Study on Indoor Air Quality and Its Effect on Health in Urban Houses of Indonesia

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A Dissertation Submitted to
the Graduate School of Advanced Science and Engineering
of Hiroshima University in Partial Fulfilment
of the requirement for the degree of
Doctor of Philosophy in Engineering

September 2023

Contents

Abstract

In Indonesia, sick building syndrome (SBS) and related health problems are suspected among the residents in dramatically emerging new urban houses constructed of modern building materials without sufficient material standards or minimum ventilation rates. This doctoral thesis aims to gather all the data and information regarding the current conditions of existing indoor air and the health of urban houses in Indonesia, particularly in the middle-class high-rise apartment and to propose a comprehensive focus and method to improve the indoor air quality (IAQ) and health of the urban houses of Indonesia towards the air quality guidelines.

The literature review in Chapter 2 focused on indoor air quality and sick building syndrome in developing countries, particularly in urban houses and hot-humid climatic regions. As reviewed, there are few studies of indoor air quality and health in urban houses of developing countries in the tropics. Most studies are focused on public buildings and more on efficiency and working performance rather than health conditions. Most research in urban houses was done in four seasons countries with different climatic conditions, which leads to different heating, cooling, and ventilation systems. Moreover, the guidelines and awareness of indoor air quality and health in residential buildings are still lacking. Therefore, it is essential to study indoor air quality and health in urban houses of the tropics, to improve further the current awareness and guidelines of indoor air quality in developing countries.

Chapter 3 explained the current conditions of indoor air quality and health of urban houses in Indonesia, particularly in newly built high-rise apartments and traditional landed houses, Kampong. Three major cities of Indonesia, Surabaya, Jakarta, and Bandung, where the growth of new apartments coexist with Kampong, are chosen as the location of the study. Results of the questionnaire survey revealed that the self-reported sick building syndrome, based on multiple chemicals sensitivity (MCS) risks, in the apartment are significantly higher, nearly doubled, compared to the risk in Kampong's respondents. Moreover, the results of indoor air quality field measurements, formaldehyde concentration, and TVOC in the apartment are also significantly higher compared to Kampong. The average concentration of mean formaldehyde in the apartment is close to the WHO standard value of 0.08 ppm, while the average maximum value exceeds the standard in the apartment. In Kampong, the average concentration of formaldehyde is lower than the standard, but similarly, with apartments, several peaks of concentration in maximum value exceed the WHO standard. Similar to formaldehyde, TVOC concentration is

also significantly higher in apartment houses. Furthermore, respondents with higher MCS risk were found to be exposed to a higher concentration of TVOC and formaldehyde. Other than the IAQ, several influential factors affect MCS risk and sensitivity of occupants in the newly constructed apartments. In Kampongs, the share of high MCS risk groups was relatively low. However, more than 80% of the measured houses were categorized within the highest fungal index, D, at an alarming rate. In fact, the survey results showed they suffered from mold and dampness. This implies that there are other IAQ problems even in Kampongs, which cannot be measured by the degree of chemical intolerance.

Chapter 4 discussed the results of further analysis using a mathematical model of factors affecting multiple chemical sensitivity and indoor air quality in urban houses in Indonesia, which later can be used as the base to improve air quality and health. The results showed that apartment respondents are likely to be affected by more factors than those living in Kampong. In Kampong, the age of the building was observed to increase the dampness, after that was possibly causing allergies conditions and MCS among residents. The results of this study implied that higher MCS in apartments is majorly affected not only by their allergic conditions but also by additional factors concerning building conditions and occupant behavior. Therefore, chemical contaminants are more prevalent in the apartment, and biological contaminants are in Kampong. Furthermore, the windows-opening pattern of occupants in apartments and Kampong are analyzed to find the most suitable opening pattern for Indonesian in their urban residentials. It was found that the longer duration of windows opening does not always result in a lower concentration of chemical contaminants. Further study of the house's exterior condition is necessary to find the best opening pattern.

Chapter 5 explained the key findings extracted from the field measurements and household surveys on the severity of indoor mold risk and its impact on respiratory health, particularly cough symptoms, across a typical unplanned neighborhood of Kampung in Bandung, Indonesia. It is found that most houses suffered severe mold risk, primarily due to extremely humid weather conditions, especially during the rainy season. The TSP and PM2.5 concentrations exceeded WHO standards in most Kampung houses. Around 66% of houses recorded higher outdoor mean PM2.5 concentrations than indoors. Moreover, respiratory health problems increased in dry and rainy seasons, particularly among children. Further path analyses showed that the indoor environment directly impacted children's respiratory health, whereas window-opening, smoking behavior, and exposure to outdoor air pollution affected respiratory health among adults.

Chapter 6 discussed the results of detailed and specific cup measurements in selected apartment units using passive sampling, DSD-DNPH, and passive gas tube for organic solvent, where the sample was analyzed by Gas Chromatography–Mass Spectrometry (GCMS). As expected, the results showed that newly built apartments tend to have higher concentrations of chemical compounds. Several cup measurements found the possible source of pollution in the ambient air coming from materials. These contaminants were found to be emitted by wallpaper and wallboard materials used in the interior of the building. On the other hand, emission rates from several materials are relatively low, resulting in no contaminants detected in the ambient air but in the cup measurement.

Chapter 7 discussed further ventilation modification study cases in selected apartment units to observe the effect of air change flow in the room to the chemical concentration. The modification was followed by long-time observation of daily cooling and ventilation activities.

Installing an exhaust-fan to improve the ventilation rate of the apartment was found to lower the IAQ concentration in the long term.

Finally, chapter 8 concluded and summarized the main finding of this study and recommended key areas for further study based on the limitations of this thesis.

Acknowledgment

This thesis was made possible with the greatest continuous support from many people and organizations. First, I sincerely thank my academic advisor, Prof. Tetsu Kubota, for giving me this fine opportunity to complete the thesis at the BUESA laboratory in the Graduate School of Advanced Science and Engineering of Hiroshima University. Throughout the development of the thesis, Prof. Tetsu Kubota has provided invaluable advice, knowledge, meaningful discussion, and exemplary effort not only in the laboratory but also in field work. I wish to thank also my academic co-advisors, Prof. Han Soo Lee and Associate Prof. Saori Kashima, together Prof. Daisaku Nishina for examining my thesis and giving useful comments.

I extend my sincerest gratitude to Monbukagakusho (MEXT) of Ministry of Education, Culture, Sports, Science and Technology Japan for providing the scholarship, study opportunity and various kinds of support that enabled me to pursue this doctoral degree in Japan. In particular, I would like to thank all of the staff at the institution and university for kindly supporting and granting my application. The work in this thesis would not have been possible without the financial support for the related projects. I thank the staff of the program and my graduate school for their kind support and assistance.I wish to thank Dr. Usep Surahman of Indonesia University of Education (UPI) Bandung and Dr. IGN Antaryama and Dr. Nastiti Ekasiwi of Sepuluh November Institute of Technology (ITS) Surabaya, and Dr. Muhammad Nur Fajri Alfata of Ministry of Public Works and Housing Indonesia for supporting the research projects. My thanks are extended to all team members who helped this study in Jakarta, Surabaya, and Bandung.

I had the opportunity to work with many fellow students at Hiroshima University in research projects, including Jumpei Sumi, Yuuki Sakita, Dopit Saputra, Sri Novianthi Pratiwi, Andhika Prasetya, Rosa Asiga, Elizabeth Buxton, Akhlis Aziz, Diego Alvarez, Hotak Naveedullah, Riko Koda, Daiki, Moe and many others who assisted in the field measurement and questionnaire surveys. It was a pleasure to learn together, and I thank all of their effort. I am most indebted to my friends, Mitya, Gretchen, Ulil, Nadia, and Hanif, who made my journey bearable, my parents and my siblings for their love, encouragement, prayers and support. Above all, I greatly thanks to the Merciful God, Allah SWT, for this blessed life.

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List of Acronyms

AC	Air conditioning
ACH	Air changes per hour
ADSEC	Advanced Diffusive Sampling Emission Cell
AQ	Air quality
ARI	Acute respiratory infections
AT	Air temperature
ATS-DLD-78	American Thoracic Society – Division of Lung Diseases 78
BR	Bedroom
CB	Chronic bronchitis
CFA	Confirmatory factor analysis
CFI	Chi-square statistics
CMIN	Chi-square statistics
COPD	Chronic obstructive pulmonary disease
DF	Degree of freedom
DSD-DNPH	Diffusive Sampling Device 2-4-Dinitrophenylhydrazine
ECA	European compliance assessment
EFA	Exploratory factor analysis
ER	Emission rate
ETS	Environmental tobacco smoke
EXS	The smoke ex-haled by active smoker
GC-MS	Gas chromatography–mass spectrometry
GMW	Gram of molecule
HPLC	High performance liquid chromatography
HVAC	Heating ventilation air conditioning
IAP	Indoor air pollutant
IAQ	Indoor air quality
IBM SPSS	IBM Statistical package for the social science
ISO	International Organization for Standardization
KIP	Kampong improvement programs
KMO	Kaiser-Meyer-Olkin
LOD	Limit of Detection
LPG	Liquefied Petroleum Gas

LR	Living room
MCS	Multiple chemical sensitivity
MSS	Active smoking breathes in the mainstream smoke
OAQ	Outdoor Air Quality
OSHA	Occupational Safety and Health Administration
PCA	Principal component analysis
PIDs	Photo-ionization detector
PM	Particulate matter
QEESI	Quick environmental exposure and sensitivity inventory
RH	Relative Humidity
RMSEA	Root Mean Square Error of Approximation
RT	*Rukun Tetangga*
SBS	Sick building syndrome
SSS	The passive smoker in-hales the smoke generated by the lit cigarette between two puffs
SEM	Structural equation modelling
SHS	Sick house syndrome
STP	Standard temperature and pressure
TSP	Total Suspended Particulate
TVOC	Total volatile organic compound
UPI	Universitas Pendidikan Indonesia
VOCs	Volatile organic compound
WB	Wallboard
WHO	World health organization
WP	Wallpaper

Nomenclature

C	Substance to measure
C_M	Concentration by weight
C_V	Concentration by volume
C_a	The outdoor CO_2 gas concentration
C_0	The initial concentration of CO_2 gas
$C(t)$	The final CO_2 gas concentration
E	Sampling site elevation
E_E	Extraction efficiency
EF	Emission rate
kPa	Kilopascal
kV	Kilovolts
M	The total weight of the substance in the sample
Me	Mean value
Mg	Microgram
M_r	molecular weight
Mx	Maximum value
mg/m^3	Milligram per meter cubic
mL	Mili liter
mol wt	Molecular weight
p	Probability value
ppb	Parts per billion
ppm	Parts per million
P_{SS}	Pressure at the sampling site
R_{SS}	The sampling rate the sampling site
ru	Response unit
t	Sampling time
T_{SS}	Temperature at site temperature
W	Weekdays
Wa	Collected quantity of targeted substance based on the calibration curve
Wb	The blank value
WE	Week ends
µL	Micro liter

μm	Micrometer
$\mu g/m^3$	Microgram per meter cubic
μg/ml	Microgram per milliliter
λ	air change rate

List of Publications

Referred Journal and Book Chapter

Sani, H., Kubota, T., & Surahman, U. (2023). Factors affecting multiple chemical sensitivity (MCS) in newly constructed apartments of Indonesia. *Building and Environment*, *241*, 110482. https://doi.org/10.1016/J.BUILDENV.2023.110482

H. Sani, T. Kubota, J. Sumi, and U. Surahman, "Impacts of Air Pollution and Dampness on Occupant Respiratory Health in Unplanned Houses: A Case Study of Bandung, Indonesia," *Atmosphere (Basel).*, vol. 13, no. 8, pp. 11–17, 2022, doi: 10.3390/atmos13081272.

Sani, H. A., Kubota, T., Surahman, U., & Erwindi, C. (2021). Indoor Air Quality and Health in Newly Constructed Apartments of Indonesia: Case Study on the Effect of Modification. Journal of Architecture & ENVIRONMENT, 20(1), 55. https://doi.org/10.12962/j2355262x.v20i1.a9035

T. Kubota, **H. A. Sani**, S. Hildebrandt, and U. Surahman, "Indoor air quality and self-reported multiple chemical sensitivity in newly constructed apartments in Indonesia," *Archit. Sci. Rev.*, vol. 64, no. 1–2, pp. 123–138, Mar. 2021, doi: 10.1080/00038628.2020.1779647.

S. Hildebrandt, T. Kubota, **H. A. Sani**, and U. Surahman, "Indoor air quality and health in newly constructed apartments in developing countries: A case study of Surabaya, Indonesia," *Atmosphere (Basel).*, vol. 10, no. 4, 2019, doi: 10.3390/atmos10040182.

Referred Conference Papers

H. Sani, T. Kubota, S. Hildebrandt, and U. Surahman, "Present states of indoor air quality and health in newly constructed high-rise apartment in major cities of Indonesia," in *the 16th Conference of the International Society of Indoor Air Quality & Climate (Indoor Air*

2020), Seoul, Korea, 1-5 Nov.

H. Sani, A. Sarkar, T. Kubota, and U. Surahman, "Influential Factors of Sick Building Syndrome in Newly Constructed Apartments of Indonesia," in *12nd International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2021)*, 2021, vol. 2017, no. November, pp. 24–26.

Non-Referred Conference Papers

H. Sani, J. Sumi, and T. Kubota (2021), Indoor and outdoor air pollution and respiratory health in unplanned houses in the hot and humid climate of Indonesia, Architecture Institute of Japan (AIJ) annual meeting, 5-8 August, Tokai, Japan.

Y. Sakita, **H. Sani**, and T. Kubota (2021), Analysis of Influential Factors of Sick Building Syndrome in Newly Constructed Apartments of Indonesia, Architecture Institute of Japan (AIJ) annual meeting, 5-8 August, Tokai, Japan.

H. Sani, T. Kubota, and U. Surahman (2022), Factors Affecting Multiple Chemical Sensitivity in Newly Constructed Apartments of Indonesia, Architecture Institute of Japan (AIJ) annual meeting, 5-8 September, Hokkaido, Japan.

1 Introduction

Through the years, humans have constructed increasingly intricate structures to shield themselves, keep out rain and snow, and provide warmth in winter while keeping cool in summer. Consequently, people now spend up to 90 percent of their time living and working in these enclosed spaces. Paradoxically, instead of safeguarding against environmental dangers, buildings do not always serve as a refuge from pollution; in fact, they can exacerbate the issue. The interior environment can harbor more concentration of molds, fungi, dust, and toxic gases than the outdoors (Hansen & H. E. Burroughs, 2011). In the face of the above issues, people started to study and improve their indoor environment towards sustainable and healthy buildings. However, to improve, an investigation to understand the characteristics of the pollutants and the best way to control them is necessary. This thesis investigates the fundamental approach toward improving the air quality in the building, focusing on urban houses in developing countries.

1.1 Background

1.1.1 development of urban houses in Indonesia

The world's fastest population and urban growth are experienced in Southeast Asian cities (Demographia, 2017). 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 (UN DESA, 2017), the shortage of houses is estimated to have reached 11.4 million by 2017 (Lamudi, 2018). As of today, Indonesia has a population of more than 250 million, and it is continuously rising, particularly in urban areas, such as Jakarta, Surabaya and Bandung (Jakarta Post, 2014; Rachmawati et al., 2015; Wardhani, 2015). Therefore, the central government reacts by quickly constructing low-cost vertical housing for rent (*Rusunawa*) and for ownership (*Rusunami*) (Wardhani, 2015). The government is actively promoting the construction of high-rise residential buildings through physical development initiatives and financial support, particularly aimed at assisting low-income individuals (Widya et al., 2023). Various programs have been implemented to encourage vertical housing development. For instance, the 1000 tower program was initiated in early 2014, followed by the one million houses program that began in 2015 and continues to the present. In 2019, the Ministry of Public

Works and Public Housing set a target of constructing 500 *rusun* (low-cost apartments) within a four-year period, spanning from 2015 to 2019 (Ministry of Public Works and Public Housing, 2015). As a result, the construction of urban houses using modern building materials is thriving, but often without sufficient standards or regulations for the building materials and the minimum ventilation rates. In these newly constructed apartments, In the high-rise apartments, the occupants tend to experience poor cross-ventilation due to their double-loaded corridor arrangements (Kumar et al., 2021) and are forced to use air conditioning (AC) which can increase the risk of SBS (Wong & Huang, 2004). In addition, liquefied petroleum gas (LPG) and electricity are commonly used for cooking among households instead of using kerosene and solid fuels such as biomass and charcoal. This shifting does not indicate that the air quality problems in the urban residential buildings are solved. This newly developed high-rise apartment can even increase new air quality and health problems. Instead, there is a possibility that IAQ problems possibly caused by chemicals have already spread among newly constructed urban houses.

On the other hand, many parts of the cities in Indonesia still comprise traditional unplanned houses, the so-called Kampungs. Most Kampung houses are tiny, detached houses constructed by non-professional workers in densely crowded settlements. Despite the different definitions, the term, Kampung, can be translated as an urban village. The houses in the Kampungs vary in size and wealth, and it is possible to see many different house types in the same Kampung (Funo et al., 2018). Moreover, houses in Kampung still carry community behaviors and building characteristics of rural life, i.e., close family ties, rich social connections (leading to a high sense of ownership), and irregular and informal building environments (Parisi et al., 2021). This morphology of Kampung leads to an urban micro-climate where relative humidity (RH) is often significantly higher compared to other urban areas. Dampness and mold are, therefore, commonly seen in Kampungs, particularly during the rainy season and seasonal floods, and thus adverse health effects, especially respiratory diseases, are suspected among residents. Therefore, studies related to IAQ in urban houses and its effect on the health of the occupants are needed to investigate and improve the air quality in urban houses of Indonesia.

1.1.2 indoor air quality and health in Indonesia

Studies related to indoor air quality and health in Indonesia mainly focused on the effects of household air pollution caused by solid fuel use and environmental tobacco smoke (ETS) on respiratory health among children and women (Surjadi, 1993; Suryadhi et al., 2019). However, the Ministry of Health in Indonesia has reported that many buildings in the country are associated with sick building syndrome (SBS). This condition leads to occupants experiencing health problems and discomfort due to various factors, including poor air ventilation, inadequate lighting, chemical emissions, furniture and wood panels pollution, and cigarette smoke exposure. Consequently, the productivity of individuals working in these buildings, particularly in office settings, is adversely affected.

Moreover, SBS and other building-related health issues have been investigated in Indonesia (Adiningsih & Hairuddin, 2021; Haryanto & Purnama, 2010; Maharani, n.d.; Winarti et al., 2003). However, most studies still focus on offices and public buildings, especially in terms of productivity and satisfaction. For example, Winarti et al. (Winarti et al., 2003) surveyed SBS in offices in Jakarta in 2002, focusing on the headache symptoms (n=240) and reported that 15% of the respondents suffered from headache during working in the building. From the AQ measurement, humidity, temperature, and air movement, it was found that slower air movement increased the risk of SBS, although no chemical and pollutant measurement was involved in this study. Furthermore, except for the present authors, there were no recent studies on SBS and IAQ in Indonesia. Therefore, it is essential to understand further and identify the complex relationship between IAQ and SBS in urban houses (apartment and Kampong) in developing countries, especially Indonesia.

1.2 Problem statement and research scope

As previously discussed, it is necessary to investigate and understand the pollutant and its effects on health in an interior environment. Based on the review, it has been reported that indoor pollutant has been a problem for developing countries. Air pollution related to biomass fuel was the main problem in developing countries, but due to urbanization and industrialization, people have been moving from biofuel and rural areas. As a result, the number of newly constructed vertical housing is increasing in urban areas. At the same time, traditional urban houses are also still emerging in urban areas. These two types of urban houses have their specific conditions and challenges. In apartments, buildings are built without sufficient ventilation standards and new materials, which can cause more pollution in the indoor environment. Whereas its density, irregular pattern, and not standardized infrastructure have caused other IAQ and health problems in Kampong.

Meanwhile, studies in IAQ and health in Indonesia mainly focused on pollution from solid fuel and ETS. In addition, the recent studies on SBS and IAQ are mainly focused on office building and working environments. These studies are mostly based on only the questionnaire survey without field IAQ measurement, except for humidity, temperature, and air velocity. There has yet to be a recent study regarding IAQ and health in urban houses in Indonesia. Whereas Hansen & H. E. Burroughs (2011) suggested that in order to manage IAQ, investigations are necessary, because each indoor environment would have its problem and specific solution.

In response to the above research gap, this study attempted to investigate the current indoor air quality conditions and the factors that lead to health problems related to IAQ in urban houses in Indonesia. A combination of questionnaires and measurement surveys was proposed to collect and understand deeply the conditions. Furthermore, improvement strategies and recommendations are proposed based on data analysis. This work is a fundamental study to accumulate the essential information and data that can be used to improve IAQ and health in the already built houses and for the future IAQ urban houses guidelines in Indonesia. First, this study investigates the IAQ and health conditions of apartments and Kampong in major cities of Indonesia by field measurement and questionnaire survey, focusing on formaldehyde along with VOCs of the house and the MCS risk of the respondents. Second, due to its different characteristics and possible IAQ problems, a further investigation focused on investigating the dampness and air pollution problem in traditional landed houses, Kampong in Bandung. Third, the interrelationship of factors that affect MCS is analyzed through structural equation modeling (SEM) to find the causal effect of each variable on the occupants. Fourth, detailed measurements are carried out and analyzed to find the possible sources of chemical pollution in the apartment building. Fifth, behavior patterns are analyzed to find the best habits to improve IAQ, and a modification project was carried out to see the effect of improved ventilation on chemical concentrations. Sixth, recommendations in terms of building attributes and behavior are proposed based on the results of field measurement and data analysis.

1.3 Research objective

The main objective of this thesis is to provide fundamental and comprehensive data and information on indoor air quality and health in urban houses in Indonesia, which help develop recommendation strategies to improve building performance in IAQ and its health effects. As described before, these urban houses are newly built high-rise apartments and traditional landed houses, Kampong, which are common residential building types in developing countries. These urban houses are located in urban areas where the populations are mixed between middle-upper and low-income, which are not yet studied in detail. The specific objectives are as follows:

1. To understand the existing situation and current IAQ and health problems of the existing apartment and Kampong through investigation of SBS and chemical concentrations in three major cities of Indonesia; to investigate the behavior, building attributes, and personal attributes of people living in urban houses of Indonesia; and to investigate factors influencing chemical concentrations and MCS risk. Primary data were collected through field measurements and interviews, and statistical analysis was conducted to find the influencing factors.
2. To evaluate dampness, air pollution, and the respiratory problem of Kampong, and find out the different environmental conditions compared to apartments; to evaluate improvement strategies based on Kampong's specific IAQ conditions. It was found that Kampong and apartments have different possible air quality and health problems. Therefore, it is logical to do separate investigations. Field measurements and questionnaire surveys were conducted in Bandung.
3. To examine the interrelation of factors that affect MCS/SBS in urban houses in Indonesia through statistical modeling. Both path and structural equation modeling are used to assess the interrelationships.
4. To evaluate the potential behavioral and building attributes in the urban houses that can improve the IAQ and propose the suggested strategies based on the IAQ and occupants' conditions.

1.4 Contribution of research

1. As previously described, in urban area, the thriving constructions of high-rise apartments have been rapidly increasing in Indonesia over the last decade (since 2014), whereas the traditional landed houses are still existed in the same area. To date, the current conditions of IAQ and occupants SBS of these apartments and Kampong have not yet been investigated: this study is probably the first attempt. The comprehensive data on these apartments and Kampong that will be provided by this study would be a fundamental and useful information in improving the urban houses conditions and public health in Indonesia.
2. Kampong settings are still existed in many parts of Indonesia and several studies have been done in this settlement, but mostly are only field measurement or questionnaire survey. This study applied a combination of objective measurements and self-reported surveys to assess dampness in health-related epidemiological studies and investigated the influential factors that affect occupants' respiratory health among children, youths, and adults.
3. Indoor air and health have become an important topic these days. People started to be aware and look for a method to improve their home air quality. Whereas air pollution is still a big issue in the world, especially in developing countries. However, studies in

understanding factors and scenario of IAQ in urban houses are limited. Therefore, extensive, and comprehensive studies in understanding SBS in urban houses can be the base for proposing the improvement scenario based on the current IAQ and respondents' conditions.

