INDOOR AIR QUALITY AND HEALTH IN NEWLY CONSTRUCTED APARTMENTS OF INDONESIA: CASE STUDY ON THE EFFECT OF MODIFICATION

Hanief Ariefman Sani*, Tetsu Kubota*, Usep Surahman**, Collinthia Erwindi***

*) Graduate School of Advanced Science and Engineering, Hiroshima University, 1-5-1 Kagamiyama, Higashi-Hiroshima, 739-8529, Japan
**) Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No. 207 Bandung, Indonesia
***) Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia
e-mail: hanifarif.sani@gmail.com

ABSTRACT

In Indonesia, Sick Building Syndrome (SBS) and related health problems are suspected among the residents in emerging new urban houses constructed of modern building materials without sufficient material standards or minimum ventilation rates. First, this study investigates the current conditions of Indoor Air Quality (IAQ) and health in newly constructed high-rise apartments in major cities of Indonesia, in contrast with traditional landed houses, the so-called Kampongs. Concentrations of formaldehyde and TVOC were measured, whereas a face-to-face interview was conducted. A total of 896 respondents were interviewed, and 207 rooms were measured during 2017-2019. The results showed that overall, the newly constructed apartments recorded higher formaldehyde levels compared to Kampongs. The self-reported Multiple Chemical Sensitivity (MCS) status among occupants was significantly different between the two building types. Furthermore, the occupants with higher levels of TVOC, in particular, were associated with higher MCS risks, especially in the apartments. Second, we conducted a modification project in several apartment units of Surabaya to examine the effects of exhaust fans on IAQ. In most companies, the concentrations of both formaldehyde and TVOC were reduced after the modification. Further, a follow-up measurement was conducted in the same units for about a month.

Keywords: Indoor air quality, Formaldehyde, TVOC, QEESI, Modification

INTRODUCTION

It is essential to have a healthy indoor home environment because people spend 90% of their time indoors (Klepeis et al., 2011). In Indonesia, one of the rapidly growing

countries, there is a possibility that sick building syndrome (SBS) has already spread among newly constructed houses. Indonesia is predicted to have a significant population increase over 2017-2050 (UN DESA, 2017). The home shortage problem was estimated to have reached 11.4 million by 2017 (Lamudi, 2018). Thus, the central government is highly promoting affordable housing, particularly high-rise apartments for urban areas. First, this study investigates the current conditions of IAQ and health in newly constructed high-rise apartments in major cities of Indonesia, in contrast with Kampong, traditional landed houses. A face-to-face interview was conducted to collect the data of building attributes, ventilation duration, personal information, and health, whereas formaldehyde and TVOC were measured. It is assumed that apartments show a worse situation in both IAQ of chemicals and the self-reported MCS than Kampongs, partly due to the lack of ventilation. Therefore, we further conducted a modification project in several apartment units in Surabaya to examine the effects of exhaust fans on IAQ as a case study.

THEORY / RESEARCH METHODS

The survey consists of face-to-face interviews and field measurements from 2017-2019 in Surabaya, Jakarta, and Bandung, three major cities with the highest metro populations (Gilbert, 2017). There are two types of urban houses surveyed, namely, Kampong and high-rise apartments. Kampong is a traditional house built below the standard and situated in a dense unplanned arrangement. The apartments here are vertical urban houses with about 20 floors or more, including low-to-mid cost apartments and condominiums, where the size of the units ranges from approximately 20-85 m^2 (Ismawati, 2019).

Interview

A face-to-face interview was conducted using a questionnaire consisting of questions concerning socio-economic backgrounds, cooling behaviour, past/present diseases, indoor air condition, and Quick Environmental Exposure and Sensitivity Inventory (QEESI). QEESI was developed by Miller & Prihoda and used in various countries (Miller and Prihoda, 1999). QEESI has been designed to differentiate the degree of Multi Chemical Sensitivity (MCS) of a chemically sensitive person and ordinary people. MCS is described as a gained disorder with chronic symptoms related to various environmental factors tolerated by most people and not interpreted as any known medical or psychiatric disorder (Kishi et al., 2009). Miller and Prihoda (1999) also proposed the ranges for the scales and interpretation guidelines using QEESI. The criteria for low, medium and high scores are listed in Table 1 and the risk criteria in Table 2. Respondents have been categorized into one of four degrees to which MCS is suggested (risk criteria) according to their symptom severity, chemical intolerance, and masking score. This variable is called 'Multiple chemical sensitivity (MCS) risk'. It describes a person considered sensitive to multiple chemicals.

Table 1. Criteria for High, Medium and Low Scale Scores

Scale / Index	Score		
	Low	Medium	High
Symptom Severity	0-19	20-39	40-100
Chemical Intolerance	0-19	20-39	40-100
Other Intolerance	0-11	12-24	25-100
Life Impact	0-11	12-24	25-100
Masking Index	0-3	4-5	6-10

Source: Miller ad Prihoda, 1999

Table 2. Risk Criteria

The degree to which MCS is suggested	Symptom Severity Score	Chemical Intolerance Score	Masking Score
Not suggestive	<40	<40	<4
Not suggestive	<40	<40	≥4
Not suggestive	≥40	<40	<4
Somewhat suggestive	≥40	<40	≥4
Problematic	<40	≥40	<4
Problematic	<40	≥40	≥4
Very suggestive	≥40	≥40	<4
Very suggestive	≥40	≥40	≥4

Source: Miller ad Prihoda, 1999

Measurement

The measured parameters include formaldehyde, TVOC, air temperature, and RH. Formaldehyde (FMM-MD, Shinyei) and TVOC (ToxiRAE Pro, RAE System) were measured in their living rooms and bedrooms as the commonly used chemical pollutant indicators. These devices were placed for three days in these rooms, respectively, at approximately 1.2 meters above the floor. This is because most international guidelines recommend that samples be taken about 1 m to 1.5 m above the bottom since this is the approximate height of the average breathing zone (ECA 1995; ISO 2004; Leidel, Busch, and Lynch 1977). Data of formaldehyde were recorded in 30 minutes interval and 1 minute for TVOC. The sampling duration of 30 min was chosen to compare with the international guidelines such as WHO (2010). Air temperature and RH were measured by the former device (FMM-MD, Shinyei Technology) at the same time.

