A Study on Total Volatile Organic Compound Emission of Plywood: Finish, Age and Environment

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Abstract

In this paper, actual emissions of total volatile organic compounds (TVOCs) of Philippine plywood were measured. The measurements were taken with the plywood having different finishes during the time period of May to October. The finishing considered was unpainted panels of plywood, newly painted with regular and green-labelled paint, and the readings were conducted in a controlled room with accompanying readings of temperature and relative humidity. Each set of test samples was measured every hour for seven straight days and compared to guideline emission and behavior of TVOC in plywood in other countries. This study can contribute as a baseline data for the TVOC emissions of a Philippine building material.

Keywords: Total volatile organic compound (TVOC), indoor air, Philippine plywood

I. Introduction

Indoor environmental quality (IEQ) refers to the overall environment that affects the health, comfort and productivity in an enclosed space. IEQ can be influenced by temperature, relative humidity, air movement, mechanical ventilation and air conditioning system (MVAC), lighting, odor, noise, vibration, and indoor air quality or IAQ (Godish, 1995). Inadequate ventilation and indoor pollutants (poor IAQ) can cause irritation of the eyes, nose, throat, and even skin, which are symptoms of sick building syndrome (SBS). This sickness can lead to absenteeism, taking more sick leaves and lower productivity. Providing better indoor environmental quality in offices means improved health, better work performance, more productivity, and higher economic benefits (Fisk & Seppanen, 2007; Croome, 2008).

According to the Guidance Notes for the Management of Indoor Air Quality in Offices and Public Spaces published in 2003, variations in the normal range in temperature and humidity can cause discomfort to the users of the building. High humidity can cause growth of mildew, other fungi, and higher emission air contaminants and chemicals such as total volatile organic compounds (TVOCs) indoors. These TVOCs can cause health issues if they exceed the threshold limit values (TLV).

A research conducted in Canada reported that there were already 545 VOCs identified and already have set TLVs by different agencies and labelling schemes from different countries (Charles et al., 2005). All of these VOCs are the components of TVOC. The most commonly known VOCs are formaldehyde, benzene, toluene, ethylbenzene, and xylene (BTEX), which are mostly found in the solvents and adhesives and other chemicals used in making building materials.

Molhave (1990) suggested in his study that there are four ranges of TVOC exposures: (1) <200µg/m^3 (450ppb or less) comfort range, (2) 200-3000 µg/m^3 (.45-8ppm) multi-factorial exposure range, (3) 3000-25,000 µg/m^3 (8-57.45ppm) discomfort range, and (4) >25,000 µg/m^3 (above 57.5 ppm) toxic range.

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To reduce the impact of TVOC emission on IAQ, countries have set the standards per building material. Under these standards, building materials are then subjected to environmental performance evaluation, emission testing, certifications, and labelling schemes. Table 1 reflects the TLVs of TVOC emission in Japan, Singapore and Hong Kong implemented by each country. 174ppb is the acceptable value of emission of TVOC Japan. In Hong Kong the allowable emission rate of TVOC is 261ppb on an eight-hour average. These guidelines have been set because of issues on health, productivity and even climate change.

For the Philippines, TVOC standards for building materials have still to be set; thus our main objective is to contribute by presenting this study focusing on TVOC emissions of plywood. In addition, we study plywood of different finishes from plain, painted with regular paint and with green-labelled paints. We also look into the effect of the age of the plywood on the TVOC emissions. We look into the TVOC emission at different times of the year, i.e. different local environment conditions. Awareness of TVOC impact on public health and the environment in the country is still limited and this study can contribute to the buildup of TVOC data for setting up an acceptable IAQ standard for the country.

Table 1. Guidelines value for TVOC emission in indoor air.

Country	TVOC
Japan	0.103ppm 400µg/m^3
Hong Kong	0.154ppm 600µg/m^3

Source: Guidance Notes for the Management of Indoor Air Quality in Offices and Public Spaces, September 2003.

