Indoor Air Quality and Its Effects on Health among Urban Residents in Jakarta and Surabaya, Indonesia

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Abstract. In rapidly growing countries, such as in Indonesia, dramatic increase in new urban houses constructed of modern building materials without sufficient material standards or minimum ventilation rates may cause health problems related with indoor air quality (IAQ). This study investigates the current IAQ and health condition in Kampongs and high-rise apartments in Jakarta and Surabaya, Indonesia. Concentrations of formaldehyde and TVOC were measured, whereas a questionnaire was conducted to collect the data of building attributes, cleaning behaviour, ventilation duration, personal information and health. 707 respondents were interviewed, and 163 rooms were measured from September 2017 to October 2018 in Surabaya and Jakarta. The results showed that overall, the newly constructed apartments recorded higher formaldehyde compared to Kampongs—more than 60% in apartments exceeded the WHO standard of 0.08 ppm. On the other hand, there was little difference in TVOC between Kampongs and apartments and the maximum values reached from 8,000 up to 21,800 $\mu g/m^3$. In general, the multiple chemical sensitivity (MCS) of occupants in apartments was twice as high as that in Kampongs. Further, the occupants with higher IAQ measurement results corresponded to the higher MCS risk. The primary results showed a high possibility of IAQ-related health problems in both Kampongs and newly constructed apartments in Indonesia although the main causes were probably different between them.

1. Introduction

People spend 70% of their time in the indoor environment of their home [1]. Therefore, it is important to have a healthy indoor home environment. Nowadays, rapid urbanization in developing countries accelerates the construction of newly built urban houses without regulating chemicals from building material and minimum ventilation rates. This leads to a concern of the spread of so-called sick building syndrome (SBS). Many researchers have studied the problem of IAQ in developing counties, but most of them focus on biomass combustion in rural houses, and only few investigated IAQ problems in urban houses [2]. Indonesia, as a developing country, is expected to experience further population increase over the period of 2017-2050 [3]. In Indonesia, home shortage is already a serious problem, which was estimated to reach 11.4 million by 2017 [4]. The government reacts by

constructing low-cost apartments for rent (Rusunawa) and for ownership (Rusunami) especially in major cities [5].

This study explores how the conditions of IAQ, especially formaldehyde and TVOC, affect the health conditions of residents of urban houses in Indonesia. We mainly focus on IAQ and SBS in newly constructed apartments, which emerge rapidly in major cities of Indonesia since 2010, but traditional landed houses, so-called Kampong, are also included for comparison. In the newly constructed apartments, it is assumed that residents face the problem of IAQ related with chemicals and reduced ventilation rates. In contrast, in Kampong, prolong rain and flooding during rainy season affect IAQ particularly in terms of mold growth and dampness. This paper presents the results of case studies conducted in the city of Surabaya (2017-2018) [6] and Jakarta (2018).

2. Methodology

2.1. Sampling

In order to gather the information on occupants and their houses, we conducted questionnaire surveys and field measurements. Most of the apartments are 20-story high-rise apartments, whereas Kampongs are built in unplanned dense residential areas without providing proper infrastructure (Fig. 1). The survey was conducted from September 2017 to February 2018 in 27 Kampong areas and 14 high-rise apartments in Surabaya, whereas it was conducted from August to Oktober 2018 in 40 apartments in Jakarta. The average response rate was 87% in Kampong and 44% in apartments in Surabaya, while it was 61% in apartments of Jakarta.

Figure 1. View of (a) kampong Surabaya, (b) apartment Surabaya and (c) apartment Jakarta

2.2. Questionnaire

Face-to-face interviews were conducted using a questionnaire, consisting of questions related to socio-economic backgrounds, detailed cooling behavior, past/present diseases, indoor air condition and Quick Environmental Exposure and Sensitivity Inventory (QEESI). QEESI was developed by Miller & Prihoda and has been used in several countries [7].

There are five scales in QEESI: chemical intolerance; other intolerance; severity of symptoms; masking index; and life impact. Each scale comprises ten questions with a 0-10 score, i.e., 0 for not having any problem and 10 for having high problem, but masking index comprises yes-no questions [3].

QEESI has been developed to differentiate the degree of Multi Chemical Sensitivity (MCS) of chemical sensitive person and normal people. MCS is described as a gained disorder with regular symptoms, related with various environmental factors tolerated by most people, and not interpreted as any known medical or psychiatric disorder [8].