Detail measurement by active sampling and gas chromatography method was done to find further the concentration of formaldehyde and detail compound of TVOC. Furthermore, after the first detailed measurement, the modification project was done. The modification was the install fan's instalment in the living room to improve the ventilation and see its effect in IAQ.

RESULTS AND DISCUSSION

The brief profile of respondents is presented in Table 3. As expected, there are significant differences between Kampongs and apartments in several variables. The respondent's age is averaged at 39.7 years old in Kampongs, while those in apartments are 25.1, 29.4, and 27.1 years old, respectively. Accordingly, living in the present houses/units is much longer (25.3 years) in Kampongs than in apartments (1.9, 3.3, and 3.24 years). The building's age is averaged at 31.7 years in Kampongs, compared with 4.5, 7.7, and 6.9 years in apartments of Surabaya, Jakarta, and Bandung, respectively. Occupation, as well as average household income, also show some differences between Kampongs and apartments.

Table 3. Brief Profile of Respondents

	Kampongs	Apartments in Surabaya	Apartments in Jakarta	Apartments in Bandung	Total
Questionnaire	298 (33%)	173 (19%)	236 (26%)	189 (21%)	896
IAQ measurement	42	40	81	44	207
Gender (M/F) (%)	35/65	43/57	44/56	34/66	39/61
Average age (years old)	39.7	25.1	29.4	27.1	32.0
Household income (%)					
<150 (US$)	24.8	9.5	0.8	12.6	13.7
150-450	56.3	46.7	21.3	26.8	41.2
450-750	9.4	16.2	20.5	22.8	15.3
>750	9.4	27.6	57.4	37.8	29.8
Average stay duration (years)	25.3	1.9	3.29	3.24	12.8
Age of buildings (years)	31.7	4.5	7.7	6.9	32.0
AC ownership (%)	20.9	99.5	100	52.5	64.1
Fan ownership (%)	99.3	29.5	25.7	50.5	56.6
Window opening in the bedroom (hours)	12.95	6.76	5.48	9.58	9.0
Window opening in the living room (hours)	13.04	8.00	5.75	8.92	9.83
No windows in the master bedroom [%]	14.9	5.5	2.7	0.7	6.2
No windows in the living room [%]	3.8	7.1	14.3	16.5	8.8

The duration of window-opening in Kampong is the most extended (12.9-13.4 hours), while in apartments, 8.9-9.5 hours in Bandung, 6.7-8 hours in Jakarta and 5.4-5.7 hours in Surabaya. The penetration rate of air conditioners (AC) is much higher in apartments of Surabaya and Jakarta (99–100%) than that of Kampongs (20.9%), while fans are used more in Kampongs (99.3%) instead. In Bandung, 52.5% of respondents

have AC, and 50.5% have fans. It is mainly depending on the income levels and climatic conditions. In apartments, AC is typically installed in the living room and the master bedroom (see Figure 2), and they often use them during the night-time (Mori, Kubota, and Arethusa 2018). About 14.9% of Kampong houses in Surabaya do not have windows in their bedrooms, while 14.3% in apartments of Jakarta are not equipped with windows in their living rooms.

There are also several significant differences in the comparison between the apartments of Surabaya, Jakarta, and Bandung. The apartments in Jakarta (7.7 years) and Bandung (6.9 years) are averagely older than those in Surabaya (4.5 years). Apartments in Jakarta (85.1%) are equipped with exhaust fans more than Surabaya (51.6%) and Bandung (52.3%).

Multiple chemical sensitivity

The final calculated results of MCS risk and sensitivity were analyzed by housing types (Figure 1). Overall, MCS risks are significantly higher ($p < 0.01$) in apartments than in Kampongs: the percentage of problematic/suggestive respondents in apartments are double Kampong: 48.8% in apartments of Surabaya; 40.7% in apartments of Jakarta; 37.4% in apartments of Bandung, whereas 21.9% in Kampong. There is also a significant difference ($p < 0.05$) in the MCS risk in apartments of Surabaya and Bandung; 51.2% of respondents were not suggestive in Surabaya while 62.6% in Bandung.
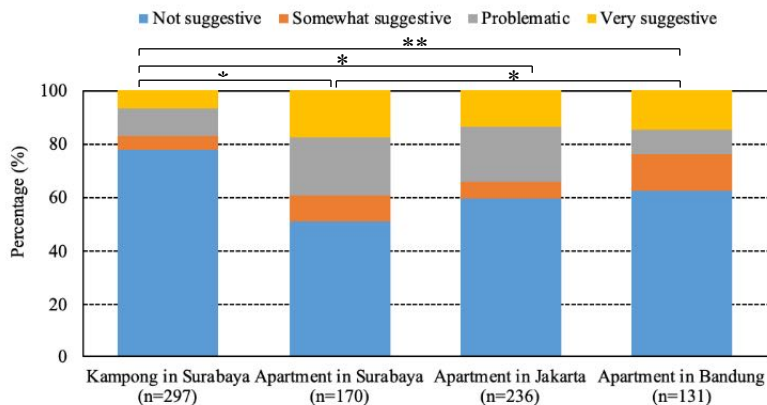

Figure 1. Multiple chemical sensitivity (MCS) risk results of Kampong and apartments of three cities.

