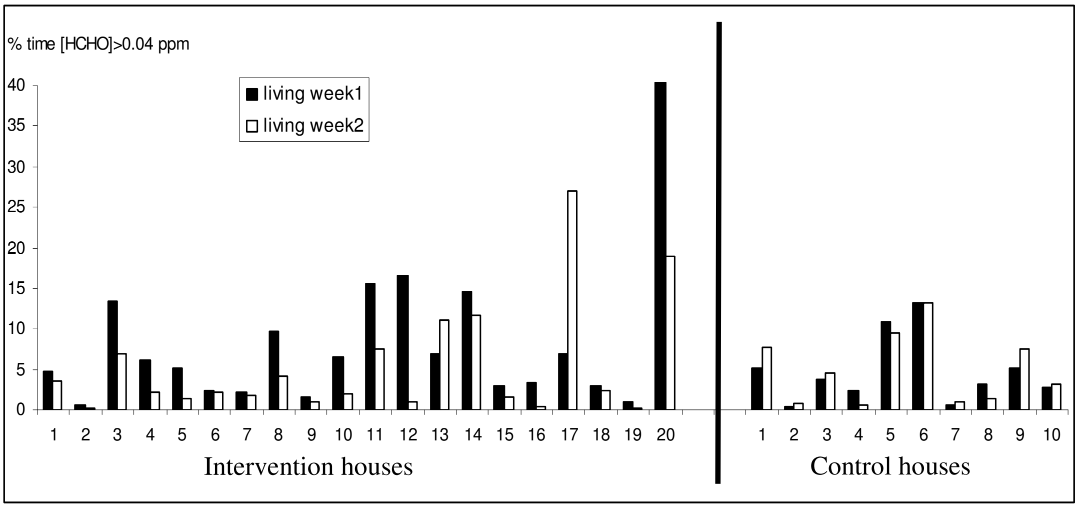

Figure 5: percentage of time with a HCHO concentration above 0.04 ppm in the living rooms.

In average, the second week HCHO levels were lower than the first week for both rooms of the intervention houses (0.0224 ppm vs. 0.0187 ppm p-value $_{\text{living room}}$ =0.005; 0.0199 ppm vs. 0.0158 ppm p-value $_{\text{bedroom}}$ = 0.003) whereas there were no significant difference in the HCHO level between week 1 and week 2 in the control group living rooms (p-value =0.95) but in the control group bedrooms the second week HCHO level was on average higher than the first week (0.0184 ppm vs. 0.0208 ppm, p-value = 0.065).

Conclusion

For the 30 houses monitored last winter, the indoor climate was different between the 20 active homes and 10 control homes.
In second week (ventilation unit installed), in the intervention homes and for both locations (living room and bedroom), the results showed a significantly lower level of RH, CO_2, and HCHO.
The results showed for both groups and for both locations that the indoor temperature during the second week was significantly warmer than the first monitoring week. However, the intervention group showed a significant higher exposure to indoor temperatures above 18°C. These results are full time weekly averaging period; future analysis will look at exposure on occupied period (from 5 pm to 9 am).

The second year monitoring started earlier and got a full winter season (15th June - 11th September 2009), and there was a better distribution of intervention and control homes during each monitoring week. The results are currently being analysed for this monitoring period.

Acknowledgements

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References

Amoore, J. E. and Hautala, E. 1983. "Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution". Journal of Applied Toxicology 3(6) 272-290.

Boulic, M., Fjällström, P., Phipps, R., Cunningham, M., Cleland, D., Pierse, N., Howden Chapman, P., Chapman, R., Viggers, H., Pollard, A. and Housing Heating and Health Team 2008. "Cold Homes in New Zealand - Does increasing the heater capacity improve indoor temperatures?" Clean Air and Environment Quality Journal 42(3) 22-29.

Butler, S., Williams, M., Tukuitonga, C. and Paterson, J. 2003. "Problems with damp and cold housing among Pacific families in New Zealand". New Zealand Medical Journal 116(1177) 1-8.