2.3. Indoor air quality measurement

Several IAQ parameters were measured in this study, including formaldehyde, total volatile organic compound (TVOC), relative humidity and air temperature. Formaldehyde and TVOC as the most common chemical indoor pollutants were measured in the place where the occupants do most of their

activities, i.e. living room and bedroom. Formaldehyde, air temperature, and relative humidity were measured by commercially available devices (Formaldemeter, PPM technology; FMM-MD, Shinyei Technology). Meanwhile, TVOCs were obtained by using the device with an advanced PIDs sensor (ToxiRae Pro, RAE systems). These devices were placed for about three days in these rooms respectively at approximately 1.2 m above the floor. Data of formaldehyde were recorded in 30 minutes interval and 1 minute for TVOC.

3. Results and discussion

3.1. Profile of respondents

Brief profile of respondents is summarised in Table 1. As shown, a total of 707 responses were obtained from the interviews, whereas 163 IAQ measurements were taken at the same time. The samples comprise different age groups between Kampong (average: 39.7 years) and apartments (24.1 and 28.6 years). As expected, building age significantly differs between the two groups: Kampong (average: 31.7 years) and apartments (4.5 and 6.9 years). The average household income for most Kampong and apartment respondents in Surabaya is approximately $150-450, but that for Jakarta's apartments is more than $750.

Table 1 Brief profile of respondents

	Surabaya		Jakarta	Total
	Kampong	Apartment	Apartment	
Questionnaire	298 (43%)	173 (24%)	236 (33%)	707
IAQ measurement	42	40	81	163
Gender (M/F) (%)	35/65	43/57	44/56	41/59
Average age (years old)	39.7	24.1	28.6	31.3
Household income				
<150 (US$)	24.8	9.5	0.8	9.5
150-450	56.3	46.7	21.3	37.2
450-750	9.4	16.2	20.5	16.1
>750	9.4	27.6	57.4	37.1
Average stay duration	25.4	2.1	3.22	8.5
Age of buildings	31.7	4.5	6.9	15.9
AC ownership (%)	20.9	99.5	100	78.8

3.2. Multi chemical sensitivity (MCS) risk

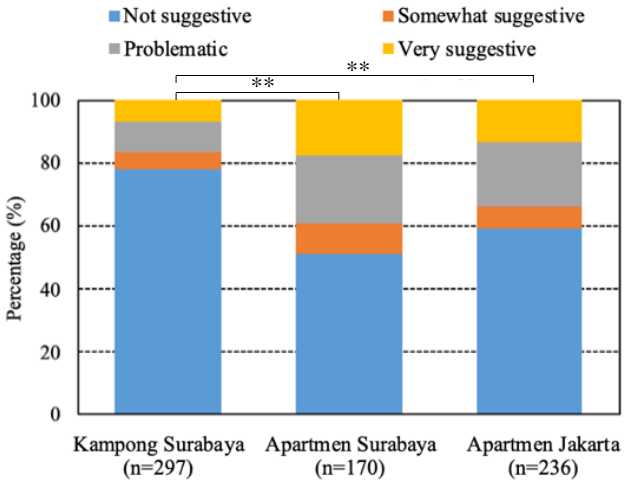

Figure 2. Results of MCS risk

The final result of MCS in respective building types is shown in Figure 2. As shown, the respondents living in apartments tend to have higher MCS risks compared to Kampong. Only 21.9% of Kampong respondents show some degrees of chemical sensitivity, but this percentage is about double or more than double in apartments (48.9% in Surabaya and 40.7% in Jakarta).

In chemical exposure, most respondents show sensitivity for diesel/gas, tobacco, insecticide, and paint. Overall, the degree of sensitivity in apartments is higher compared to Kampong. For example, in apartments of Surabaya, respondents showed a scale of 5.43 out of 10 against tobacco disturbances on average. In other chemical exposures, alcoholic beverage, allergic reaction and chlorine water show significant differences between Kampong and Apartments, but in general the magnitudes of intolerance are not as high as previous chemicals.

3.3. Factors affecting MCS risk

We conducted correlation analysis to identify the factors affecting MCS risk and sensitivity scores in Kampongs and apartments respectively using the Spearman's test or Chi-square test, depending on the types of the variable. Table 2 summarizes the relations of MCS risk with personal attributes and building attributes.