As described in Hildebrandt et al. (2019), in the previous studies, similar shares of MCS risk in apartments (37%) were reported in South Korea (Jeong et al., 2014). Still, in Japan, only 25% of the respondents were categorized as 'very suggestive' or 'problematic' MCS risk groups (Hojo et al., 2016). Moreover, in the US, the percentage of people with high sensitivity in three scales was found to be just 6.6% (Miller and Prihoda 1999). The share of high MCS risk groups and respondents with high sharpness in Kampongs is far lower than those reported in these previous studies.
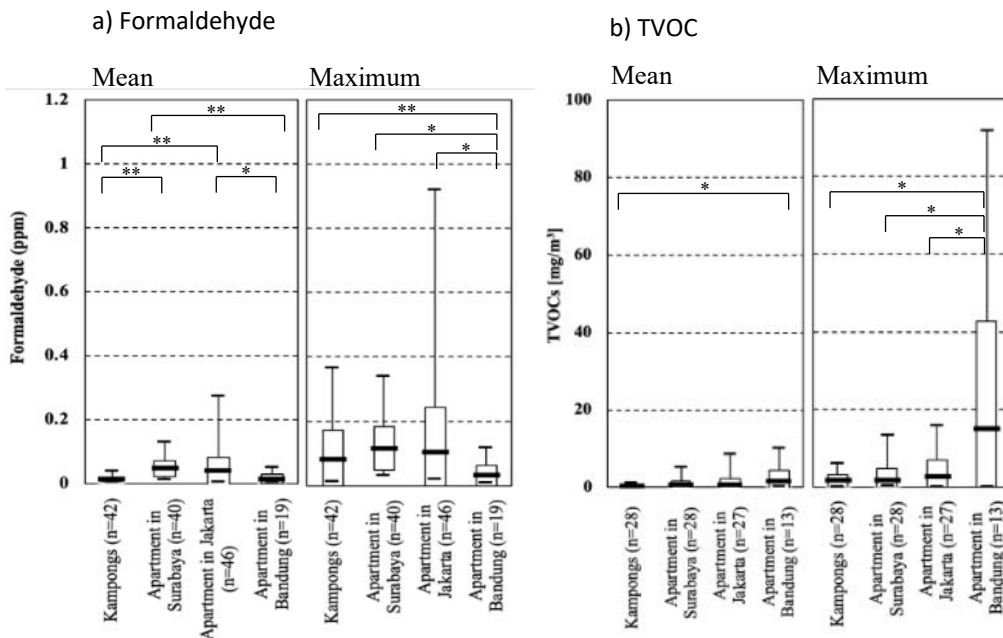
Indoor air measurement

Figure 2. Statistical summary of IAQ measurement results

The measurement results of formaldehyde and TVOC were the result of the average air condition, calculated with 30 minutes. Based on these conditions, the maximum value can be compared with international standards. Figure 2(a) explains in general that formaldehyde concentrations of most apartments are higher than Kampong, especially in the mean value. It ranges up to 0.02 ppm in Kampong, but in the flats, it ranges from 0.02-0.07 ppm (Surabaya) and 0.007-0.138 ppm (Jakarta). An exciting result appeared in Bandung's apartments, where the formaldehyde concentration is close to Kampong, ranging up to 0.03 ppm. Between apartments in Surabaya and Jakarta, there are significant differences, where the apartments in Jakarta tend to have higher formaldehyde. For example, at the maximum value, the average of apartments in Jakarta is 0.187 ppm, with the upper range of 0.38 ppm, while in Surabaya, the standard is 0.115 ppm, ranging up to 0.183 ppm.

Furthermore, the mean values of 0.01 ppm (Kampongs) and 0.04–0.05 ppm (apartments) were found to be higher than those in most previous studies (Hildebrandt et al. 2019), including 0.01– 0.02 ppm in France (Bentayeb et al. 2013), 0.03 ppm in Japan (Araki et al. 2010; Saijo et al. 2011) and 0.03–0.04 ppm in China (Huang et al. 2011). As discussed in the previous publication (Hildebrandt et al. 2019), the maximum measured concentrations of 0.34–0.92 ppm are also much higher than in Japanese studies – 0.15ppm (Saijo et al. 2011) or 0.16ppm (Takigawa et al. 2010) and the United Arab Emirates (0.14 ppm) (Yeatts et al. 2012) and higher in China (0.22 ppm) (Guo et al. 2013) – and exceeds even the measured maximum of 0.29 ppm in a study on 'very suggestive' MCS cases in Japan (Hojo et al. 2016).

A similar result was obtained in TVOC (Figure 2(b)). Overall, the TVOC concentrations in apartments are higher than in Kampong, both in mean and maximum values. The average values of apartments in both Surabaya (0.58 mg/m^3) and Jakarta (0.53 mg/m^3) are almost two times that of Kampong (0.23 mg/m^3). However, in Bandung's apartments, where the formaldehyde levels were similar to Kampong, the average of TVOC (1.45 mg/m^3) is six times higher than Kampong (0.23 mg/m^3). Interestingly, in maximum value, Bandung's apartments show significantly different ($p<0.05$) compared to Kampongs and apartments in Surabaya and Jakarta. Apartments (average: 1.76 mg/m^3) and Kampong (1.50 mg/m^3) in Surabaya obtained similar values, and in Jakarta are relatively higher (2.63 mg/m^3), but they are significantly lower than those of Bandung's apartments (14.88 mg/m^3). However, there are several cases where the TVOC recorded highly high values in the three case studies, including Bandung.

