International Proceedings of Chemical, Biological and Environmental Engineering, V0l. 90 (2015)
DOI: 10.7763/IPCBEE. 2015. V90. 14

The Effect of Vapour-Control Membrane Technology on Indoor Air Quality in Buildings

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Abstract. The impact of the inclusion of a vapour check membrane in timber buildings on indoor air quality, measured as volatile organic compounds (VOCs), was determined by Photo Ionization Detection. Two identical buildings were constructed except one building (test) contained an Intello vapour check membrane and the other building was the control. A VOC source (Wattyl Estapol High Performance Interior Clear Polyurethane Satin varnish) was placed in each building and the subsequent concentrations were monitored until background levels were resumed. Data analysis demonstrated that the VOC levels in the test house were consistently higher than those established in the control house (student t-test > 99.9% confidence). Average concentrations for VOC, temperature and relative humidity respectively were 3.23 ppm (control), 6.54 ppm (test); 17.3℃ (control), 17.4℃ (test) and 52.4% (control) and 54.7% (test). The humidity was also significantly higher in the test house (student t-test >99.9% confidence). Originally temperature differences were not found to be statistically conclusive; however this appeared to have been because the diurnal pattern of the temperature profile masked the difference in temperature. By removing this diurnal pattern, the temperatures in the houses were found to be significantly different over a 7 day timescale (student t-test >99.9% confidence). Diurnally, there was a strong link between VOC concentration and temperature and an inverse relationship with relative humidity.

The use of the vapour control membrane had a significant effect on the indoor air quality of the buildings (based on the concentration of VOCs) which may have been due to (1) the increased temperature and humidity, (2) the change in air flow from outside the buildings or (3) a combination of all three factors. There is a strong link between VOC concentration and temperature within the houses which may explain the highly variable profile of VOC concentration with time. An inverse relationship was observed with relative humidity.

Keywords: Indoor air quality, volatile organic compounds, vapour-control membranes,

1. Introduction

Various pollutants such as moulds and bacteria, radon and volatile organic compounds (VOC's) may exist at elevated concentrations in indoor atmospheric environments. There are many different sources of air pollution in the home and these substances may cause health issues both independently and in combination with each other. The potential synergistic effects of multiple toxic exposures are extremely difficult to quantify [1], [2]. Of particular concern are volatile organic compounds which are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to several times higher) than outdoors [3].

VOC sources include paints and lacquers, furniture, combustion products from cooking and tobacco smoke and deodorisers. Many of these pollutants have negative effects on human health or are strong enough to cause nuisance and odour problems. Indoor air quality (IAQ) is measured through various standards and guidelines. The World Health Organizations Guidelines for Indoor Air Quality sets recommended levels for

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various chemicals like formaldehyde (a common VOC) [4]. VOC concentrations are closely related to temperature and relative humidly (RH), with VOC emissions increasing by 3.5 fold from a 10℃ increase in temperature and 2.6 fold from a 35% increase in RH [5]. In modern housing, construction vapour checks are used in the walls and roofs to control temperature and humidity and increase airtightness with the aim of increasing the houses overall thermal efficiency [6]. This study assesses the impact of a vapour check membrane on indoor VOC concentrations whilst examining how temperature and humidity may affect these factors.

2. Materials & Methods

The Series 500 portable indoor air quality monitor and attachments used in this study were supplied by Aeroqual. The sensor head used Photo Ionization Detection and had a range of 0.1-25ppm with an accuracy of ±0.1ppm + 10%. A Plug-in SHT7x Sensirion temperature and relative humidity sensor designed specifically for use on the Series 500 portable monitors recorded temperature and humidity levels at the same intervals as the VOC sensor head. The sensors were elevated 100mm off the surface of the floor.

50ml of varnish (Wattyl Estapol High Performance Interior Clear Polyurethane Satin varnish) was measured into two identical glass petri dishes of diameter 90mm. Each glass petri dish was then placed in the test room (Bedroom 2) within in each house (Figure 1).

Each monitor was set to record at 5 minute intervals and the sensors were left in each test room with all the windows and doors closed for an average of 2 weeks until the VOC concentration had returned to background levels or a constant level was reached. Data was downloaded from the sensors every 6-7 days with entry and exit times recorded to justify any sudden changes in VOC concentration ([VOC]), temperature or humidity levels.