For both house types, a significant correlation exists between stress levels and sensitivity as well as MCS risk. The higher the stress is, the higher the risks would be. In Kampong, people aged more than 50 years old tend to have higher MCS risk (p<0.05). Moreover, the respondents with occupation of private jobs, housewife and students are found to have higher MCS. In contrast, it is found that female respondents tend to have higher MCS risk for all samples in apartments (p<0.05). Meanwhile, respondents who have a medical history of asthma and allergy tend to have higher MCS risk in Kampong of Surabaya and apartments of Jakarta. Smoking behavior and/or ETS is associated with MCS risk in Kampong of Surabaya and apartments of Jakarta. Furthermore, exposure of other chemicals and scented products have a significant relation with MCS in Kampong.

Several variables on building attributes show significant relations with MCS particularly in Kampong. For example, the number of windows in living room and master bedroom has a significant relation with MCS risk (p<0.01). Nevertheless, although window-opening duration has significant relation with MCS risk in all samples (p<0.01), there is little relation for Kampong and apartments respectively, except for apartments of Jakarta. AC availability also significantly affects the sensitivity and MCS risk only among Kampong residents, due to the fact that most apartment respondents have AC in their home. In Kampong, mold growth also has significant relation with MCS risk.

Table 2. Results of correlation analysis.

R = MCS Risk S = Sensitivities	**All**		**Kampongs Surabaya**		**Apartment Surabaya**		**Apartment Jakarta**	
	R	**S**	**R**	**S**	**R**	**S**	**R**	**S**
Personal attributes								
Age group[a]	.002	.000	.047	.047	.312	.312	.414	.186
Sex[a]	.028	.157	.474	.885	.032	.009	.035	.119
Income[b]	.000	.000	.000	.000	.496	.372	.090	.097
Occupation[a]	.006	.020	.001	.001	.778	.936	.042	.213
Psychology								
Stress[b]	.000	.000	.000	.000	.004	.000	.017	.001
Health								
Asthma[a]	.011	.007	.041	.012	.740	.309	.035	.017
Eczema[a]	.000	.000	.000	.000	.055	.012	.327	.387
Allergy[a]	.001	.000	.031	.053	.117	.076	.037	.018
Masking index								
Smoking and/or ETS[a]	.011	.000	.022	.201	.488	.126	.026	.006

Fumigation[a]	.106	.764	.947	.535	.015	.108	.492	.771
Exposure other chemicals[a]	.001	.039	.046	.030	.475	.150	.052	.600
Scented products[a]	.010	.020	.472	.722	.682	.394	.337	.182
Fabric Softener[a]	.073	.017	.239	.045	.492	.263	.430	.816
Building attributes								
Living in home [years][b]	.000	.000	.405	.804	.474	.701	.192	.127
Windows_ masterbedroom[b]	.424	.513	.004	.002	.924	.827	.351	.493
Windows_living room[b]	.000	.014	.000	.000	.280	.077	.050	.273
AC[a]	.000	.000	.007	.000	.608	.147	.840	-
Fan[a]	.000	.000	.509	.351	.526	.716	.042	.255
Modifications[a]	.394	.290	.017	.123	.987	.942	-	-
Water leakage[a]	.018	.034	.387	.161	.143	.152	.115	.621
Interior								
Mold[a]	.751	.874	.005	.010	.660	.772	.055	.026
Mite[a]	.187	.310	.921	.919	.107	.238	.856	.604
Furniture_living room[b]	.130	.152	.014	.015	.177	.317	.457	.496
IAQ								
Smell[a]	.276	.297	.024	.029	.160	.551	.022	.388
IAQ rating[b]	.926	.779	.893	.998	.056	.024	.288	.153
OAQ rating[b]	.014	.055	.089	.106	.148	.095	.068	.074
Behavior								
Window-opening_ bedroom[b]	.000	.000	.416	.696	.063	.141	.515	.396
Window-opening_ livingroom[b]	.003	.002	.773	.959	.457	.853	.029	.075
Cleaning of rooms[b]	.002	.001	.012	.001	.060	.354	.272	.320
Cleaning of bathroom[b]	.077	.022	.976	.570	.280	.030	.993	.498

[a] p-value of Chi-Square-Test, [b] p-value of Spearman rho, red: Correlation is significant at the 0.01 level (2-tailed), green: Correlation is significant at the 0.05 level (2-tailed)

In Kampong, the modification (p<0.05), the number of furniture (p<0.01), and the frequency of cleaning rooms (p<0.05) have significant relations with MCS risk. For example, the less frequent they clean and the more number of furniture they have, the higher the MCS risk would be. In the surveyed indoor air quality, the outdoor air quality rate has a significant relation with MCS risk (p<0.05), but this relation is neither seen in each group. In addition, those who experience smell in their house in Kampong and apartments of Jakarta tend to obtain higher MCS risk scores (p<0.05).

