

Article

# Indoor Air Quality and Health in Newly Constructed Apartments in Developing Countries: A Case Study of Surabaya, Indonesia

Sophia Hildebrandt <sup>1</sup> , Tetsu Kubota <sup>2,3,\*</sup> , Hanief Ariefman Sani <sup>2</sup> and Usep Surahman <sup>4</sup>

<sup>1</sup> Institute of Building Design and Management, Leipzig University, Grimmaische Str. 12, 04109 Leipzig, Germany; sophia.hildebrandt@posteo.de

<sup>2</sup> Graduate School for International Development and Cooperation, Hiroshima University, 1-5-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8529, Japan; hanief.sani@yahoo.com

<sup>3</sup> Research Institute for Human Settlement and Housing, Ministry of Public Works and Housing, Bandung 40393, Indonesia

<sup>4</sup> Department of Architectural Education, Universitas Pendidikan Indonesia (UPI), Jl. Dr. Setiabudhi No. 229 Bandung, West Java 40154, Indonesia; u\_surahman@yahoo.com

\* Correspondence: tetsu@hiroshima-u.ac.jp; Tel.: +81-82-424-6925

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**Abstract:** In times of rapid urbanization, increasing usage of chemicals in buildings, and energy saving measures, the topic of indoor air quality (IAQ) demands reinforced attention. Nevertheless, especially in developing countries with urgent building construction needs, IAQ has hardly been examined. This study investigates the condition of IAQ and health of occupants in newly constructed high-rise apartments in contrast to traditional detached houses (Kampongs) in Surabaya, Indonesia. Information on building attributes, cleaning and ventilation behavior, interior sources, personal characteristics and health, especially multiple chemical sensitivity (MCS), was collected through 471 questionnaires. In addition, 76 measurements of TVOCs, formaldehyde and 30 measurements of mold risk were carried out. The results showed that the share of people in apartments with a very suggestive risk of MCS was twice as high as that in Kampongs (17.6% vs. 6.7%). Correlation analysis suggested that for both residential types, health problems, negative smell or perception of IAQ, and higher levels of stress determined higher degrees of MCS. For IAQ, high concentrations of formaldehyde and TVOCs were measured in apartments and corresponded to higher MCS risk, whereas severe mold issues were predicted in Kampongs. This study suggests major shortcomings in the indoor environment in newly constructed apartments for the physical and the mental health of occupants.

**Keywords:** indoor air quality; multiple chemical sensitivity; QEESI; high-rise apartment; residence; developing countries

## 1. Introduction

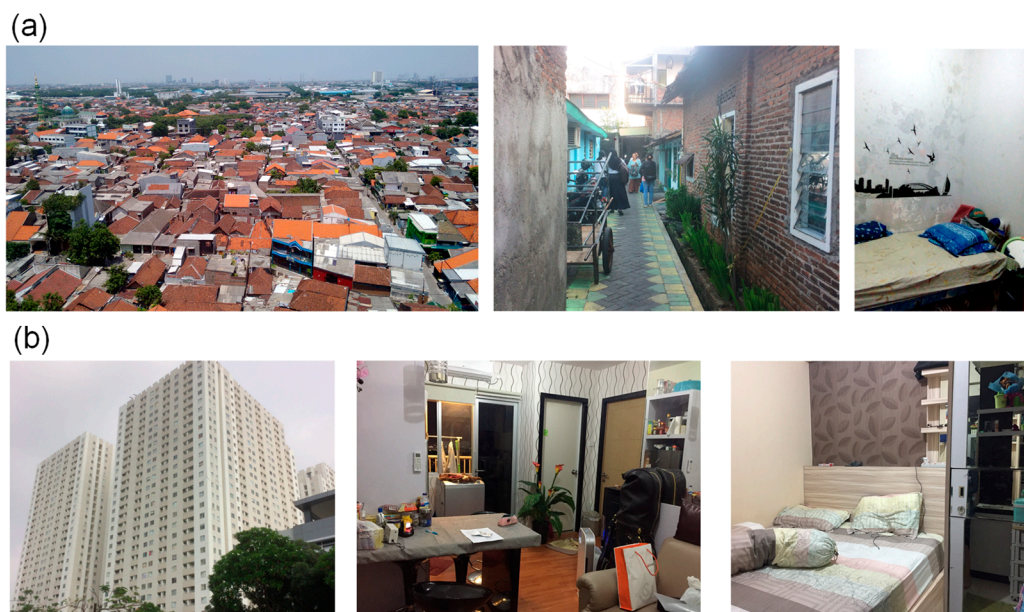
Today's world is facing population growth, urbanization, and climate change, resulting in rapid building construction, energy efficiency measures, and consequent changes in indoor air quality (IAQ). This, in turn, has implications for human health. Health outcomes from poor IAQ are an increase in asthma and allergies, specific infectious diseases like legionella pneumonia and several nonspecific health complaints, often conceptualized in the terms sick building syndrome (SBS), sick house syndrome (SHS), or multiple chemical sensitivity (MCS). These concepts comprise complaints about headaches, muscle or joint pain, depression, fatigue, skin irritation, confusion, dry eyes, dry mucous membranes, wheezing, etc.

People spend about 80–90% of their time indoors, and 70% of this at home [1]. Consequently, the home environment is particularly important for human health [2]. Still, in contrast to a large body of literature on IAQ, health and performance in offices, research about residences and home-related health issues in the general population is lacking [3,4]. Likewise, most research on IAQ originates from North America and Europe, where research on lung cancer, allergies, SBS, and other building-related health-issues and their influencing factors such as VOCs, particles, and allergens can partly be traced back for several years [5,6]. Here, changes in materials and their impact on IAQ and health partly resulted in the prohibition of certain materials and new standards [7,8]. On the other hand, in developing countries, most IAQ studies focus on the issue of exposure to biomass combustion, and thus there are few studies investigating IAQ in urban areas [9,10]. However, population growth and urbanization take place at the most rapid pace in developing countries [11], where 85% of the future building stock is predicted to be built [12]. In the case of Indonesia, one of the ten countries which are projected to contribute to more than half of the world's foresaid population increase over the period 2017–2050 [13], home shortages are estimated to have reached 11.4 million by 2017 [14]. The central government reacts by quickly constructing low-cost apartments for rent (Rusunawa) and for ownership (Rusunami) [15]. But the implementation of such building projects often does not satisfy the inhabitant's needs or applies to the existing regulations [16–18].

This study aims to contribute to the research gap in IAQ research (a) in residences and (b) in developing countries, particularly in urban areas. It explores the situation of IAQ and health in two representative types of residential buildings in the city of Surabaya, Indonesia: high-rise apartments and landed houses (so-called Kampongs). In the newly constructed high-rise apartments, it is assumed that residents face increased exposure to chemicals in the indoor air, because of reduced ventilation owing to energy-saving needs associated with the dependence on air-conditioning as described above. In Kampongs, in contrast, flooding during the rainy season is frequently happening and affects landed houses with potential problems of mold growth and dampness. Both occupant groups consequently might suffer from health problems related to their buildings. Recently, SBS and other building-related health-issues in offices have been investigated in Indonesia [19,20]. For example, Winarti et al. [19] conducted a survey on SBS in offices of Jakarta in 2002 ( $n = 240$ ) and reported that 15% of the respondents suffered from headache, although no IAQ measurement was involved in this study. However, to the best of the authors' knowledge, no IAQ study has yet been conducted for newly constructed urban houses in Indonesia. In the following sections, the materials and methods utilized in the study in Surabaya and its outcomes are described and discussed in comparison to findings from other studies around the world.