2.1. Test buildings

Two identically constructed single storey timber houses were used, both of which were undecorated and without floor coverings or wall finishes. The houses were constructed to the same standard by students in the Carpentry Programme (Unitec). The houses have both electrical and plumbing fittings installed but are not connected to mains supply. The houses were built with the purpose of being moved to a final offsite location by the buyer.

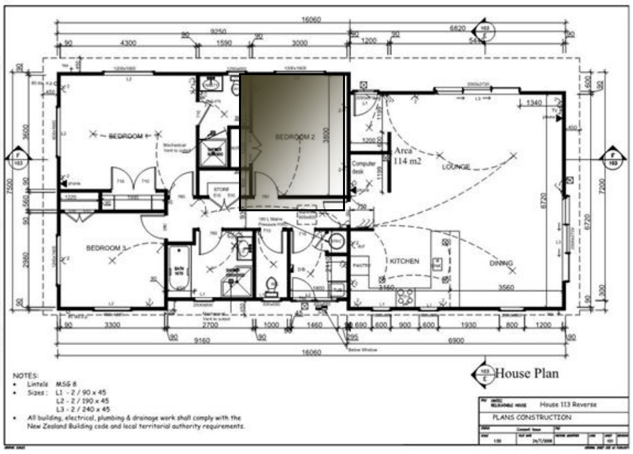

Fig. 1: House plan (test room shaded)

The test house was constructed using an Intello vapour check in the internal surfaces of the external walls and the ceiling [7]. In the control house, insulation was placed on top of the ceiling material and in the test house the insulation was placed on top of the Intello vapour check. The Intello vapour check controls the passage of vapour through the timber reducing condensation forming during cold periods which is a major cause of rot in building frames [7]. The vapour check also prevents air from passing through the wall into the inside environment helping to control comfortable living conditions during humid summer days/nights. The vapour check reduces infiltration which is an important factor in reducing heating costs of a building. The cavity that the 45x45 battens create is used for internal services, reducing the need to create holes in the vapour check, as well as creating a void for condensation to dry thus protecting the jib lining from moisture damage [7].

2.2. Background monitoring

Background levels in each house were tested in bedroom two (Figure 1). Bedroom two has a floor space of 11.4m^3 with a built in wardrobe. Bedroom two faces to the northwest and so receives both mid-day sun and the late afternoon sun. Background levels were recorded at 5 minute intervals over a 2 week period with the data collected every 7 days. The portable indoor air quality monitor was elevated 100 mm off the ground to ensure both the VOC sensor and the temperature and humidity sensor were not in direct contact with the floor. Sensors in both houses were set up in the same location in each room opposite the wardrobe 500 mm from the side of the wall. After background testing was completed the sensors were then both placed in the test house to measure if there were any discrepancies between the sensors. Whilst testing was carried out all windows and doors remained closed in both houses.

2.3. Blower door testing

Previously air flow across external walls was analysed for both houses using blower door tests [8]. Blower door tests were carried out by a certified tester, TECTTITE. The value of interest from these reports is the air change rates (air changes per hour, ACH). These rates are calculated from air leakage rates in each of the buildings. As indoor air pressure changes during a pressurization test air leakage rates are recorded. An average of these rates is then taken and divided by the building volume to find the air change rate per hour. For the test house, an average ACH taken from 6 consecutive tests was 1.88 and 8.27 for the control house [8]. The air exchanged with outside air was calculated to be 2372m^3.hr and 539m^3.hr for the control and test houses respectively.

3. Results and Discussion

Initial background testing of the VOC concentrations in the two houses produced average values (over a one day period) of 0.034 ppm for the control house and 0.026 ppm for the test house (Table 1). The Aeroqual monitors may be subject to a variation in measurement of ±10%, which supports that this variation is not significant. Over a longer time period (7 days), the variation was slightly greater, with average values of 0.045 ppm for the Control house and 0.0070 ppm for the Test house. These values lie just outside the specified variation and may need further investigation. Figure 2 shows the profile for the background testing of the VOCs in both houses over a four day duration. Whilst both profiles show a number of peaks on a regularly repeating pattern, this observation is more marked in the test house. This pattern appears to match the diurnal temperature variations which will be discussed further.