3.4. Indoor air quality (IAQ) measurements

The measurement in Surabaya was carried out in two different seasons, i.e. dry season and rainy season. This caused differences in measurement results of air temperature and relative humidity. In the dry season, the room temperature ranges from 29°-32°C in Kampong and 27°-31°C in apartments, whereas the corresponding outdoor temperature ranges from 25.1°-36.3°C. In contrast, during the rainy season, the average outdoor temperature was 28.1° with an average humidity of 77%. This resulted in increased indoor humidity conditions particularly in Kampong. Relative humidity in most Kampong houses was measured to be less than 70% during the dry season, but they were increased up to 87% with the reduction of air temperature to 27°-29°C during the rainy season. In the apartments, however, due to the use of AC, the relative humidity was increased in the rainy season, but they are not as high as in Kampong. On the other hand, in Jakarta, measurements were only carried out in apartments during the dry season. The measured indoor air temperature ranges from 24.4° to 32.8°C with an average of 28.3°C, and relative humidity is always below 70% with an average of 55.9% due to the dry season.

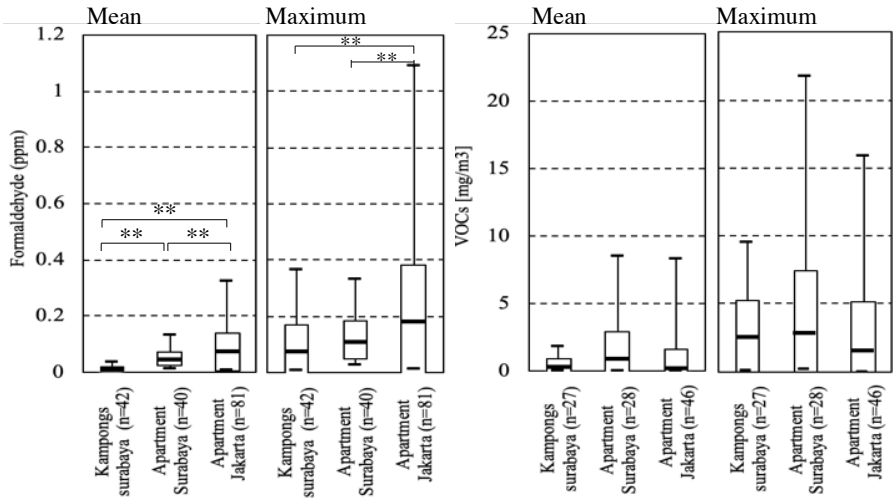

Figure 3. Statistical summary of IAQ measurement results

The measurement results of formaldehyde and TVOC are summarized in 30 minutes average value, and then the maximum and mean values during measurement period were calculated for the following analysis. As shown in Figure 3, in general, formaldehyde concentration in apartments is higher than that in Kampong, especially in the mean value. The mean value of formaldehyde ranges up to 0.02 ppm in Kampong with an average of 0.013 ppm, but those in apartments range from 0.024-0.07 ppm (average: 0.047 ppm) in Surabaya and 0.007-0.138 ppm (average: 0.073 ppm) in Jakarta, respectively. The difference between Kampong and apartments of two cities are larger than that between apartments of two cities. For example, in the maximum value, the average of Jakarta's apartments is 0.187 ppm with the upper range of up to 0.38 ppm, while in Surabaya the average is 0.115 ppm and range up to 0.183 ppm.

Interestingly, the tendency is different in TVOC. In the maximum values, apartments (average: 2.58 mg/m^3) and Kampong (2.90 mg/m^3) in Surabaya obtained similar values, but they are rather higher than those of Jakarta's apartments (1.55 mg/m^3). The range of Kampong and Jakarta's apartments is similar, which is up to 5.20 and 5.11 respectively, while those in Surabaya's apartments range up to 7.39 mg/m^3. However, there are several cases where the TVOC recorded extremely high values in the three case studies.

Figures 4 and 5 show cumulative frequency of formaldehyde and TVOC respectively. As shown in Figure 4b, more than 60% of the measured maximum formaldehyde values in apartments of Surabaya and Jakarta exceed the WHO standard, 0.08 ppm, whereas in Kampong of Surabaya, about 20% exceed the standard. Even in Kampong, there are several cases with extremely high formaldehyde levels, but more extremely high cases are found in apartments of Jakarta.