Background of the Study

Plywood is one of the most commonly used construction materials because of its flexibility, strength, and economy. It is composed of three or more thin layers of wood bonded (glued) together with the grain of adjacent layers running at right angles to their neighbors to give increased strength and resistance to warping (Oxford Dictionary of Architecture and Landscape Architecture, 2006). In 2011, the production of plywood had an eight percent increase over the previous year from 276,000 cubic meters to 299,860 cubic meters (2011 Philippine Forestry Statistics, DENR Forestry Management Bureau). Plywood can be used as concrete forms, ceilings, partition walls, cabinets and even for furniture. Plywood used for interiors are applied with different finishes like wallpaper, varnish, veneer, and paint.

Building materials such as plywood and paints contain TVOCs that can cause health problems especially indoors. The adhesive used for bonding wood veneers in plywood contains VOCs such as formaldehyde and toluene. The solvents used in paints contain formaldehyde, toluene, and xylene. TVOC emission of plywood ranges from 215-1,450 µg/m2-hr (van der Wal et al., 1990) and TVOC emission of paints ranges from 3.2-430 µg/m^2-hr (Wallace et al., 1987; Molhave, 1982). The Philippine Green Building Council (Phil GBC) is currently developing a code for Ecologically Responsive Design Excellence (BERDE) rating system. Once this code is implemented, it will be used as the guideline on construction, building performance and construction materials assessment in the Philippines.

II. Related Studies

TVOC theory states that even low exposure to TVOC in an enclosed space is harmful to humans due to the combined effects of individual VOCs (Godish, 1995). Subjects exposed to TVOC of 25mg/m^3 for 2.75 hours were found to experience headache, discomfort and decreased perception of air quality (Molhave, 1986 & 1990).

Recommended RH in a room ranges from 40-70 percent (CIBSE Guide). Higher RH can encourage growth of molds and mildew (Rostron, 1997) and affect the concentration of TVOCs in a building (Godish, 1995).

The standard method for measuring TVOC emissions from building materials is the environmental chamber method (ASTM D5116). The California Department of Health (CA Section 01350) and GreenGuard Environmental Institute have created their standard methods for measuring TVOC emission of building materials and finishes using the same method guided by ASTM D5116. This environmental test chamber is basically where the material specimen is placed for testing. The chamber should have non-adsorbent, chemically inert, and smooth surface materials so the compounds of interest will not react to the chamber itself. It has an air-tight access door, an inlet for temperature and humidity, and outlet for air sampling. Air flow, temperature, and RH are monitored, controlled, and remain constant during the whole testing. The gas sample from the chamber is then drawn to a gas tight syringe and brought to laboratory for gas chromatography – mass spectrometer (GC/MS) analysis.

In a study conducted in Japan, a small-scale chamber was developed to measure the individual VOCs and TVOC of new buildings materials; wall coverings, adhesive, flooring and insulation materials. Results show that emission rates of the new materials were relatively high from first to third day but decreased and became stable one to two weeks after (Funaki and Tanabe, 2002).

A similar study was conducted to measure wood-based composites using a developed small-scale chamber together with a VOC analyzer, which was developed in Japan, and GC/MS method to propose a standard method for emission in Korea. The reading from the VOC analyzer was compared with the GC/MS and found that there is a good correlation between the results of both methods (Kim et al, 2006).

Small chamber and field and laboratory emission cell (FLEC) were used to measuring formaldehyde and TVOC emissions from paints and coating materials and both methods are comparable and found to have a good relation for oil based, emulsion and water dispersion paint. But because FLEC has a smaller cell volume and a higher air flow rate, the emission of formaldehyde and

TVOC stabilized faster (24 hours) than the 20L small chamber (seven days) (Kim et al., 2012).

Actual emissions of VOCs of 75 apartments in urban areas in China were measured using GC/MS. A survey was also conducted to get the actual indoor air conditions of the residential units. Results show that higher concentrations of VOCs were found in apartments with more interior decorations and apartments where windows are always closed because of low outdoor temperature. However, relative humidity was not found a significant factor for formaldehyde. Exposure to indoor chemical concentrations is also relative to the length of stay inside the premises (Yoshino et al., 2005).