2

Literature Review: Indoor air quality and Sick Building Syndrome in Urban Houses

This chapter presents a literature review of relevant studies of indoor air quality and its effects on health, particularly in urban houses. Firstly, the fundamental principle and development of sick building syndrome and its relationship with indoor air quality are explained, particularly in newly constructed vertical housing/apartment (section 2.1 and 2.2). Secondly, air quality problems related to dampness and air pollution in traditional type of urban houses, kampong, are considered and explained in section 2.3. From these sections, the information regarding indoor air quality rating and its effect on the health of occupant as well as the method to investigate and improved are extracted. Eventually, the recent development of indoor air quality and sick building syndrome for urban houses of developing countries in tropics are reviewed in section 2.4.

2.1 Indoor air quality and sick building syndrome

People spend 80-90% of their time indoors, where 70% of them are at home, thus, it is essential to have a healthy indoor environment (Klepeis et al., 2011). Exposure to the indoor environment is experienced from an early age till old age, even from the fetus stage during pregnancy. At the same time, the ability to cope with the exposure developed and depended on each person's immune system (Herbstman et al., 2010). However, due to population growth & density, climate change, and the development of new materials & products, exposure to indoor air pollutants (IAP) is increasing (Tham, 2016). Several most significant pollutants that cause great concern found indoors are tobacco smoke, nitrogen dioxide, carbon monoxide, woodsmoke, biological agents, formaldehyde, volatile organic compound (VOC), and radon. These pollutants might differ depending on the indoor setting, such as the home, office, and transportation environment (Samet et al., 1987, 1988).

Nitrogen dioxide, woodsmoke, and environmental tobacco smoke (ETS) in indoor settings have primarily been associated with changes in pulmonary function, which can cause shortness of breath and wheezing, leading to asthma. In a severe condition, this can lead to bronchitis

(Berglund et al., 1991). In 2019, 1.85 million new childhood asthma cases were reported to be related to nitrogen dioxide (Vaughan, 2022). Formaldehyde and VOC can affect the skin and mucous membranes in the eyes, nose, and throat. Irritation by formaldehyde occurs over a wide range of concentrations, usually as standardized by WHO, sensory irritation begins at approximately 0.1 ppm, but more cases are found at or above 1 ppm. Many VOCs are implicated with SBS because of their mucous membrane irritant and neurotoxic tendencies, especially in new buildings, but no clear relationship has been found. Several alarming substances are acetone, benzene, toluene, cyclohexane, n-hexane, styrene, formaldehyde, chlorinated solvents, and several other organic solvents (Berglund et al., 1991).

Indoor air quality (IAQ) assessment, ventilations, identification and modification related to the pollutant source are several control measures suggested for IAP. IAQ is a multi-disciplinary phenomenon determined by indoor environmental composition related to chemical, biological, and physical contaminants. (Tham, 2016). The indoor environment is dynamic and can be influenced by several factors, such as (Tham, 2016):

- Materials (wall finishes, furniture, fabric) that depend on motivating environmental parameters such as temperature, surface air velocity, and humidity can potentially emit or absorb pollutants.
- Equipment and processes that may generate pollutants (such as cooking process, sprays, and others).
- Heating/cooling processes that, during ventilation and air distribution tend to mix the air and generate flow paths that carry contaminants and facilitate exposure.
- Occupant behavior that possibly generates pollution and resuspends deposited particulate matter.
- Humans present, which contributes to bio-effluents and respiratory contamination (especially if they are not in good health and carry viruses or bacteria) (Fadeyi et al., 2013; Weschler, 2016)

Therefore, there is no specific ventilation rates or strategy that can be applied for all building to protect against health risk due to its complexity (Carrer et al., 2015). In several cases, if there are changes in materials which impacted IAQ and health, there would partly result in the prohibition of certain materials and new standards that only applied in specific regions (Goldstein, 2010). Indoor air science was originally funded by the government agencies in attempt to reduce the cost for health care and energy usage in the building (Sundell, 2017).

Research related to indoor air quality (IAQ) issues has progressed significantly and become a primary research focus in the last decade. At the same time, its effects on the health of occupants and its improvement technologies have been studied widely both in developed and developing countries (Dhital et al., 2022; Tham, 2016; Van Tran et al., 2020). Most research on IAQ originate from North America and Europe around 1970s, ranging from various topic on lung cancer, allergies, sick building syndrome (SBS), and other building-related health issues, as well as their influencing factors such as allergens, particles, and VOCs (Sundell, 2004, 2017). As shown in Figure 2.1 Exponential trend began in 1990, and in the last ten years, the number of publications on this topic has increased eight times compared to the first decade. In fact, within the last three decades, the USA has been the country with the highest number of publications in IAQ, with 945 publications (Table 2.1) (Dhital et al., 2022). In Asia, the concern about IAQ start in Japan around 1990s, resulting in an amendment for building law (2003), followed by China and Korea resulting regulations and standards for IAQ.

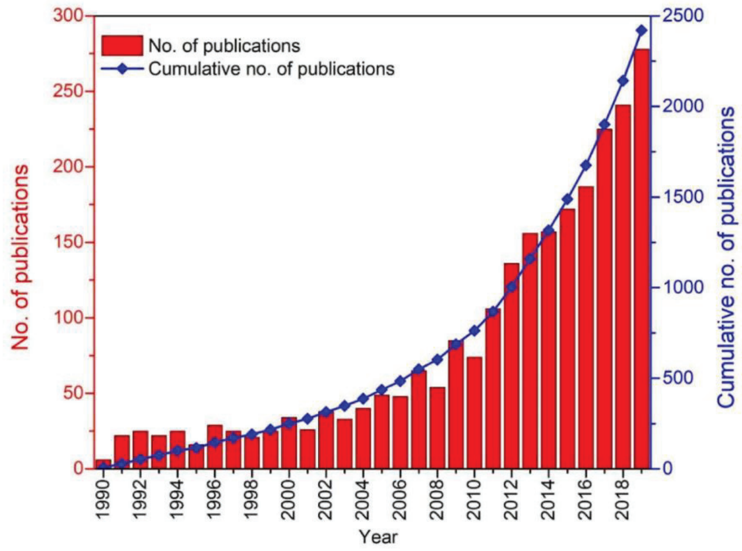


Figure 2.1 Trend of publication on indoor air pollution research during 1990–2019 (Dhital, 2022)

Asian developing countries with the highest number of IAQ publications are China and India, due to the significant air pollution issues they are facing. However, this only 28% of the publications where the 72% still from developed countries (Dhital et al., 2022). On the other hand, in developing countries, most IAQ studies focus on the issue of exposure to biomass combustion especially in rural houses. Whereas the health problem and symptoms of this issues are distinguished, which the occupant could have acute respiratory infections, tuberculosis, lung cancer, and even blindness due to solid fuel use (Bruce et al., 2000; Smith & Mehta, 2003; Tham, 2016). On the other hand, another focus in urban areas of developing countries is environmental tobacco smoke effects on children (Romieu et al., 2002).

Table 2.1 Top ten countries with the highest number of publications, burst, and betweenness centrality (Dhital et al., 2022).

Country	Publications	Country	Bursts	Country	Centrality
USA	945	USA	11.34	Netherland	0.56
China	439	Japan	10.17	England	0.42
England	274	Nigeria	9.07	Thailand	0.35
India	251	Guatemala	7.26	Norway	0.35
Canada	143	Denmark	7.00	Columbia	0.33
Germany	96	Sweden	6.96	Finland	0.29
Australia	92	Switzerland	5.77	Guatemala	0.28
France	85	Singapore	5.12	India	0.27
Japan	82	Pakistan	4.52	Canada	0.24
Sweden	76	Finland	4.43	USA	0.20

Indoor air quality issues are strongly related to sick building syndrome (SBS) in urban areas. Sick building syndrome (SBS) is a complication that can appear in building occupants along with nasal, eyes, skin, general manifestation, stress, anxiety, and lower productivity, which can also affect the increase of building energy consumption. SBS is likely linked to decreasing productivity due to endangered occupants' health status (Ghaffarianhoseini et al., 2018). Due to its strong relation with productivity, SBS researchers mainly focused on public buildings and offices in the early decades (Burge, 2004). Several building factors associated with SBS in offices and hospitals are building materials, ventilation rate, temperature, humidity, freshness of the ambient air, indoor air chemistry, dust, bacteria, and fungi. However, no proof that altering these factors will likely reduce the symptoms of SBS (Burge, 2004; Sundell, 2004).

Ventilation rates in a building help dilute pollutants inside the building but simultaneously increase the risk of other pollutants from outside entering the building. However, ventilation rates below 25 l/s per person in a commercial building increase the risk of SBS and reduce productivity (Wargocki et al., 2002). Temperature, humidity, and dampness in Western countries are varied depends on the seasons, thus, the IAQ will depend on the outdoor conditions. In addition, in most four-seasoned countries, the HVAC system is the primary source of thermal comfort. Buildings containing a humidifier and AC are found to have a higher risk of SBS symptoms (Burge, 2004; Sundell, 2004). On the other hand, naturally ventilated building is highly related to dust, bacteria and fungi problems, where the association of these factors to SBS are less clear than with respiratory problems, such as asthma (Burge, 2004). Furthermore, moisture and thermal building conditions affect the emission from building materials that can increase indoor air chemistry. These organic and chemical pollutants react quickly with/on skin or mucous membranes which can lead to SBS (Sundell, 2017).

In developing counties, similar to Western countries, the study of IAQ and SBS are primarily focused on public buildings, where the studies are focused on productivity, satisfaction, and behavioral effects of the occupants (Ganesh et al., 2021; Gupta et al., 2007; Jung et al., 2022; Quoc et al., 2020; Salvaraji et al., 2022; Thach et al., 2019; Yau & Phuah, 2022). At the same time, in developing countries, SBS was found to be higher compared to the previous studies, and it is essential to study the residential building also, especially in Southeast Asia (Surawattanasakul et al., 2022; Suzuki et al., 2021).

2.2 Indoor air quality and sick building syndrome in urban houses

As mentioned before, in developing countries, most IAQ studies focus on the issue of exposure to biomass combustion, especially in rural houses (Bruce et al., 2000; Smith & Mehta, 2003; Tham, 2016). It was reported that globally, 41% of households, over 2.8 billion people, rely on solid fuels (coal and biomass) for cooking and heating, whereas 1 billion of it are from developing countries in Southeast Asia (Bonjour et al., 2013). In developing countries, solid fuels caused high pollutant emissions, typically when it is burnt in open fires and inefficient, traditional cookstoves, often in poorly ventilated cooking spaces (Amegah & Jaakkola, 2016; Ezzati, 2005). In fact, more than 30% of women and children living in low-income households have the most significant exposure to indoor air pollution from solid fuel use as they spend much time near cookstoves (Gordon et al., 2014; Mannucci & Franchini, 2017; Rumchev et al., 2017). The results of systematic study and meta-analysis suggested that there is a significant risk for acute respiratory infections (ARI) in children and chronic bronchitis (CB) along with chronic obstructive pulmonary disease (COPD) in women due to household biomass fuel use, while the association between asthma and biomass fuel exposure is still unclear (Po et al., 2011). Furthermore, Pope et al. (2010) reported that indoor air pollution from solid fuel use was associated with an increased risk of the percentage of low birth weight and stillbirth, whereas women in developing countries are rarely able to avoid it.

Environmental exposures in low- and middle-income countries lie at the intersection of increased economic development and the rising public health burden of cardiovascular disease because of exposure to ambient air pollution and household air pollution (Burroughs Peña & Rollins, 2017). In urban areas, people are moving from solid fuels in response to rapid population growth, which leads to urbanization (WHO, 2014). However, at the same time, this growth also leads to the thriving constructions of urban houses using modern building materials – but often without sufficient standards or regulations for the building materials and minimum ventilation rates. Hence, there is a possibility that SBS and other building-related health issues mainly caused by chemicals have already spread widely among newly constructed urban houses in these rapidly growing countries (Kubota et al., 2021).

Hansen & H. E. Burroughs (2011) suggested that there are five symptom complexes associated with Sick Building Syndrome (SBS), which can occur individually or in combination. These symptoms can be cyclical or episodic. They typically worsen as the day progresses, may worsen over the course of the work week, and tend to ease or disappear when occupants are away from the building for a while.

1. Eye Discomfort: Individuals experience a burning, dry, gritty sensation in the eyes without any signs of inflammation.
2. Nasal Issues: Symptoms include stuffiness, nasal irritation, and a runny nose. These symptoms often suggest an allergic cause.
3. Throat and Lower Respiratory Tract Symptoms: People may experience persistent dryness in the throat without noticeable inflammation, as well as shortness of breath unrelated to lung infections or bronchial asthma. Stepping outside for fresh air often provides relief.
4. Headaches, Fatigue, General Malaise: Headaches can range from moderate to severe migraines. Headaches, along with related fatigue, dizziness, difficulty concentrating, and a general feeling of illness, are the most commonly reported symptoms associated with sick buildings.
5. Skin Problems: Dry skin is frequently reported by occupants, especially females. Exposure to certain contaminants may result in skin rashes or irritation. SBS can also exacerbate existing health conditions such as sinusitis and eczema, although these fall outside the general symptom complexes of SBS

Contaminants can enter a building from external sources and be transported or ventilated inside, or they can be generated within the building itself. Once inside, these contaminants have limited pathways to follow. Figure 2.2 illustrates the indoor flow of pollutants, offering an overview of the lifecycle of contaminants within a building.

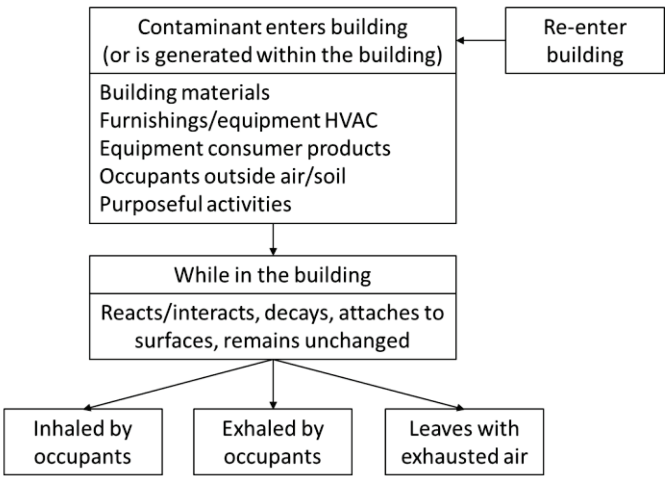


Figure 2.2 Indoor pollutant flow (Hansen & H. E. Burroughs, 2011)

Furthermore, indoor air quality can be adversely affected by various air pollutants. However, evaluating each pollutant for every individual building can be time-consuming, resource-intensive, and costly. Therefore, as part of the indoor air quality risk assessment process, Abdul-Wahab (2011) proposed that initially a pre-assessment is conducted to gather data for subsequent steps and avoid unnecessary losses. The pre-assessment phase involves defining the building and its occupants in terms of indoor air quality risk analysis. Additionally, potential indoor air pollutants originating from the building, or the occupants are identified in this phase. The pre-assessment step, as shown in Figure 2.3, allows for the classification of pollutants based on:

- Building identification
- End user interviews
- Potential threat analysis

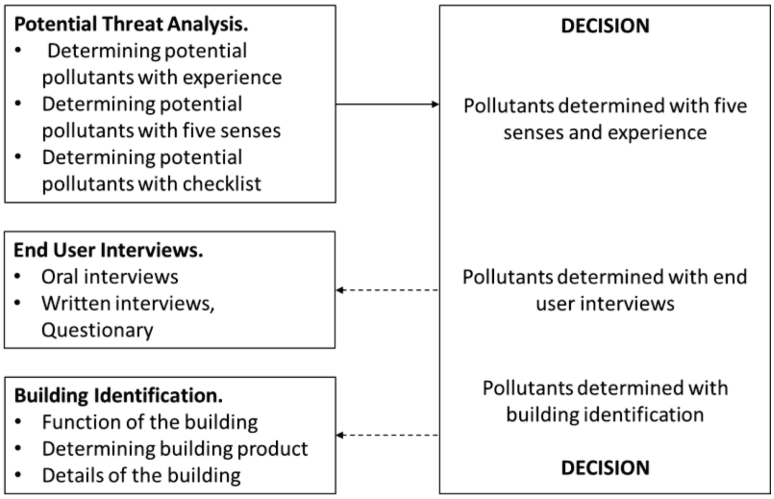


Figure 2.3 Pre-assessment step of indoor air quality risk analysis model (Abdul-Wahab, 2011)

2.3 Air pollution and dampness in urban houses of developing countries

Building dampness is one of the causes of IAQ problems that commonly occur in many countries (Sundell, 2017; Takaoka & Norback, 2011; L. Wang et al., 2015; WHO, 2009). Compared to developed countries, the risk of the occupants in residential buildings being exposed to a complex mix of air pollution not only from indoor sources but also from outdoor sources is higher in developing countries (Romieu et al., 2002). Furthermore, in developing countries, dampness and mold proliferation are supported to initiate and accelerated by climatic conditions, diversified housing characteristics, poor housing conditions, and lack of affordability for the building owner for renovation (Manivannan et al., 2017). Common built-environment-related challenges such as dampness in housing have been thoroughly associated with numerous adverse health symptoms, particularly respiratory system, including (i) aggravation of asthma, (ii) increased occurrence of wheezing, coughing, and other respiratory symptoms, (iii) increased rate of upper respiratory infections, and (iv) irritation of airways (WHO, 2009).

Though not much, several evidences proposed that indoor mold growth and subsequent human exposure to spores, as well as to mold cell wall proteins, may cause occupant health problems (Bornehag et al., 2004; Choi et al., 2014; Fisk et al., 2007; Gunnbjörnsdottir et al., 2003; Ignatavičius & Ignatavičius, 2005; Jaakkola et al., 2005; Larsson et al., 2009; Sun et al., 2009; Sundell, 2017; Takaoka & Norback, 2011; L. Wang et al., 2015; Zhang et al., 2012), especially diseases related to asthma and allergic (Hsu et al., 2012; Naydenov et al., 2008; Smedje & Norbäck, 2003; Sun & Sundell, 2011, 2013; Tham et al., 2007). In Sweden, the combination of visible mold and water damage is associated with most kinds of respiratory symptoms, especially breathlessness and long-term cough (Gunnbjörnsdottir et al., 2003). In China, a winter to early summer survey found that condensation correlated to dry cough, moisture problems in building correlated to eczema, and dampness indicators correlated to the common cold (Sun et al., 2009). In addition, Zhang et al. (2012) found that health effects related to building dampness can be caused by microbial growth and chemicals emission from mold and dampness. In addition to indoor ventilation conditions, occupant behavior like window-opening behavior (Deng et al., 2020), indoor smoking habits (Lin et al., 2007), ventilation-related behavior, such as installation of active cooling devices (Yu et al., 2009) also modifies indoor mold growth and IAQ levels.

While there are no specific ways to measure the dampness, there are observable qualitative signs of current or/and past dampness, including visible mold spots, water damage or leakage, floor moisture, damp clothing or bedding, visible damp spot, and condensation on windows (Choi et al., 2014; Y. Hu et al., 2014; Sun et al., 2009). A combination of objective measurement and self-reported information would be appropriate to assess dampness in health-related epidemiological studies conducted in developing countries (Manivannan et al., 2017). Intermediate flood incidents and highly humid weather conditions are often ideal for indoor mold growth, imposing severe concerns about the possible adverse direct and indirect health effects of indoor mold exposure.

Mold visibility and fungal contamination are one of the signs to indicate dampness problem (Adan & Samson, 2011; WHO, 2009). A microclimate that encourages fungal growth, damp environment, must be maintained for fungal contamination to occur. Therefore, a fungal index that quantifies the capacity for fungal growth in an environment was proposed to determine in advance whether the environment at a particular site within a home is damp and supports fungal growth (Abe, 1993). The fungal index serves as a measure to assess the potential of microclimates for fungal growth. To calculate this index, a test-piece called a fungal detector, containing fungal spores, is exposed at the test area. These fungi act as biological sensors, reflecting the microclimate conditions of the site. The growth of the fungus that exhibits the most significant reaction is measured, and the fungal index is determined based on this response and the duration of exposure. The procedure used was as follows. (i) A fungal detector was exposed to a test environment; (ii) after the exposure, the detector was placed in a container with silica gel, and the development of hyphae was terminated by desiccation with silica gel; (iii) photographs of fungal growth in the detector were taken under a microscope; (iv) the length of hyphae was measured on the photographs; (v) the number of fungal response units (*ru*), was determined from the length of hyphae using a standard curve; and (vi) the fungal index was calculated using the greatest response among the sensor fungi in the detector (Abe, 2010). Fungal detectors and fungal indices are good tools for detecting dampness, where conditions with fungal indices exceeding 18 *ru*/week were considered damp, where life cycles of the fungi would proceed repeatedly (Abe, 2012a).

On the other hand, outdoor air pollution (e.g., SO2, NO2, O3, and PM) can increase the risk and incidence of IAQ problems based on the outdoor spatiotemporal patterns of concentration and by the proximity of the building to outdoor sources (e.g., busy road) (WHO, 2021). Outdoor air pollution is still increasing in most developing countries, primarily due to industrialization and urbanization (AMPA, 2002). PM (particulate matter) is a common air pollutant with different health effects for each characteristic and particle size. Its aerodynamic properties commonly classify it. The focus in recent decades has been on particles with aerodynamic diameters of less than or equal to 2.5 µm ($PM_{2.5}$) or 10 µm (PM_{10}) (WHO, 2021). A study by Qian et al. (2000), Lu et al. (2013), and Chen et al. (2018), in China found a positive and significant association between total suspended particle levels, $PM_{2.5}$ along with exposure to traffic-related air pollution, and cough, phlegm, hospitalization for diseases, asthma, allergic and pneumonia in urban children. The other results are that parental smoking status was associated with cough and phlegm, and use of coal in the home was associated only with cough.

In addition, general respiratory health can be evaluated by using the American Thoracic Society – Division of Lung Diseases (ATS-DLD-78) questionnaire. The questionnaire comprises questions for symptoms of cough, phlegm, wheezing, breathlessness, chest colds and chest illnesses (Ferris, 1978). This questionnaire has been used in several studies from many countries and many age groups, for example elderly in USA (Enright et al., 1994), adults in South Africa (Nkosi & Voyi, 2016), and children in Thailand (Langkulsen et al., 2006). As mentioned before, it is essential to measure PM2.5 and PM10 simultaneously during the evaluation of respiratory health, due to its high correlation with the health risk. Measurement in homes, schools and urban residential areas, researchers generally cannot afford to deploy expensive, laboratory-grade measurement equipment. Therefore, the advancing microelectronic technology for sensing, data acquisition, communication and storage gave more opportunities for real-time indoor environmental monitoring, including for particles (Clausen et al., 2011).

Furthermore, previous studies analyzed air pollution and dampness, mainly focusing on the region of the global north (BRE, 2007; WHO, 2009) and four-season counties (Bai et al., 2021) which have very distinct climatic features compared to the tropics. Whereas the risk of dampness is higher in tropics due to high humidity, unpredicted rain and the possibility of seasonal rain. The limited studies related to this topic in the tropics focused on non-residential buildings, like schools and offices, and children as the primary samples (Fu et al., 2020; Norbäck et al., 2017, 2021; Yap et al., 2009; Zuraimi & Tham, 2008). Other studies focused on the health and house but had limitations in the assessment method, which was based on self-reported information (Tham et al., 2007), and focused only on investigating the current indoor environment condition of the schoolchildren's houses (J. Hu et al., 2020). Whereas as mentioned before, studying about air pollution along with dampness and health in tropic developing countries would be appropriate using a combination of objective measurement and self-reported information (Manivannan et al., 2017).