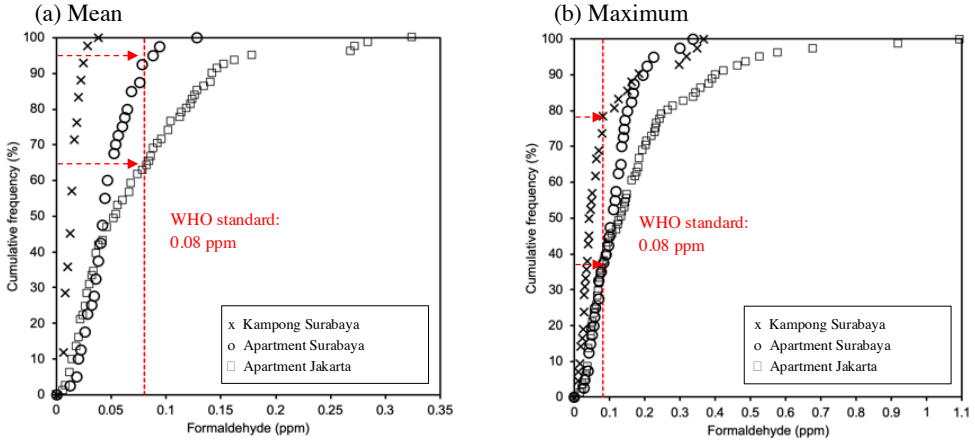

Figure 4. Cumulative frequency of the measured formaldehyde

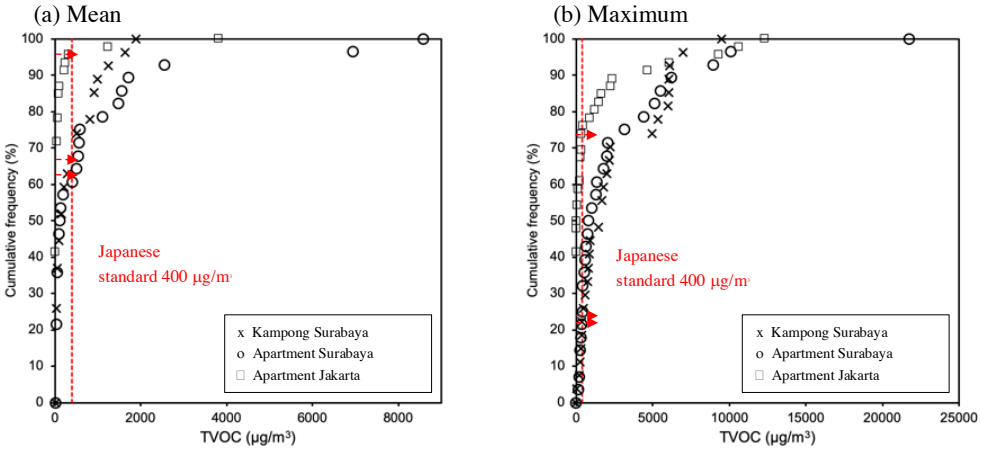

Figure 5. Cumulative frequency of the measured TVOC

Meanwhile, the measured TVOCs in Surabaya show similar values between Kampong and apartments, where approximately 75% of maximum values exceed the Japanese recommendation of 400 μ g/m^3, compared to Jakarta's apartments, where only 25% exceed the recommendation. However, there are several extreme cases where the maximum value of Kampong and apartments in both Jakarta and Surabaya, range from 8000 to 21,800 µg/m^3. Further investigation is required to identify the reasons why TVOCs in Jakarta's apartments are relatively lower compared to the others despite higher formaldehyde levels.

3.5. Relation of IAQ and MCS risk

We analyzed the relationship of the results of formaldehyde and TVOC measurement with MCS risk by dividing the samples into two MCS groups: 'not suggestive' and 'problematic' to 'very suggestive'. From Figure 6, it can be seen that both the mean and maximum values of formaldehyde from Kampong and apartments are associated with MCS risks. Basically, the respondents who are exposed to higher formaldehyde values tend to have higher levels of MCS risk, except for Kampong of Surabaya, where the 'not suggestive' group has higher formaldehyde values. This could be related to the fact that there were several cases of extremely high formaldehyde levels in Kampong. This result implies that long-term exposures to high levels of formaldehyde may have stronger effects on their health rather than the intermittent but extremely high exposures.