Haghigat et al. (1998) conducted a study on effects of different indoor air conditions; temperature, RH and surface air velocity on paint and varnish and reported temperature and RH have significantly affected the emission of individual VOCs and TVOC of the materials. The TVOC emission increased as the temperature increased although individual VOCs did not reflect the same result. Some VOCs increased emission at lower temperatures. No trend can be found on the effect of RH on the materials because emission rates showed different results. Although increase in RH reflected higher TVOC emission rates, individual VOCs showed increase in emission rates at 32 percent RH.

Wolkoff (1998) also studied the emissions of VOCs of five different building products (BP) i.e. carpet, PVC flooring, sealant, floor varnish, and wall paint under different climate parameters like air velocity, temperature and RH, and synthetic air (O2) vs nitrogen (N2). The study reported that air velocity does not directly affect the VOC emission without oxidation of BP while temperature and RH very much affected the emission rates depending on the type of BP and type of VOC. Texanol in PVC flooring was found not affected by different RHs. 2-ethylhexanol emitted from carpet and dimethyloctanols emitted from sealant showed increase concentration/time at 50 percent RH. Increase in VOC emissions from BPs was most observed at 60 degrees Celsius.

Field measurements were conducted to determine the temperature, RH, air velocity, HCOH, CO2, CO, TVOCs, and particulate matters in four pharmaceutical laboratories in Malaysia using different instruments. It is reported that all four rooms are generally safe and emissions of different contaminants are within acceptable levels except for one room which has a higher TVOC emission. It is then recommended that the room with higher TVOC emission should increase ventilation rate to keep the emission level below the acceptable limit (Yau et al. 2012).

III. Methodology

A. Site, Instrument, Plywood and Weather Conditions

The site is located at Lot 6, Block 18 Daisy Street, United Paranaque IV Subdivision, Marcelo Green, Parañaque City. Vicinity map is shown in Figure 1. Figures 2 - 7 show the exterior and interior images of the house. The structure was built particularly for the experiment. Interior room dimensions are 2.4 meters x 2.4 meters with a total floor area of 5.76 square meters and ceiling height of 2.4 meters. Plain plywood was installed on the floor and ceiling. Fiber cement board (Hardiflex) was used for the exterior wall and nailed to 2" x 2" wood frame. The structure is ensured to be sealed from the outside.

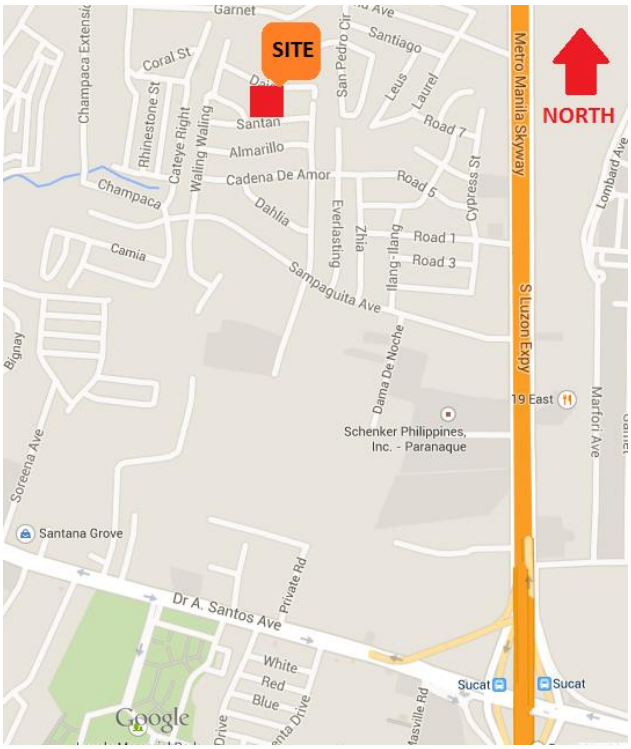

Figure 1. Vicinity map.
Source: Google Earth

The site was chosen for reasons of its availability during the entire experiment and that it can provide open space for a simple structure to be built where the measurements were to be taken. Ample space around the structure was also considered in order that effects of local environment condition reflecting the different times of the year will manifest during the experiments. The size of the structure was based on the standard commercial plywood size of 1.2 x 2.4 meters. We note right away that there are available lab standards in testing for TVOC emissions of building materials but such facilities are still lacking in the country (ASTM D6803). This study presents a rather resourceful approach but nonetheless, the experiments are done in actual weather and environment conditions with the simple structure acting as mock-up.