2.4 Recent developments of indoor air quality and sick building syndrome in developing countries, study case Indonesia.

In Indonesia, acute respiratory infection (ARI) has been the first in the top 10 most prevalent diseases for over two decades. One of the causes of ARI is poor indoor and outdoor air quality, including biological, physical, and chemical factors. ARI predominantly affects children under the age of 5 (toddlers) and leads to the deaths of approximately four million toddlers each year (Ministerial Regulation of Health, 2011). On the other hand, according to the Ministry of Health in Indonesia, numerous buildings in the country are linked to sick building syndrome (SBS), which causes the occupants of these buildings to suffer from health issues and discomfort resulting from factors such as inadequate air ventilation, insufficient lighting, chemical emissions, pollution from furniture and wood panels, as well as exposure to cigarette smoke. As a consequence, the productivity of the building occupants is negatively affected, especially in the offices (Kusumaputra, 2011). Indonesian Ministry of Health (Ministerial Regulation of Health, 2011) stated that some of the diseases associated with SBS include eye and nasal irritation, dryness of the skin and mucous membranes, mental fatigue, headaches, ARI, coughing, sneezing, and hypersensitivity reactions. In addition, knowledge related to SBS is highly related to the working environment, offices and bio-pollutant in Indonesia (Ministerial Regulation of Health, 2011, 2016). Whereas, as Sundell (2017) mentioned, chemical pollutants can also act as an allergen that increases the risk of respiratory diseases and SBS.

WHO (2009) stated that health problems related to IAQ problems result from a complex chemical and biological reaction of several factors, for example, the moisture content in the room, which, in turn, leads to biological growth and physical and chemical deterioration. Ultimately, these processes result in the release of harmful biological (toxins, spores, MVOC) and chemical substances (formaldehyde, VOC) (Figure 2.4). Therefore, several standards and guidelines are proposed to protect and prevent IAQ health problems. Table 2.2 shows several regulations regarding indoor air pollutants from WHO, Japan, and Indonesia. As shown, the standards in Indonesia are relatively higher than those from WHO and Japan. Whereas the standards in Japan and WHO are relatively the same. In the case of VOCs, other standards define their regulations based on the specific chemical, but in Indonesia, for indoor air VOC is defined as one. However, in the case of the working environment, the Indonesian standard also defined the regulations based on specific pollutants/compounds (Ministerial Regulation of Health, 2016). Furthermore, as indicated by the regulations, it is possible that the air pollution regarding $PM_{2.5}$ and PM_{10} in developing countries is relatively more prominent. Additionally, the regulations in other countries like Japan are based on the nationwide investigation of IAQ and health. Furthermore, the results from the investigation indicated what are the possible causes of IAQ problem which were later listed and regulated in the building law for preventing the SBS. The regulation not only lists the safe concentration but also the emission rate from the specific building materials that pollute the IAQ in the urban houses. Unfortunately, investigations and detailed regulations has not yet been established in Indonesia.

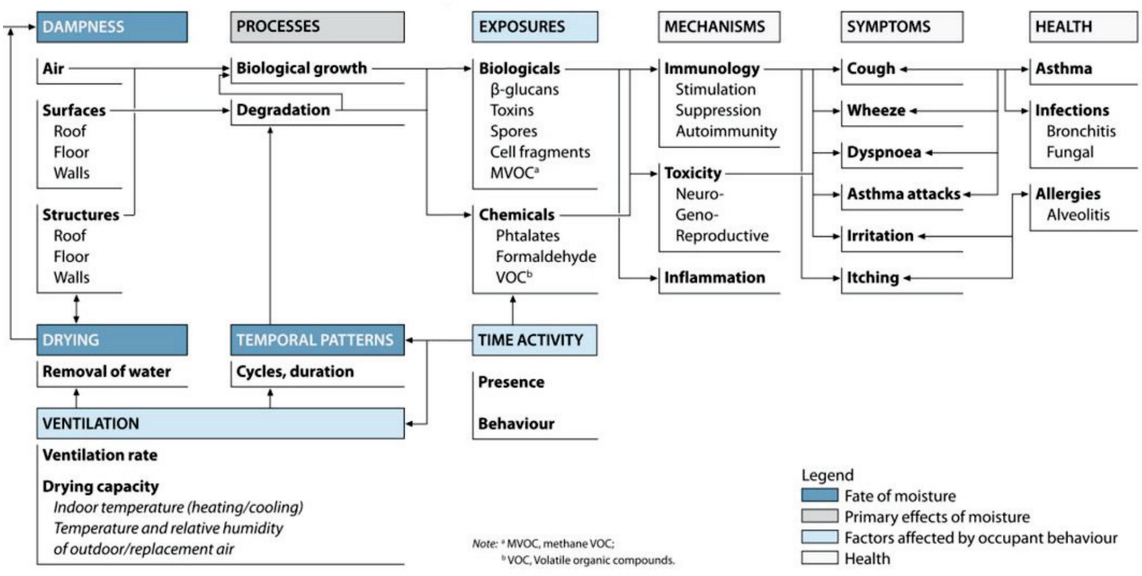


Figure 2.4 Pathways linking sources of IAQ problems with health (WHO, 2009).

Table 2.2 Regulation comparison of several indoor air quality parameters in Indonesia and other countries.

<table>
<tr><th>Parameter</th><th>WHO[1]</th><th>Japan[2]</th><th>Indonesia[3]</th></tr>
<tr><td>Formaldehyde</td><td>0.08 ppm
(30 min)</td><td>0.08 ppm
(30 min)</td><td>0.1 ppm
(30 min)</td></tr>
<tr><td>VOCs</td><td>Reported as individual chemical substance</td><td>Reported as individual chemical substance. The advisable value limit for TVOCs is 0.4 ppm
(24 hours)</td><td>3 ppm
(8 hours)</td></tr>
<tr><td>$PM_{2.5}$</td><td colspan="2" rowspan="2">No guidelines for indoor PM</td><td>35 $\mu g/m^3$
(24 hours)</td></tr>
<tr><td>PM_{10}</td><td>< 70 $\mu g/m^3$
(24 hours)</td></tr>
<tr><td>Fungi</td><td colspan="3">No guidelines for indoor fungi and dampness</td></tr>
</table>

Source: [1] WHO guidelines for indoor air quality: selected pollutants (WHO, 2010)
[2] Committee on Sick House Syndrome: Indoor Air Pollution, Ministry of Health, Labor and Welfare, Japan (Ministry of Health Labor and Welfare, 2000)
[3] *Peraturan menteri kesehatan republik indonesia nomor 1077/menkes/per/v/2011 tentang pedoman penyehatan udara dalam ruang rumah*, Ministerial Regulation of Health, Indonesia (Ministerial Regulation of Health, 2011)

Furthermore, informal settlements and slums can be found in numerous countries, particularly in developing nations of the global south. Although they have distinct meanings and unique social-cultural aspects, they share similar physical features. Examples include the Kampungs in Indonesia and the favelas and urban occupations in Brazil. While there are various definitions of Kampung, it can be described as an urban village. One common characteristic emphasized by all authors is the unplanned and irregular nature of the houses, often self-constructed and interconnected by asymmetrical pathways. Additionally, these settlements retain community customs and building characteristics resembling rural life, such as strong family bonds, extensive social networks (which foster a strong sense of ownership), and an informal and irregular building environment (Parisi et al., 2021). The houses in Kampungs vary in size and wealth, resulting in a diverse range of house types within the same settlement (Figure 2.5) (Funo et al., 2018).

SBS and other building-related health issues in offices have been investigated in Indonesia (Winarti et al. 2003; Maharani 2018). For example, Winarti et al. (2003) 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. Previous studies found that the IAQ was poorer in Surabaya's urban houses compared to other countries (Hildebrandt et al., 2019) and possible spread indication of SBS in Surabaya and Jakarta (Kubota et al., 2021). In addition, the trend towards high-rise buildings was correlated with decreasing health in Surabaya, whereas in both cities, the level of stress is found to be the most influential factor for Multiple Chemical Sensitivity (MCS) (Hildebrandt et al., 2019; Kubota et al., 2021). However, there are still limitations in the number of samples and measurement methods, which made the leading environmental causes of MCS and IAQ problems in these urban houses have yet to be analyzed further (Hildebrandt et al., 2019; Kubota et al., 2021).

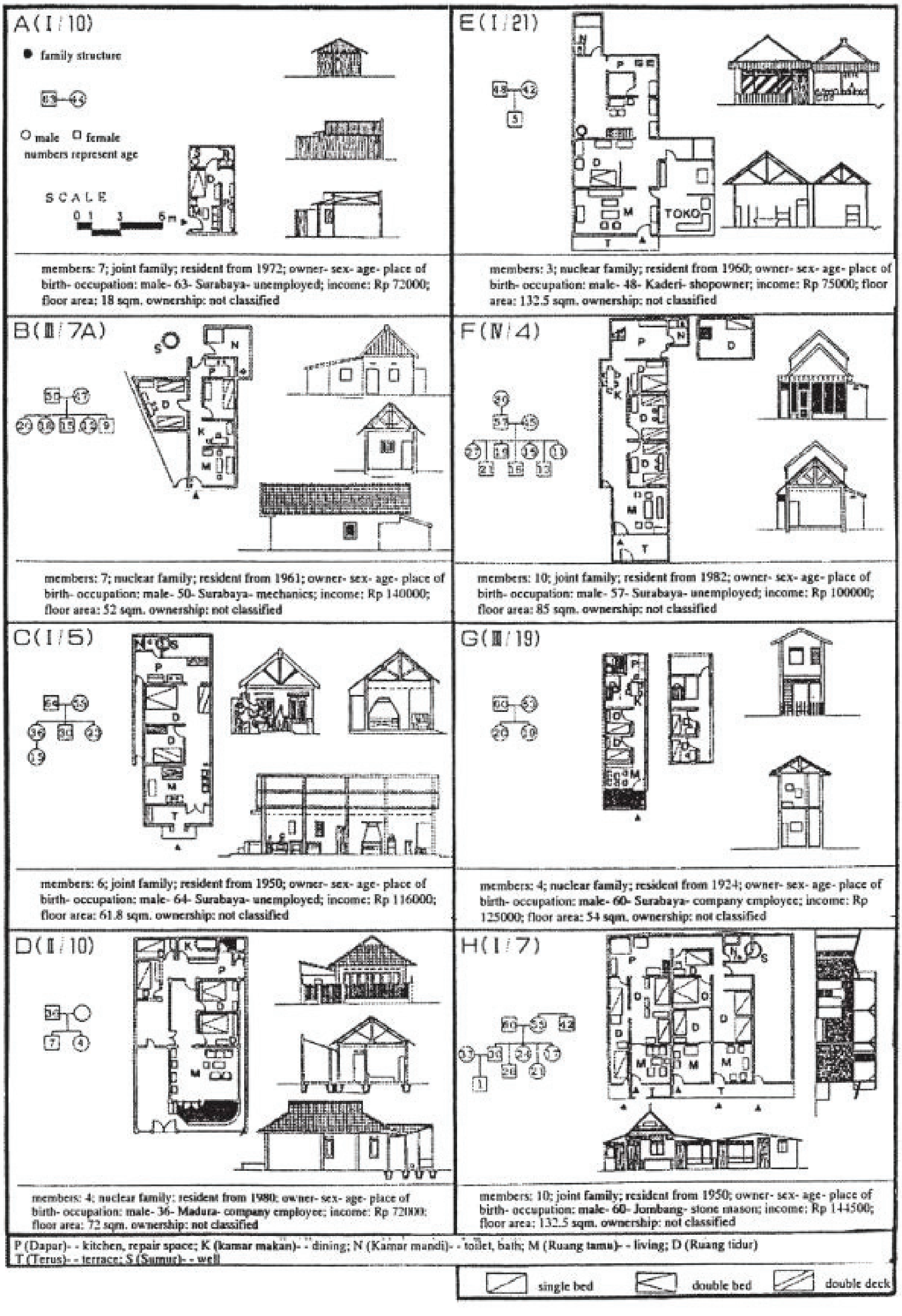


Figure 2.5 Layout and Household Constitutions of Kampong (Funo et al., 2018).

3

Indoor Air Quality and Health in Existing Newly Constructed High-rise Apartments of Indonesia

3.1 Introduction

This chapter evaluates the current conditions of IAQ and health in newly constructed high-rise apartments in contrast with those in traditional landed houses, the so-called Kampongs in Jakarta, Surabaya and Bandung. Both occupant groups consequently may suffer from health problems related to their buildings, but the main causes of health issues can be quite different. 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 the use of air-conditioning. Hence, we mainly measured formaldehyde and TVOC concentrations in these apartments. In Kampongs, in contrast, flooding during the rainy season is frequently happening and affects landed houses with potential problems of dampness and mold, and therefore we mainly focused on mold risk.

First, sections 3.3 and 3.4 analyze the results of the questionnaire survey and s health of occupants, focusing primarily on multiple chemical sensitivity (MCS) risks. Section 3.5 explains the result of measurement analysis in Apartment and Kampong. Furthermore, sections 3.6 and 3.7 discuss the results of correlation analysis to find out the factors affecting MCS risk & IAQ measurement and the results of IAQ measurement and its relationship with MCS risk.

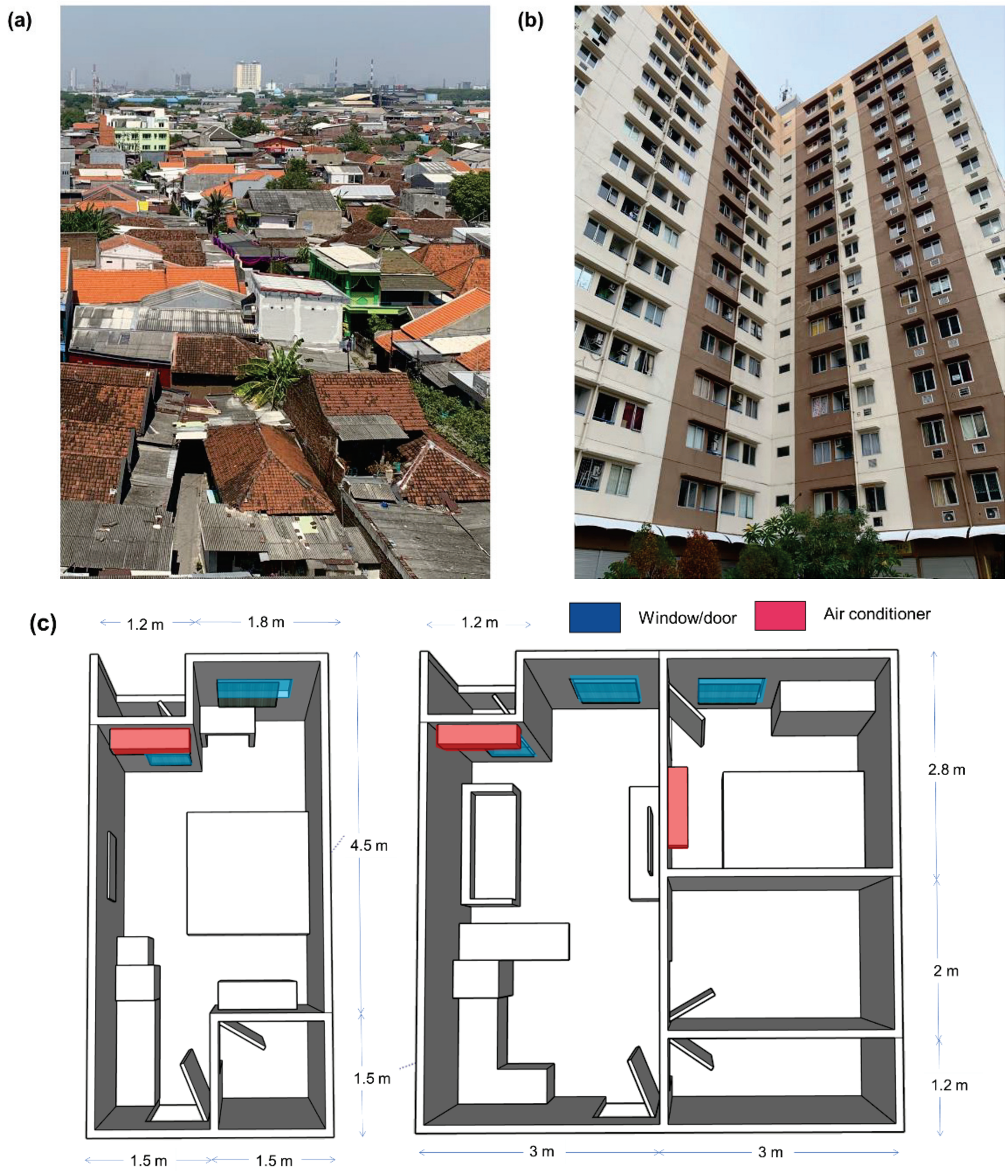


Figure 3.1 (a) Kampong, (b) apartments and (c) the typical layout of apartment units, studio & two bedrooms unit, in Indonesia

3.2 Methods

To examine the present health and indoor air quality (IAQ) conditions in urban homes across Indonesia, field investigations were carried out in Surabaya, Jakarta, and Bandung. These studies included measurements and face-to-face interviews. In Surabaya, the study encompassed five high-rise apartments, including both low-medium cost apartments and condominiums, as well as five kampong neighborhoods. This investigation spanned from September 2017 to January 2018. Both the dry season (Sep to Oct.) and the wet season (Nov to Jan.) are somewhat covered by this time frame. In Surabaya, 82 rooms were measured, and a total of 471 people were surveyed (Table 3.1a). In Jakarta, a similar investigation was conducted during the dry season from August to October 2018, focusing on 40 high-rise apartments. A total of 236 respondents were interviewed, and 43 rooms were measured (refer to Table 3.1a). In Bandung, the investigation took place in four apartment buildings during the rainy season from December

2018 to April 2019, where the team measured 44 rooms and interviewed 189 respondents (Table 3.1a). Finally, the collected data was combined and analyzed, categorizing it into two types of urban houses: kampong with 298 respondents (42 rooms) and apartments with 598 respondents (165 rooms) (Table 3.1b).

Table 3.1 Sample size of the study (a) in three cities and (b) in apartment and Kampong.

(a)

Samples		**Kampongs in Surabaya**	**Apartments in Surabaya**	**Apartments in Jakarta**	**Apartment in Bandung**	**Total**
Questionnaires		298	173	236	189	896
Measurements	IAQ parameters	42	40	81	44	207
	Mold risk	14	16	43	-	73

(b)

Samples	**Kampongs**	**Apartments**	**Total**
Questionnaires QEESI	298 (33%)	598 (67%)	896
IAQ Measurement (rooms) Formaldehyde and TVOC	42	165	207

3.2.1 Questionnaire survey

The self-reported health of the respondents in the face-to-face interviews was assessed using the Quick Environmental Exposure and Sensitivity Inventory (QEESI), developed by Miller and Prihoda in (1999). To supplement the questionnaire, cleaning practices, window-opening behavior, and socioeconomic characteristics were included as additional questions. Residents of randomly picked Kampong homes and apartments from the previously identified regions completed questionnaires during face-to-face interviews. Prior approval for the investigation was obtained from the Ethical Committee at Universitas Pendidikan Indonesia (UPI), and informed consent was obtained from the head of the residents' association, apartment managers, and participating households. The response rates averaged 87% in kampongs, 66% in Surabaya apartments, 61% in Jakarta apartments (Kubota et al., 2021), and 60% in Bandung apartments.

The QEESI is an instrument used to measure one of the terms used to represent general health issues brought on by poor indoor environmental quality, which is multiple chemical sensitivity (MCS) (Walker et al., 2011). This instrument has been used in various studies on building-related symptoms conducted worldwide, including studies by Huang et al. (2011) and Nakaoka et al. (2013). Numerous nations have evaluated the validity and reliability of it (Hojo et al., 2005; Nordin et al., 2010; Skovbjerg et al., 2012). (1) chemical intolerances, (2) other intolerances, (3) symptom severity, (4) life impact, and (5) masking index are the five main components of the QEESI. Each part includes ten sub-questions that require responses on a scale ranging from 0 to 10, except for the masking index, which requires a 'yes' or 'no' response (Miller & Prihoda, 1999).

Miller and Prihoda (1999) provided ranges and interpretation guidelines for the scales used in the QEESI. Table 3.3 lists the criteria for low, medium, and high scores whereas Table 3.4 lists the risk criteria. Depending on their symptom intensity, chemical intolerance, and masking score, respondents have been grouped into one of four levels suggesting the presence of MCS (risk criteria) (see Table 3.4). This variable is referred to as 'Multiple chemical sensitivity (MCS) risks,' indicating a person's sensitivity to multiple chemicals.

Additionally, there is a category within the QEESI calculation known as "sensitivity," and it was evaluated in terms of how many times the respondent achieved a "high" score in each of the three categories of "symptom severity," "chemical intolerance," and "other intolerances" (Table 3.3). The respondent's sensitivity is generally closely related to MCS risk, indicating their overall sensitivity rather than just chemical sensitivity. Both categorizations, MCS risk and sensitivity, reflect the self-reported health status of the occupants and serve as the main dependent variables in the subsequent analyses.

Table 3.2 Criteria for high, medium and low scale scores (Miller & Prihoda, 1999)

	Score		
Scale / Index	**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 3.3 Risk criteria (Miller & Prihoda, 1999)

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

3.2.2 Field Measurement

The current investigation conducted for indoor air quality (IAQ) measurements in urban houses in Indonesia is considered a preliminary screening aimed at understanding the existing IAQ conditions before undertaking a detailed characterization of indoor volatile organic compounds (VOCs). As a result, real-time direct measurements were employed instead of commonly used methods such as DNPH-HPLC for formaldehyde and GC-MS or GC-FID for VOCs. In the master bedroom and living room of the homes, formaldehyde (FMM-MD, Shinyei Technology) and TVOCs (ToxiRAE Pro, RAE Systems) were monitored along with air temperature and relative humidity (RH) for approximately three days. The measurement period lasted a total of six days for a single house, except in cases where the unit was a studio type, where the measurement period was only three days. In accordance with EU guidance (ECA 1995), the meters were positioned in the middle of the room to prevent being directly influenced by the walls or furniture and at a height of around 1.5 m. If placing the devices on a surface was not feasible due to potential disturbance by occupants, such as children, an alternative approach was adopted by suspending the meters from the ceiling at a height above 2 meters.

The formaldehyde sensor had an accuracy of ±0.01 ppm under an air temperature of 25°C with 50% RH. In contrast, VOCs were measured using a device equipped with advanced photo-ionization detectors (PIDs) sensors (accuracy: ±0.1 ppm). All of the mentioned sensors were calibrated by the manufacturers a year before the measurements began in order to ensure accuracy. Data were recorded at 30-minute intervals continuously throughout the measurement period (approximately three days). A sampling duration of 30 minutes was chosen for formaldehyde measurements to facilitate comparison with international guidelines such as the World Health Organization (WHO) guidelines from 2010. The former device (FMM-MD, Shinyei Technology) simultaneously monitored air temperature and RH. VOCs (ToxiRAE) and air temperature with RH (T&D TR-72Ui) were measured at minute intervals, with an average of 30 minutes used for analysis purposes.