IAQ and MCS

The relationship of formaldehyde and TVOC measurement results with MCS risk analyzed by dividing the samples into two MCS groups: 'not suggestive' and 'problematic' to 'very suggestive'. Both the mean and maximum values of formaldehyde from Kampong and apartments are associated with MCS risks. The respondents exposed to higher formaldehyde values tend to have lower levels of MCS risk, except for Apartments of Surabaya, where the 'not suggestive' group has higher formaldehyde values. This could be related to the fact that the average formaldehyde levels in apartments in Surabaya was the highest compared to other cities. This result implies that long-term exposures to high levels of formaldehyde may have more substantial effects on their health than intermittent but highly high exposures.

As shown in figure 3, combined all apartment data from three cities compared to Kampong, the 'problematic' to 'very suggestive' groups are exposed to a higher concentration of TVOC. In apartments Surabaya, the TVOC was 778.9 mg/m compared to 204.8 mg in 'not suggestive' groups. In apartments of Jakarta, the 'problematic' to 'very suggestive' group was exposed to a 17 times higher level of TVOC compares to another group. Therefore, it became apparent that respondents with an MCS risk were exposed to increased TVOC concentrations in apartments of the two cities, just like other studies reported previously (Sahlberg et al., 2013).
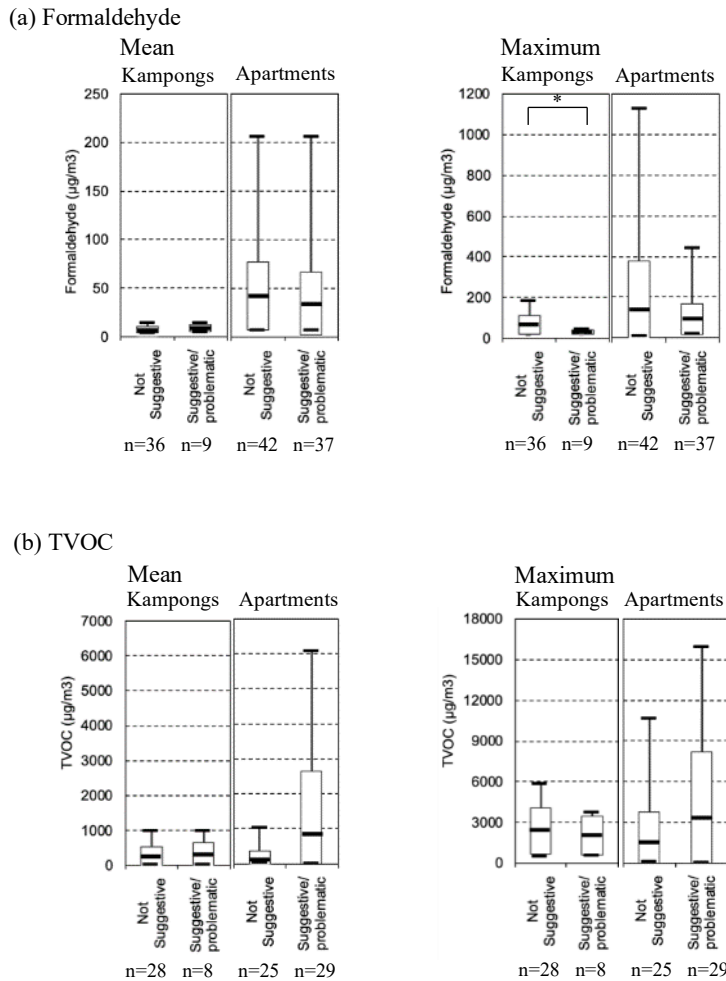
(a) Formaldehyde

(b) TVOC

Figure 3. IAQ concentration by different MCS group (a) Formaldehyde and (b) TVOC

Factors affecting MCS risk

Correlation analysis was conducted to identify the factors affecting MCS risk and sensitivity scores in all apartments continued with Kampongs and apartments, respectively, using the Spearman's test or Chi-square test, depending on the types of the variable. Table 4 summarizes the relations of MCS risk with personal attributes and building attributes. In apartments, the strongest correlation exists between higher levels of stress and MCS risk. As discussed in Kubota et al. (2020), some studies suggest a relationship between mental well-being and reporting of symptoms for MCS, which the home environments can cause, that related to noise, size of the apartments and cleaning activities (Cui et al. 2015; Mendelson, Catano, and Kelloway 2000; Runeson-Broberg and Norbäck 2013).

Furthermore, building attributes, interior characteristics and personal attributes did not show significant overall analysis, except for all apartment data. Age of the building, the number of windows in the living room, window-opening duration in master bedroom IAQ, and OAQ perceptions are several variables that showed significant relations with the MCS both in all data and all apartment analysis. Correlation analysis of Surabaya and Jakarta data also showed a similar result in a previous study (Kubota et al., 2020), where MCS risks are increased with the reduction of building age. These significant correlations cannot be seen in the analysis of each city. These relations can be related to the fact that the building age of apartments, number of windows, IAQ and OAQ in the three cities are significantly different. For example, in personal IAQ rating, 13.8% of Jakarta' respondents rate their IAQ as dirty, whereas 11% in Surabaya and 9.7% in Bandung rate their IAQ as dirty. Besides, the living room and bedroom have different condition. In the master bedroom, respondents tend to be affected by the window opening behaviour and the living room by the number of windows. This indicates that occupants of apartments tend to circulate more in the bedroom compare to the living room.

Furthermore, with the increases in age, people aged more than 50 years old tend to have higher MCS risk ($p<0.05$), and household income tend to increase the MCS risk and sensitivity in Kampongs. Moreover, respondents' occupation has a significant relationship with MCS risk and sensitivity: in particular, government officers and retired respondents tend to have higher sensitivity. As shown in the apartments, the increase in stress level significantly increases MCS risk and sensitivity. Meanwhile, those who have a prevalence of asthma, eczema, and other allergies tend to have higher sensitivities. In contrast with all apartment data, the all data, Kampong and apartments, the analysis showed that outdoor air quality significantly affected the MCS risk and sensitivity.