A multifunction IAQ monitor (Model DPM 1084) was used. The instrument can measure temperature, relative humidity and TVOC emission of a room every minute for 30 straight days. It can only read TVOC emissions from building materials, furniture and equipment such as formaldehyde, toluene, ammonia, carbon monoxide and CO2, and not any of a specific VOC. Data were recorded from the device to a USB flash drive and results were

tabulated in a computer. The IAQ monitor can measure TVOC emission up to 30 square meter area. Two units of IAQ Monitor were placed in different locations inside the room. The instruments were set on top of 0.8-meter high stools and located equally 0.8 meters from the wall and each other. Image of IAQ monitor is shown in Figure 8 and location of IAQ monitor in floor plan and section are shown in Figure 9. The position of the monitor follows standard placement for testing.

B. Testing Methods and Documentation

All set samples were measured for 10 days using the IAQ Monitor. The room was cleaned and left open on the first day of the experiment. On the second day, the room was cleaned before it was closed and sealed for another two days to register a reference reading. The room was again carefully opened on the fourth day to install the test samples using a wood screw on the 50x50 millimeter lumber wall frame. A 24-hour, seven-day observation period was implemented on all data sets for all the samples. No human intervention or contact was permitted during the tests. On Week 2, the first test specimen was removed. The room was cleaned again and the entrance door opened to let the natural air flow inside the room. For two days, a baseline reading was conducted and the next experimental set were installed and measured for seven days. The values for the temperature, RH, and TVOC levels were then collected and tabulated after each observation period.

C. Weather Conditions

The measurements were conducted during the period of May to October 2014 to cover both wet and dry seasons of the year. Although the room was sealed, exterior weather conditions still affect the interior environment. Temperature, RH, and rainfall data were collected from PAGASA for comparison of actual exterior weather conditions during the experiment period. Table 2 shows the sample set description, schedule, average temperature and average relative humidity taken from PAGASA. The period May 11-21 was recorded to have highest temperature and lowest RH at 31.6 degrees Celsius and 61 percent respectively. The lowest temperatures were observed during the periods of July 12 to August 7 at 27.3 degrees Celsius. Highest RH was found at 87 percent during periods of August 22 to September 11 of 2014.

Figure 2. Exterior images of the site: rear view

Figure 3. Exterior images of the site.

Figure 4. Interior image of the site.

Figure 5. Interior image of the site.

Figure 6. Interior image of the site.

Figure 7. Interior image of the site.

Figure 8. Multifunction IAQ Monitor.
Source: http://www.tongdy.com

Table 2. Schedule of experiment per set sample.

Set No.	Materials Description	Date	Ave. Temp. °C	Average RH (%)
1	Plain Plywood	May 11-21, 2014	31.6°C	61.8%
2	New Plywood Regular Paint	May 21-31, 2014	30.50°C	70.1%
3	New Plywood Regular Paint	May 31 to June 10, 2014	31°C	76.1%
4	New Plywood Green Labelled Paint	June 12-22, 2014	28.7°C	84%
5	6 months-1 yr. old Plywood Regular Paint	June 22 to July 2, 2014	28.7°C	83.3%
6	2 years or older Plywood Regular Paint	July 2-12, 2014	28.3°C	87%
7	1-month old Plywood Regular Paint	July12-15, 20-27, 2014	27.3°C	80.2%
8	1-month old Plywood Green Labelled Paint	July 28 to August 7, 2014	27.3°C	80.2%
9	New Plywood Regular Paint	August 12-22, 2014	28.8°C	81.4%
10	6 months-1yr old Plywood Regular Paint	August 22 to September 1, 2014	27.6°C	87%
11	2 years or older Plywood Regular Paint	September 1-11, 2014	27.6°C	87%
12	New Plywood Green Labelled Paint	September 22 to October 2, 2014	29.1°C	86.4%
13	1-month old Plywood Regular Paint	October 2-12, 2014	29°C	86.3%
14	1-month old Plywood Green Labelled Paint	October 21-31, 2014	28°C	81%