Table 3.4 Instruments for field measurement (H. Sani et al., 2023)

Measured variable	**Instrument model**	**Accuracy**
Air temperature, relative humidity	T&D TR-72Ui	Accuracy: ±0.3℃, ±5%RH Unit:0.1℃,1%RH Rang:0~50℃,10~95%
Formaldehyde, Air temperature, relative humidity	Shinyei technology FMM-MD	Accuracy: ±10% at 2ppm, over a 25-70% RH ±0.4℃, ±3%RH Unit: ppb or μg/m³, Range: 20-1000 ppb
TVOC	ToxiRAE Pro, RAE system	Accuracy: ±3% at the calibration point Unit: ppm, Range: 0-2000 ppm
Formaldehyde, Air temperature, relative humidity	Formaldemeter™ htV-M, PPM Technology	Accuracy: ±10% at 40, 80, 160ppb, under AT 25°C & 50% RH Unit: ppm or μg/m³, Range: 0 – 10 ppm

FMM-MD and Formaldemeter record the concentration of formaldehyde both in ppm and $\mu g/m^3$. While ToxiRAE records the concentration of VOCs in ppm. in order to compare VOCs concentrations with the Indonesian standard, 430 $\mu g/m^3$, the measurement result was converted to $\mu g/m^3$ by this formula:

$$\frac{\mu g}{m^3} = \frac{ppm \times mol\,wt}{22.41} \times 1000 \tag{3.1}$$

where ppm is the concentration of the VOCs recorded by the direct reading device (ppm), mol wt is the molecular weight of the VOCs (gram/mol) and at standard temperature and pressure (STP), 1 gram of molecule (GMW) of any gas occupies 22.41. However, the STP was considered in this study due to various temperature changing conditions in the measurement process. Therefore, the final formula considers AT (°C) in the calculation:

$$\frac{\mu g}{m^3} = \frac{ppm \times mol\,wt}{22.41} \times \frac{273.15}{275.15 + AT} \times 1000 \tag{3.2}$$

3.2.3 Calibration measurement

After the direct measurements using simple devices, a calibration measurement was conducted to enhance the accuracy of the collected data. The calibration involved comparing the direct measurement device with the commonly used DNPH-HPLC method for formaldehyde, with a confidence level of 95% (Eide, 2005). The calibration was carried out in a construction material company's chamber facility in Okayama, Japan (Figure 3.2). The measurement results from the simple direct reading devices mentioned above (Shinyei and Formaldemeter) were compared with those from the passive sampler for formaldehyde in a parallel measurement system. In the flowing air and the measuring chamber, the background air temperature and relative humidity were set to reflect typical circumstances in the case study cities of Indonesia (27°C and 71% RH for Bandung and 29°C and 54% RH for Jakarta and Surabaya). These settings were chosen based on the average temperatures in the three cities, taking into account the different climate of Bandung (high altitude area) compared to Surabaya and Jakarta (low altitude areas) which have similar climates.

The calibration measurement technique is described in Figure 3.2. First, a mass flow meter was used to circulate air with a formaldehyde concentration of 10 ppm. The diluted formaldehyde gas flowed through a tube connected to the valve for the DNPH sampler and the 5L airbag, where the simple direct reading devices were placed, at a rate of 500 ml/min. The outlet tube was connected to another DNPH sampler valve. An air sampling pump sampled the diluted formaldehyde gas at a suction rate of 200 ml/min before and after the measurement inside the airbag. This setup included two DNPH samplers, one before and one after the direct reading measurement device, to increase measurement accuracy. The DNPH sample procedure was carried out after the 5L airbag had been properly inflated. The measurement was performed three times for each background condition. The DNPH samples were analyzed using high-performance liquid chromatography (HPLC) in the same facility. As a result, the calibration curve was developed using a comparison of the measurement outcomes from DNPH passive sampler and direct reading devices.

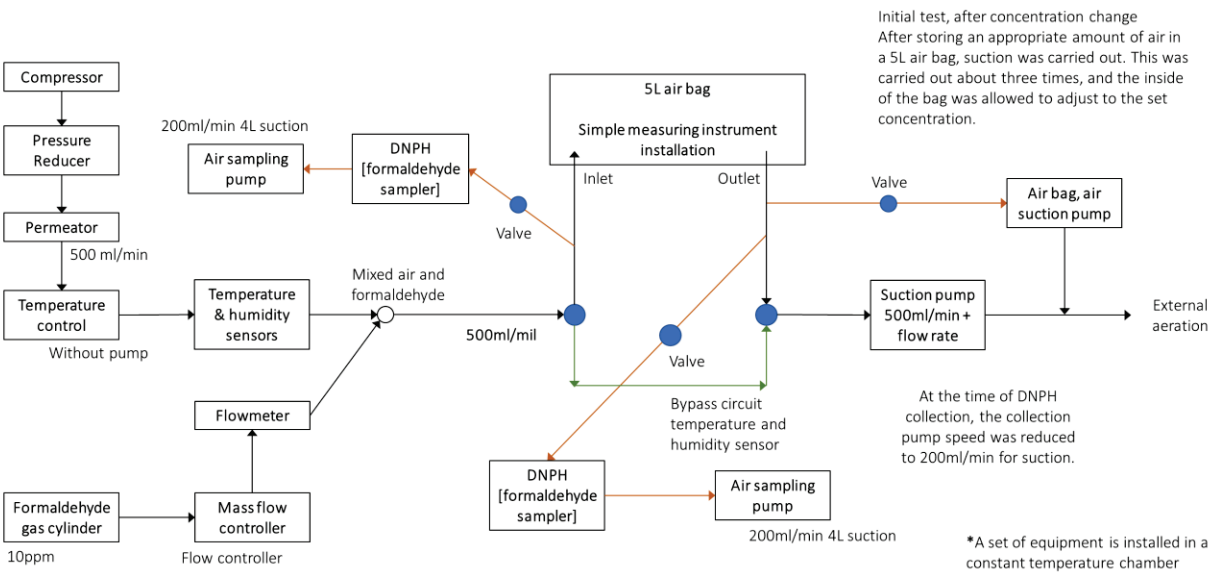


Figure 3.2 Direct reading devices calibration process diagram (H. Sani et al., 2023)

3.3 Profile of respondents

Table 3.5 provides an overview of the respondents' characteristics in this study, categorized into two types of urban houses: Kampong and apartments. As expected, the profiles of the respondents differ greatly between Kampongs and apartments in several variables, particularly those related to building characteristics and interior specifications. Differences are also observed in personal attributes, health, and perceived IAQ factors.

In terms of personal attributes, respondents in Kampong are significantly older than those in apartments, with an average age of 39.7 years and 27.6 years, respectively. As anticipated, Kampong residents have lived in their current houses for a longer duration. The proportion of female respondents is larger than the proportion of male respondents in both dwelling types. The most common occupation in Kampong is housewife (24.6%), followed by private sector employees (21.9%) and entrepreneur (21.5%). In apartments, the majority of occupants are students (52%), followed by private sector employees (21.3%). There is a significant difference in income rates between Kampong and apartment respondents, ranging from 150-450 USD/month in Kampong compared to >750 USD/month in apartments. Additionally, compared to apartments, residents in Kampong tend to open windows 13 hours more frequently than they do for 7 hours. However, Kampong also has a higher level of passive smoking exposure than apartments do. Regarding health aspects, people in Kampong show a significantly higher percentage of allergy symptoms compared to those in apartments, 31.6% and 23.8%, respectively. Conversely, people in apartments have higher stress levels, nearly double the rate of Kampong residents, 3.99/2.08, respectively.

In Kampongs, the average age of the building is 31.7 years, compared to 6.5 for apartments. As mentioned earlier, residents in Kampongs have lived in their current houses for a longer period than apartment residents. The penetration rate of air conditioners (AC) and exhaust fans, which is substantially higher in apartments (85.4 and 66.7%) than that in kampongs (20.9% and 10.6%), is correlated with the greater use of natural ventilation (opening windows) in kampongs compared to apartments. In contrast, Kampongs (99.3%) use fans more frequently. AC units in apartments are typically installed in the living room and main bedroom, and they are often used during nighttime (Mori et al., 2018). Water leakage is more common in Kampongs (69.8%) than in apartments (23.2%), resulting in a higher reported occurrence of mold growth in Kampongs (42.4%) compared to apartments (25.4%). In Surabaya, over 14.9% of Kampong homes lack any windows in the bedrooms, while 12.4% of apartments lack windows in the living rooms. Moreover, even though the apartment's rooms are relatively small, there are more pieces of furniture in the living room and master bedroom (3–4 units) than there are in Kampong (3 units).

Additionally, the occurrence of smells is more common in Kampong (51%) compared to apartments (40%). However, Kampong and the apartments both have generally neutral ratings for the respondents' perceptions of the indoor and outdoor air quality. Similarly, the perceived humidity level is also neutral, but a higher percentage of Kampong respondents rate their homes as relatively humid (23.5%) compared to apartment respondents (13.7%).

Table 3.5 Brief profile of respondents from the survey in Kampong and apartments

	K = Kampongs, A = Apartments		**K**	**A**	**All data**	n	*p*-value K-A
Personal attributes	Age [%]	Years [mean]	39.7	27.6	32.0	791	<.001[a]
		< 20	14.3	15.6	18.0		
		20 – 29	13.0	53.0	37.3		
		30 – 39	17.7	7.4	12.4		
		40 – 49	27.0	8.2	16.4		
		> 50	28.0	8.0	15.9		
	Gender [%]	Male/ Female	36/64	41/59	39/61	827	.115 [b]
	Living time in house	Years [mean]	25.3	2.8	12.8	769	<.001[a]
	Income (US$) [%]	< 150	24.8	7.8	13.7	738	<.001[b]
		150-450	56.4	32.2	41.2		
		450-750	9.4	19.3	15.3		
		> 750	9.4	40.7	29.8		
	Occupation [%]	Government	4.0	5.3	5.0	824	<.001[b]
		Private	21.9	21.3	21.5		
		Entrepreneur	21.5	8.9	13.5		
		Student	19.2	52	40.2		
		Housewife	24.6	8.3	14.2		
		Retired	6.7	8	2.9		
		Other	2.0	3.4	2.8		
	Window opening in bedroom	Hours	12.95	7.1	9.0	678	<.001[a]
	Window opening in living room	Hours	13.04	7.2	9.8	610	<.001[a]
	Smoking Behavior [%]	Active	14.5	14.2	14.3	837	.881 [b]
		Passive	45.4	17.4	27.4	834	<.001[b]
Health	Asthma	[%]	12.8	14.4	13.8	831	.516 [a]
	Eczema	[%]	25.3	23.8	24.4	829	.628 [a]
	Allergy	[%]	31.6	22.6	25.8	824	.005 [a]
	Stress	[mean: 0 = no stress, 10 = very stressful]	2.08	3.99	3.36	876	<.001[a]
Building attributes	Age of building [%]	Average age [a] [years]	31.7	6.5	15.0	747	<.001[a]
		<5 years	3.7		25.0	746	<.001[a]
		5-10 years	11.9		40.8		
		11-50 years	63.4		28.2		
		>50 years	20.9		6.0		
	No. of windows in master bedroom [%]	0	14.9	3.7	6.2	629	<.001[b]
		1	66.3	75.3	73.0		
		>1	18.8	21.0	20.8		
	No. of windows in living room [%]	0	3.8	12.4	8.8	558	<.001[b]
		1	74.3	59.6	65.8		
		>1	21.9	28	25.4		
	HVAC system [%]	AC	20.9	85.4	64.1	816	<.001[b]
		Ceiling / stand fan	99.3	33.5	57.7	771	<.001[b]
		Exhaust fan	10.6	66.7	44.9	732	<.001[b]
	Modification(s)	[%]	71.1	23.4			
	Water leakage	[%]	69.8	23.2	39.2	824	<.001[b]

Interior sources	Mold	[%]	42.4	25.4	32.9	819	<.001[b]
	Mite	[%]	6.0	14.2	11.5	827	<.001[b]
	Furniture (units)	Living room [mean]	3	4	3	718	<.001[a]
		Bedroom [mean]	3	5	4	663	<.001[a]
Perceived IAQ	Smell / Odor	[%]	51.0	40.8	44.5	820	.012 [b]
	IAQ [%]	0-3: (rather) clean	42.1	42.9	42.5	756	.765 [a]
		4-6: neutral	46.7	45.7	45.2		
		7-10: (rather) dirty	11.2	11.4	12.3		
	OAQ [%]	0-3: (rather) clean	38.8	24.3	31.4	749	.568 [a]
		4-6: neutral	43.4	50.1	47.0		
		7-10: (rather) dirty	17.8	25.6	21.6		
	Humidity [%]	0-3: (rather) dry	30.9	30.0	31.3	725	.121 [b]
		4-6: neutral	45.6	56.3	50.2		
		7-10: (rather) humid	23.5	13.7	18.5		

[a] Independent Samples t-Test [b] Chi-Square-Test [c] One-way Anova

3.4 Multiple chemicals sensitivities (MCS) risk

Figures 3.3 and 3.4 depict the results of calculated MCS risk and sensitivity in different study locations. It can be observed that only 21.9% of respondents in Kampongs exhibit some degree of intolerance. However, apartments had a substantially larger proportion of problematic respondents, at 48.8% in Surabaya, 40.7% in Jakarta, and 37.4% in Bandung, respectively (Figure 3.3). Similarly, in terms of chemical sensitivity, Kampong respondents demonstrate significantly lower levels of sensitivity (Figure 3.4). Apartments in Surabaya displayed the highest levels of MSC risk and sensitivity when compared to other places, with percentages more than double that of Kampong. Previous studies, such as those described by Hildebrandt et al. (2019), reported similar shares of MCS risk in apartments in South Korea (37%) (Jeong et al., 2014), while only 25% of respondents in Japan were categorized as 'very suggestive' or 'problematic' for MCS risk (Hojo et al., 2005). Additionally, in the United States, the percentage of individuals with high sensitivity across three scales was found to be just 6.6% (Miller & Prihoda, 1999). Additionally, compared to what was observed in these earlier research, the proportion of high MCS risk categories and responders with high sensitivities is much lower in Kampongs.

Furthermore, Figure 3.5 presents the final comparative results of QEESI between Kampong and apartments. It is evident that MCS risk and degree of sensitivity in apartments are substantially higher compared to Kampong. The percentages of respondents falling into the "somewhat suggestive," "problematic," and "very suggestive" categories are almost double in apartments compared to Kampong, with MCS risk at 42.5% / 21.9% and sensitivity at 47.7% / 26.3%.

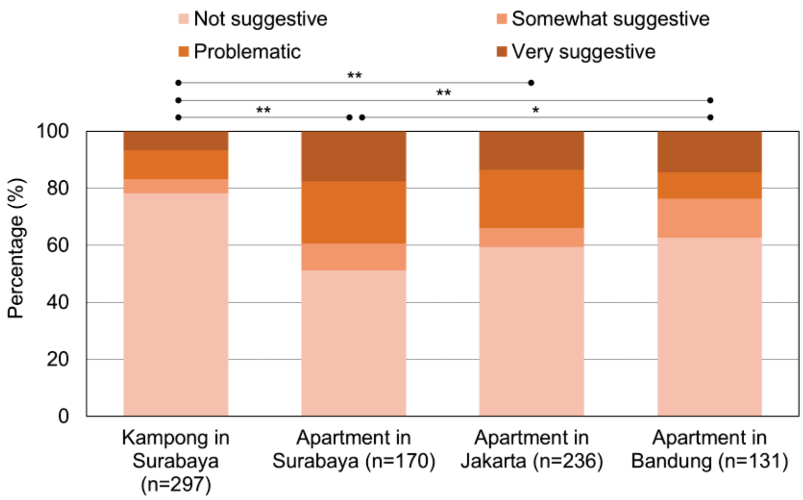


Figure 3.3 Results of MCS risk in all house types in three major cities of Indonesia

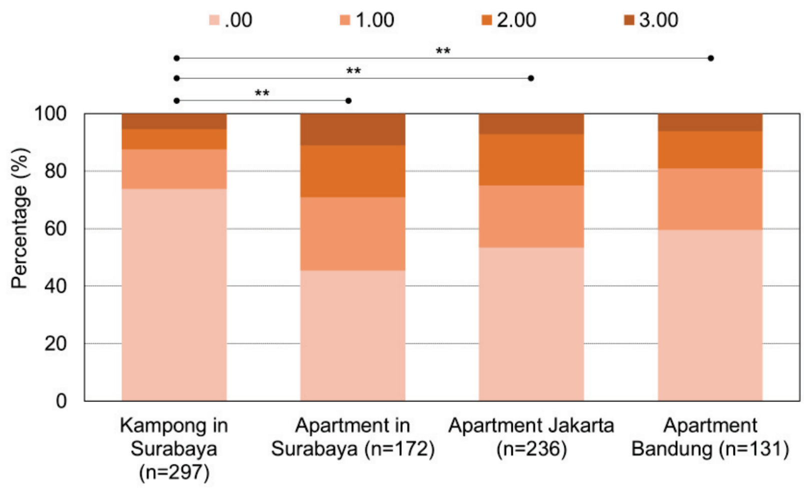


Figure 3.4 Results of Sensitivity risk in all house types in three major cities of Indonesia

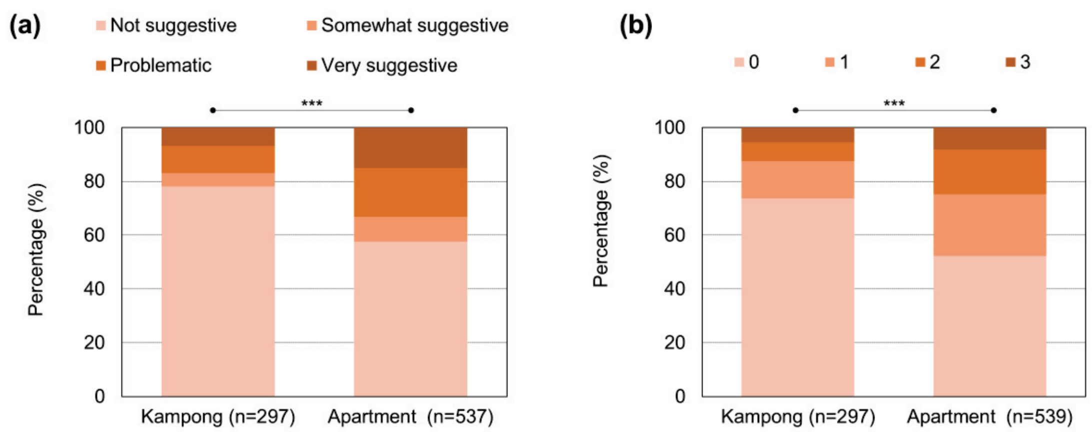


Figure 3.5 Results of (a) MCS risk and (b) Sensitivity in apartments and kampongs (H. Sani et al., 2023)

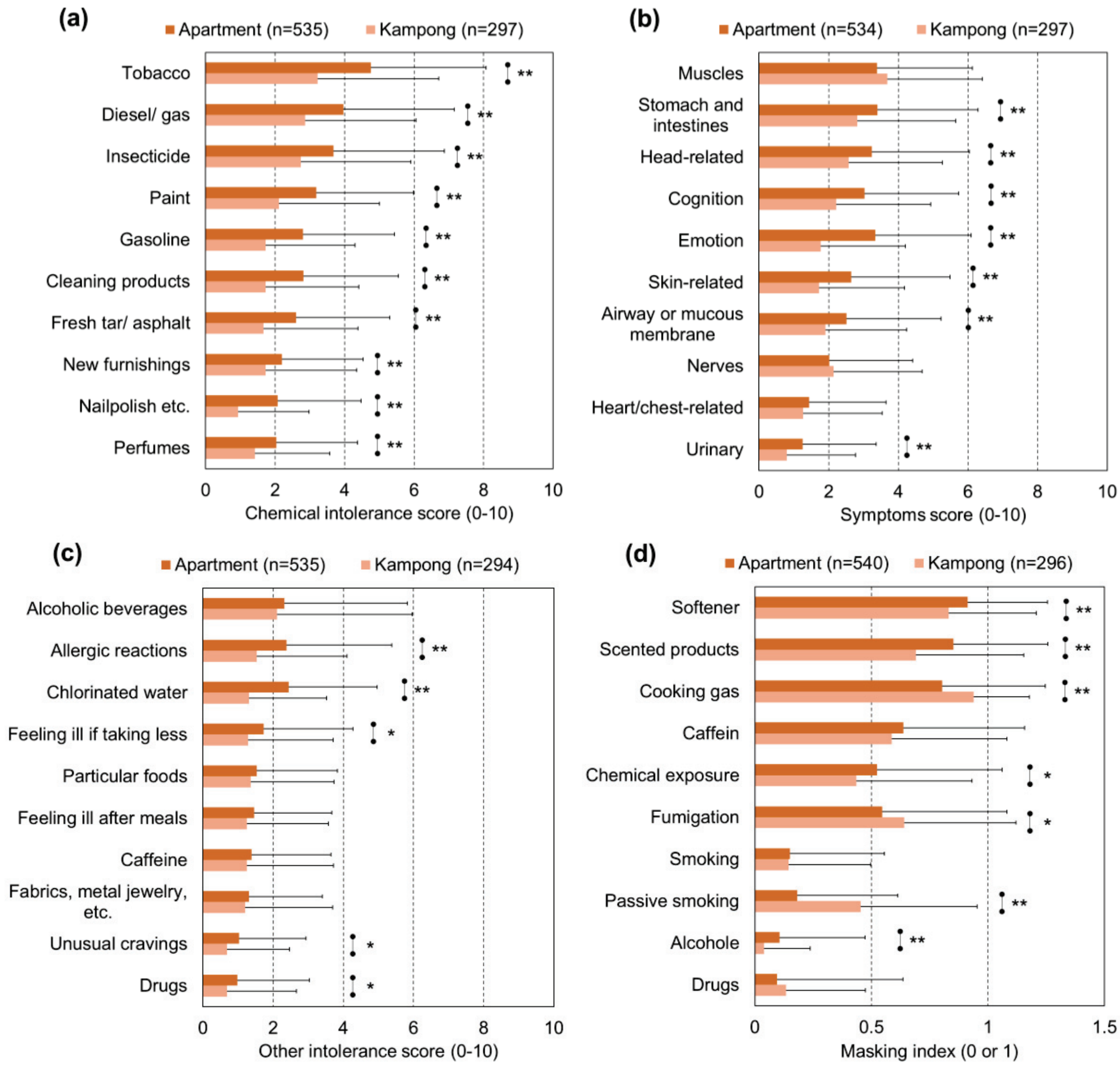


Figure 3.6 QEESI scale of all apartments and Kampongs for (a) chemical intolerance score, (b) symptoms, (c) other intolerances and (d) masking index

Figure 3.6 illustrates the results of the QEESI questionnaire comparing Kampongs and all apartments. Overall, the average levels of intolerance in all chemicals reported by respondents who live in apartments are much higher than those in Kampongs. As depicted in Figure 3.6a, respondents exhibit high levels of intolerance, particularly towards tobacco and diesel/gas, followed by insecticides, paints, gasoline, and cleaning products. The level of intolerance fell within the categories of mild symptoms on average. Additionally, the degrees of intolerance to other chemicals are relatively lower, indicating a minor problem for both apartments and Kampongs (Figure 3.6c). Allergic reactions and exposure to chlorinated water show significantly higher response levels in apartments compared to Kampongs.

Regarding symptom scores, on average, kampongs and apartments demonstrate moderate scores for muscle-related, stomach and intestine-related, head-related, and cognition-related symptoms (Figure 3.6b). Except for the items related to muscles, nerves, and the heart or chest, significant variations in symptoms scores can be observed across the majority of the categories. Similarly, apartment scores are higher than those in Kampongs, but the average symptom scores for muscles and nerves in Kampongs are relatively higher than in apartments. Additionally, the masking index highlights whether there is any ongoing exposure from regularly used household products (Miller & Prihoda, 1999). Figure 3.6d demonstrates that the average index score for the softener, scented goods, chemical exposure, and alcohol is much higher in the apartments. In contrast, cooking gas, fumigation, and passive smoking are significantly more prevalent in Kampongs.

3.5 Indoor air quality (IAQ) measurement

The collected data from the survey underwent calibration to enhance data accuracy. Devices are divided into groups according to type and manufacturer. First, with the temperature set at 28 °C, all devices are examined to identify the representative device for the calibration. The representative device was selected based on its proximity to the average value obtained from all initial measurements for each manufacturer. The calibration curve was developed using data from two representative direct reading devices and the measurement outcomes of the DNPH passive sampler (refer to Table 3.6 and Figure 3.7). As a result, the following formulas can be used to determine the calibrated values for both formaldehyde measurement devices, namely Shinyei (3.3) and Formaldemeter (3.4):

$$y = 3.078^{x1.5106} \quad (3.3)$$

$$y = 1.9921^{x1.2547} \quad (3.4)$$

where x represents the initial values from the direct reading devices (ppm) and y represents the calibrated values (ppm).