Table 4. Results of MCS correlation analysis

KS: Kampong in Surabaya AS: Apartments in Surabaya AJ: Apartments in Jakarta AB: Apartments in Bandung	**All data**	**All data are apt.**	**KS**	**AS**	**AJ**	**AB**
Personal attributes						
Age group[a]	.001	.104	.047	.312	.414	.410
Gender[a]	.018	.005	.474	.032	.035	.652
Living in home [years][b]	.000	.470	.405	.474	.192	.026
Income[b]	.000	.546	.000	.496	.090	.744
Occupation[a]	.020	.105	.001	.778	.042	.675
Window-opening_ bedroom[b]	.000	.016	.416	.063	.515	.787
Window-opening_ livingroom[b]	.001	.782	.773	.457	.029	.150
Cleaning of rooms[b]	.010	.076	.012	.060	.272	.552
Cleaning of bathroom[b]	.136	.594	.976	.280	.993	.300
Health						
Asthma[a]	.005	.043	.041	.740	.035	.073
Eczema[a]	.000	.001	.000	.055	.327	.001
Allergy[a]	.000	.000	.031	.117	.037	.000

Table 4. Results of MCS correlation analysis (*continued*)

KS: Kampong in Surabaya AS: Apartments in Surabaya AJ: Apartments in Jakarta AB: Apartments in Bandung	**All data**	**All data apt.**	**KS**	**AS**	**AJ**	**AB**
Stress[b]	.000	.000	.000	.004	.017	.005
Building attributes						
Age of building [years][b]	.005	.011	.405	.474	.192	.855
Windows_ masterbedroom[b]	.371	.175	.004	.924	.351	.470
Windows_living room[b]	.000	.035	.000	.280	.050	.776
AC[a]	.000	.321	.007	.608	.840	.622
Fan[a]	.002	.648	.509	.526	.042	.199
Modifications[a]	-	-	.017	.987	-	-
Water leakage[a]	.101	.855	.387	.143	.115	.174
Interior						
Mold[a]	.446	.171	.005	.660	.055	.532
Mite[a]	.011	.073	.921	.107	.856	.053
Furniture living room[b]	.024	.139	.014	.177	.457	.192
IAQ						
Smell[a]	.035	.093	.024	.160	.022	.153
IAQ rating[b]	.030	.004	.893	.056	.288	.003
OAQ rating[b]	.001	.045	.089	.148	.068	.276

[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)

Factors affecting IAQ

Further correlation analysis was conducted to identify the factors that affect the IAQ measurement results, i.e., formaldehyde and TVOC concentrations, focusing on apartments of the three cities using the Spearman's test, Pearson's test or Chi-square test, depending on the types of the variable. As shown in Table 5, building attributes established significant relations with the formaldehyde level in all apartments. There are some different correlations; for example, the number of windows in the master bedroom (p<0.05), number of furniture in the living room (p<0.05), and age of the building (p<0.01) correlates with the mean of formaldehyde. Still, no correlation is seen in maximum formaldehyde. Also, AC, fan, and exhaust fan ownership, followed by water leakage, mould, and smell, showed a significant relationship with all mean and maximum formaldehyde. A similar correlation can also be seen in the TVOC correlation analysis in Table 6. However, in TVOC, the number of windows in the bedroom correlates with the mean and maximum value of TVOC. The possessions of fan and exhaust fan are negatively associated with formaldehyde: formaldehyde concentrations are lower in the apartments with fans and exhaust fans. However, the controls of the two items and AC have positive relationships with TVOC on the other hand. Further investigation is required to clarify this discrepancy.

On the other hand, personal attributes showed no significant relations in all apartment data, but some are in a specific city. In apartments of Surabaya, window opening behaviour in the master bedroom correlated with a mean value of

formaldehyde and living duration connect with a mean value of TVOC ($p<0.05$), similarly with apartments in Jakarta ($p<0.01$). However, correlation analysis of Surabaya and Jakarta IAQ data in Kubota (2020) showed, among all the flats, the durations of opening windows in both bedroom and living room correlate with maximum values of formaldehyde. Still, in this correlation with additional data from Bandung, there is no significant correlation. This condition can be related to the low concentration of formaldehyde in the apartment of Bandung (Figure 2).

Table 5. Results of IAQ formaldehyde values correlation analysis.

Me = Mean Mx = Maximum	All apartments (n=82)		Apartments in Surabaya (n=29)		Apartments in Jakarta (n=43)		Apartments in Bandung (n=10)	
	Me	**Mx**	**Me**	**Mx**	**Me**	**Mx**	**Me**	**Mx**
Personal attributes								
Age[c]	.699	.305	.022	.440	.739	.193	.970	.932
Gender[a]	.512	.384	.397	.457	.533	.415	.247	.247
Living in home [years][c]	.787	.955	.889	.906	.855	.165	.903	.058
Income[b]	.843	.402	.554	.823	.673	.512	.632	.099
Occupation[a]	.115	.070	.088	.078	.485	.463	.029	.029
Window-opening_ bedroom[c]	.078	.290	.046	.130	.689	.076	.787	.164
Window-opening_ living room[c]	.178	.790	.127	.159	.343	.129	.843	.066
Cleaning of rooms[b]	.622	.143	.186	.087	.189	.027	.208	.442
Cleaning of bathroom[b]	.266	.251	.647	.709	.000	.003	.936	.222
Health								
Asthma[a]	.657	.831	.260	.212	.525	.550	.717	.717
Eczema[a]	.388	.457	.341	.416	.318	.424	.549	.549
Allergy[a]	.402	.278	.330	.273	.512	.375	.308	.308
Stress[b]	.744	.287	.498	.876	.920	.265	.177	.407
Building attributes								
Age of building [years][c]	.003	.053	.375	580	.221	.093	.002	.903
Windows_ master bedroom[c]	.041	.097	.249	.207	.859	.838	.137	.199
Windows_living room[c]	.574	.420	.206	.241	.751	.723	.446	.457
AC[a]	.005	.003	.088	.066	.639	.582	.017	.017
Fan[a]	.005	.009	.088	.066	.021	.042	.029	.029
Exhaust fan	.012	.005	.088	.066	-	-	.247	.274
Water leakage[a]	.001	.001	.088	.066	.010	.007	.017	.017
Interior								
Mold[a]	.002	.006	.088	.132	.020	.037	.017	.017
Mite[a]	.003	.011	.088	.123	.062	.148	.023	.023
Furniture_living room[c]	.012	.189	.451	.414	.074	.440	.029	.387