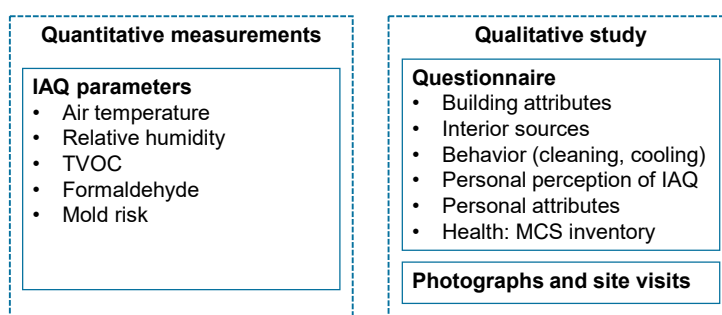
## 2. Methods

In 2015, the Indonesian government set the target to develop 1 million affordable homes [21]. Low-cost high-rise apartments for the middle-class, as part of this program, are proposed to a major extent in Surabaya and Bandung [22]. Surabaya is thus a good starting point for investigation of high-rise apartments. At the same time, the traditional Kampongs make up most of the city and still accommodate the majority of people. The investigation includes both building types to make out differences in IAQ and health status of citizens within the Indonesian urban population (Figure 1).



**Figure 1.** (a) Kampongs and (b) high-rise apartments in Surabaya, Indonesia.

In this research, quantitative measurements of specific IAQ parameters provide information on indoor air constituents (pollutant levels) and a questionnaire on IEQ and personal behavior identifies potential influential parameters. The questionnaire also examines personal factors and occupants' health (Figure 2). The survey took place from September 2017 until February 2018 in 27 Kampong areas and 14 high-rise apartments. Questionnaires were filled during a face-to-face interview with randomly chosen Kampong house and apartment occupants from the previously selected areas. The average response rate was 87% in Kampongs and 66% in apartments, respectively. Sites for the measurements of IAQ parameters were determined by the following criteria: first, in each Kampong area and high-rise apartment, five samples were to be taken to cover different locations and building situations; second, only houses and apartments with a permission by occupants were measured.



**Figure 2.** Instruments utilized for data collection.

IAQ parameters collected in both living room and master bedroom, when available, were total volatile organic compounds (TVOC) and formaldehyde concentrations as two of the major indoor air pollutants [23–25], as well as air temperature and relative humidity (RH). The present investigation is considered to be a preliminary screening to understand the current conditions of IAQ in urban houses of Indonesia, before the detailed characterization of indoor VOCs. Hence, real-time direct measurements were adopted instead of widely used methods such as DNPH-HPLC for formaldehyde and GC-MS or GC-FID for VOCs. Both formaldehyde and VOC measurements were taken over a period of 2–3 days per room. Formaldehyde concentration was measured by a commercially available device (FMM-MD, Shinyei Technology). This portable device is equipped with a photoelectrical photometry-based sensor that detects the absorbance change induced by formaldehyde. The accuracy of the sensor is  $\pm 0.01$

ppm under the air temperature of 25 °C with 50% RH. Meanwhile, VOCs were obtained by using the device with an advanced PIDs (photo-ionization detectors) sensor (accuracy:  $\pm 0.1$  ppm) (ToxiRae Pro, RAE systems). The PIDs use high-energy photons, typically in the ultraviolet (UV) range. The use of UV light to excite the molecules results in the ionization of gas molecules. The resulting ions produce an electric current proportional to the signal output of the detector [26]. All of the said sensors (formaldehyde and VOCs) were calibrated by the manufactures within one year before the start of measurements. The specifications and sensitivities of VOC sensors are reported in [27]. The meters were placed centrally in the room to avoid direct influences from the walls or furniture and at a height of about 1.5 m. If a standing application was not possible, the meters were placed by hanging it from the ceiling at above 2 m from the floor. Data were recorded every 30 min. Air temperature and RH were measured by the former device (FMM-MD, Shinyei Technology) at the same time.

Fungal contamination, a result from dampness, which Kishi et al. (2009) [4] consider ‘one of the important risk factors for symptoms relating to buildings, such as SHS’ was predicted by using a fungal detector developed by Abe (1993) [28]. The fungal detector encapsulates dried fungal spores and nutrients to measure a fungal index (Figure 3). The fungal index, defined by Abe (1993) [28], quantifies the capacity for mold growth in an environment being examined, and therefore it is considered one of the useful indices for evaluating microclimates for potential mold growth [29]. The sensor fungi used in the investigation include moderately xerophilic *Eurotium herbariorum* J-183, strongly xerophilic *Aspergillus penicillioides* K-712, and hydrophilic *Alternaria alternate* S-78. As described in Abe (1993; 2010; 2012) [28,30,31], the measurement procedure is as follows: (1) a fungal detector was exposed for two days to four weeks at each survey location; (2) after exposure, the detector was placed in a container with silica gel and the development of hyphae was terminated by desiccation; (3) the length of hyphae in each sensor fungus was measured under a microscope in the Laboratory for Mold Prediction, Japan; (4) the number of response units, ru, was determined from the length of hyphae in each sensor fungus; and (5) the fungal index was calculated using the greatest growth response among the sensor fungi in the detector. The value of the index was defined as the growth of response (ru) per exposure period (week) as indicated in Table 1 [32]. Mold measurements were taken in the master bedroom in January and February 2018, at the same places as the other measurements or, in case of unavailability of the family at that time, in the same area or building.

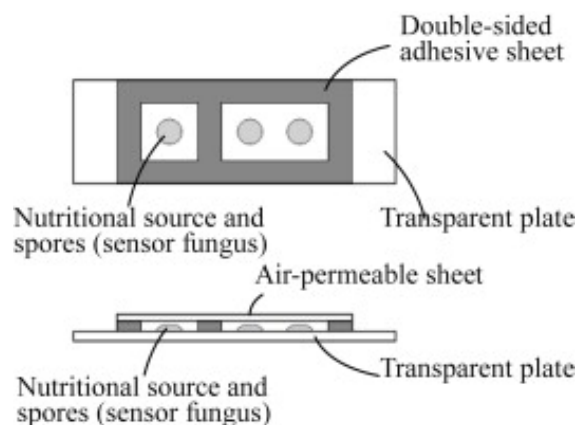


Figure 3. Fungal detector [30].

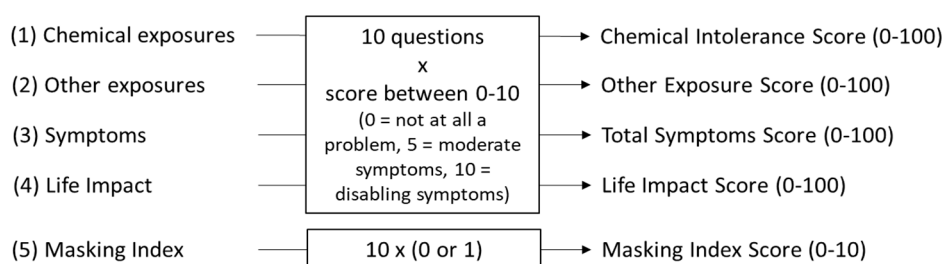


**Table 1.** Fungal index [32].

Level	Fungal Index	Predicted Propagation of Fungi	Remarks
A	<2	No propagation	Good environment
B	2–5	Low possibility of propagation	There is no problem in terms of fungi, but there is a possibility of propagation of mites, which requires countermeasures. Dehumidification is recommended.
C	5–15	Possibility of propagation	Fungi prevention measures are recommended. Dehumidification is recommended.
D	>15	High possibility of propagation	Fungi prevention measures are required. Dehumidification is needed for living rooms and regular cleaning is needed for wet areas, such as bathroom.

The questionnaire comprised two versions: one for household representatives and one for other family members. The questionnaire for household representatives included questions about building and interior space characteristics as well as cleaning and ventilation behavior and perceived IAQ, the influential parameters of interest for this study (independent variables). In the second part, personal attributes and health status-related indicators were gathered. The questionnaire for household members, including children, only contained this second part, since living conditions could be derived from the household representatives' questionnaire.