Over a one day period, the three controlled experiments demonstrated significant variations in average VOC concentration between control and test houses (Table 1). The average values across the three experiments were 3.23 ppm for the control house and 6.54 ppm for the test house (significant according to student t-test, confidence >99.9%). The VOC profiles with time for both houses and for each of the experiments are shown in Figures 3-5. Over the same timescale, temperature differences between the two houses were not found to be significant (average values 17.3 °C control and 17.4 °C test) when based purely on temperature data from each house. Further analysis identified that the diurnal profile of the temperature masked the variation between the houses. When a student t-test was performed on the temperature difference between the houses (which removed the underlying diurnal variation), the difference was significantly different (confidence >99.9%) over a seven day period. In each instance, the test house showed significantly higher temperatures than the control house. Relative humidity showed some variation over a one day timescale with average values of 52.4 % control and 54.7 % test which were significant for a confidence of >99.9% (student t-test).

Clusters of high VOC concentrations can be seen in Figures 3, 4 and 5. The concentration then drops before stabilising at a more constant value before 1000 minutes for each of the three tests. The major cause was most likely due to the forming of a hard crust on the surface of the varnish samples in the Petri dishes which prevented further volatilsation.

Table 1: Variations in [VOC], temperature and humidity in the control and test houses during background testing and controlled experiments

	[VOC] Ave (ppm)	[VOC] Std dev (ppm)	Temperature Ave (℃)	Temperature Std dev (℃)	Humidity Average (%)	Humidity Std Dev (%)
Background -Control	0.03	0.01	16.2	3.6	52.6	2.4
Background - Test	0.03	0.01	16.1	3.0	53.2	2.5
Control 1	3.69	1.44	16.4	2.7	50.4	0.9
Control 2	2.63	0.98	17.2	3.3	52.0	0.9
Control 3	3.37	2.32	18.2	3.2	54.8	1.3
Average (Control)	3.23	-	17.3	-	52.4	-
Test 1	6.02	1.26	16.8	2.5	53.9	1.5
Test 2	5.37	1.01	16.9	2.5	54.6	1.8
Test 3	8.23	3.67	18.6	2.9	55.8	2.0
Average (Test)	6.54	-	17.4	-	54.7	-

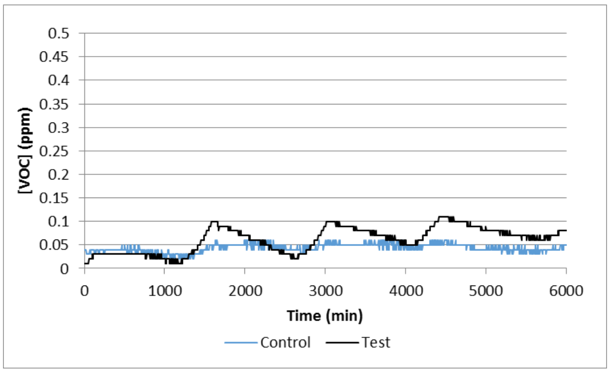

Fig. 2: VOC concentrations in Control and Test house during background testing period