Table 5. Results of IAQ formaldehyde values correlation analysis (*continued*)

Me = Mean Mx = Maximum	All apartments (n=82)		Apartments in Surabaya (n=29)		Apartments in Jakarta (n=43)		Apartments in Bandung (n=10)	
	Me	**Mx**	**Me**	**Mx**	**Me**	**Mx**	**Me**	**Mx**
IAQ								
Smell[a]	.029	.044	.088	.108	.068	.074	.023	.023
IAQ rating[b]	.029	.009	.989	.744	.150	.216	.020	.024
OAQ rating[b]	.179	.142	.048	.023	.830	.685	.379	.387

[a] *p*value of ChiSquareTest, [b] *p*value of Spearman rho, [c] *p*value of Pearson
test light red: Correlation is significant at the 0.01 level (2tailed), green:
Correlation is significant at the 0.05 level (2tailed)

Table 6. Results of IAQ TVOC value correlation analysis.

Me = Mean Mx = Maximum	All apartments (n=82)		Apartments in Surabaya (n=29)		Apartments in Jakarta (n=43)		Apartments in Bandung (n=10)	
	Me	**Mx**	**Me**	**Mx**	**Me**	**Mx**	**Me**	**Mx**
Personal attributes								
Age[c]	.684	.333	.748	.593	.257	.465	.464	.464
Gender[a]	.606	.594	.390	.390	.526	.497	.495	.495
Living in home [years][c]	.605	.657	.039	.194	.005	.141	.699	.701
Income[b]	.834	.660	.212	.042	.055	.039	.838	.838
Occupation[a]	.124	.090	.119	.119	.076	.039	.136	.136
Window-opening_ bedroom[c]	.521	.601	.878	.611	.927	.916	.948	.948
Window-opening_ living room[c]	.262	.255	.559	.220	.797	.927	.898	.898
Cleaning of rooms[b]	.571	.746	.284	.082	.533	.978	.689	.692
Cleaning of bathroom[b]	.629	.853	.121	.338	.595	.572	.719	.717
Health								
Asthma[a]	.162	.230	.222	.222	.061	.117	.212	.495
Eczema[a]	.107	.091	.331	.331	.020	.014	.212	.212
Allergy[a]	.128	.110	.296	.296	.063	.045	.350	.350
Stress[b]	.268	.232	.176	.017	.878	.579	.067	.067
Building attributes								
Age of building [years][c]	.086	.194	.332	.296	.337	.564	.214	.214
Windows_ master bedroom[c]	.003	.006	.401	.277	.857	.223	.000	.000
Windows_living room[c]	.383	.331	.533	.981	.007	.619	.136	.136
AC[a]	.036	.030	.074	.074	.017	.012	.071	.071

Table 6. Results of IAQ TVOC value correlation analysis (*continued*)

Me = Mean Mx = Maximum	All apartments (n=82)		Apartments in Surabaya (n=29)		Apartments in Jakarta (n=43)		Apartments in Bandung (n=10)	
	Me	**Mx**	**Me**	**Mx**	**Me**	**Mx**	**Me**	**Mx**
Fan[a]	.041	.037	.074	.074	.100	.088		
Exhaust fan	.017	.015	.074	.074	-	-	.350	.350
Water leakage[a]	.006	.005	.074	.074	.218	.169	.011	.011
Interior								
Mold[a]	.013	.010	.074	.074	.262	.208	.005	.005
Mite[a]	.006	.005	.074	.074	.002	.000	.003	.003
Furniture_living room[c]	.701	.686	.049	.108	.344	.221	.789	.789
IAQ								
Smell[a]	.000	.000	.074	.074	.012	.003	.412	.412
IAQ rating[b]	.712	.915	.042	.005	.135	.034	.685	.556
OAQ rating[b]	.614	.759	.023	.028	.064	.148	.788	.788

[a] *p*value of ChiSquareTest, [b] *p*value of Spearman rho, [c] *p*value of Pearson test light red: Correlation is significant at the 0.01 level (2tailed), green: Correlation is significant at the 0.05 level (2tailed)

Modification project/case study

Window opening duration and number of windows, followed by AC, fan and exhaust fan availability, are several variables that showed a significant relationship with both MCS and IAQ. All those variables are related to ventilation and air treatment of the house. It is known that improved ventilation is one of the solutions to make a healthy indoor air condition. In this chapter, the effects of strengthening ventilation by exhaust fan will be analyzed.

Apartments in Surabaya, with the highest average value of formaldehyde, relatively high TVOC, and highest rate of MCS risks, is selected as the case study site. There are four apartment units/rooms in this project. Detailed measurement by active sampling and gas chromatography (GS-MS) method was done to find further the concentration of formaldehyde and clear compound of TVOC before and after the modification.