Table 3.6 Calibration measurement results

Device	Flow rate (ml/min)	Plastic bag			ppm			Direct Reading Devices			
		AT (°C)	RH (%)	μg/m³	mg/m³	WHO	ppm	AT (°C)	RH (%)	ppm	μg/m³
Formaldemeter	10	28.87	50.22	190.8	0.191	0.814	0.155	29.32	52.2	0.132	160
	20	28.57	51.03	385.1	0.385	0.814	0.313	29.56	51.7	0.232	280
	30	29.2	48.57	594.9	0.595	0.814	0.484	29.92	50.2	0.31	374
	40	29.42	47.85	741.3	0.741	0.814	0.603	30.08	49.7	0.385	464
	60	28.82	47.34	1116.3	1.116	0.814	0.909	29.28	50.4	0.557	674
	80	29.14	44.05	1532.0	1.532	0.814	1.247	29.57	46.6	0.678	819
Shinyei	10	28.65	53.56	190.8	0.191	0.814	0.155	29	44.7	0.152	184
	20	28.57	54.13	385.1	0.385	0.814	0.313	29	44.71	0.205	248
	30	28.7	52.06	594.9	0.595	0.814	0.484	29	43.4	0.286	346
	40	29.15	50.34	741.3	0.741	0.814	0.603	29	43	0.317	383
	60	28.48	50.68	1116.3	1.116	0.814	0.909	29	42.6	0.471	570
	80	28.39	48.18	1532.0	1.532	0.814	1.247	29.5	40.5	0.562	679

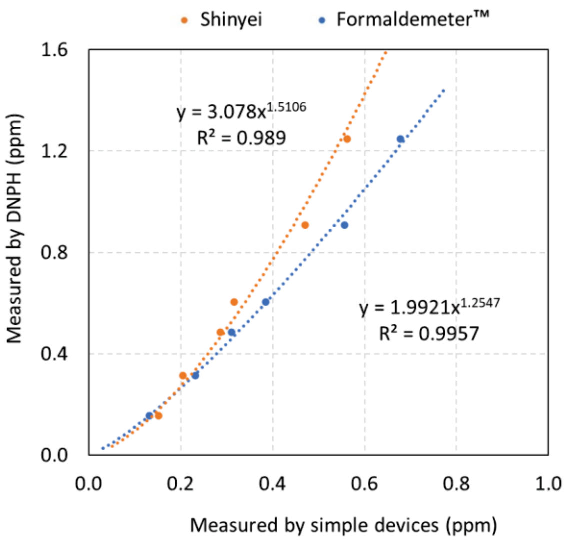


Figure 3.7 Calibration curve for direct reading measurement devices (H. Sani et al., 2023)

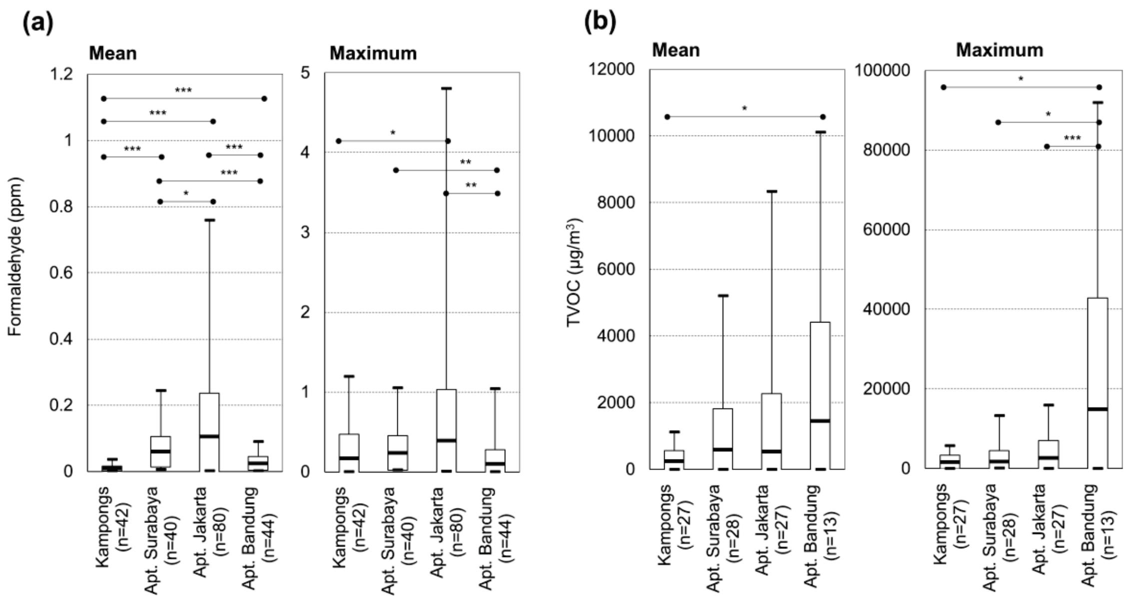


Figure 3.8 Statistical summary of IAQ measurement results of (a) formaldehyde and (b) TVOC in all locations

Figure 3.8 illustrates the calibrated mean and maximum values of formaldehyde and TVOCs during the measurement periods. Moreover, the maximum values across the measurement period can be compared with the main international/domestic standards on IAQ because these values were derived in the field measurement process based on the measured 30 min temporal average values. As shown, the mean formaldehyde concentration in Kampongs significantly differs from that in apartments in Surabaya, Jakarta, and Bandung (Figure 3.8a). On the other hand, the Bandung apartment had significant differences with the mean value of formaldehyde in the apartments in Surabaya and Jakarta in both the mean and maximum values. Apartments in Jakarta exhibit the highest formaldehyde concentration, both in mean (0.106 ppm) and maximum (0.391 ppm) values. Apartments in Bandung have a higher concentration compared to Kampongs (mean: 0.024 ppm and 0.009 ppm), but it is relatively lower than the apartments in the other two cities (Surabaya: 0.060 ppm, Jakarta: 0.106 ppm). However, compared to Kampung and other apartments, the maximum concentration of formaldehyde in apartment Bandung is the lowest at 0.102 ppm. In contrast, Bandung apartments have the greatest TVOC concentration, both in terms of mean value (1.455 mg/m^3) and maximum value (14.883 mg/m^3). As a result, there is a considerable difference between apartments in Bandung and other places, particularly in terms of maximum value (Figure 3.8b). In contrast to Kampong, the apartment had a higher concentration of TVOC overall.

Figure 3.9 presents the combined formaldehyde and TVOC data for all apartments compared to Kampongs. As expected, both the mean and maximum values of formaldehyde and TVOC concentrations in apartments are greater than those in Kampong. The mean formaldehyde concentrations in Kampongs vary from 0.002 to 0.036 ppm (mean: 0.009) and the maximum values from 0.005 to 1.197 ppm (mean: 0.172 ppm). Conversely, in apartments, the concentrations are significantly higher ($p<0.01$), with mean values ranging from 0.002 to 0.759 ppm (mean: 0.073 ppm) and maximum values ranging from 0.002 to 4.802 ppm (mean: 0.275 ppm). Similarly, the average concentration of TVOCs in apartments is three times higher than that in Kampongs, both in mean ($p<0.05$) and maximum values. Furthermore, TVOC concentrations in apartments range up to 10.12 mg/m^3 in mean value and 91.90 mg/m^3 in maximum value.

The previous result from the measurements shows several extreme readings from both mean and maximum value of formaldehyde and TVOC. Those extreme cases happened in several houses in a short time, indicating a sudden exposure from certain source. Therefore, those extreme values which considered as outliers are removed and the results are depicted in Figure 3.10. Overall, the tendency of higher concentrations in apartments, both mean and maximum values ($p<0.01$), remains the same as before removing the outliers. The average values for formaldehyde in apartment were 0.060 ppm (mean value) and 0.198 ppm (maximum value) and in Kampong were 0.008 ppm (mean value) and 0.072 ppm (maximum value). Additionally, in kampong the measurement results for formaldehyde range up to 0.024 ppm (mean) and 0.346 ppm (maximum), whereas it reaches 0.27 ppm (mean) and 1.043 ppm (maximum) in apartment. In TVOC, the maximum values were reduced from 91.90 mg/m^3 to 15.89 mg/m^3 (maximum value) and from 10.12 mg/m^3 to 4.6 mg/m^3 in apartment after removing the outliers. However, measurement results from apartment units remain higher compared to the TVOC concentration in Kampong.

Moreover, the mean values of formaldehyde (0.009 ppm in Kampongs and 0.073 ppm in apartments) were found to be higher than those reported in most previous studies. For instance, in France, formaldehyde concentrations ranged from 0.01 to 0.02 ppm (Bentayeb et al., 2013), while in Japan, concentrations were around 0.03 ppm (Araki et al., 2010; Saijo et al., 2011), and in China, concentrations ranged from 0.03 to 0.04 ppm (Huang et al., 2011). As previously discussed in the paper by Hildebrandt et al., (2019), the measured maximum concentrations of 0.274.802 ppm are also significantly higher than those found in Japanese studies, which were 0.15 ppm (Saijo et al., 2011) or 0.16 ppm (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 even exceeded the maximum of 0.29 ppm reported in a study on 'very suggestive' MCS cases in Japan (Hojo et al., 2005).

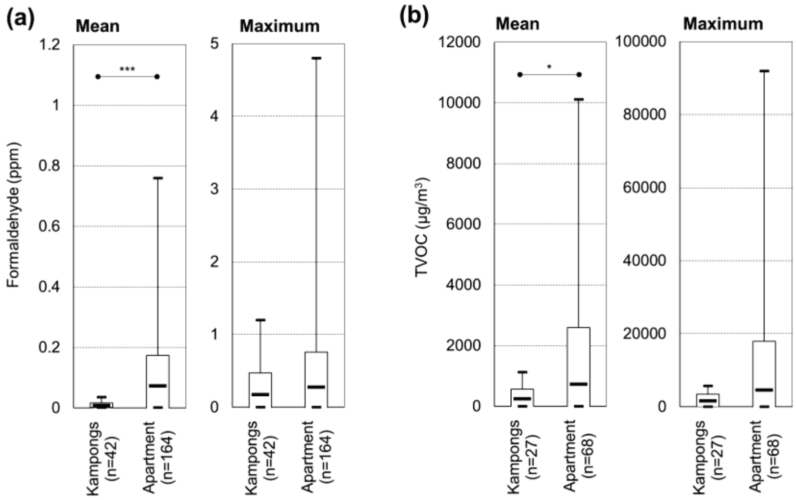


Figure 3.9 Statistical summary of IAQ measurement results of (a) formaldehyde and (b) TVOC of apartment compared to Kampongs (H. Sani et al., 2023)

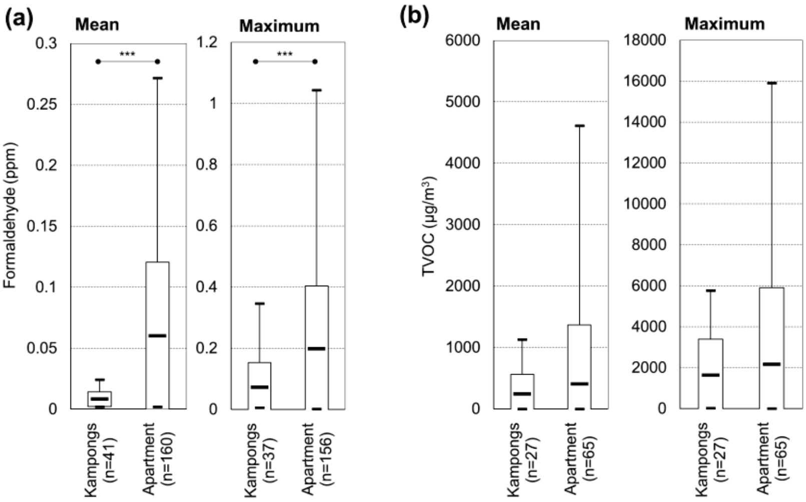


Figure 3.10 Statistical summary of IAQ measurement results of (a) formaldehyde and (b) TVOC of apartment compared to Kampongs after removing the outliers

Formaldehyde and TVOC cumulative frequencies are shown in Figures 3.11 and 3.12, respectively. Figure 3.12 shows the Indonesian standard of 430 g/m^3 for TVOC as a reference because there is no worldwide standard for the TVOC, while the WHO guideline of 0.08 ppm and the Indonesian standard of 0.1 ppm for formaldehyde are also displayed in Figure 3.11. Overall, and especially in the mean value, Figure 3.11 demonstrates that the formaldehyde concentrations in apartments are higher than in kampongs. More than 20% of the measured apartment samples exceeded both the Indonesian and WHO standards in mean value, with 22% exceeding the Indonesian standard and 27% exceeding the WHO standard. Additionally, 85-87% of apartment samples and 57-64% of Kampong samples exceeded the two standards in maximum value. However, it should be emphasized that extremely high maximum values can be found in both apartments and kampongs. This indicates that compared to kampongs, apartments appear to have higher background formaldehyde concentrations. Even in Kampongs, there are, however, a few unusual instances where formaldehyde levels are sporadic very high (Kubota et al., 2021).

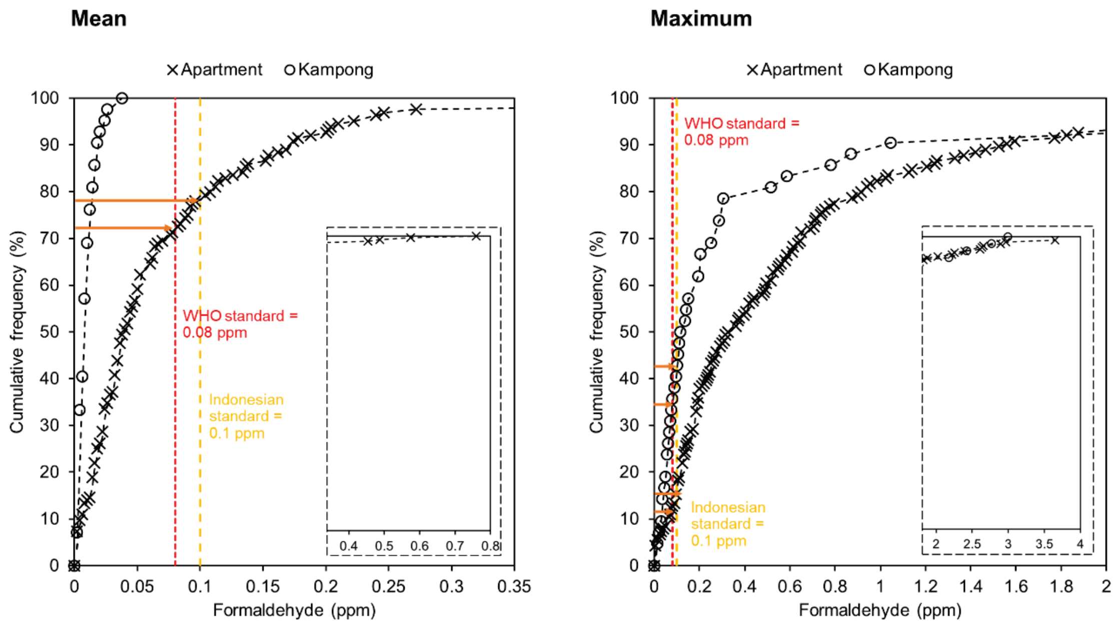


Figure 3.11 Cumulative frequency of formaldehyde concentration (H. Sani et al., 2023)

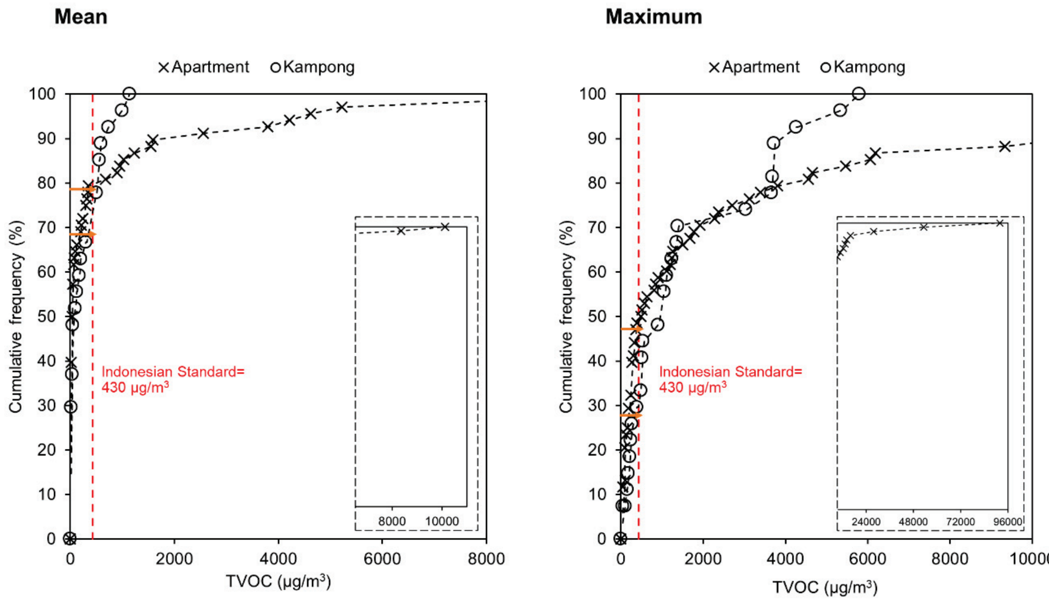


Figure 3.12 Cumulative frequency of TVOC concentration (H. Sani et al., 2023)

Similarly, higher TVOC values were observed, especially in apartments compared to Kampongs (Fig. 3.12). The total number of rooms exceeding the standard was higher in apartments than in Kampongs, with 14 rooms exceeding the standard in mean value and 45 rooms exceeding the standard in maximum value in apartments, while Kampong had 9 rooms exceeding the standard in mean value and 19 rooms in maximum value. However, a higher percentage of the Kampong samples—both in mean and maximum values—than the apartment samples surpassed the Indonesian threshold of 430 g/m^3. For TVOC, extremely high amounts were seen in a number of apartment samples. These measurement results are significantly higher than those from Japan, where 8% of buildings were found to have the TVOC levels stated (Takigawa et al., 2010), and, in the case of the maximum value, higher than those from China (61%) as well (Huang et al., 2011).

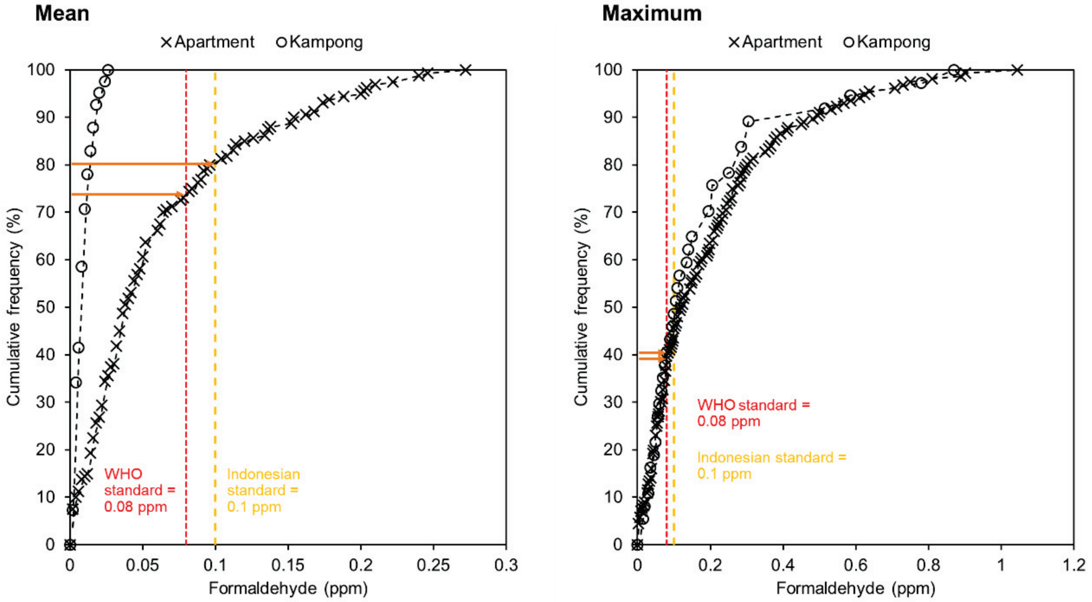


Figure 3.13 Cumulative frequency of formaldehyde concentration after removing the outliers

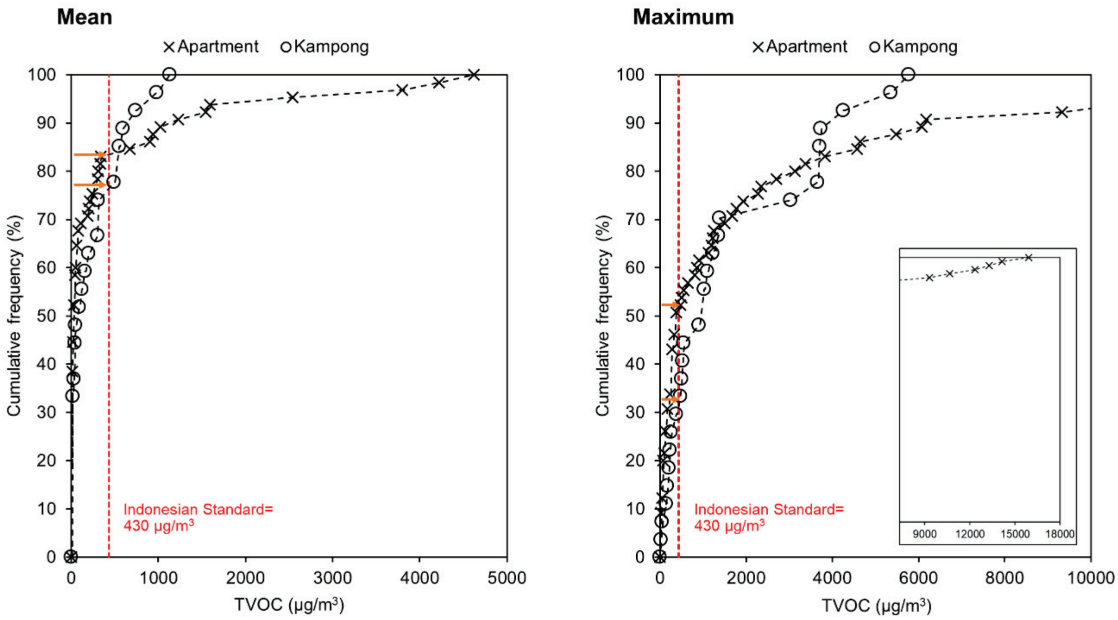


Figure 3.14 Cumulative frequency of TVOC concentration after removing the outliers

Figures 3.13 and 3.14 depict the cumulative frequency of the measurement result after removing the extreme values (outliers). Compared to WHO and Indonesian standard for formaldehyde, 20-25% of the units in apartments exceed the suggested value of 0.08 -0.1 ppm. Whereas in Kampong, all houses have a low concentration less than the suggested value. Additionally, in maximum value, both apartment and Kampong, 60% of the units/houses have formaldehyde concentration higher than the standard. In TVOC, the percentage of the houses exceeding Indonesian standard for VOCs is higher in Kampong compared to apartment, in both mean and maximum value, 22/18% and 68/48%, respectively. However, the number of samples are more in apartment compared to Kampong overall.