To evaluate participants' well-being in relation to their home environment, the Quick Environmental Sensitivity Inventory (QEESI) was applied. The QEESI is an instrument to measure multiple chemical sensitivity (MCS), one of the concepts that are used to describe nonspecific health complaints due to poor indoor environmental quality [33]. It has been used in other studies on building-related symptoms in various countries across the world [34,35] and its validity and reliability has been tested in several countries [36–38]. The QEESI has been developed by Miller and Prihoda in 1999 and is available at [www.chemicalexposures.org](http://www.chemicalexposures.org) [39]. In four major parts, information on (1) chemical intolerances, (2) other intolerances, (3) symptom severity, and (4) life impact is collected (Figure 4). Ten subquestions in each part require a response on a scale between 0 and 10, for example evaluating the severity of symptoms towards a certain exposure. The fifth part, the masking index, helps to identify ongoing exposures (e.g. alcohol, smoking). The subquestions in this case only ask for a 'yes' or 'no' response.

**Figure 4.** Calculation of Quick Environmental Sensitivity Inventory (QEESI) scores.

Since the calculation procedure of QEESI is described elsewhere [39], we would just like to mention that the ranges for the scales and interpretation guidelines suggested by Miller and Prihoda [40] have been applied for evaluation purposes, which are based on previous research and examined groups. The criteria for low, medium, and high scale scores are listed in Table 2, and the risk criteria in Table 3. 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 (see Table 3). This variable is called 'Multiple chemical sensitivity (MCS) risk' hereafter. It describes a person considered sensitive to multiple chemicals.

**Table 2.** Criteria for high, medium, and low scale scores [40].

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

**Table 3.** Risk criteria [40].

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

Additionally, it was assessed in how many of the three scores ‘symptom severity’, ‘chemical intolerance’, and ‘other intolerances’ the respondent reached a ‘high’ score (Table 2). The variable thus ranges from 0, when the respondent did not exceed ‘high’ score criteria in any of the three scales, to 3, when all three scores reached ‘high’ values. This categorization is in the following called ‘sensitivity’. The respondent’s sensitivity is related closely to MCS risk (since it includes two similar scores), but rather indicates if the respondent is generally sensitive, not only with regards to chemicals. Both categorizations, MSC risk as well as sensitivity, reflect the occupants’ health status and are the core dependent variables in the evaluation part. In the end, 471 questionnaires, 76 IAQ parameter measurements, and 30 samples of mold prediction were collected (Table 4).

**Table 4.** Number of samples.

Samples		Kampong	Apartment	Total
Questionnaires		298 (63%)	173 (37%)	471
Measurements	IAQ parameters	36	40	76
	Mold risk	14	16	30

IBM SPSS Statistics version 22 was used to conduct the statistical analysis for the questionnaire. Differences between the two groups (levels of significance) concerning the profile of respondents and their health status were verified by conducting Independent Samples *t*-test. Chi-Square-Test and Spearman rho analysis were carried out between respondents’ MCS variables and their living environment and behavior to tentatively search for linkages. Because the main interest of this research is IAQ and its effects on health, gender, which was found to correlate strongly with the respective degree of MCS in apartments, was evaluated separately

### 3. Results and Discussion

#### 3.1. Profile of Apartment Units and Kampong Houses

Unsurprisingly, Kampong and apartments and their respective occupants need to be looked at separately when describing the situation of IAQ and health, since several aspects in the profiles of occupants, buildings, behavior, and health conditions differ significantly (Table 5). In apartments, incomes are higher: 26% of the households earn more than 750 US\$ per month, which is the case for

only 9% in Kampongs. Sixty percent of apartments were built within the past five years, and Kampong houses are rather old with more than 60% of them having been constructed within the past 11–50 years, which reflects the overall situation in Indonesia.

**Table 5.** Profile of respondents and overview of building attributes, interior sources, and perceived air quality.

K = Kampong, A = Apartment		K	A	Total	n	p-Value	
Personal attributes	Age [%]	Years [mean]	39.7	25.1	34.4	462	<0.001 <sup>a</sup>
		<20	14.3	16.0	14.9		
		20–29	13.0	68.0	33.1		
		30–39	17.7	5.9	13.4		
		40–49	27.0	4.7	18.8		
	>50	28.0	5.3	19.7			
	Gender [%]	Male/Female	35.5/64.5	42.1/57.9	37.9/62.1	467	155 <sup>b</sup>
	Living time in house/flat [%]	Years [mean]	25.3	1.9	15.2	260	<0.001 <sup>a</sup>
	Income (US\$) [%]	<150	24.8	10.5	18.3	273	<0.001 <sup>b</sup>
		150–450	56.4	49.2	53.1		
		450–750	9.4	14.5	12.1		
		>750	9.4	25.8	16.5		
	Occupation [%]	Government	4.0	7.0	5.1	469	<0.001 <sup>b</sup>
		Private	21.9	14.5	19.2		
Entrepreneur		21.5	6.4	16.0			
Student		19.2	66.3	36.5			
Housewife		24.6	3.5	16.8			
Retired		6.7	0.6	4.5			
Other	2.0	1.7	1.9				
Homes covered by questionnaire		155 (54%)	132 (46%)	287.0			
Building attributes	Establishment [%]	Average age <sup>a</sup> [years]	31.7	4.5	25.2	176	<0.001 <sup>a</sup>
		<5 years	3.7	61.9	17.6		
		5–10 years	11.9	38.1	18.2		
		11–50 years	63.4	0.0	48.3		
		>50 years	20.9	0.0	15.9		
	No. of windows in master bedroom [%]	0	14.9	5.5	10.0	211	0.066 <sup>b</sup>
		1	66.3	76.4	71.6		
		>1	18.8	18.2	18.5		
	No. of windows in living room [%]	0	3.8	7.1	5.3	190	0.002 <sup>b</sup>
		1	74.3	49.4	63.2		
>1		21.9	43.5	31.6			
HVAC system [%]	AC	20.9	99.2	57.6	278	<0.001 <sup>b</sup>	
	Ceiling/stand fan	99.3	29.5	66.9	278	<0.001 <sup>b</sup>	
	Exhaust fan	10.6	51.6	29.9	268	<0.001 <sup>b</sup>	
Modification(s)	[%]	71.1	25.2	50.2	279	<0.001 <sup>b</sup>	
Water leakage	[%]	69.8	27.6	50.4	276	<0.001 <sup>b</sup>	
Interior sources	Mold	[%]	42.4	37.0	39.9	278	0.362 <sup>b</sup>
	Mite	[%]	6.0	18.1	11.5	278	0.002 <sup>b</sup>
	Mattresses [%]	Kapok	30.7	1.6	18.7	300	
		Spring bed	40.9	91.9	62.0		
		Sponge	27.3	4.8	18.0		
	Bedclothes [%]	Cotton	93.5	89.7	91.8	291	
		Silk	2.6	8.1	5.2		
Furniture (units)	Living room [mean]	3.8	5.1	4.4	219	<0.001 <sup>a</sup>	
	Bedroom [mean]	3.1	3.3	3.2	225	0.453 <sup>a</sup>	
Smell/Odor	[%]	51.0	60.5	55.4	280	0.112 <sup>b</sup>	
Perceived IAQ	IAQ [%]	0–3: (rather) clean	42.1	42.3	42.2	282	0.748 <sup>a</sup>
		4–6: neutral	46.7	43.8	45.4		
		7–10: (rather) dirty	11.2	13.8	12.4		
	OAQ [%]	0–3: (rather) clean	38.8	33.8	36.5	282	0.387 <sup>a</sup>
		4–6: neutral	43.4	54.6	48.6		
7–10: (rather) dirty		17.8	11.5	14.9			
Humidity [%]	0–3: (rather) dry	15.8	22.5	18.3	277	0.578 <sup>b</sup>	
	4–6: neutral	21.5	35.3	26.5			
	7–10: (rather) humid	13.1	15.6	14.0			

<sup>a</sup> Independent Samples *t*-Test; <sup>b</sup> Chi-Square test.