Furthermore, the modification project was done by installing the exhaust fan in the living room of the apartment unit. One apartment unit was not modified as a controlled unit (unit 1). In two units (unit 2 and unit 4), the exhaust fan was installed on the door that leads to the balcony, whereas in unit 3, it is installed on the window to the patio. All exhaust fans are installed 10 cm from the top of the window/door frame. Another direct measurement was done before the modification and continued for 30 days to follow the modification effects.
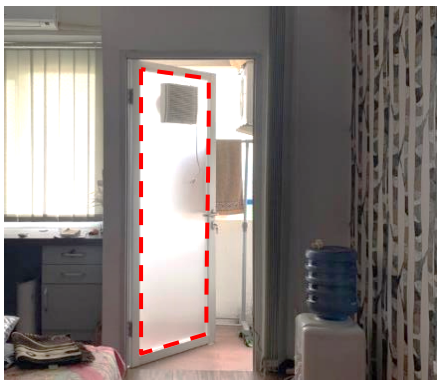
Figure 4. An exhaust fan installed on the door of the balcony.

Air change per hour (ACH) was also measured to see the house's ventilation rate before the modification, using a CO2 concentration decay method. There are two conditions measured, open window and closed window. Firstly, CO2 gas was injected into the closed room until reaching 2500-3000 ppm with a steady level, and then in 15 seconds, the CO_2 concentration decay was measured. Indoor CO2 concentration was measured using GRAPHTEC Serie GL100-WL-CO2 (accuracy ±(5% of reading + 30 ppm) In the range between 0 and 5000 ppm). The equation from Lausmann and Helm (2011) used to calculate the air change rate.
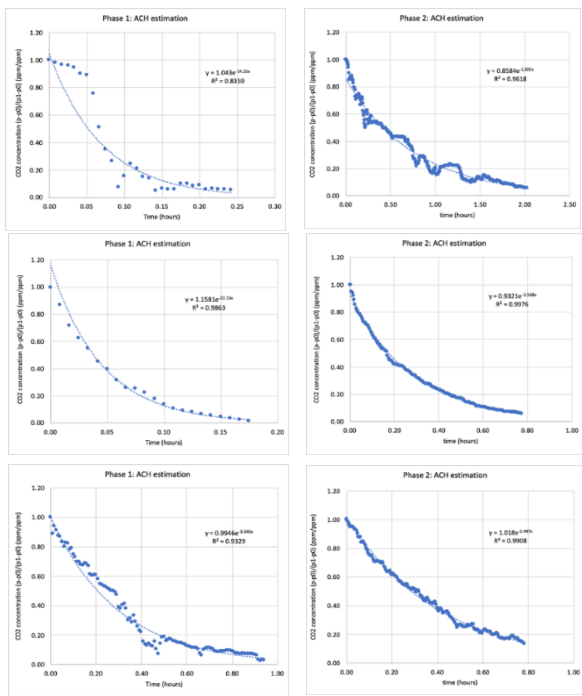
Figure 5. Diagrams of ACH of the houses, phase 1 (open window condition) and phase 2 (close window condition)

Table 7. ACH measurement results of the houses.

	ACH (times/h)	Volume (m³)	Q (m³/h)
Phase 1 (open window condition)			
Unit 1 (apartment Gunawangas Manyar)	22.13	33.32	737.37
Unit 2 and 4 (apartment Menara Rungkut)	3.35	45.12	150.96
Unit 3 (apartment Educity)	14.26	13.74	195.93
Phase 2 (closed window condition)			
Unit 1 (apartment Gunawangas Manyar)	3.57	33.32	118.89
Unit 2 and 4 (apartment Menara Rungkut)	2.50	45.12	112.66
Unit 3 (apartment Educity)	1.19	13.74	16.38

Figure 5 and Table 7 show the results of the calculation in opened window condition. The ACH of unit 1 in apartment Gunawangsa is the highest 22.13 times per hour, compared to 14.26 times in Educity apartment the lowest one, 3.35 times in apartment Menara Rungkut. On the other hand, in closed window condition (Figure 6.3), Educity apartment (unit 3) shows the lowest ACH by 1.19 times per hour, while in apartment Menara Rungkut 2.50 times per hour. Similarly, with open window conditions, apartment Gunawangsa has the highest ACH in closed window conditions, which is 3.57 times per hour.
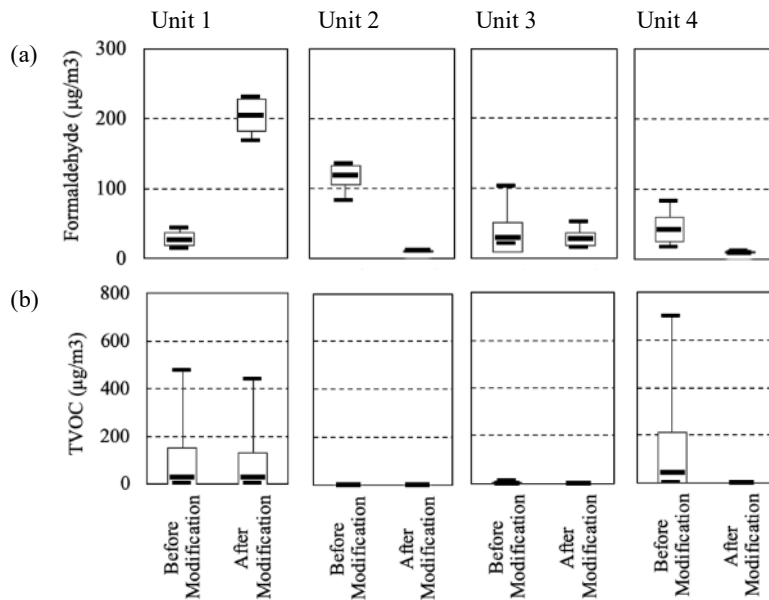

Figure 6. IAQ measurement result before and after modification, a) Formaldehyde and b) TVOC.