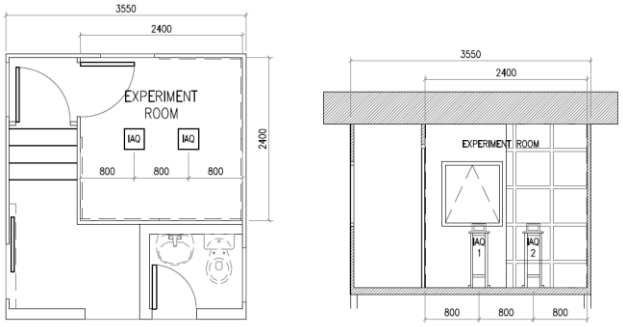

Figure 9. IAQ Monitor Location in Plan and Section.

IV. Results and Discussion

Table 2 shows the test results of the TVOC emission for all sample set average per day for a 10-day period. Results show that the new plywood with regular paint has the highest average emission rate at 26.59 ppm during its seven-day period and the lowest average emission rate of 14.36 ppm was found at the one-month old plywood with green labelled paint sample set. However, the new plywood with green labelled paint was found to also have a high emission rate at 26.39 ppm during its first measurement. It also reflected that TVOC emission rate decreased for both sets of one-month old plywood with regular and green labelled paint.

Figure 10 shows the results of the measurement of temperature, RH, and TVOC emission rate of new plywood applied with regular paint for the periods May 21-31 and August 12-22. Average emission rate for both periods are 26.31 ppm and 26.59 ppm respectively. Highest emissions were found on the first day of installation of the panels for both reading at 28.50 ppm and 29.79 ppm. It was observed that the emission decreased gradually for both samples from the first to the last day of reading. The lowest recorded reading of TVOC emission for May 21-31, 2014 was at 23.03 ppm after the installation of the panels and closing the room. The rate increased to 27.79 ppm after an hour. For the August 12-12 reading, the lowest emission rate was found on the last day of the measurement at 23.51 ppm.

In Figure 11, temperature, RH, and TVOC emission rate of new plywood applied with green labelled paint are reflected. Data were recorded during the period of June

12-22 and September 22 to October 2. Average emission rates of both samples were 26.39 and 23.61, respectively. For June 12-22 period, the highest TVOC emission rate was at 27.7 ppm while the lowest was recorded at 24.20 ppm. In this period, decrease in TVOC emission was found on the sixth to the seventh day of the reading. For the period of September 22 to October 2, highest and lowest TVOC emission rates were recorded at 27.79 ppm and 12.61 ppm. It was observed to have a gradual decrease in the emission rate from first to the sixth day and significantly went down when the temperature went up from 29.50 degrees Celsius to 32.98 degrees Celsius and the RH decreased from 54.77 percent to 44.22 percent.

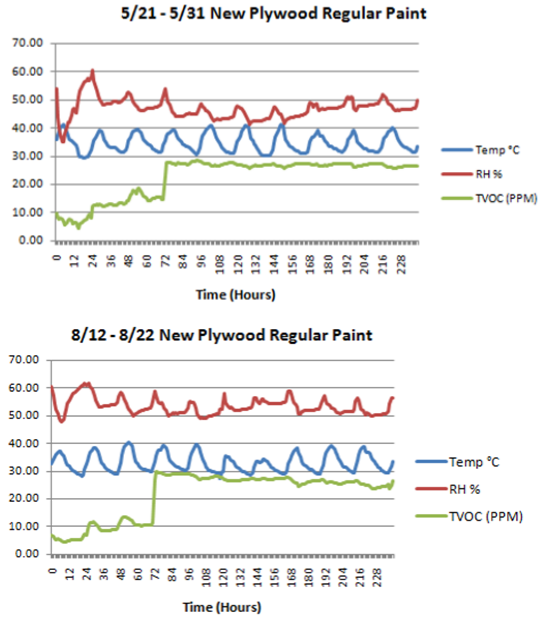

Figure 10. TVOC emission rate of new plywood applied with regular paint.