### 3.2. Mold Risk, Mites, and Smells

As shown in Table 5, many Kampong houses and apartment units face problems with mold growth (42% and 37% respectively), which is more than reported in Sweden and Finland (4%) [41,42], and China (5%) [43], but close to that reported in Korea: 35% [44]. According to the mold risk measurements, in Kampongs, 80% of the measured houses are categorized within the highest fungal index, D, an alarming sign, as compared to just 17% of the measurements in apartments (Figure 5).

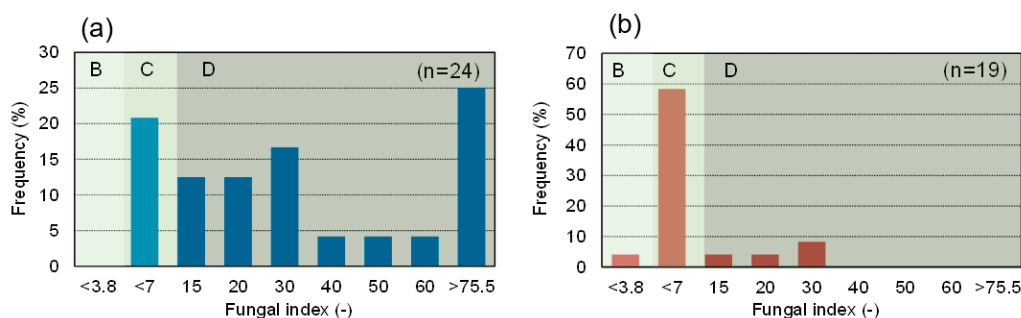


Figure 5. Measured fungal indexes in (a) Kampongs and (b) apartments.

In return, apartment occupants report more mite problems (18%) and 61% complain about odor or smell in their flat, as opposed to Kampongs (6% and 51% respectively) (Table 5). The share of complaints about smell is higher than in other studies, too. In a Chinese study, only 26.5% report unpleasant odors in their homes [45] and in an early study in Sweden in the 90s it was 33% [46]. One reason for larger issues with mites and odors could be the cleaning behavior of apartment occupants, which is less frequent than that of Kampong residents or reported in other studies. Daily cleaning is done only by 28%, as compared to 90% in Kampongs. Cleaning the bedclothes less than once per week, as done by 35%, has been associated with increased mite levels [47]. Another critical point is that 25% of the ACs are never cleaned, and another 15% only once per year. The US Energy Department recommends cleaning of ACs every one to two months, which is done by less than 40%.

### 3.3. Health Status

The health status of apartment respondents appears poorer than that of Kampong residents and other countries (Table 6). First, the prevalence of asthma (17%), allergies (37%), and especially eczema (36%) is higher than in Kampongs (13%, 32%, and 25%, respectively). A worldwide study on the prevalence of asthma concludes that 4.27% of adults have doctor-diagnosed asthma and 8.61% have wheezing symptoms, with a slightly higher prevalence in the Pacific region (5.85 and 8.88%, respectively) [48]. Although the numbers are not directly comparable due to the different nature of the questions, they are an alarming sign. The occurrence of eczema in apartments correlates with the reported presence of mites: 53% of mite-infested unit occupants indicate eczema, but only 32% in mite-free unit occupants. When it comes to allergies, studies in Sweden and Japan report a lower prevalence of around 12–24% [49–52]. Eczema has been stated in China from 1.6 to 5.7% [25,53], in Sweden from 6.3% up to 23% [50,54] and in Japan from 4 to 15% [55,56], which means that apartment and Kampong occupants impairments in Surabaya are once more elevated.



**Table 6.** Health and stress variables.

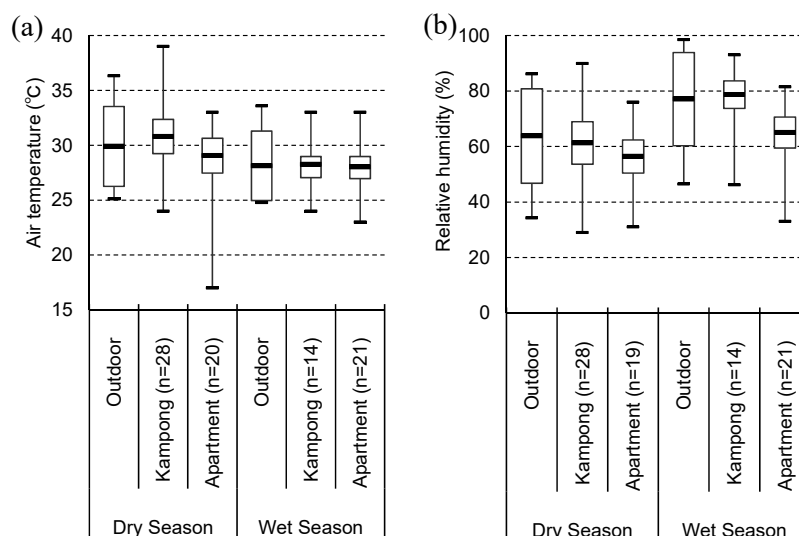
		Kampong	Apartment	Total	<i>n</i>	<i>p</i> -Value
Asthma	[%]	12.8	17.4	14.5	469	0.168 <sup>a</sup>
Eczema	[%]	25.3	36.0	29.3	468	0.014 <sup>a</sup>
Allergy	[%]	31.6	36.5	33.4	464	0.287 <sup>a</sup>
Stress [mean: 0 = no stress, 10 = very stressful]		2.1	4.3	2.9	464	<0.001 <sup>b</sup>

<sup>a</sup> Chi-Square test; <sup>b</sup> Independent Samples *t*-test.

Second, the degree of reported stress is significantly higher in apartment occupants (mean of 4.3 on the scale between 0 = no stress and 10 = very stressed) than in Kampong residents (2.1). Here, although work or studies are mentioned as the major reasons for stress in both building types, a considerable share of Kampong residents also relates their stress to money issues and family problems. Apartment respondents, on the other hand, additionally state social and environmental causes ('lonely', 'apartment too small', 'noise').

#### 3.4. Indoor Air Temperature and Relative Humidity

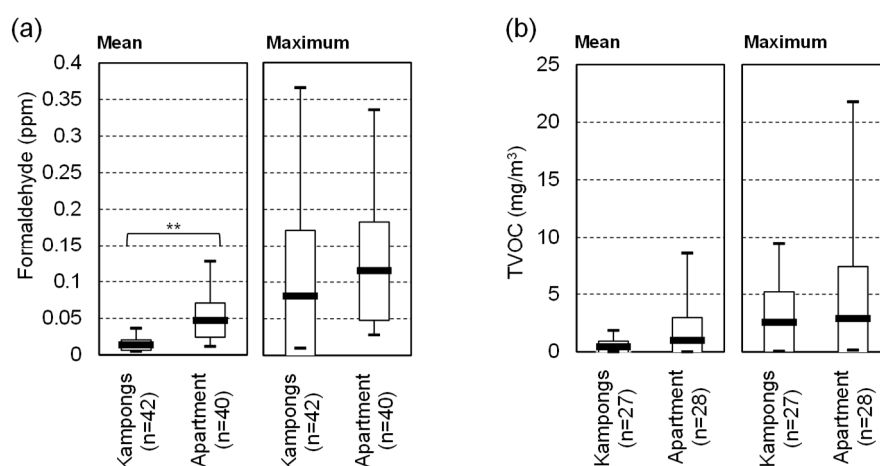
Figure 6 depicts air temperature and RH conditions in the homes and outside. For regulating thermal conditions, nearly all apartments (99%) are equipped with ACs but residents open their windows for six to seven hours per day. Indoor RH is with 56–60% less than outdoor humidity (64–75%) and a factor which eases thermal comfort compared to Kampongs. Here, occupants possess fans (99%) and only few an AC (21%) and mostly open their windows more than half of the day to regulate temperature and humidity conditions. During site visits, small permanent openings above windows or doors, which help in constant (cross-) ventilation, were also found. The exchange of indoor air with outdoor air and consequently the removal of indoor pollutants such as VOCs can thus be considered higher in Kampongs than in apartments, although some other indoor pollutants (e.g., ozone, nitrogen dioxide, etc.) are strongly influenced by outdoor concentrations. Furthermore, in Indonesia, outdoor humidity is often higher than that of indoors as described before, and thus outdoor humidity can increase the indoor humidity levels through ventilation. Previously, the present authors conducted measurements on ACH through a CO<sub>2</sub> tracer gas method in Kampongs (Bandung) and apartments (Surabaya). The results showed that the measured ACH in Kampongs ranged from 2.9 to 34.9 times/h with an average of 15.3 times/h under open-window conditions, whereas those in apartments were averaged at 0.7 times/h [57]. However, in Kampongs, thermal conditions inside are often worse than outside conditions. Higher averages in air temperatures and RH have been recorded. Extreme air temperatures up to 39 °C were noted and the mean RH (64% to 79%) clearly exceeds the recommended maximum level of 60%, above which increased mold growth and health effects are generally observed [58].