Figure 6 presents formaldehyde and TVOC concentrations changes, respectively, before installing the exhaust fans in the measured rooms. As shown, the formaldehyde level was decreased after the modification in all modified units,

especially unit 2 and unit 4. In contrast, as expected, in unit 1, the formaldehyde level increased in the second measurement. In unit 2, formaldehyde concentration went down significantly from 118.6 μg/m³ to 11 μg/m³ after the modification. Similarly, in unit 4, before the measurement, the attention was 43.4 μg/m³, and after the change, 11 μg/m³. Furthermore, TVOC concentration reduced, ranging from 24% to 76% due to the modification. In the control unit, there was a reduction, but not as significant in unit 4. In the other modified companies, the concentration of TVOC was also decreasing, but the concentration before modification was already low. Therefore, the change was not significant.

A Follow-up measurement of IAQ, together with AC and ventilator usage recording, was done after the modification for a one-month duration. Unfortunately, not all respondents agreed. Respondents were asked to do activities as usual and motivated to try to turn on the ventilator when suitable for them. Other than ventilator and AC, detailed window-opening behaviour for 30 days was also recorded by a questionnaire filled by the respondents themselves. Figure 6.6 shows the overall formaldehyde and TVOC temporal changes during this measurement. As shown, formaldehyde concentration tends to decrease over time, especially in unit 3 (apartment Educity). In contrast, the attention of TVOC tends to increase and fall by the time in unit 2 and unit 3.
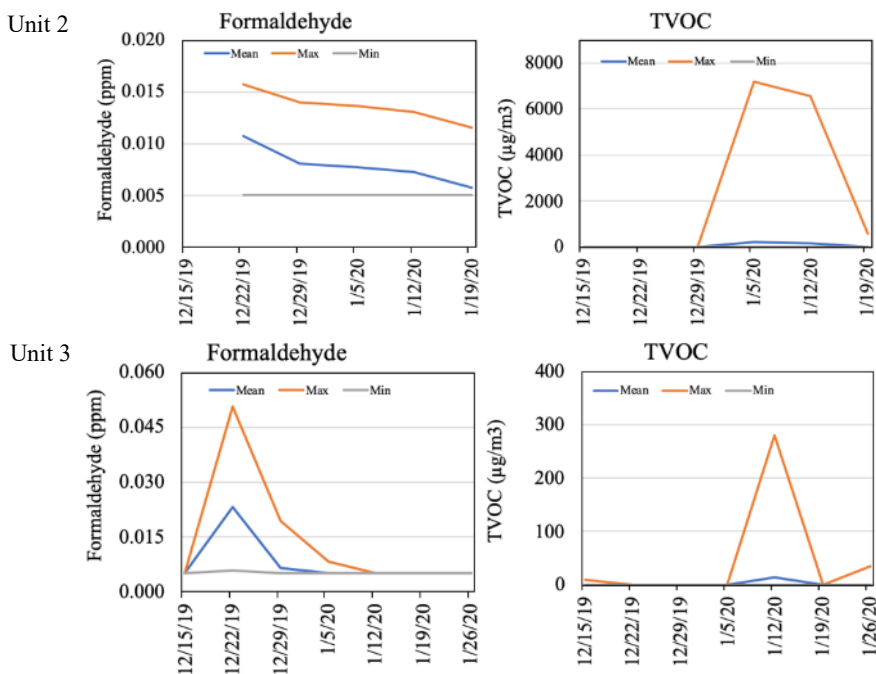

Figure 7. Follow-up measurement results in the temporal variation of weekly concentration of formaldehyde and TVOC.

The IAQ concentration was categorized into two groups (on/open and off/closed) to analyze the effect of AC and ventilator usage and window opening. The

installation of ventilation and window opening improves the IAQ concentrations, especially in maximum value in unit 3. AC usage was not analyzed in unit 3 because, in this unit, AC was on all the time. In contrast, in unit 2, apartment Menara Rungkut, when the ventilator or AC was on, the TVOC concentration was higher than when it was off. However, window opening behaviour showed a lower level of formaldehyde and TVOC in unit 2, similar to unit 3. This result showed that the IAQ concentration level might decrease by improving the room's air ventilation, but there is a possibility where the indoor source is still contaminating the air. Therefore, investigating the primary source of the high formaldehyde and TVOC level is essential for better indoor air quality.

CONCLUSIONS

Key findings of this study are summarized as follows:

There was a significant difference in MCS risk scores between Kampong and apartments. The percentage of respondents with high MCS risk in apartments was almost double or double compared to those in Kampong. Around 49% (Surabaya), 41% (Jakarta), and 37% (Bandung) of respondents in the apartments showed some degrees of MCS risk, indicating the possible spread of sick building syndrome.

In IAQ measurements, formaldehyde and TVOC concentrations of most apartments are higher than Kampong, especially in the mean value for formaldehyde. However, in Bandung's apartments, the formaldehyde concentration is close to Kampong, ranging up to 0.03 ppm.

Stress levels were associated with MCS risk in all groups, but there were several different factors for Kampong and apartments. In Kampong, age, income, occupation, health conditions, smoking behaviour, number of windows, possession of AC, mould growth, the number of furniture, smell, and cleaning behaviour for rooms were associated with sensitivity and MCS risk. In contrast, in apartments, gender, health conditions, consciousness for IAQ, the number of windows, window-opening, and age of the building were related to sensitivity and MCS risk in Surabaya, Jakarta and Bandung.

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

Age of the building, the number of windows and duration of opening windows were significantly associated with MCS risk and IAQ levels.

The improvement of ventilation rate by using exhaust fans was effective in lowering the formaldehyde and TVOC levels. However, further study is needed to improve the overall IAQ of the room.

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