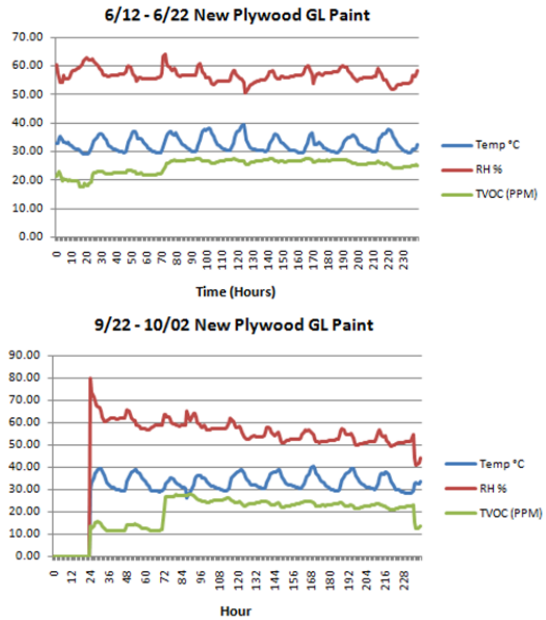

Figure 11. TVOC emission rate of new plywood applied with green labelled paint.

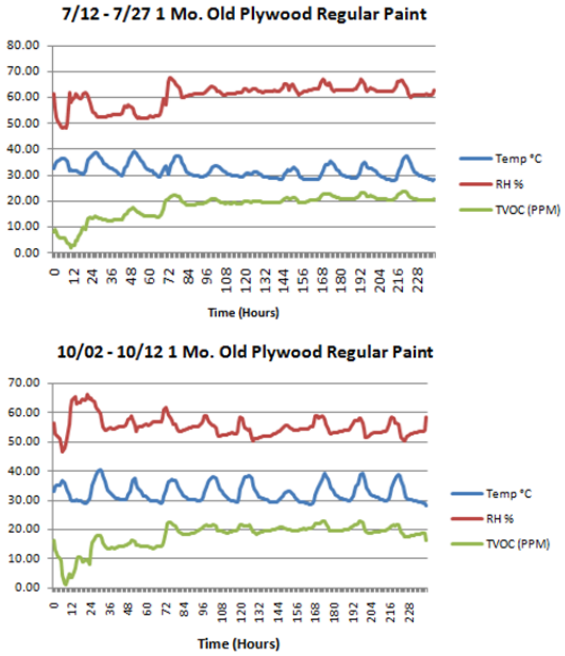

Figure 12. TVOC emission rate of one-month old plywood applied with regular paint.

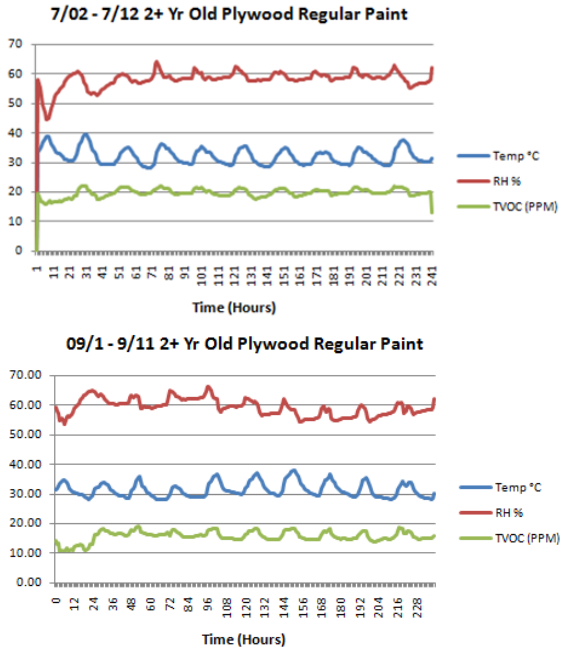

Figure 13. TVOC emission rate of 2-year-old plywood applied with regular paint.