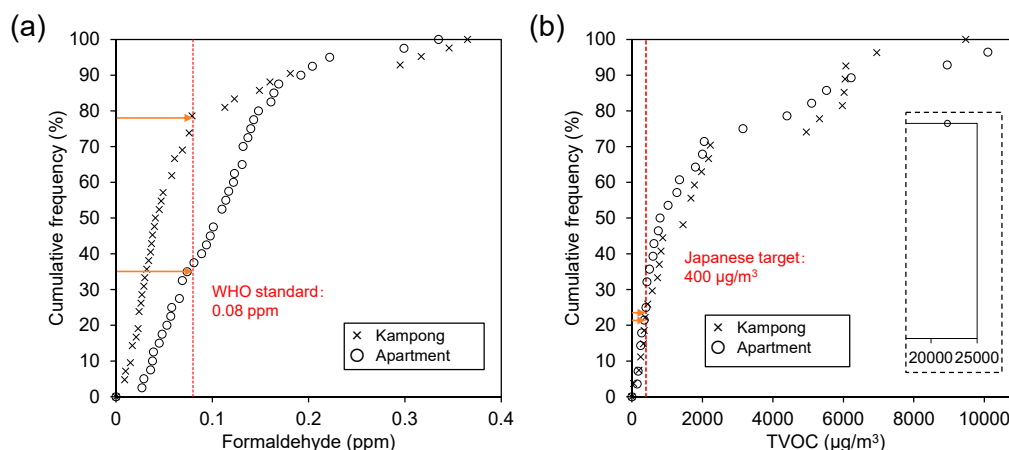
**Figure 6.** Statistical summary of (a) outdoor and indoor air temperature and (b) relative humidity in dry and wet season.

### 3.5. IAQ Measurements

Figures 7 and 8 show the measurement results for formaldehyde and TVOCs of apartments and Kampong houses calculated by mean (mean concentration of all measurements in the homes) and maximum (maximum concentration measured in the homes) concentration. In Kampongs, formaldehyde concentrations exceeded the WHO guideline of 0.08 ppm in 9 out of 42 measured houses (21%) at least once during the measurement period. In apartments, this was the case in 26 rooms out of 40 (65%) and the mean concentration of formaldehyde (0.05 ppm) was higher than observed in Kampongs (0.01 ppm), in France (0.01–0.02 ppm\*) (Values were calculated from  $\mu\text{g}/\text{m}^3$  in ppm for better coherence from the original studies, assuming the indoor temperature to be 25 °C.) [59], Japan (0.03 ppm\*) [56,60], and China (0.03–0.04 ppm) [34]. The maximum concentration of 0.34 ppm also is double than in Japanese studies—0.15 ppm [56] or 0.16 ppm\* [52] and the United Arab Emirates (0.14 ppm) [61], and higher than in China (0.22 ppm\*) [62]—and exceeds even the measured maximum of 0.29 ppm found in a study on ‘very suggestive’ MCS cases in Japan [63].



**Figure 7.** Statistical summary of indoor air quality (IAQ) measurement results: (a) Formaldehyde and (b) total volatile organic compounds (TVOC).

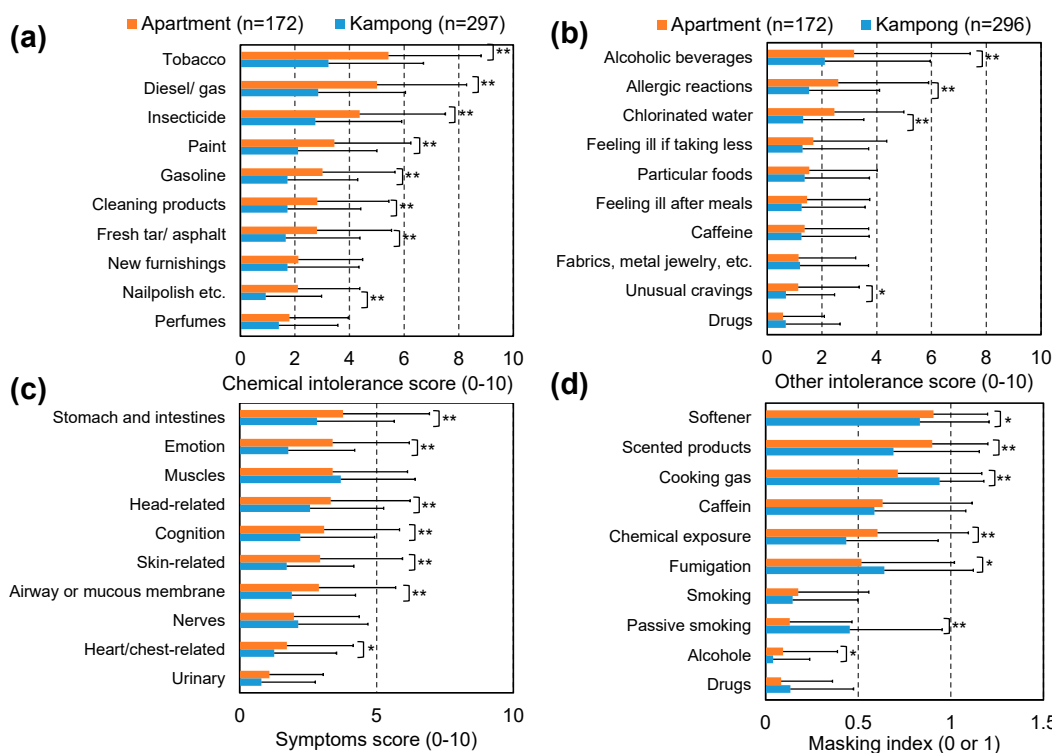


**Figure 8.** Cumulative frequency of maximum concentrations of (a) formaldehyde and (b) TVOC. These maximum values were calculated based on the measured 30 min temporal average values, and therefore considered comparable with international/domestic standards.

For TVOC concentrations, 6 out of 27 apartment measurements (21.4%) and 7 out of the 28 measurements in Kampongs (25.9%) were above  $5 \text{ mg}/\text{m}^3$ , which are assumed to cause objective effects and subjective reports of irritation [64]. The Japanese tentative target of  $400 \mu\text{g}/\text{m}^3$  was crossed in 79% of apartment units and 78% in Kampongs (Figure 7b), far more than in Japan, where 8% of the buildings were observed with heightened TVOC levels [52] and more than in China (61%) [34]. Just as for formaldehyde, even the mean values in the apartment units result in a concentration of  $964 \mu\text{g}/\text{m}^3$ , which is thus double than measurements in Kampongs ( $403 \mu\text{g}/\text{m}^3$ ), in Japan ( $112\text{--}482 \mu\text{g}/\text{m}^3$ ) [55,56] or China ( $360/397 \mu\text{g}/\text{m}^3$ ) [34]. The peaks of TVOCs in Kampongs could be explained by smoking, short-term utilization of cleaning products, or gas exhaust from cars parked close to the building and entering from outdoors. However, further investigations need to be carried out for verification.