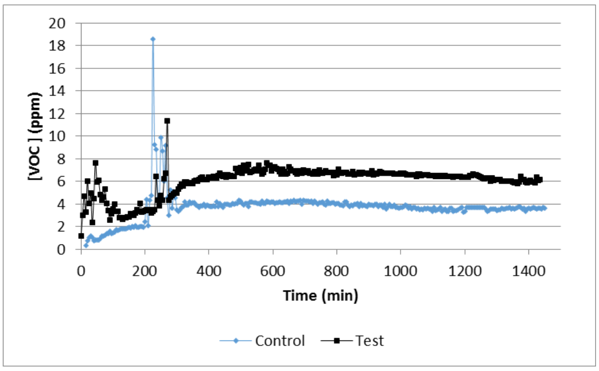

Fig. 3: VOC concentrations in Control and Test house during first experiment

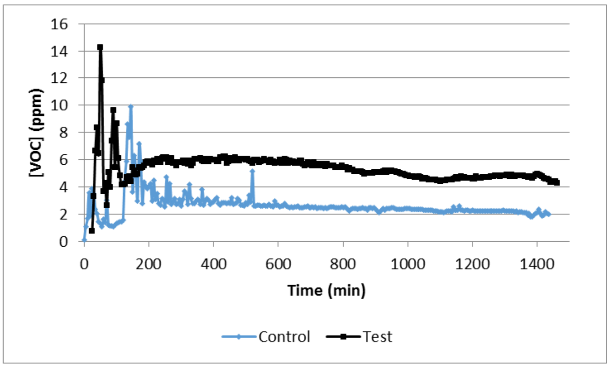

Fig. 4: VOC concentrations in Control and Test house during second experiment

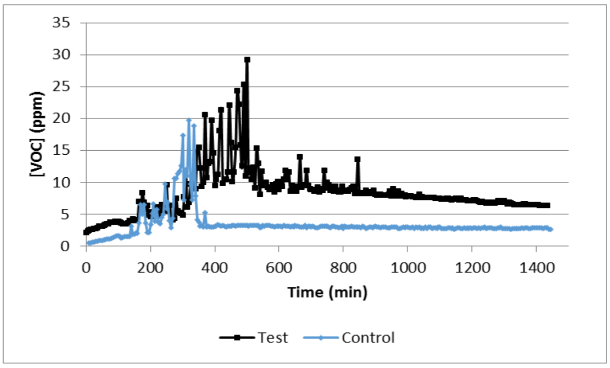

Fig. 5: VOC concentrations in Control and Test house during third experiment

Over a longer timescale (seven days), there remains a marked variation in VOC concentration; average values were 1.93 ppm control and 4.82 ppm test. Over the same timescales, temperature and humidity produced average values of 17.4 ℃ and 53.1 % respectively (control) and 17.5 ℃ and 54.4 % (test).

Data shown in Figure 6 shows a clear positive correlation between diurnal temperature cycles and VOC emissions during the background testing. It has been observed that there is a positive correlation between temperature and vapour pressure, this is known as the Clausius–Clapeyron relationship [9]. A similar pattern is shown in Figure 7 however there is a lag between relative humidity levels dropping and VOC levels dropping. This lag could possibly be due to the fact that temperature has a greater influence on VOC levels than relative humidity and is masking the effects. Generally VOC concentrations increase with humidity, however not all VOC's respond equally to humidity variations [10]. Each individual VOC would need to be tested separately to establish the exact effect of relative humidity on concentration. In a previous study, effect of temperature and humidity on formaldehyde emissions in temporary housing units [11] showed formaldehyde emissions increased as temperature and humidity increased. In this instance, temperature had a greater effect on VOC emissions than humidity.

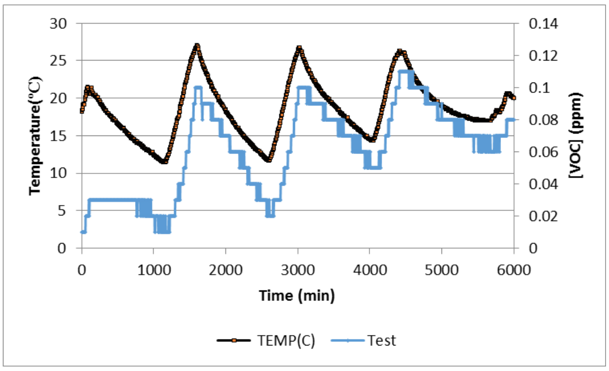

Fig. 6: The relationship between internal temperatures and [VOC] in the Test house over a four day background sampling period

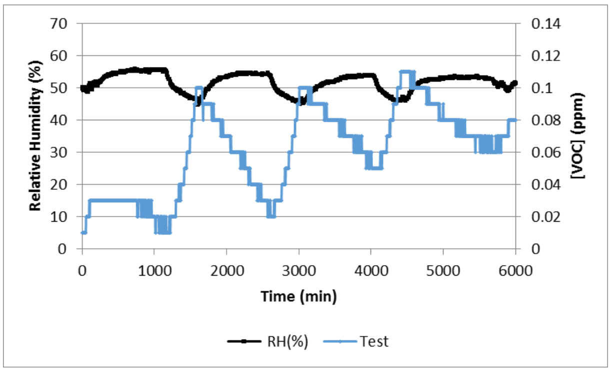

Fig. 7: The relationship between relative humidity and [VOC] in the Test house over a four day background sampling period