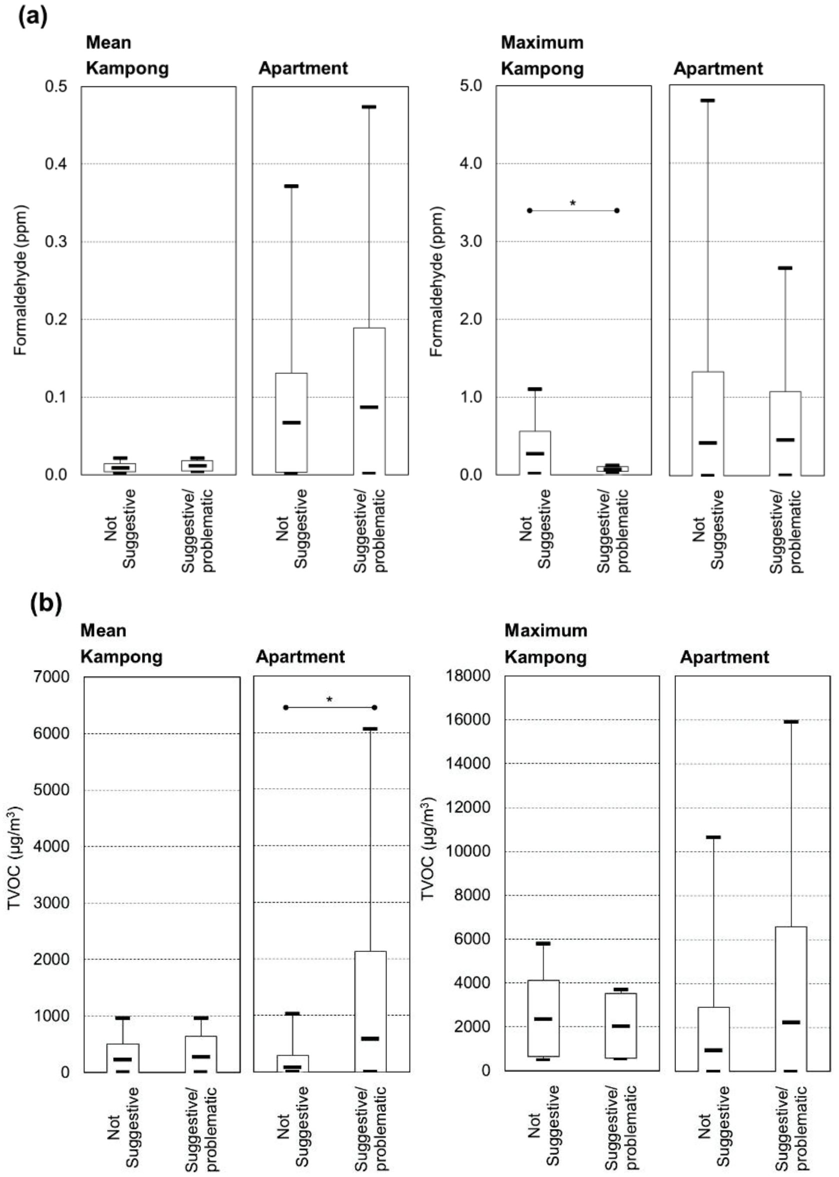


Figure 3.15 IAQ concentrations based on different MCS risk group (a) Formaldehyde and (b) TVOC (H. Sani et al., 2023)

Furthermore, the average values of formaldehyde and TVOCs were analyzed to explore the correlation between measured IAQ and the degree of MCS risk. Four MCS risk groups were consolidated into two groups, with the 'somewhat suggestive,' 'problematic,' and 'very suggestive' groups merged into one group, while the 'not suggestive' group formed the second group (Figures 3.15). Overall, the results show that respondents who reside in apartments with higher TVOC and formaldehyde concentrations tend to have a higher propensity for chemical sensitivity. As can be shown in Figure 3.15b, the 'suggestive/problematic' group in the apartments was typically exposed to a level of TVOC that was six times higher in mean value than another group (123.6 g/m^3 and 848.7 g/m^3). The average for the "suggestive/problematic" group, on the other hand, is higher than twice as high (1.512 mg/m^3) as the "not suggestive" group in maximum value. Similar results were observed for mean and maximum formaldehyde values (Figure 3.15a). The 'suggestive/problematic' group in apartments had a mean value of 0.02 ppm higher than the other group, and the maximum value was 0.038 ppm higher. However, higher maximum formaldehyde values were observed in the 'not suggestive' group in apartments compared to the 'suggestive/problematic' group. This suggests that the effect on respiratory health may be more apparent when occupants are exposed to consistently high concentrations of formaldehyde rather than sudden increases.

3.6 Factors correlated to MCS risk

Depending on the variables, Spearman's test or Chi-square test correlation studies were performed to determine the parameters affecting MCS risk and sensitivity in Kampongs and apartments (Table 3.7). The variables were divided into five groups, consistent with Table 3.5: personal attributes, health, building attributes, interior, and IAQ. The entire dataset was also combined to examine the correlations across all samples.

In Kampong, apartments, and all data, it was discovered that health parameters were substantially connected with MCS risk and sensitivity levels. As discussed in Hildebrandt et al. (2019), several studies suggest a relationship between stress or mental well-being and the reporting of MCS symptoms (Cui et al., 2015; Mendelson et al., 2000; Robert Koch-Institut, 2018; Runeson-Broberg & Norbäck, 2013). Additionally, another study (J. Wang et al., 2013) discovered that the prevalence of asthma, eczema, and allergies is related to MCS risk and/or sensitivity.

In terms of personal attributes, increasing age, decreased cleaning frequency, and higher income were found to increase MCS risk and sensitivity in Kampongs. Conversely, in apartments, MCS risk and sensitivity were higher among male respondents, in newer buildings, and with reduced window-opening duration in the bedroom. However, in the overall dataset, less time spent opening windows, more furniture, and female respondents are found to have increased MCS risk and sensitivity in all data. These findings are related to the fact that flats and Kampong have significantly different window-opening times (Table 3.5). Additionally, certain variables did not show a significant correlation in the apartment and Kampong analyses but exhibited a significant correlation in the combined dataset analysis. For instance, the duration of living in the current house and window-opening duration in the living room were significantly correlated with sensitivity and MCS risk in the combined data.

The MSC risk and sensitivity are found to be substantially connected with building age, the number of windows in the living room, and air conditioning (AC) ownership in buildings, as is to be predicted. In the overall dataset, MCS risk and sensitivity were higher in newer buildings, which is also associated with shorter durations of occupancy in the current house. However, in apartments, older buildings were found to increase MCS risk and sensitivity, suggesting that apartments pose a higher risk of sick building syndrome (SBS) compared to Kampongs, but it may take a longer exposure period for respondents to become aware of the symptoms and risks. In the meantime, MCS risk and/or sensitivity in Kampongs are increased by the history of modifications and the rise in the number of windows in the main bedroom and living room. Additionally, AC ownership had a substantial impact on MCS risk and sensitivity, particularly in Kampong and combined data, but not for apartment respondents, where AC is present in 85.4% of units (Table 3.5). In Kampongs, reports of mold growth significantly increased sensitivity and MCS risk. Similarly, an increasing number of furniture in the living room exhibited a significant correlation with MCS and sensitivity in Kampongs and the overall dataset. Likewise, in the IAQ factor, reports of smell were significantly related to MCS and sensitivity in Kampongs and the overall dataset. However, self-rated IAQ and outdoor air quality were significantly correlated with MCS and sensitivity in apartments, indicating that worsened air quality was associated with higher risk and severity levels.

Table 3.7 Results of MCS correlation analysis

R = MCS Risk S = Sensitivities	**All data**		**Apartment**		**Kampongs**	
	R	**S**	**R**	**S**	**R**	**S**
Personal attributes						
Age[b]	-.043	-.063	.027	-.009	.100	.121*
Gender[a]	1850**	1799**	658.1**	615.7**	309.4**	311.8**
Living in home [years][b]	-.178**	-.183**	-.010	-.021	-.044	.018
Income[b]	.182**	.200**	.008	.038	.283**	.268**
Occupation[a]	43.86**	43.65**			43.86**	43.65**
Window-opening_ bedroom[b]	-.186**	-.183**	-.097*	-.108**	-.047	-.019
Window-opening_ livingroom[b]	-.148**	-.160**	-.041	-.077	-.006	.011
Cleaning of rooms[b]	.072*	.108*	-.063	-.024	.143*	.184*
Cleaning of bathroom[b]	.062	.098*	.038	.071	-.001	.033
Cleaning of bedcloths[b]	.049	.069*	.008	.042	.062	.037
Health						
Asthma[a]	1863**	1834**	655.2**	631.1**	306.2**	308.9**
Eczema[a]	1866**	1847**	648.7**	635.0**	325.4**	325.3**
Allergy[a]	1872**	1843**	671.2**	649.6**	307.8**	306.8**
Stress[b]	.309**	.349**	.198**	.253**	.365**	.368**
Building attributes						
Age of building [years][b]	-198**	-.192**	-.105*	-.099*	-.026	.022
Windows_ masterbedroom[b]	.019	.037	-.098*	-.075	.177**	.173**
Windows_living room[b]	.108**	.119**	.036	.055	.265**	.262**
AC[a]	136.2	141.6	205.9**	200.3**	28.25	35.72
Fan[a]	894.6**	880.9**	602.5**	598.5**	2.27	3.32
Modifications[a]	-	-	-	-	10.86	6.55
Water leakage[a]	18.30	22.60	25.05	35.05**	5.06	7.17
Interior						
Mold[a]	24.90	20.60	32.71	30.31	14.23	13.00
Mite[a]	47.02*	35.93	42.53*	35.62	.560	.571
Furniture_living room[b]	.064	.083*	-.045	-.017	.136*	.136*
Furniture_bedroom[b]	.069*	.056	.050	.048	.001	-.028
IAQ						
Smell[a]	109.4	104.3	105.6	104.5	11.04	10.78
Humidity[b]	.023	.017	.039	.023	.022	.033
IAQ rating[b]	.080*	.068*	.126**	.115**	.003	-.004
OAQ rating[b]	.129*	.130**	.082*	.084*	.105	.099

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

3.7 Factors correlated to formaldehyde and TVOC concentrations

Another correlation analysis was conducted to examine the influence of building attributes and occupants' behavior on IAQ measurement results, specifically formaldehyde and TVOC concentrations. Spearman's test, Pearson's test, or Chi-square test were employed based on the types of variables. Table 3.8 illustrates the findings in Kampongs. In Kampongs, behavioral factors such as window opening and cleaning showed significant correlations with formaldehyde and TVOC concentrations. The length of window openings and the mean formaldehyde concentration in Kampong's bedroom had a negative connection (-.417, $p<0.01$), suggesting that the lower the formaldehyde level, the longer the window openings last. This suggests that the main source of formaldehyde in Kampongs may be within the bedroom. In contrast, Kampong's and the apartment's bedrooms' window-opening times have a positive association with the mean TVOC, suggesting that the source of TVOC may be somewhere outside of the rooms. A similar pattern was observed in the living room for the maximum value of formaldehyde, indicating that sudden increases in formaldehyde occurred when the windows were opened. However, in apartments, window-opening duration did not significantly correlate with formaldehyde concentrations, despite its significant correlation with MCS risk and sensitivity (Table 3.7).

Additionally, there is a positive correlation between the highest formaldehyde in Kampong and the frequency with which bedclothes are cleaned (.433, $p=0.01$), suggesting that the more frequently they clean, the greater the average maximum concentration of formaldehyde would be. In terms of TVOC, the frequency of bathroom cleaning (.389, $p<0.05$) was significantly correlated with maximum TVOC concentrations. Additionally, in apartments, room and bedclothes cleaning frequencies positively correlated with the mean and maximum TVOC concentrations. This greater formaldehyde and TVOC percentage is probably due to the cleaning supplies. However, cleaning frequency in apartments did not exhibit a significant correlation with mean and maximum formaldehyde concentrations, necessitating further investigation to clarify this discrepancy.

Despite the MCS and sensitivity statistical analysis results where building age indicated a strong negative correlation., there was no significant link between formaldehyde and TVOC for either Kampong or apartments. Additionally, AC ownership demonstrated a significant correlation with formaldehyde and TVOC in Kampongs ($p<0.01$). While TVOC is not substantially connected with AC ownership in apartments ($p>0.01$), the mean and maximum levels of formaldehyde are. Mold and water leakage occurrences only showed significant correlations with formaldehyde and TVOC concentrations, while no significant correlation was found with MCS and sensitivity. These results indicate that IAQ problems and MCS risk may share common causes, but some IAQ problems are not directly correlated with SBS.

In apartments, the mean and maximum formaldehyde concentrations significantly correlated with the number of furniture in the living room and bedroom ($p<0.01$). In Kampongs, the number of furniture in the bedroom correlated with mean formaldehyde ($p<0.01$), and the number of furniture in the living room correlated with maximum formaldehyde ($p<0.05$). Indicating that furniture may be a potential source of formaldehyde in both apartments and Kampong, the concentration of formaldehyde increases with the number of pieces in the space. Additionally, wallpaper usage exhibited a positive correlation with TVOC and formaldehyde concentrations. When wallpaper was installed, the mean and maximum TVOC and formaldehyde concentrations were generally higher in apartments. Additionally, formaldehyde and TVOC substantially correlate with the presence of smells. In example, the presence of organic smells is positively correlated with greater TVOC concentrations in residences and kampongs, whereas the presence of smells is negatively correlated with higher formaldehyde concentrations. Furthermore, self-rated humidity and IAQ were strongly correlated with TVOC concentrations, whereas in apartments, personal ratings of humidity, IAQ, and OAQ showed no correlation with TVOC and formaldehyde.

Table 3.8 Results of IAQ formaldehyde and TVOC value correlation analysis

Me = Mean Mx = Maximum	Apartments				Kampongs			
	Formaldehyde (*n*=130)		TVOC (*n*=61)		Formaldehyde (*n*=47)		TVOC (*n*=35)	
	Me	**Mx**	**Me**	**Mx**	**Me**	**Mx**	**Me**	**Mx**
Behavioral factors								
Living in home [years][c]	.010	.001	.097	.040	.040	.274	-.515**	-.408*
Window-opening_ bedroom[c]	-.070	-.088	-.262*	-.231	-.417**	.081	.395*	.229
Window-opening_ living room[c]	-.107	-.024	-.183	-.070	-.168	.323*	.292	.142
Cleaning of rooms[b]	.049	-.028	.262*	.238	-.095	.205	.058	.126
Cleaning of bathroom[b]	-.001	.151	.052	-.019	-.045	.246	.299	.389*
Cleaning of bedclothes[b]	-.026	-.120	.337**	.256*	.156	.433**	.050	.208
Building attributes								
Age of building [years][c]	-.088	-.030	-.052	.218	.038	.247	-.101	-.209
AC availability[a]	508**	634**	106.1	106.1	34.8**	47**	35**	35**
Fan availability[a]	703**	863**	212.7	212.7	8.58	47**	35**	35**
Exhaust fan availability[a]	423**	491**	122**	122**	77.8**	141**	35**	35**
Water leakage[a]	311**	328**	118**	118**	29.8**	47**	35**	35**
Interior								
Mold[a]	245**	249**	61*	61*	24.04*	47**	35**	35**
Mite[a]	255**	274**	73.2	73.2	22.4*	47**	-	-
Wallpaper usage[a]	559**	574**	244**	244**	-	-	-	-
Gypsum usage[a]	520**	551**	244**	244**	-	-	-	-
Furniture_living room[c]	.181*	.078	-.043	-.089	.244	.335*	-.035	.154
Furniture_bedroom[c]	.260**	.256**	.058	.038	.525**	-.097	-.254	-.197
IAQ								
Smell[a]	371**	372**	57.9*	57.9*	36.4**	47**	35**	35**
Humidity[b]	.150	-.110	.029	.035	-.320*	-.050	.468**	.182
IAQ rating[b]	.137	-.013	-.192	-.246	-.166	-.268	.485**	.328
OAQ rating[b]	.016	.038	-.078	.033	.276	-.146	-.239	-.125

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

3.8 Summary

The circumstances of indoor air quality and their consequences on health in Indonesian urban homes are being revealed for the first time through this chapter. The primary findings from the investigations conducted in Surabaya, Jakarta, and Bandung are as follows:

MCS risk and sensitivity varied significantly between Kampongs and the recently built apartments. About 42% of apartment respondents displayed some level of MCS risk, indicating a potential spread of sick building syndrome. In Kampongs, the average maximum level of formaldehyde was 0.172 ppm, whereas it was 0.275 ppm in the newly built apartments. All the above-average values exceeded the WHO standard of 0.08 ppm and values reported in prior studies. Similarly, the total volatile organic compound (TVOC) levels were not significantly different from formaldehyde levels. On average, the maximum TVOC values were 1,643 $\mu g/m^3$ in Kampongs and 4,620 $\mu g/m^3$ in apartments, surpassing the Indonesian standard of 430 $\mu g/m^3$. In apartments, roughly 80% of the rooms had relatively low average TVOC levels, while the remainder exhibited higher values, reaching up to 10,122 $\mu g/m^3$

TVOC concentrations in apartments were found to be higher for the responders who had a higher MCS risk. Notably, opening windows for longer durations resulted in lower formaldehyde levels, particularly in the main bedroom of Kampongs. Nevertheless, the age of the building was considered a significant factor contributing to increased formaldehyde levels in apartments, with older buildings showing higher levels. However, there was a strong correlation between SBS risk (MCS and sensitivity) and the newer building. IAQ is not the only important factors that influences MCS risk and sensitivity of residents in recently built apartments. These factors included higher stress levels, male gender, outdoor air quality (OAQ) ratings, the prevalence of allergic diseases, and the number of windows in the living room.

In Kampongs, the proportion of high MCS risk groups and respondents with high sensitivity was relatively low, at 22% and 26%, respectively. However, there is a significant correlation between the concentration of TVOC and formaldehyde and the self-rate humidity, IAQ, and OAQ. Additionally, an alarming percentage of the measured homes (more than 80%) fell into the highest fungal index category, D, indicating issues with mold and moisture (Kubota et al., 2021). This suggests that there may be more IAQ issues even in Kampongs that cannot be determined by the level of chemical intolerance and that additional research is necessary to ascertain.

4

Factors Affecting MCS Risk in Newly Constructed High-rise Apartments

4.1 Introduction

In parallel with the previous chapter, further statistical analysis and measurement were performed to examine the factors affecting MCS risk (see Chapter 3). This chapter's objectives are to investigate the main reasons for SBS problems. This information is essential for the basics in the decision-making for the planning and design for future study and simulation for improving indoor air quality. In this chapter, several variables found to be significant in previous results (see Chapters 3) were analyzed further with principal component analysis (PCA), path analysis, and structural equation modeling (SEM). Path analysis and SEM model analysis process to find the interrelations of the variable affecting MCS are described in Section 4.4.

4.2 Methods

This chapter discusses the results of a further statistical analysis based on the existing data. In the first part, the existing data from the previous survey in 2017-2019 were further analyzed with principal component analysis. Secondly, following the statistical analysis, path, and structural equation modeling were performed.

In the previous chapter, it was found that there are several variables significantly affecting MCS risk in the apartments and Kampong (see Chapter 3). However, the interrelationship of those variables has not been explored yet. Therefore, path analysis and structural equation modeling were performed to understand the interconnection between each factor affecting self-reported health (MCS risk) and SBS in urban houses in Indonesia. The analysis was done based on the house type, Kampong, and apartment, for both path and SEM analysis. In total, there are 298 samples in Kampong and 598 samples in apartments.

A structural equation model (SEM) is an advanced statistical methodology widely used in the social sciences that overcome the limitations of previous statistical models such as multiple regression, factor analysis, ANOVA, and discriminant analysis (Lee & Kim, 2015). SEM has a very flexible model structure to represent various interdependent variables simultaneously and demonstrate the relative influences of causalities and correlations and thus can be used to verify the causalities of variables produced by other statistical methods (Lee & Kim, 2015; Nugroho et al., 2011). This study's data mining began with correlation and linear regression and continued with path analysis. In addition, significant variables were identified in the explanatory and confirmatory factor analysis to find the latent variables for SEM analysis (Figure 4.1).

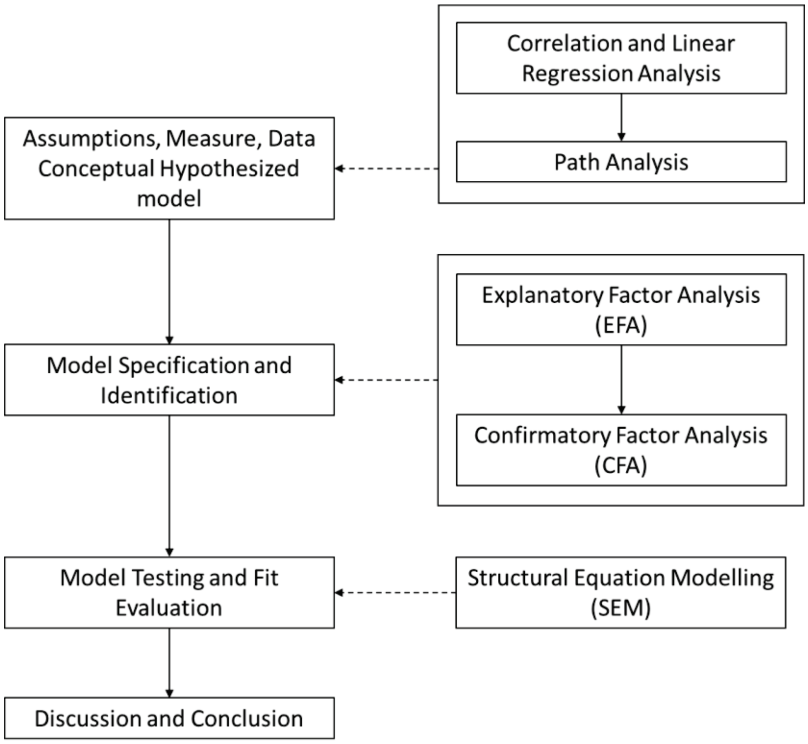
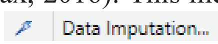


Figure 4.1 Structural equation modelling process

4.2.1 Structural equation modeling (SEM) analysis

Following path analysis, it was found that there is missing data in this survey, which must be prepared before the model identification stage. On average, there are 4% missing data in Kampong and 15% in the apartment. In the path analysis, SPSS Amos performed the analysis and treated missing data with the full information maximum likelihood, which allowed model parameters and standard errors to be estimated directly from the available data. However, this method only estimates and calculates the model without inputting the original missing data (Collier, 2020). In this study, a regression imputation method is a suitable approach for handling missing values due to the moderate amount of missing data and the situation where our data were missing completely at random. Regression imputation substitutes a predicted value for the missing value of a variable (Schumacker & Lomax, 2016). This method can be calculated with SPSS Amos, using the imputation function 

, and select “Regression Imputation” (Figure 4.2). It applied the linear regression from the variable, in this case, the path model, as the base for the calculation.

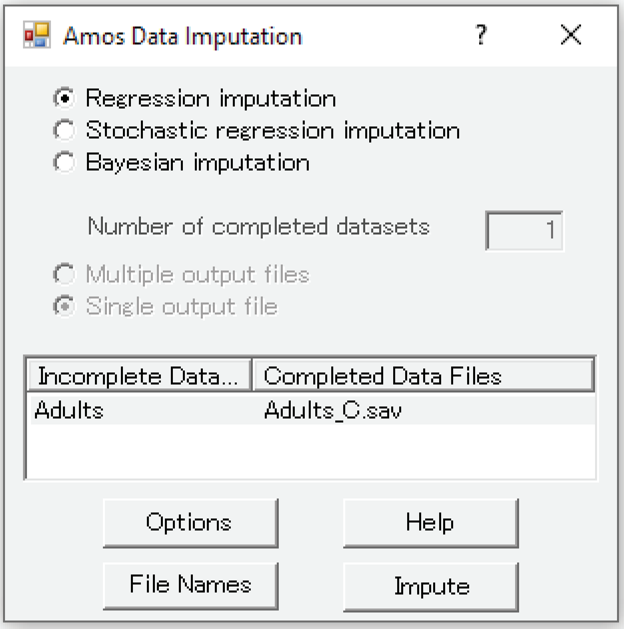


Figure 4.2 SPSS Amos imputation and renaming menu of data file

The significant variables were analyzed with explanatory factor analysis (EFA) and confirmatory factor analysis (CFA) before going to SEM analysis (Figure 4.1). In EFA, the variables are explored to reduce the large number of variables and identify the possible latent variables, which later will be confirmed whether the explanatory variables in the latent variable fit or not in the CFA (Collier, 2020; Schumacker & Lomax, 2016). Latent variables resulting from the specification and identification process are evaluated in the SEM analysis process based on the interrelationship in the path analysis. This study determined the following six latent variables from the factor analysis: building attributes, allergies, cleaning behavior, air quality, window opening behavior and dampness. The SEM analysis was performed using the IBM SPSS Amos 27 to find the factors affecting MCS.