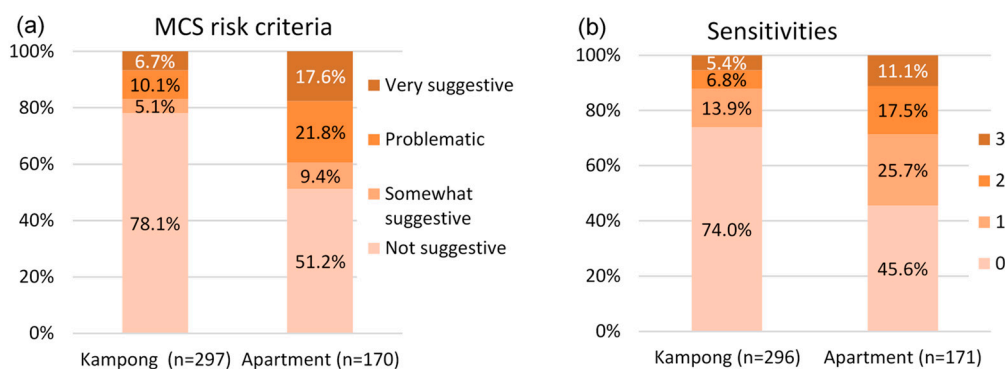
### 3.6. QEESI

Figure 9 shows the specific QEESI scale outcomes. Apartment respondents generally reach higher scores in chemical and other sensitivities, symptoms, and life impact. Kampong occupants, on the other hand, face more ongoing exposures. Still, though differing in severity, residents of both building categories are sensitive to similar chemicals and other exposures. Ongoing exposures that can influence people's sensitivities are mostly the usage of fabric softeners, gas stoves, and scented products. More apartment respondents make use of scented products (90% versus just around 70% of Kampong occupants) and are exposed more to other chemicals (60% vs. 43%). Kampong respondents, on the other hand, more frequently own gas stoves (94% vs. 71% of apartment occupants) and are exposed more to fumigation (64% vs. 52%) and ETS (45% vs. 13%).



**Figure 9.** QEESI scales for (a) chemical intolerance score, (b) other intolerance score, (c) symptoms, and (d) masking index.

Overall, MCS risk and sensitivities are significantly higher in apartments than in Kampongs: 39% have a problematic or very suggestive risk of MCS and 29% meet high scores in two or three of the three scales chemical intolerances, other intolerances and symptoms (Figure 10). 74% of Kampong respondents did not exceed ‘high score’ criteria in any score and can thus be considered free from chemical sensitivities. This is the case for only 46% of apartment respondents. A similar picture evolves when looking at the MCS risk criteria. The QEESI results reveal that the proportion of respondents in apartments with a problematic or very suggestive risk of MCS is more than two times higher than that of Kampongs (39.4% vs. 16.8%).



**Figure 10.** (a) Multiple chemical sensitivity (MCS) risk criteria: MCS according to MCS risk criteria, involving chemical intolerance, symptom and masking index score; (b) Sensitivities: number of scales that meet ‘high’ score criteria, involving chemical intolerance, other intolerance, and symptom severity score.

Both ways of interpreting the scores thus indicate a significant difference between the health of Kampong and apartment occupants. Similar shares as the MCS risk in apartments have been observed in Korea (37%) [65], but in Japan, only 25% of the respondents were categorized in the



‘very suggestive’ or ‘problematic’ MCS risk groups [63]. Similarly, in the US, the percentage of people with a high sensitivity in three scales was found to be just about half (6.6% as compared to the apartment respondent’s 11.1%), and those with high scores in two scales was 15.8% as compared to this study’s 17.5% [40]. The share of high MCS risk groups and people with high sensitivities in Kampongs is far lower than compared to these.

### 3.7. Factors Influencing MCS

Table 7 shows the correlation analysis results. In apartments, the strongest correlation exists between higher levels of stress and sensitivity as well as MCS risk. There are studies which suggest a relationship between mental well-being and reporting of symptoms for MCS. As such, the Robert Koch-Institut [66] in an extensive study has not found any correlations between reported or attested MCS and environmental influences, but found a causal connection to psychosomatic problems. Other studies carried out for workers’ link MCS, SBS, or SHS with mental health, too [67–69]. As the causes for stress are also partly related to the home environment, it can be argued that this home-related stress (noise, loneliness, apartment too small) has a negative impact such as it has been stated for asthma in children [70]. For sensitivities, the prevalence of eczema, a worse perception of IAQ and less frequent cleaning of the bathroom also played a role. This finding corresponds to other studies, where eczema, asthma, and allergic rhinitis were related to SBS symptoms or negative IAQ perceptions led to more symptoms reporting [43].

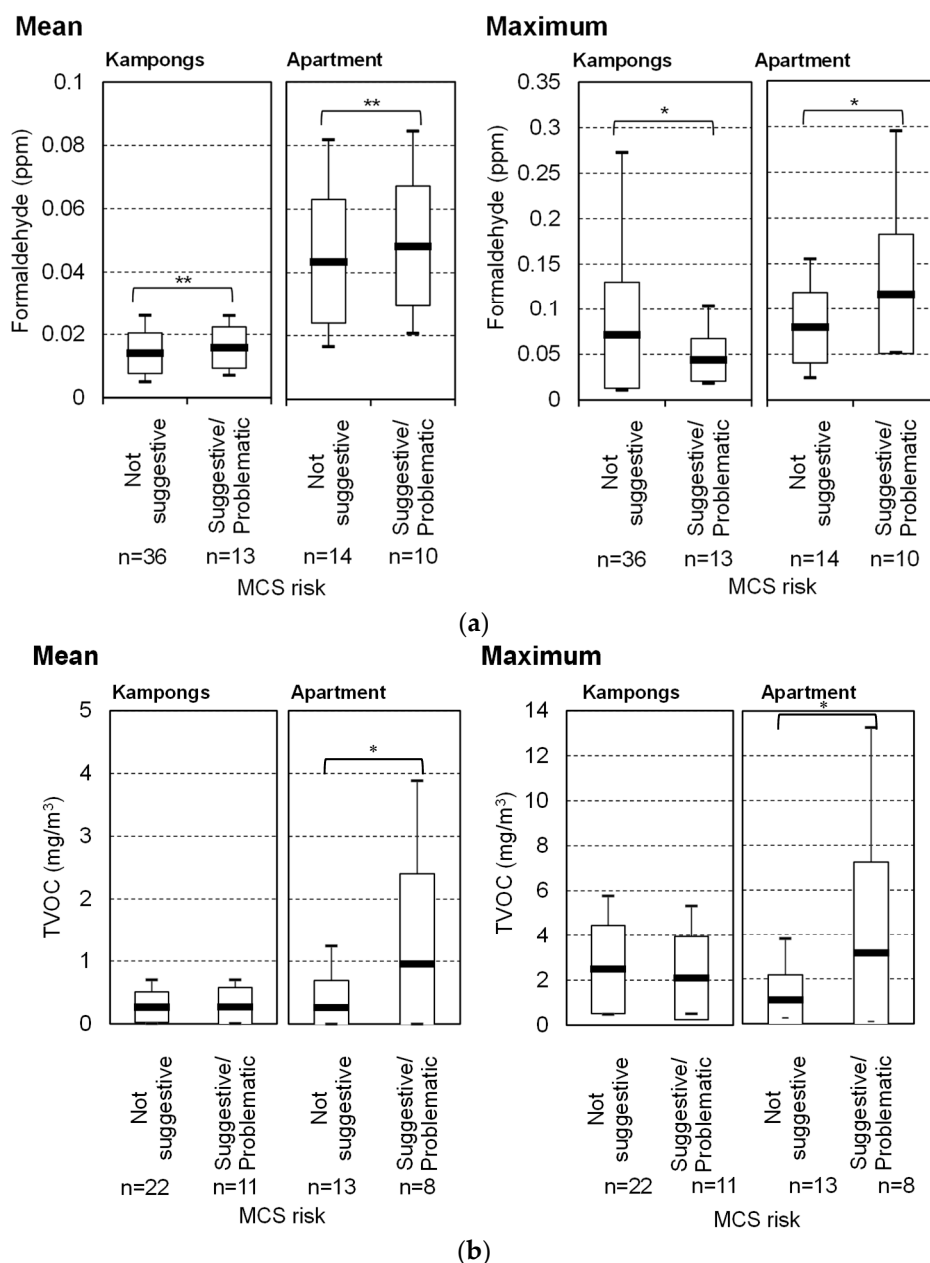
Moreover, in apartments, MCS risk did not correlate with any building attributes, interior characteristics, IAQ, or behavioral variables. However, a highly significant difference in MCS risk and sensitivities exists between females and males, which has also been found in other studies [8,45,56,71,72]. An investigation of the gender differences revealed that for females, stress correlated strongly, but water leakage and disturbing smell also negatively affected MCS risk. Men with asthma had significantly more sensitivities, and men who are exposed to fumigation are categorized into higher MCS groups. The influence of incense sticks, which may be a comparable exposure, has been found to result in headaches and neurologic effects [61]. Cleaning behavior in men had a slightly contradictory influence on MCS risk and sensitivities; whereas a more frequent cleaning of the rooms led to heightened MCS risk, the opposite was true for bathrooms. One possible explanation could be the utilization of cleaning products or the quite frequently used scented products for rooms. Frequent cleaning can have as much negative impact on health as smoking 20 cigarettes per day [73]. It is also possible, on the other hand, that people with more symptoms try to reduce those through improved ventilation and cleaning behavior. More research is needed to investigate if the correlations are truly relevant, and if so, which cleaning products are used and to what extent.