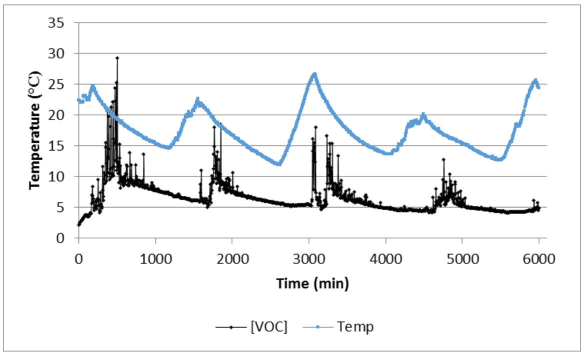

Fig. 8: The relationship between internal temperatures and [VOC] in the Test house over a four day testing period

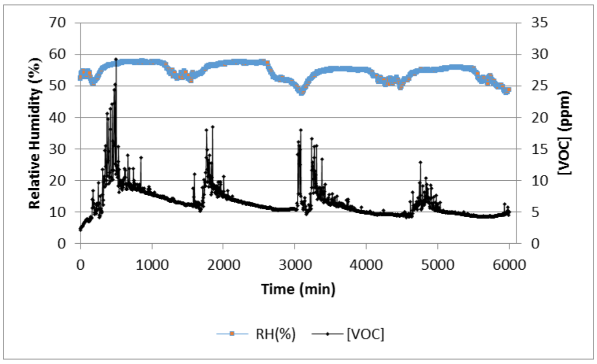

Fig. 9: The relationship between relative humidity and [VOC] in the Test house over a four day testing period

During the testing period, peaks in VOC concentration also showed a direct correlation with temperature peaks as observed in Figure 8 and an inverse correlation with humidity (Figure 9). The VOC source used in this experiment contained benzene which is a common VOC. As with all VOCs, vapour pressure increases with ambient temperature [12], In the case of benzene, (b.p = 80 ℃), the vapour pressure increases from 45 mm Hg at 10 ℃ to 119 mm Hg at 30 ℃, which is a 2.6 fold increase. Therefore, the number of molecules of benzene in the atmosphere at 30 ℃ will be substantially greater than at 10 ℃, which may explain the highly variable diurnal profile.

Overall, the higher VOC levels in the test house may be explained by the greater air-tightness of the test house (as demonstrated by the lower ACH value in the Test house). With less infiltration of clean outside air, levels of indoor VOC's from the varnish in the petri dish are subject to less dilution. This observation is in part supported by the profiles in Figures 3, 4 and 5. After the crust forms on the varnish VOC levels in the test house remain higher than the control house for the remainder of the experiment. Temperature and relative humidity, which are known to increase VOC emissions rates [12], are increased by the Intello vapour check which would increase emission rates. However the biggest factor most likely contributing to the increased levels of VOC in the test house is the increased air-tightness which reduces air exchange rates with clean outside air thus decreasing dispersal of the VOC in the indoor environment.

VOC is a broad term for a variety of volatile organic chemicals for which the recommended limits for indoor air quality depend on the individual chemical. Benzene, which is found in the varnish used in this experiment (0.1%) has no safe exposure limit and is a confirmed carcinogen [4]. The data shows that the test house recorded higher levels of VOC's due to the effects of the vapour control membrane. This shows that in terms of VOC's, the vapour control membrane may have a negative impact on human health.

4. Conclusion

The use of the vapour control membrane had a significant effect on the indoor air quality of the test building (based on the concentration of volatile organic compounds) which may have been due to (1) the increased temperature and humidity, (2) the change in air flow from outside the buildings or (3) a combination of all three factors.

There is a strong link between VOC concentration and temperature within the houses which may explain the highly variable profile of VOC concentration with time. An inverse relationship was observed with relative humidity.

5. Recommendations

Future work will involve the assessment of the spatial variation within the test room of the distribution of VOCs as the monitors were restricted to floor level and data closer to the ceiling may produce higher levels at the warmer temperatures and support theory on diurnal variation with internal temperature. It is intended that both rooms in the test and control houses will be painted with general household paint to establish the VOC levels in a realistic scenario. Finally, further testing will be carried out to establish VOC decay rates within both houses.

6. Acknowledgements

The authors would like to acknowledge Roger Birchmore (Unitec, Dept. of Construction), Sarah Hangartner and Lance Laulala (Unitec, Te Puna Ako) and Emma Chapman (Unitec Library) for their help and assistance.

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