4.3 SEM modelling and analysis

4.3.1 Factor analysis

As indicated in the path analysis, there are large numbers of variables considered to be correlated to MCS risk, especially in the apartments. In total, there are 120 questions asked in the interview, multiple choice, five-point scale, ten-point scale, yes-no, and open-ended questions. In order to reduce the large number of variables, significant variables were analyzed with the principal factor analysis method to find respective factors based on the result of correlation and path analysis. The most common method of factor rotation is by varimax, because it is a good general approach that simplifies the interpretation of factor but resulting in independent and less correlated factors. On the other hand, direct oblimin method gives result of factors that might correlate (Field, 2009). Direct oblimin rotation was employed in these analyses considering the connection between factors are expected in the personal perception data and other variables in the questionnaire. The analysis was separated between apartments and Kampongs, where the variable with rotated factor loads significant (more than 0.3) were grouped into the same groups of each factor (Field, 2009). The analysis was also separated based on the domain, where the total percentage of variances, the eigenvalue (more than 1.0), and the simplicity of interpreting the factors were considered in deciding the number of factors in the respective domain.

Apartments

The rotated principal factor analysis results from the significant variables in apartment data can be seen in Table 4.1. The results were considered fitted considering the KMO value of 0.627 (>0.6), representing in total 61% variance. 13 factors were extracted from 38 variables. Each factor was called based on the representative variables, Factor 1 "window opening behavior", Factor 2 "MCS", Factor 3 "cleaning behavior", Factor 4 "smoking behavior", Factor 5 "Interior", Factor 6 "building condition", Factor 7 "the number of windows", Factor 8 "air quality", Factor 9 "HVAC", Factor 10 "Wall", Factor 11 "health", Factor 12 "Dampness", and Factor 13 "duration". However, there are several factors that only have two variables, and more analysis and modification are needed in the confirmatory factor analysis.

Table 4.1 Summary of factor analysis results for significant variables in apartments

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
Window opening BR WD	.903												
Window opening LR WE	.901												
Window opening LR WD	.897												
Window opening BR WE	.866												
Other intolerances		.828											
Chemical intolerance		.821											
Life impact		.781											
Symptoms severity		.689											
Cleaning room freq.			-.798										
Cleaning bathroom freq.			-.749										
Cleaning bedsheet freq.			-.411			.269	-.269						
Gender			-.313	.227									
Passive smoking				.738									
Smoking				.697									
Masking index				.683									
Furniture bedroom					.823								
Furniture living room					.773						-.219		
Painted wall					.364		-.322		.342	.243			
Stress		.283			.357		-.215						
Smell						.694							
Humidity				-.297		.619							
Mite						.464					.327	.208	
Number of windows LR							.632						
Number of windows BR							.632						
OAQ								-.835					
IAQ								-.821					
AC									.749				
Fan									-.632	.204			
Building age									-.559				.371
Wallpaper										.690			
Exhaust fan							-.325			.576		.234	
Allergic											.750		
Eczema											.634		
Asthma			-.270				.210			.244	.513		
Water leak												.824	

Mold						.503						.516	
Living duration												.213	.792
Age of respondents													.750
Variance (%)	9.5	8.8	5.5	5.1	4.7	4.6	4.1	3.9	3.5	3.4	3.2	2.8	2.7

Furthermore, other principal factor analyses were done based on the domain of the variables to see the other possible factors coming from each domain. These analyses were considered based on the format of the questionnaire form where these questions are grouped in several domains. Table 4.2 – 4.4 show the rotated factor matrix from the respective domain of apartments data. The values shown in the tables are specified to be more than 0.2, which indicates the significancy (Field, 2009). Two to four factors were extracted from each domain and in total eight factors were obtained from 30 variables. A brief interpretation of each factor is summarized for each domain.

Firstly, Table 4.2 indicates the results of factor analysis in the "health" domain, where nine questions were asked during the interview. Factor 1, "chemical intolerance", "life impact", "other intolerance", "symptoms severity", and "masking index" are considered as one factor. This factor represents the QEESI parameter in calculating the MCS risk of the respondents. Therefore, this factor was called "MCS". Factor 2 was called "Health", comprising of "allergies", "asthma", "eczema", and "stress". However, Factor 2 was also considered "allergies" since the highest loading factor was coming from the "allergies" variable.

Table 4.2 Summary of factor analysis results for health domain in apartments

Variables	MCS	Health
Chemical intolerance	0.834	
Life impact	0.787	
Other intolerances	0.766	
Symptoms severity	0.724	0.236
Masking index	0.332	
Allergic		0.703
Asthma		0.619
Eczema		0.682
Stress	0.381	0.261
Variance (%)	33.8	13.6

Table 4.3 shows the factor analysis results of respondents' behavior and perceptions of the air quality domain, consisting of nine questions. Factor 1 was called "window opening behavior", consisting of "window openings in bedroom weekdays", "window opening in bedroom weekend", "window opening in living room weekdays", and "window opening in living room weekend". Factor 2 consisted of the cleaning frequency of the respondents, "cleaning room frequency", "cleaning bathroom frequency", and "cleaning bedsheet frequency", thus, this factor was called "cleaning behavior". Factor 3 represents the "air quality" rate of the respondents, consisting of "indoor air quality rate" and "outdoor air quality rate".

Table 4.3 Summary of factor analysis results for respondent's behavior and perception of air quality domain in apartments

Variables	Window	Cleaning	AQ

Window opening BR WD	0.893		
Window opening BR WE	0.870		
Window opening LR WD	0.900		
Window opening LR WE	0.900		
Cleaning room freq.		0.800	
Cleaning bathroom freq.		0.791	
Cleaning bedsheet freq.		0.583	
IAQ			0.864
OAQ			0.858
Variance (%)	35.7	17.8	16.7

Table 4.4 shows the last domain related to building attributes in the apartments. There are seven questions considered in this domain. Factor 1 was named “interior”, considering the variables “the number of furniture in the living room”, “the number of furniture in bedroom” and “wall finished by painting”. Factor 2 consisted of “the number of windows in the bedroom”, “the number of windows in the living room”, thus, it was called the number of windows. Factor 3 was called “building”, consisting of “building age” and “wall finished by wallpaper”. These factor results were still tentative. Further confirmatory analysis was needed to examine the fitness of this factor because several factors consist of only two variables which mostly do not fit the SEM model.

Table 4.4 Summary of factor analysis results for building domain in apartments

Variables	**Interior**	**Wall**	**Building**
Furniture living room	0.825		
Furniture bedroom	0.791		
Number of windows LR		0.777	
Number of windows BR		0.685	
Painted wall	0.447	-0.451	
Building age	0.297		0.765
Wallpaper			-0.646
Variance (%)	14.8	11.9	9.9

Kampongs

The rotated principal factor analysis from the significant variables in Kampong data extracted 12 factors from 33 variables (Table 4.5). The KMO value was 0.616 (>0.6), representing 63.8% variance, indicating that the results were fitted. The results showed that several factors can be identified where other factors are not identified due to the variables in the factor. The identified factors are Factor 1 “MCS”, Factor 2 “building attributes”, Factor 3 “HVAC”, Factor 4 “air quality” Factor 6 “the number of windows”, Factor 8 “cleaning behavior”, and Factor 9 “windows opening behavior”. The unidentified factors are Factor 5, Factor 7, Factor 10, Factor 11, and Factor 12. Therefore, further principal analysis based on the domain was carried out to explore other factors.

Table 4.5 Summary of factor analysis results for significant variables in apartments

Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Life impact	.788											-.228
Other intolerances	.785											

Chemical intolerance	.770								-.233			
Symptoms severity	.726											.295
Stress	.445						.275	.239			-.233	.289
Eczema	.411							.225	.201			
Building age		.827										
Living duration		.788										
Modification		.657	.203					.220				
Mold		.436	-.208			-.345		-.206				
Exhaust fan			.754									-.263
Fan			-.723									-.235
AC			.421			-.238	.252		-.254			
IAQ				.783								
OAQ				.758								
Humidity				.454				-.262		.236		
Smoking					.859							
Gender					.785							
Masking index					.567		-.565					
Number of windows BR						-.853						
Number of windows LR						-.541				.525		
Passive smoking							-.794					
Furniture living room							.595		-.238		.232	
Cleaning bedclothes freq.								.781				
Cleaning bathroom freq.			-.231					.645				
Window opening LR									.760	-.248		
Window opening BR			-.204			.231			.638			
Cleaning room freq.	.243					.402			-.494			
Mite										.886		
Furniture bedroom				.341					-.299	-.366	.275	
Allergies	.257										.704	
Water leaking		.342	-.212	.240							.421	-.207
Asthma												.813
Variance (%)	10.9	8.0	6.0	5.5	5.5	4.9	4.5	4.1	3.9	3.8	3.4	3.3

The rotated factor matrix from the respective domain of Kampong was presented in Table 4.4 – 4.6. Similar to apartment data, the values shown in the table were significant values more than 0.2. three factors were extracted in each domain, and eight factors were obtained from 30 variables. Several variables are inserted in two domains, considering those variables' correlation with the other questions in the domain. For example, allergy variables were analyzed in the health and in behavior domains to show the possibility of factors.

The first factor, "MCS", can be seen in Table 4.6. Similar to factor 1 in apartment data (Table 4.3), the factor "MCS" represents the QEESI questions for calculating the MCS risk of the respondents, consisting of "chemical intolerance", "life impact", "other intolerance", "symptoms severity", and "masking index". The other factors in Table 4.6 were not considered due to the similarity and limited number of variables.

Table 4.6 Summary of factor analysis results for health domain in Kampong

Variables	MCS	Health	Health
Chemical intolerance	0.819		
Symptoms severity	0.782		0.214
Other intolerances	0.703	0.248	
Life impact	0.684	0.222	-0.290
Masking index	-0.224	0.563	0.496
Stress	0.613		
Allergic		0.659	
Eczema	0.229	0.574	
Asthma	0.221		0.789
Variance (%)	33.9	12.4	11.5

Table 4.7 indicates the factor analysis results of the health and behavior domain in Kampong. There are three factors resulting from nine variables. The first factor, "Health", consisted of "eczema", "allergies", "stress", and "asthma". This factor was the same as the "health" factor in the apartments. Factor 2 consisted of "windows opening in the living room" and "windows opening in the bedroom", which were considered "window opening behavior" factors. Lastly, Factor 3 consisted of cleaning frequency variables, therefore, it is called "cleaning behavior".

Table 4.7 Summary of factor analysis results for health and behavior domain in Kampong

Variables	Health	Opening	Cleaning
Eczema	0.617		
Allergic	0.565		
Stress	0.564		-0.264
Asthma	0.510		0.316
Window opening LR		0.732	
Window opening BR		0.729	
Cleaning room freq.	0.225	-0.534	
Cleaning bedsheet freq.			-0.734
Cleaning bathroom freq.			-0.708
Variance (%)	16.3	16.1	13.0

Table 4.8 presents the domain related to building attributes and the air quality rate from respondents. There are nine variables analyzed, resulting in three factors. Factor 1, "building attributes", represented the "building age", "living duration in the present house", "modification occurrence", and "mold appearance". The second factor was similar to the "air quality" factor in the apartment, consisting of "indoor air quality rate" and "outdoor air quality rate". Lastly, the "dampness" factor consisted of "humidity rate" and "mite".

Table 4.8 Summary of factor analysis results for building and air quality domain in Kampong

Variables	Building	AQ	Dampness
Building age	0.853		
Living duration	0.801	-0.219	
Modification	0.625		

Mold	0.506		
OAQ		0.873	-0.239
IAQ		0.726	
Mite			0.917
Humidity		0.394	0.416
Variance (%)	25.4	20.5	12.7

4.3.2 Confirmatory factor analysis

Before going to SEM, the first step was to do the confirmatory factor analysis (CFA) to obtain the latent variables from several observed variables. This process was done in IBM SPSS statistics and IBM Amos. Based on the previous results of EFA, the CFA was done to confirm the factor, which can be called the latent variable for the SEM analysis, by utilizing IBM Amos. The variables were rotated and tested in several latent variables to find a good fit, more than 0.90 or slightly fitted, close to 0.9, CFI value. In addition to CFI, the standardized estimates and significant value of each variable to the latent variables are also considered in the CFA.

As shown in Table 4.9, seven latent variables are extracted from the CFA in the apartment data. Most variables showed a significant relationship and standardized estimates above 0.4, except masking index, asthma, cleaning bedsheet freq., humidity, mite, building age, wallpaper, painted wall, smell, and the number of windows. In contrast, Table 4.10 shows the results of CFA in Kampong data. There are eight latent variables extracted, whereas similarly to the apartment, there are several variables with lower standardized estimates value, but the majority of the variables are above 0.4. "MCS risk" was the dependent variable, and the other latent variables were the explanatory variables in the SEM analysis to explain the factors affecting SBS among respondents.

Table 4.9 List of variables and standardized estimates for each latent variable in apartments

Latent factors	Observed variables	Standardized estimates	Sig.
MCS Risk	Life impact	0.725	***
	Masking index	0.178	***
	Symptoms severity	0.728	***
	Other intolerances	0.768	***
	Chemical intolerance	0.67	***
Allergies	Stress	0.459	***
	Allergic	0.422	***
	Eczema	0.471	***
	Asthma	0.328	***
Cleaning behavior	Cleaning bedsheet freq.	0.323	***
	Cleaning bathroom freq.	0.628	***
	Cleaning room freq.	0.73	***
Air quality	OAQ	0.986	*
	IAQ	0.499	*
Dampness	Humidity	0.379	**
	Mite	0.326	***
	Mold	0.706	***
Building attributes	Furniture bedroom	0.489	**
	Furniture living room	0.936	**
	Building age	0.139	*

	Wallpaper	0.098	
	Painted wall	0.22	**
	Smell	0.024	
	Number of windows BR	0.024	
	Number of windows LR	0.153	*
Windows opening behavior	Window opening LR Weekend	0.93	***
	Window opening BR Weekdays	0.769	***
	Window opening BR Weekend	0.732	***
	Window opening LR Weekdays	0.922	***

Table 4.10 List of variables and standardized estimates for each latent variable in Kampongs

Latent factors	Observed variables	Standardized estimates	Sig.
MCS Risk	Life impact	0.634	***
	Masking index	0.065	
	Symptoms severity	0.784	***
	Other intolerances	0.76	***
	Chemical intolerance	0.678	***
Allergies	Stress	0.497	***
	Allergic	0.212	**
	Eczema	0.392	***
	Asthma	0.222	**
Dampness	Mite	0.248	**
	Mold	0.314	**
	Humidity	0.294	**
Air quality	OAQ	0.379	**
	IAQ	1.048	**
Cleaning behavior	Cleaning bedsheet freq.	0.435	**
	Cleaning bathroom freq.	0.391	**
	Cleaning room freq.	0.232	*
Building attributes	Modification	0.359	***
	Building age	1.045	***
	Living duration	0.594	***
Window opening behavior	Window opening LR	0.536	***
	Window opening BR	0.586	***
Number of furniture	Furniture BR	0.502	***
	Furniture LR	0.278	**

4.3.3 Structural model

This section explains the modeling of SEM, considering the correlation analysis results. The process was based on the hypothesis in path analysis that the MCS risk is correlated to several factors, which can be directly and indirectly, such as health and environmental quality in their dwelling. At the same time, the environment quality is affected by factors surrounding the respondents and their dwellings, such as behavior and building attributes. Similarly to the path analysis, the SEM model is also divided based on the housing type, apartment, and Kampongs.

Figure 4.3 explains the procedure for creating the MCS risk model in the apartment. The most related latent variable to MCS risk was decided by examining the correlation results of each variable with MCS risk. As shown in Figure 4.3(1), it was found that “allergies” have the highest standard estimates (0.65), and the CFI value was a good fit (0.919). “Cleaning behavior”, “building attributes”, and “window opening behavior” were found to have a relatively low standard estimate directly to MCS risk. Therefore, these variables were considered not to directly affect the apartment’s MCS risk. “Air quality” was the second variable highly correlated with MCS risk, loading factor 0.19, CFI 0.957, thus it is considered as the additional variable (Figure 4.3(2)). The variables affecting “allergies” were analyzed following the model (Figure 4.3(3)). All variables are analyzed except “MCS”. It was found that “cleaning behavior” and “window opening behavior” were correlated with “allergies”, 0.21** and -0.07, respectively. Whereas the “cleaning behavior” was significantly correlated to “window opening behavior”, -0.12*. The final step was to find the variables correlated to “air quality”. The process was further tested by correlating the other possible latent variables to meet the model’s fitness based on the correlation’s logic and the significance score.

Similarly, the process was repeated in the kampong model. As shown in Figure 4.4, “allergies” were found to have the highest SE, 0.96***, and the air quality was the additional variable, the same as the one in the apartment model. “Dampness” was found to be correlated to “allergies” and “air quality”, where the model has 0.974 CFI and 0.037 RMSEA value, indicating a good fit (Figure 4.4(3)). Even though the model was fitted in this process, a significant relationship between variables was not observed. Therefore, in the following process, the significant relationship between variables was also considered in the modeling process. The variables correlated to “dampness” and “air quality” were added. “Building attributes” was found to be significant to “dampness” SE 0.32*. At the same time, by adding “building attributes”, the correlation between “dampness” to “air quality” and “allergies” is improved. The model was further tested by correlating the latent variables, and the final model was achieved (Figure 4.4(4)).

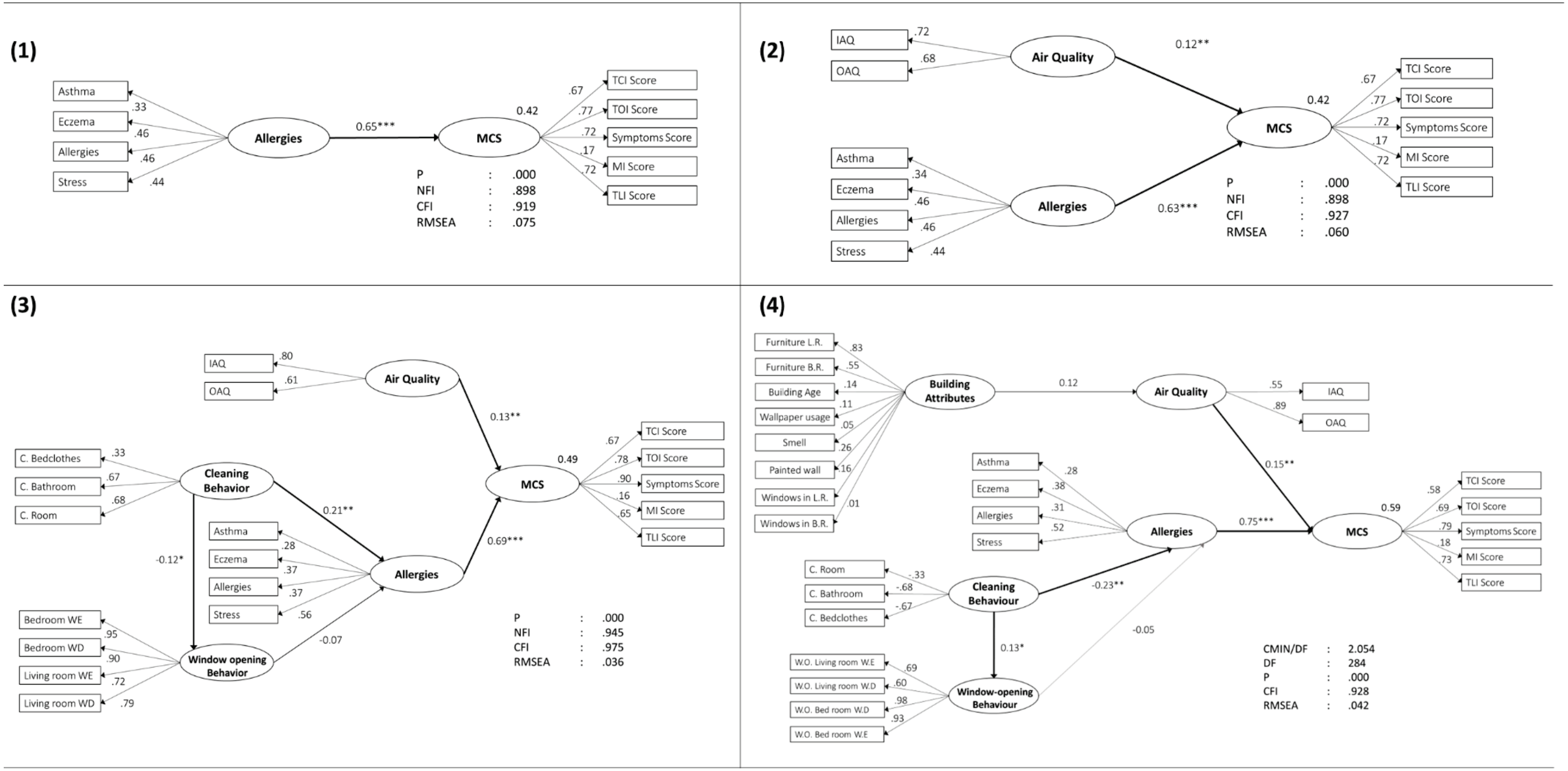


Figure 4.3 Modelling process of MCS risk in the apartment (standardized estimates)

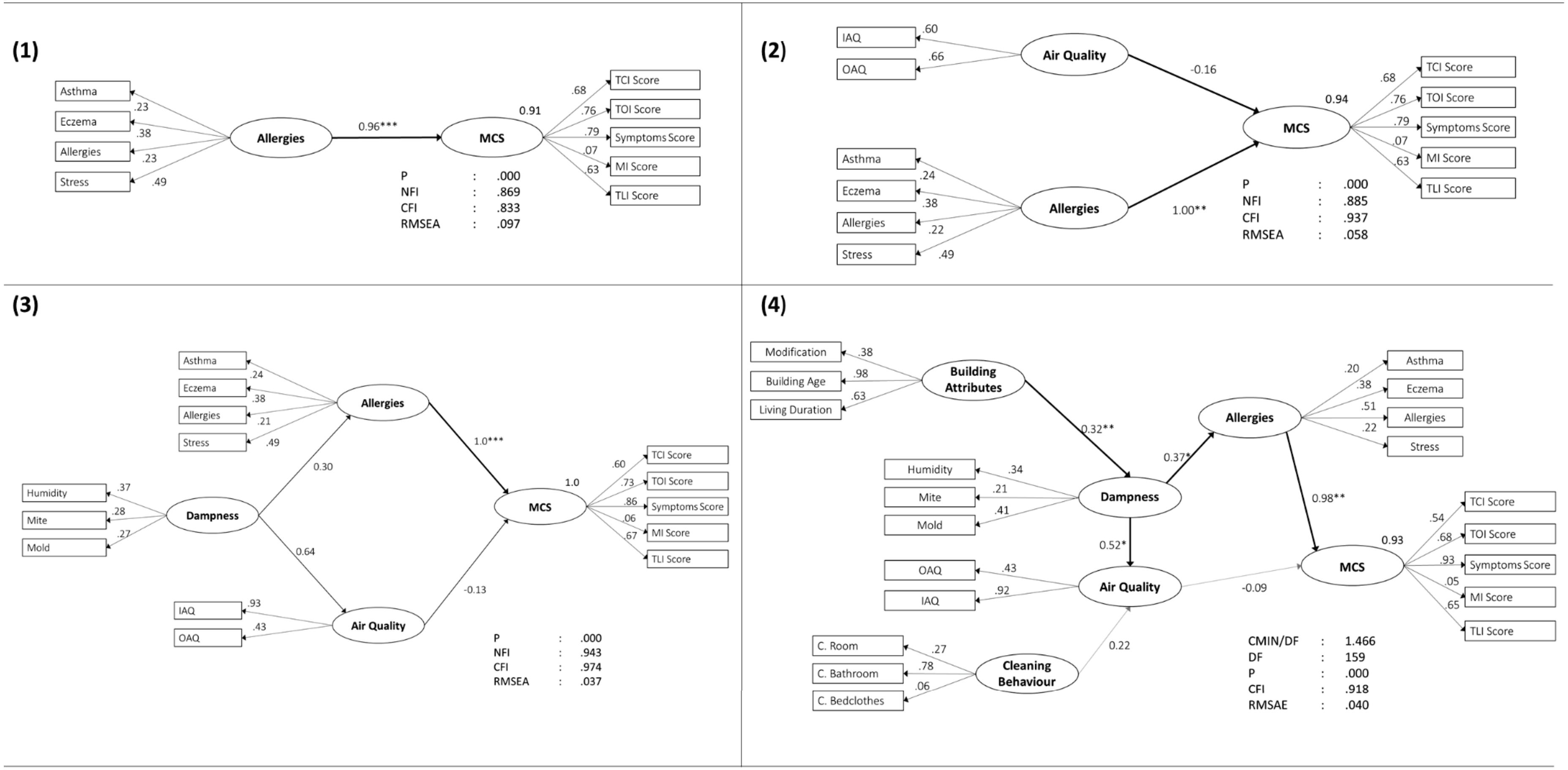


Figure 4.4 Modelling process of MCS risk in the Kampongs (standardized estimates)

4.3.4 Results of SEM

The results of the Structural Equation Modeling (SEM) analysis for Multiple Chemical Sensitivity (MCS) among the apartment residents are depicted in Figure 4.5. The CFI (comparative fit index), RMSEA (root mean square error of approximation), and p-value were used to measure the quality of fit. A successful model should have a CFI > 0.9, RMSEA 0.05, and p-value 0.001. The model demonstrated acceptable fit with reported values of CFI=0.928 and RMSEA=0.042. These results indicate that the model adequately represents the data. The R-square value for apartments was found to be 0.59, suggesting that 59% of the MCS risk factors in the apartments can be explained by this model.