Table 7. Results of correlation analysis.

R = MCS Risk S = Sensitivities f = female m = male	All		Kampongs		Apartments					
	R	S	R	S	All		Controlling for gender			
					R	S	R		S	
	f	m	f	m						
<b>Personal attributes</b>										
Age group <sup>a</sup>	0.004	0.004	0.047	0.047	0.312	0.312	0.402	0.435	0.561	0.241
Sex <sup>a</sup>	0.146	0.179	0.474	0.885	0.032	0.009				
Income <sup>b</sup>	0.000	0.000	0.000	0.000	0.496	0.372	0.209	0.723	0.223	0.495
Occupation <sup>a</sup>	0.001	0.002	0.001	0.001	0.778	0.936	0.730	0.723	0.732	0.304
<b>Psychology</b>										
Stress <sup>b</sup>	0.000	0.000	0.000	0.000	0.004	0.000	0.031	.217	0.001	0.034
<b>Health</b>										
Asthma <sup>a</sup>	0.080	0.004	0.041	0.012	0.740	0.309	0.444	0.289	0.321	0.008
Eczema <sup>a</sup>	0.000	0.000	0.000	0.000	0.055	0.012	0.113	0.518	0.018	0.138
Allergy <sup>a</sup>	0.007	0.003	0.031	0.053	0.117	0.076	0.302	0.205	0.193	0.541
<b>Masking index</b>										
Smoking and/or ETS <sup>a</sup>	0.004	0.001	0.022	0.201	0.488	0.126	0.865	0.516	0.750	0.277
Fumigation <sup>a</sup>	0.257	0.239	0.947	0.535	0.015	0.108	0.371	0.004	0.531	0.002
Exposure other chemicals <sup>a</sup>	0.004	0.001	0.046	0.030	0.475	0.150	0.291	0.862	0.562	0.174
Scented products <sup>a</sup>	0.052	0.079	0.472	0.722	0.682	0.394	0.551	0.924	0.436	0.229
Fabric Softener <sup>a</sup>	0.197	0.010	0.239	0.045	0.492	0.263	0.321	0.207	0.018	0.805
<b>Building attributes</b>										
Living in home [years] <sup>b</sup>	0.000	0.000	0.405	0.804	0.474	0.701	0.663	0.187	0.246	0.081
Windows_masterbedroom <sup>b</sup>	0.049	0.041	0.004	0.002	0.924	0.827	0.868	0.260	0.114	0.839
Windows_living room <sup>b</sup>	0.000	0.000	0.000	0.000	0.280	0.077	0.173	0.670	0.558	0.891
AC <sup>a</sup>	0.000	0.000	0.007	0.000	0.608	0.147	-	-	-	-
Fan <sup>a</sup>	0.001	0.001	0.509	0.351	0.526	0.716	-	-	-	-
Modifications <sup>a</sup>	0.394	0.290	0.017	0.123	0.987	0.942	0.360	0.231	0.609	0.396
Water leakage <sup>a</sup>	0.065	0.151	0.387	0.161	0.143	0.152	0.013	0.601	0.069	0.832
<b>Interior</b>										
Mold <sup>a</sup>	0.296	0.579	0.005	0.010	0.660	0.772	0.842	0.809	0.624	0.667
Mite <sup>a</sup>	0.007	0.030	0.921	0.919	0.107	0.238	0.263	0.064	0.718	0.224
Furniture_living room <sup>b</sup>	0.257	0.154	0.014	0.015	0.177	0.317	0.461	0.228	0.253	0.592
<b>IAQ</b>										
Smell <sup>a</sup>	0.064	0.043	0.024	0.029	0.160	0.551	0.032	0.430	0.674	0.007
IAQ rating <sup>b</sup>	0.324	0.302	0.893	0.998	0.056	0.024	0.111	0.196	0.159	0.029
OAQ rating <sup>b</sup>	0.027	0.022	0.089	0.106	0.148	0.095	0.057	0.906	0.135	0.399
<b>Behavior</b>										
Window-opening_bedroom <sup>b</sup>	0.000	0.001	0.416	0.696	0.063	0.141	0.341	0.926	0.121	0.522
Window-opening_livingroom <sup>b</sup>	0.008	0.005	0.773	0.959	0.457	0.853	0.185	0.886	0.644	0.639
Cleaning of rooms <sup>b</sup>	0.000	0.000	0.012	0.001	0.060	0.354	0.922	0.031	0.658	0.681
Cleaning of bathroom <sup>b</sup>	0.030	0.001	0.976	0.570	0.280	0.030	0.922	0.042	0.348	0.001

<sup>a</sup> p-value of Chi-Square test, <sup>b</sup> 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).

To see if there is a correlation between these indoor air chemical concentrations and multiple chemical sensitivities, the four MCS groups were merged into two by joining the somewhat suggestive, problematic, and very suggestive group of respondents into one, and the not suggestive group into the second group. It became obvious that respondents with an MCS risk were exposed to significantly higher formaldehyde and increased TVOC concentrations (Figure 11), just like other studies reported [51].



**Figure 11.** IAQ levels by different MCS risk groups, (a) formaldehyde and (b) TVOC.

For Kampongs, more variables correlate with MCS risk and sensitivities (Table 7). Influential personal attributes are age group, occupation, and income. Government (50%) and private employees (17%) and retired people (20%) are mostly affected (categories ‘problematic’ or ‘very suggestive’ of MCS). There is a possibility that the two former groups are exposed to chemicals or other exposures during their work. This conclusion can be derived because those who report exposure to other chemicals also have a higher MCS risk. In Indonesia, more than 50% of office workers experience SBS, as estimated in 2008 by the Association of Indonesian Public Health Expert (IAKMI) [20].