Table 2. TVOC emission results for the 14 sample set per day.

Set/ Day	Description	1 (ppm)	2 (ppm)	3 (ppm)	4 (ppm)	5 (ppm)	6 (ppm)	7 (ppm)	8 (ppm)	9 (ppm)	10 (ppm)	Ave. (ppm)	Temp °C	RH %
1	Plain Plywood	4.19	8.91	10.36	14.72	15.87	14.68	13.45	13.94	13.1	14.42	14.41	36.36	42.68
2	New Plywood Regular Paint	7.23	12.95	15.92	27.51	27.23	26.72	26.92	27.09	27.03	26.36	26.31	34.83	46.90
3	New Plywood Regular Paint	-	17.44	17.96	29.37	29.54	29.43	29.2	28.74	28.5	28.72	29.06	33.96	49.33
4	New Plywood GL Paint	19.73	22.57	22.31	26.77	26.72	26.67	26.77	26.95	26.01	24.86	26.39	32.83	56.71
5	6 Mos. old Plywood Regular Paint	21.88	22.99	22.81	22.68	22.47	22.81	22.27	22.03	22.52	22.25	22.2	32.99	55.06
6	2+ years Plywood Regular Paint	17.31	19.72	20.47	20.36	19.79	19.45	19.85	19.96	20.39	19.91	19.92	31.85	58.13
7	1Mo. Old Plywood Regular Paint	6.84	13.37	15.49	19.92	19.65	19.63	20.46	21.54	21.48	21.48	20.6	31.37	60.48
8	1Mo. Old Plywood GL Paint	13.93	16.66	17.35	19.81	20.09	20.57	20.93	20.6	21	21.08	20.58	30.85	62.65
9	New Plywood Regular Paint	5.47	9.53	11.56	29.02	27.86	26.91	27.26	26.13	25.96	24.63	26.59	33.14	53.34
10	6 Mos. old Plywood Regular Paint	6.3	17.85	18.73	18.13	18.06	17.68	17.26	18.32	18.17	17.83	17.92	31.55	56.57
11	2+ years Plywood Regular Paint	11.95	16.76	16.95	16.28	15.98	16.1	16.11	15.79	15.35	16.15	15.97	31.56	59.24
12	New Plywood GL Paint	-	12.73	12.84	26.87	25.04	23.85	23.47	23.27	22.61	20.17	23.61	33.27	50.62
13	1Mo. Old Plywood Regular Paint	8.07	15.01	14.65	19.89	20.15	20.08	20.27	20.69	20.24	19.02	20.05	32.52	55.30
14	1Mo. Old Plywood GL Paint	0.19	4.16	4.93	13.76	13.72	13.78	13.06	14.38	16.05	15.79	14.36	31.94	53.73

Figure 12 shows the results of measurement of temperature, relative humidity and TVOC emission rate of one-month old plywood applied with regular paint. The readings for both periods of July 12-27 and October 2-12 are almost close. Average TVOC emission rates are at 20.60 ppm and 20.05 ppm, respectively.

In Figure 13, temperature, RH, and TVOC emission rate of two-year old plywood applied with regular paint are reflected. Data were recorded during the period of July 2-12 and September 1-11. Average emission rate of both samples are 19.92ppm and 15.97ppm, respectively. For July 2-12 period the highest TVOC emission rate was at 21.88ppm while the lowest was recorded at 13.20 ppm. For the period of September 1-11, highest and lowest TVOC emission rates were recorded at 18.79 ppm and 14.60 ppm. It was observed that no significant amounts of increase or decrease were found in both periods.