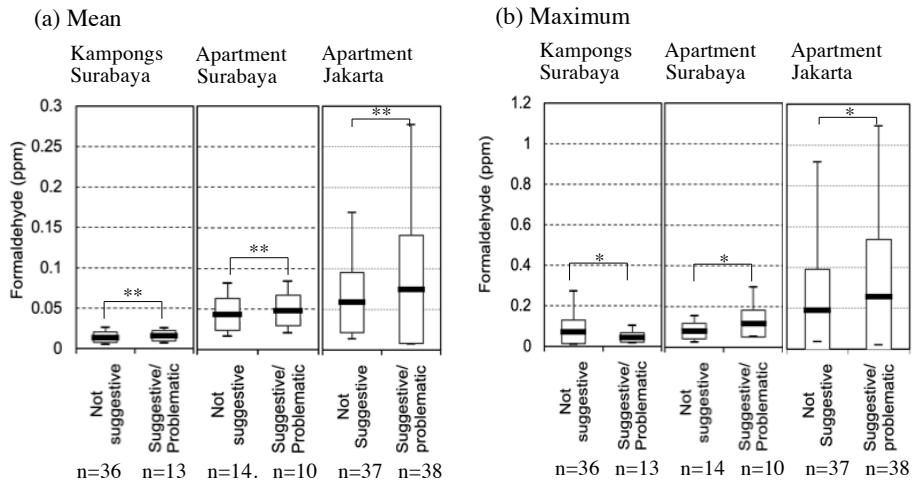

Figure 6. Formaldehyde level by different MCS risk group

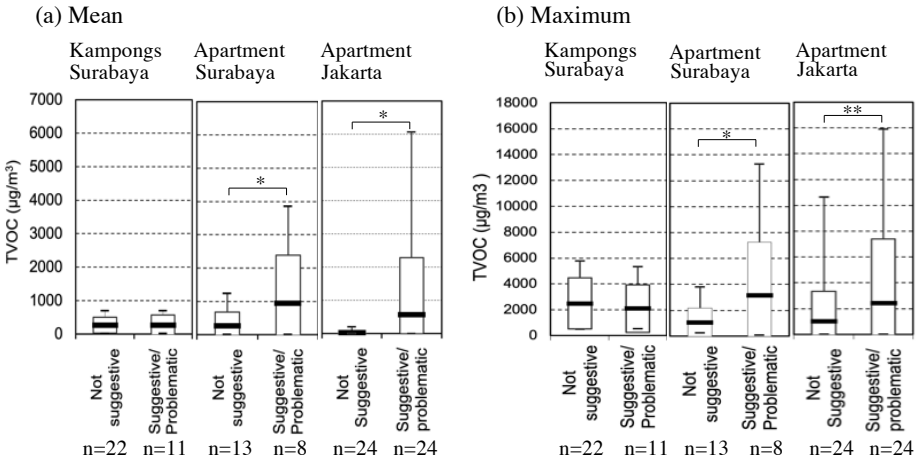

Figure 7. TVOC level by different MCS risk group

4. Conclusions

This paper presented the results of questionnaire and IAQ measurements among urban houses in the major cities of Indonesia. The key findings from the case studies of Surabaya and Jakarta are as follows:

(1) There was a significant difference in MCS risk score between Kampong and apartments. The percentage of respondents with high MCS risk in apartments was almost double or more than double compared to those in Kampong.

(2) In IAQ measurements, there was no significant difference in TVOC levels between Kampong and apartments. Nevertheless, more than 60% of the measured formaldehyde concentration in apartments of the two cities far exceeded the WHO standard, 0.08 ppm, whereas in Kampong, around 20% exceeded the standard.

(3) Stress levels were found to be associated with chemical sensitivity and MCS risk in all groups, but there were several different factors for Kampong and apartments respectively. In Kampong, age, income, occupation, health conditions, smoking behaviour/ETS number of windows, possession of AC, mold growth, number of furniture, smell, and cleaning behaviour for rooms were associated with sensitivity and/or MCS risk. In contrast, in apartments, gender, occupation, health conditions, occupation, smoking behaviour/ETS, use of fumigation, possession of fans, mold growth, smell, consciousness for IAQ, window-opening, and leaning behaviour for bathroom were related with sensitivity and/or MCS risk in Surabaya and/or Jakarta.

(4) It was found that the respondents living in the rooms with higher formaldehyde and TVOC levels tended to have higher MCS risks, particularly in the newly constructed apartments.

Acknowledgements

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