A very clear positive relationship exists between income and MCS risk as well as sensitivities in Kampongs. This is surprising, as usually higher income is associated with improved health. In this case, a higher income goes along with the possession of ACs, which is found to be another significantly influential factor detrimental for health. Especially the age groups between 20–29, 30–39, and above 50 years have higher MCS risks. Although higher age in other studies has been associated with increased health risks, this does not explain the cause for the younger generations.

Here, the degree of stress is higher, and the respondents in these groups also more often have eczema. These two variables, in turn, have an impact for the prediction of MCS risk. For the psychological variable 'stress', 40% of those who indicate a score of 7 or more on the range between 0 (no stress) to 10 (very stressed) also have a problematic or very suggestive MCS risk, whereas among respondents who feel less or not stressed (a score below 4), only 10% are likely to have MCS. Also, people with health-issues such as asthma, eczema, or allergies are more suggestive of MCS. Twenty percent of the very suggestive MCS risk cases have asthma, and 60% have eczema or allergies (as compared to an average of 13%, 25%, and 32% respectively). This fits into findings of other studies as mentioned before. In smoker households, less people face MCS risks (18% problematic and very suggestive respondents) as compared to nonsmoking households (30%). The reason behind this reverse relationship between smoking and/or ETS and MCS risk in Kampongs remains unclear, but it might be that people with chemical intolerances automatically refrain from smoking and dislike the smell. Also, fabric softener usage influences sensitivities (more).

When it comes to the parameters connected to IAQ, two variables show a highly significant correlation with MCS risk and sensitivities in Kampongs: ownership of an AC and observation of mold growth in the house (Table 7). Eleven percent of occupants confronted with mold growth face very suggestive MCS risks as compared to 3% of occupants in mold-free homes. Mold is a well-known cause for respiratory diseases and SBS symptoms. This outcome confirms this finding once more. The share of problematic or very suggestive risk of MCS within AC-owners is double of those who do not have an AC (28% against 13%). Why exactly the possession of ACs is a risk factor needs to be investigated. Possible explanations could be the spread of bacteria and viruses due to a lack of maintenance or reduced or no ventilation in order to save energy and consequently the accumulation of pollutants in the room.

Other relevant factors in Kampongs are the number of furniture items in the living room (the more furniture, the higher the share of MCS risk cases), modifications (20% of occupants in homes with modifications have a problematic or very suggestive risk of MCS versus 10% within those who did not modify their rooms), smell (the share of people with MCS who report a disturbing smell in their homes is larger than those who do not), and the frequency of cleaning the rooms (18% of respondents who clean every day have a problematic or very suggestive MCS risk, but 50% of those who clean only once a week or less). However, regarding this point it must be noted that only 10% of Kampong occupants indicate a less frequent cleaning than once per day. Similar findings were obtained in other studies: SBS problems were associated with redecoration in China [43], odor or negative perception of IAQ [74], and relieved in the case of regular cleaning [47].

Lastly, indoor air concentrations of formaldehyde in Kampongs were inversely correlated with MCS risk when it is assessed by the maximum values (see Figure 11): not suggestive respondents were exposed to higher levels than some problematic and very suggestive respondents. It is possible that formaldehyde concentrations, which in the case of Kampongs usually had lower long-term averages than apartments but instead suddenly reached exceptionally high peaks, have a smaller effect on the health of occupants than the more long-term exposure in some of the apartment cases. Further investigation is recommended.

#### 4. Conclusions

The survey in Surabaya revealed that IAQ in apartment units and Kampong houses appears to be poorer than in other countries. Formaldehyde and TVOC concentrations in apartments are especially critical and exceed standards in many units. Owing to the hot, humid climate in Indonesia, apartments and Kampong houses are confronted with high humidity and outdoor temperatures, which impede thermal comfort and facilitate mold growth. Therefore, mold growth is highly predicted in around 40% of the homes, with severe situations particularly in Kampongs. In Kampongs, the occurrence of ETS potentially adds up to higher indoor air pollution.



Asthma, eczema, and allergy prevalence were found to be worse in this sample of Indonesian residents than in other studies around the world. For the prevalence of MCS and eczema, living in a high-rise apartment in Indonesia is a risk factor, just as suggested in a study in Shanghai on allergic diseases [53]. In apartment units, 39% are categorized as problematic or very suggestive of MCS, whereas Kampong respondents' level of MCS risk is comparable to other studies or even lower (17%).

The results imply that the trend towards high-rise buildings is coupled with decreasing health. Heightened chemical concentrations in indoor air and elevated stress levels are the major risk factors found in this study, as well as people reporting asthma and eczema or negatively perceiving IAQ and smells. Neglected cleaning also contributes. Meanwhile, stress, personal health condition (asthma, eczema, allergies), and reports of smell make up strong factors for MCS risk in Kampong respondents. Several additional building, interior, and behavioral factors are also influential. More windows and daily room cleaning had a positive impact on health. ACs, mold reports, and more pieces of furniture, on the other hand, resulted in higher MCS risk. Particularly interesting is the observation that people with higher incomes were more affected, which is partially explainable by elevated stress levels in higher income groups.

This study attempted to be inclusive and raise awareness of the complex nexus between sustainable development of buildings with regard to residential indoor air quality, energy efficiency, and the health of occupants. However, the scale of the research in Surabaya and the aim to find comparable studies on a world-wide scale led to only brief evaluations and more aspects need to be analyzed and discussed in depth. All in all, shortcomings in the indoor environment in high-rise apartments for the physical as well as the mental health of occupants have been identified. Still, more investigations need to be carried out on the potential sources of the high TVOC and formaldehyde concentrations, and which other environmental factors may increase occupants' stress at home. Enlarging the sample size, especially for measurements, is also essential for better reliability and representativeness. To our knowledge, this is the first study of such an extent to be carried out in Indonesia. It provides a broad basis for future studies.

Nevertheless, there are several points in our study that need to be noted. First, the samples of respondents in Kampongs and apartments differ a lot and it is thus difficult to compare them directly. This problem was solved partly by evaluating the health and impacting factors of the two building categories separately, but there is still a lack of information for a great part of occupants. The interviewed apartment occupants are mainly aged between 20 and 29 years, which makes general statements about the situation of all apartment residents questionable. Health impairments such as asthma and allergies are relatively new developments, mostly affecting children and people of younger ages, when they are exposed to certain triggers. This could be one reason for the high share of asthma and allergies in the sample. More age groups above 30 years need to be included in future studies on apartments, which most probably will also lead to a more heterogeneous sample of occupations.

Second, interviewing people also relies on their ability to remember symptoms and actively perceive characteristics of their indoor environment. This could lead to reporting bias, just as an influence from the interviewer's side by talking about the aim of the study cannot be fully excluded.

Third, some instruments and evaluations require improvements. For QEESI, as the screening instrument for MCS, the application of the American cut-off points can be questioned. Just as Hojo et al. [63] suggest for the utilization of QEESI for the Japanese population, it could be necessary to determine different cut-off points for the Indonesian population. Therefore, more studies are needed. For IAQ measurements, it is important to conduct more detailed investigations to analyze quantitative information about the constituents of air contaminants.

This study focused on IAQ, but it could be informative to collect data on indoor environmental aspects, too. Complaints of apartment respondents that they feel lonely, are disturbed by noise, or find their flat too small are hints that there might be larger dissatisfaction with the housing conditions in high-rise buildings in Indonesia. The study has revealed the first hints of questionable IAQ and compromised health of occupants in apartments, which showcases the need for more sustainable and

healthy living environments in rapidly developing countries—a crucial element to ensure quality of life for future generations and avoid path dependencies aggravating climate change.

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