Christian, J. E. 1994. "Moistures sources". *In* "Moisture Control in Buildings" (Eds, Trechsel, H. R.) ASTM Manual Series, Philadelphia, 176-182.

Clark, S. J., Jones, M. and Page, I. C. 2005. "New Zealand 2005 House Condition Survey. Study report No. 142". (Eds, BRANZ). BRANZ Porirua, New Zealand,

Department of Building and Housing 2006. "Building for the 21st century, Review of the Building Code". (Eds, Department of Building and Housing). Department of Building and Housing, Wellington, New Zealand,

enHealth Council 2007. "The health effects of unflued gas heater use in Australia". (Eds, Commonwealth of Australia). Department of Heath and Ageing, Canberra, Australia,

Harriman, L. G. (Eds). 1990."The Dehumidification Handbook." Munters Cargocaire, Amesbury, 103 pp.

Isaacs, N., Camilleri, M., French, L., Pollard, A., Saville-Smith, K., Fraser, R., Rossouw, P. and Jowett, J. 2006. "Energy use in New Zealand households: report on the year 10 Analysis for the Household Energy End-use Project (HEEP). No SR 155". (Eds, BRANZ). Porirua, New Zealand,

Kovesi, T., Zaloum, C., Stocco, C., Fugler, D., Dales, R. E., Ni, A., Barrowman, N., Gilbert, N. L. and Miller, J. D. 2009. "Heat recovery ventilators prevent respiratory disorders in Inuit children." Indoor Air early view August 2009

Lloyd, C. R., Callau, M. F., Bishop, T. and Smith, I. J. 2008. "The efficacy of an energy efficient upgrade program in New Zealand". Energy and Buildings 40(7) 1228-1239.

New Zealand Standard 1990. "NZS 4303:1990 Ventilation for acceptable indoor air quality." (Eds, Standards Council). Wellington, New Zealand,

NICNAS 2006. "Priority Existing Chemical Assessment Report No 28: Formaldehyde". (Eds, Commonwealth of Australia). Department of Health and Ageing, Sydney, Australia,

NIWA Climate Data Base, Mean hourly relative humidity from Henderson Monitoring Station (agent number:12327) http://cliflo.niwa.co.nz

Phipps, R., Fortes, R., Fleming, M. and Jackson, A.2005. "Investigation of a home ventilation system for moisture and fungi control in 14 New Zealand Houses". *In* "Proceedings,17th International Clean Air and Environment Conference". CASANZ, Hobart, Australia

R Development Core Team, R: A language and environment for statistical computing, Vienna, Austria

Rumchev, K. B., Spickett, J. T., Bulsara, M. K., Phillips, M. R. and Stick, S. M. 2002. "Domestic exposure to formaldehyde significantly increases the risk of asthma in young children". Eur Respir J 20(2) 403-408.

Sakai, K., Norback, D., Mi, Y., Shibata, E., Kamijima, M., Yamada, T. and Takeuchi, Y. 2004. "A comparison of indoor air pollutants in Japan and Sweden: formaldehyde, nitrogen dioxide, and chlorinated volatile organic compounds". Environmental Research 94(0) 75-85.

Seppanen, O. A. and Fisk, W. J. 2004. "Summary of human responses to ventilation". Indoor Air 14(suppl 7) 102-118.

Smith, I. J., Carson, B. R. and Bassett, M. R.2008. "Is there free heat in the roof spaces of New Zealand houses? Mechanical ventilation systems and heat transfer". *In* "Proceedings,3rd International Solar Energy Society Conference - Asia Pacific Region". ANZSES, Sydney, Australia

Stephen, R. K. 1998. "Airtightness in UK dwellings: BRE's results and their significance. Report BR359." CRC Ltd London,

World Health Organisation 1987. "Health impact of low indoor temperatures: report on a WHO meeting". (Eds, World Health Organisation Regional Office for Europe). Copenhagen, Denmark,

World Health Organisation 2006. "Development of WHO guidelines for indoor air quality". (Eds, World Health Organisation Regional Office for Europe). Bonn, Germany,