We show in Figure 14 the comparison of the TVOC emission rate from May 11- July 27, 2014, for dry season, and July 28-October 31, 2014, for wet season. As observed, the TVOC emissions during the dry season were higher compared with the rainy season. New plywood with regular paint for both sets, wet and dry season, has highest emission along with new plywood with green labelled paint during dry season with average emission of 26.39ppm, 26.59ppm and 26.39ppm, respectively. Lower TVOC emission was observed in older samples sets; one-month old regular and green labelled paint, six months and two-year old plywood with regular paint for both wet and dry season.

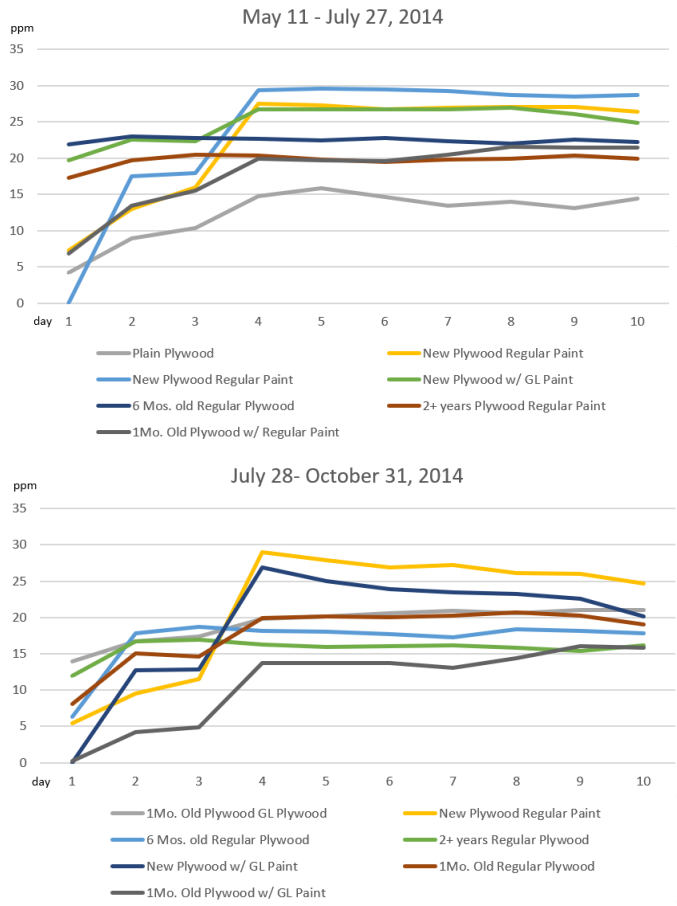

Figure 14. TVOC emission rate from May 11- July 27, 2014 and July 28-October 31, 2014

V. Conclusion

Indoor TVOC emission rates of plywood with different age, and finishes were investigated in a specifically-built room using an IAQ Monitor. Results show that the new plywood with regular paint has the highest emission rate than all other sample sets. High emission continued until its last day of sample sets. New plywood with green labelled paint was also recorded to have high emission rate. However, decrease on the emission rate during the seven-day experiment period was more visible in this sample set than the new plywood with regular paint. A significant decrease in TVOC emission rates was observed in both one-month old plywood with regular and green labelled paint. This decline was continued to be observed at the two-year old plywood applied with regular paint.

The measurements of new plywood with regular paint and one-month old plywood with regular paint during different periods and exterior weather conditions were found to have a good correlation. Both sample sets have almost the same average for both measurements when compared with each other despite having different exterior environmental conditions.

Although large amount of TVOC emission decreased as the plywood ages, the results show that the Philippine plywood TVOC emission rate are still found within the discomfort range (8-57.5 ppm) and above the TLVs of countries such as Japan and Hong Kong. Since TVOC emission is largely dependent on local environmental conditions (Jung et al., 2019), it is most ideal that the Philippines develop its own set of standards. Standards are based on continuous and controlled testing, and this paper is an attempt to provide initial base data on TVOC emission of plywood as well as the changes in the emission as a result of finish chosen, age of material, and weather conditions. Factors such as these have to be considered in future standards.

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