The analysis revealed that the most influential direct factor impacting MCS in the apartments is the allergic conditions of the respondents. The total effects and direct effects of allergies on MCS were both 0.752, with a p-value less than 0.001. The air quality rate came in second (total effects: 0.148, direct effects: 0.148, p<0.01). Additionally, the air quality is only marginally impacted by the building characteristics (0.12, p<0.1), which indirectly contributes to MCS (total effects: 0.018, indirect effects: 0.018). Furthermore, cleaning behavior was found to affect allergies (-0.23, p<0.01) and window-opening behavior (0.13, p<0.05), indirectly leading to MCS (total effects: 0.18, indirect effects: 0.18). Additionally, window-opening behavior was negatively associated with allergies (total effects: -0.05, indirect effects: -0.05).

In detail, several factors were found to decrease the self-reported air quality rates. These factors include building age (0.14), the number of furniture in the bedroom (0.55), the number of furniture in the living room (0.83), the use of wallpaper in the house (0.11), painted wall finishing (0.26), the number of ventilations in the living room (0.16), the number of ventilations in the bedroom (0.01), and the occurrence of unpleasant smells in the room (0.05). This suggests that older apartments, apartments with more furniture, stronger odors, and the use of wallpaper tend to result in lower personal air quality rates (p<0.1), thereby increasing the risk of MCS among the respondents. In the earlier study (Kubota et al., 2021), it was discovered that the building age was inversely correlated with the measured formaldehyde and TVOC levels, with the older the structure, the lower the chemical concentration, particularly in the apartments. The IAQ levels and MCS risk in the apartments in this model, however, were positively impacted by the age of the building. This may be due to the fact that there is a correlation between the age of the building and the amount of furniture in the living room and bedroom, with the older apartment units generally having a more number of furniture (p<0.01). These findings emphasize that the number of furniture is a significant factor affecting apartment IAQ, as indicated by its highest loading factor. Furthermore, painted walls and the occurrence of unpleasant smells in the rooms showed a negative correlation (p<0.01), suggesting that apartments with painted walls generally have fewer odors compared to other finishing materials like wood boards and wallpaper.

In the case of allergies, cleaning behavior was found to be significantly influencing allergy incidence (-0.23, p<0.01), followed by an unimportant but unfavorable link with window-opening behavior (total effects: -0.05 indirect effects: -0.05). Additionally, the behavior of opening windows exhibits a negligible but inverse relationship with allergies (total effects: -0.05, indirect effects: -0.05), suggesting that extending the time windows are opened may lessen allergies in apartments. Furthermore, cleaning behavior was found to significantly impact the duration of window opening in the apartment (0.13, p<0.05), suggesting that respondents are more likely to open their windows when cleaning the house. This finding suggests that the respondents might only open their windows when they were cleaning the house. The overall and indirect effect of cleaning behavior on MCS risk is 0.18, indicating that the self-reported health risk would increase the less frequently respondents clean their rooms.

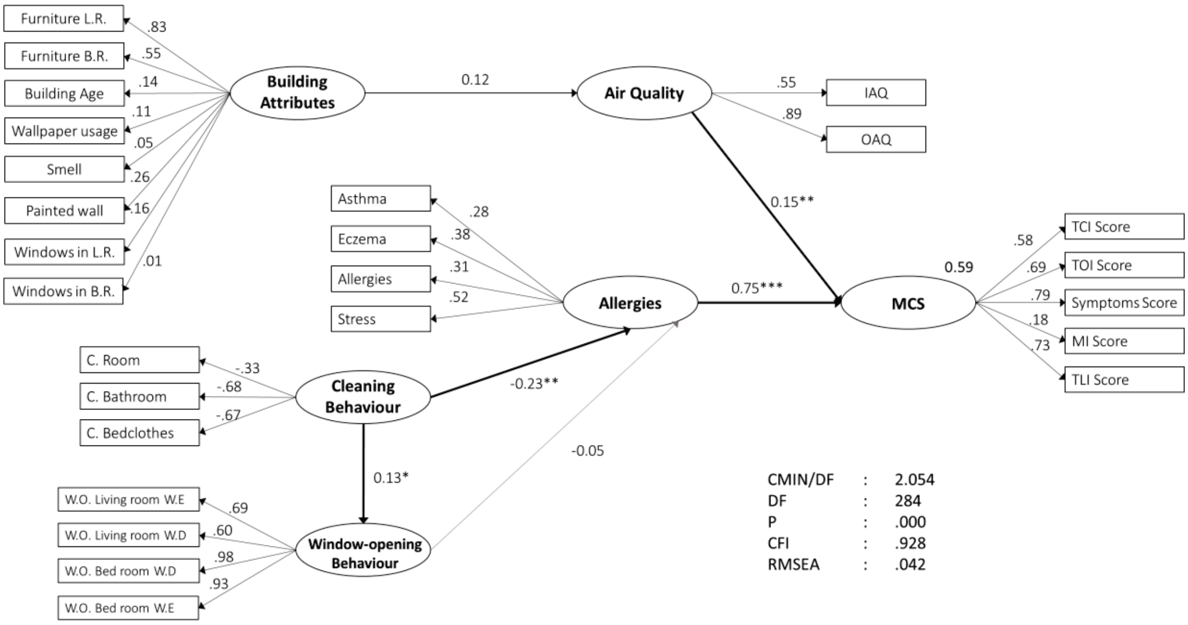


Figure 4.5 Structural equation modeling for MCS risk among respondents in apartments (H. Sani et al., 2023)

Table 4.11 Total, direct and indirect effects of latent variables for MCS risk in the apartments

Variables	Total effects	Direct effects	Indirect effects
Cleaning behavior	-0.177	0	0.177
Window opening behavior	-0.035	0	-0.035
Building attributes	0.018	0	0.018
Air quality	0.148	0.148	0
Allergies	0.752	0.752	0

The results of the Structural Equation Modeling (SEM) analysis for Multiple Chemical Sensitivity (MCS) among Kampong respondents are presented in Figure 4.6. The R-square value indicates a strong relationship, with a value of 0.93, suggesting that the diagram explains 93% of the MCS risk in the Kampongs. The model's goodness of fit is supported by the conformance values, CFI=0.918 and RMSEA=0.040, indicating an acceptable fit. Similar to the apartment model, MCS in Kampongs is directly impacted by the respondents' allergy symptoms (total effects: 0.975, direct effects: 0.975, $p<0.01$) and their self-reported air quality rates (total effects: -0.090, direct effects: -0.090). However, the presence of dampness as a latent factor is specific to the Kampong model. Dampness directly affects the air quality rates (0.52, $p<0.05$) and allergies (0.37, $p<0.05$), leading to MCS risk (total effects: 0.311, indirect effects: 0.311). This suggests that dampness may be a significant factor affecting Kampong people' respiratory health as well as the quality of the air (H. Sani et al., 2022). Additionally, the wetness is directly impacted by the building characteristics (0.32, $p<0.01$), which results in MCS (total effects: 0.099, indirect effects: 0.099).

In the case of Kampongs, variables such as modification (.38), building age (.98), and living duration (.63) have a positive and significant loading factor on the dampness variable. This supports the hypothesis that increased mold growth, higher humidity levels, and more mite issues are caused by older buildings and prolonged occupancy. Consequently, higher humidity, mold, and mites in Kampong contribute to increased allergies and decreased air quality rates. In contrast to the apartment model, the number of furniture is not a significant variable in the Kampong model. This may be connected to the issue with the air quality that was raised before (Chapter 1), where Kampong has much lower chemical concentrations than apartments. Therefore, chemical exposure from furniture does not impact the health conditions in Kampong, but rather the dampness factor. Additionally, the effect of building age on MCS risk differs between Kampongs and apartments, with building age leading to dampness issues in Kampong and more furniture and higher chemical concentration in apartments. Further research is needed to gain a deeper understanding of this situation.

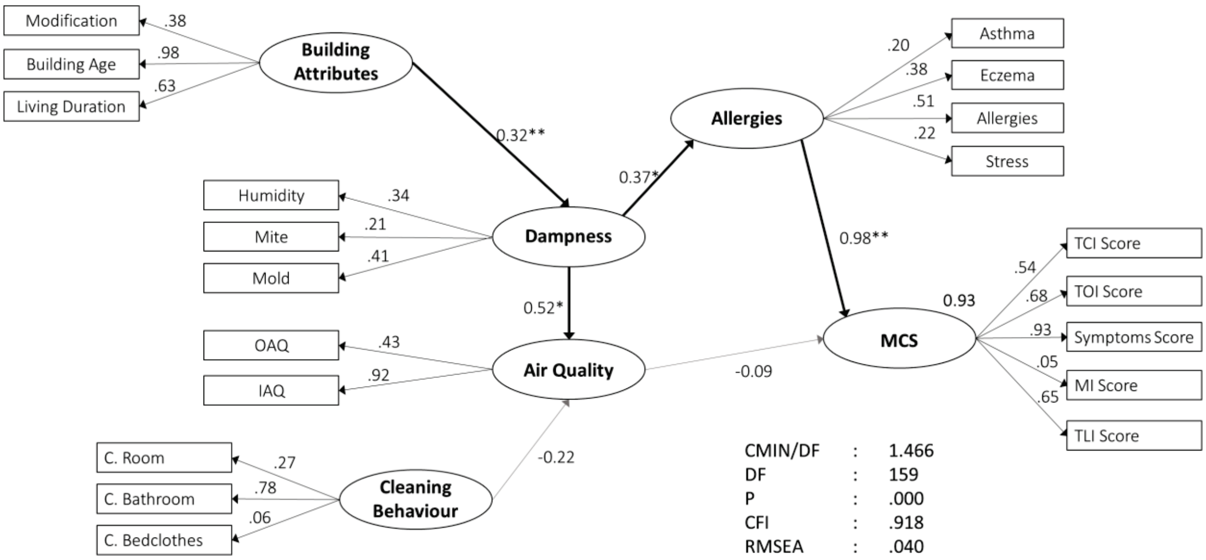


Figure 4.6 Structural equation modeling for MCS risk among respondents in Kampongs (H. Sani et al., 2023)

Table 4.12 Total, direct and indirect effects of latent variables for MCS risk in Kampong

Variables	Total effects	Direct effects	Indirect effects
Building attributes	0.099	0	0.099
Cleaning behavior	0.02	0	0.02
Dampness	0.311	0	0.311
Allergies	0.975	0.975	0
Air quality	-0.09	-0.09	0

Additionally, as demonstrated by the apartment model, cleaning behavior has an impact on MCS in Kampongs (total effects: 0.02, indirect effects: 0.02). However, in Kampongs, cleaning behavior directly affects air quality (-0.22) rather than allergies. Whereas air quality negatively affected MSC insignificantly. This negative correlation can be caused by the personal air quality preference of people in Kampong, which increases by cleaning behavior. The more they clean the room, the cleaner the air quality they perceive. Therefore, in kampong the cleaner they perceive the air the more MCS risk they have, due to the possible chemical concentration coming from the cleaning product they use during cleaning. In apartments, cleaning behavior significantly affects health conditions (i.e., allergies and MCS) and window-opening behavior, whereas in Kampongs, cleaning behavior does not significantly influence MCS through the air quality rates. Meanwhile, building attributes, including furniture, finishing materials, and smell occurrence, impact the air quality rates in apartments, but in Kampongs, building attributes leading to dampness problems are more significant factors for air quality rates and health. In conclusion, in apartments, behavioral factors like window opening and cleaning as well as building characteristics are typically associated with the IAQ and thereby potentially increase the risk of MCS, whereas in kampongs, building characteristics typically result in dampness issues and potentially increase the risk of MCS.

4.4 Windows-opening patterns and IAQ

4.4.1 Cluster Analysis

A data mining approach extracted each urban house's typical daily occupant behavior patterns. The total samples of 896 respondents were first classified by their household before analyzing their adaptive behavior in detail. Similarly, with the previous analysis, the urban house types are classified into two: Kampong and apartment. Firstly, the data was prepared through weighting methods. Secondly, principal component and hierarchical cluster analysis were performed.

The binary data from the questionnaire survey represented the occupant behavior, "1" indicating active usage situation and "0" indicating not in use situation. The questionnaire was also separated into weekday usage and weekend usage. Therefore, the data were calculated through the weighting method to make the data into one 24h usage data.

$$Data = \frac{5(W) + 2(WE)}{7} \tag{4.1}$$

where W is the value of weekdays data, and WE is the value of weekend data.

Principal component analysis was conducted based on 24h binary data of the occupant behavior, which later classified the samples into several sub-groups with similar behavioral patterns and showed the factor score coefficient for each data. Therefore, in hierarchical cluster analysis (Euclid square distance, Ward method), principal component values for 24 h (factor score) were adopted instead of the raw binary data. For each of the two attribute groups (kampong and apartment), we selected the number of clusters adequate to represent typical behavior patterns from the results of the cluster analyses. Similar method was done to find the windows-opening pattern in kampong houses in the previous research (Mori et al., 2020). Furthermore, we analyzed window-opening patterns and indoor air quality based on the room: main bedroom, and living room, to explore the possibility of different opening-patterns. In the case of window-opening patterns, multilevel logistic regression analyses were conducted to identify the influential factors affecting the classified window-opening patterns.

4.5.2 Windows-opening pattern

A hierarchical cluster analysis was performed to find the behavior pattern of occupants that might affect the MCS risk and IAQ problems in the apartments and Kampong. Hourly binary data regarding whether the respondents opened their windows or not was analyzed. In the apartment data, clusters/components one to five showed a normal eigenvalue (>1). As shown in Figure 4.7a, the marked location of clusters one to six, the closeness between each cluster is relatively distant. On the other hand, in Kampong (Figure 4.7b), the closeness between clusters is more distant, where clusters one to four were in a normal eigenvalue.

Figure 4.8 compares the windows-opening pattern in an apartment based on the component/ cluster. Different patterns can be seen from cluster five up until cluster two. Cluster five is selected as the representative of the opening pattern in the apartment to explore the possibility of coming from many different window-opening patterns. The first pattern depicts opening windows only in the morning behavior with an average duration of 4.7 hours. The second pattern shows the duration of the least opened windows, 2.2 hours. Pattern 3 shows opening behavior where respondent opened their windows in the morning, closed them in the afternoon, and opened them again in the evening, with 6.3 hours opening duration. Pattern 4 indicated the most extended opening duration, 19.5 hours. Lastly, Pattern 5 shows opening windows during daytime and closing at nighttime behavior with 10.6 hours average opening duration. Overall, 24% of respondents in the apartment rarely opened their windows (pattern 2), 30% opened their windows only in the morning (pattern 1), 25% opened them in the daytime only (pattern 5), and only 9% frequently open windows (pattern 4).

On the other hand, window-opening patterns in Kampong are shown in Figure 4.9. Compared to apartments in Kampong, different patterns can be seen from clusters four to two. Cluster 3 is selected as the representative of the windows opening pattern in the kampung. The first pattern shows opening windows in the morning, closing in the afternoon, and opening again in the evening, with 9.3 hours average opening duration (30% of respondents). The second pattern is opening in the daytime only, with 13.9 hours duration (59% of respondents). Lastly, the pattern of the always-open windows represents the 24-hour opening duration (11% of respondents). Overall, the opening patterns were similar to the opening pattern in the apartment, but the one in the apartment had a longer average opening duration.

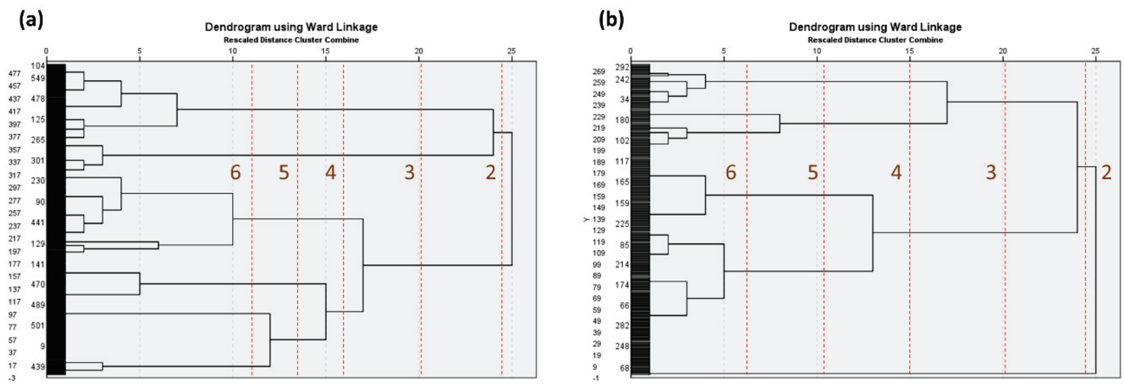


Figure 4.7 Hierarchical cluster analysis dendrogram of daily windows-opening pattern in (a) apartments and (b) Kampong

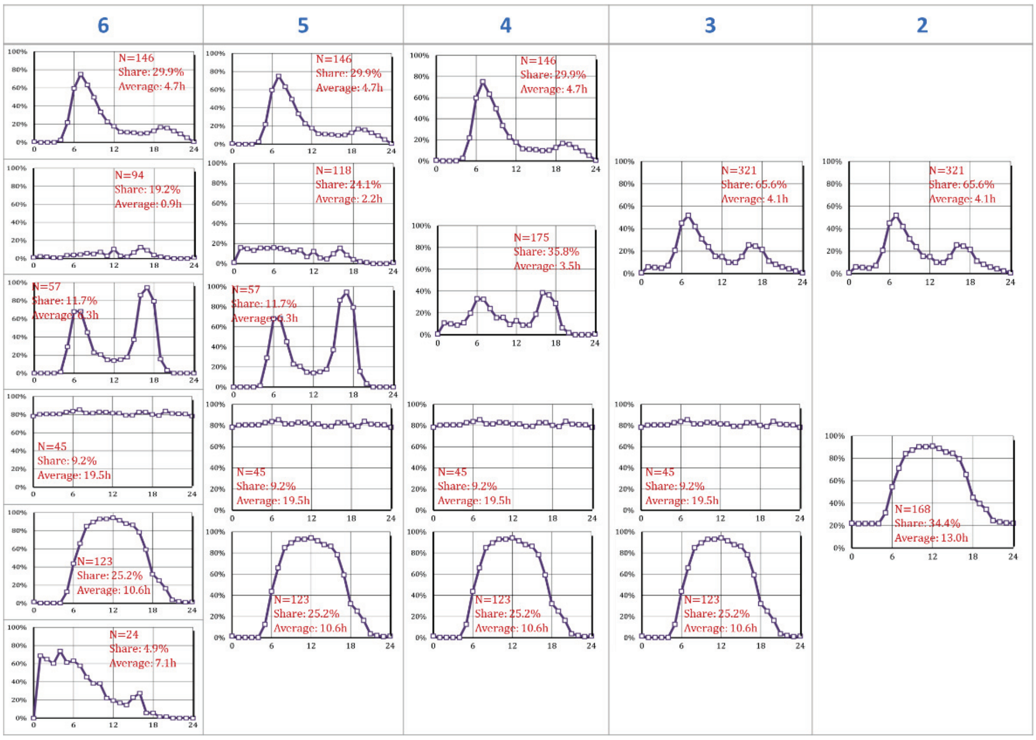


Figure 4.8 Groups of windows-opening pattern based on the number of clusters in apartments

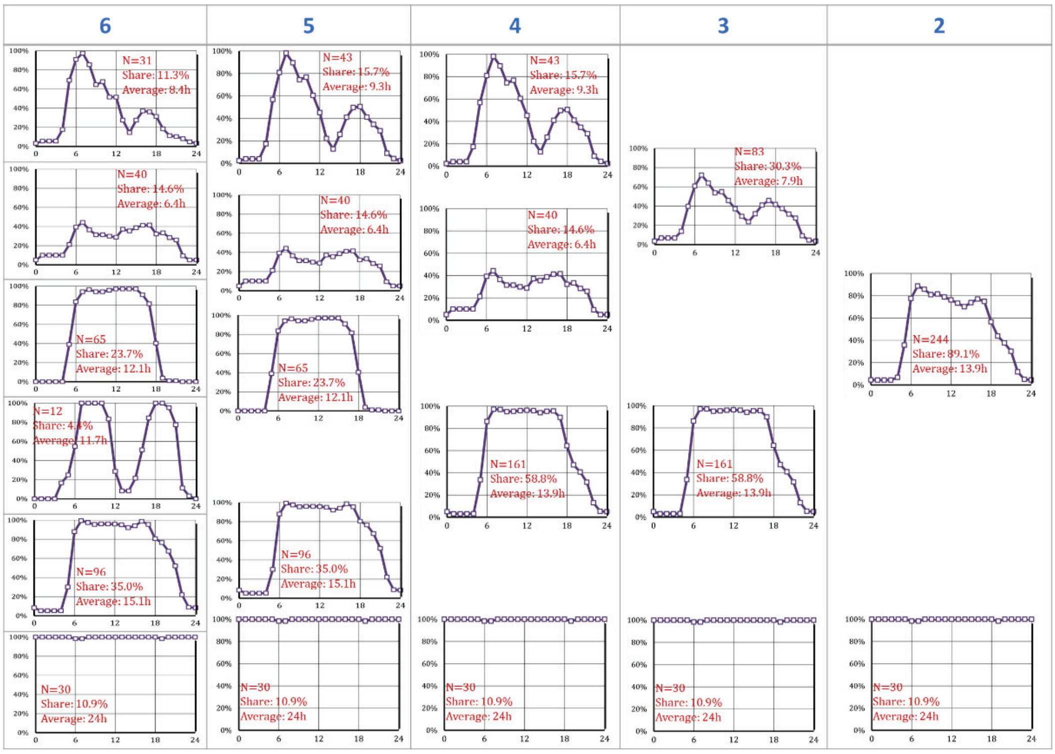


Figure 4.9 Groups of windows-opening pattern based on the number of clusters in Kampong

Furthermore, the window opening data in each location is analyzed based on the room type, main bedroom, and living room. Figure 4.10 depicts the dendrograms from the hierarchical cluster analysis of bedrooms and living rooms in the apartments. Similarly, there are six clusters/components considered in the dendrogram. Overall, the closeness of the cluster in the bedroom (Figure 4.10a) was more distant compared to the cluster in the living room (Figure 4.10b).

The window-opening patterns in apartment bedrooms are depicted in Figure 4.11. Similarly, there are five patterns representing the opening windows behavior in the bedroom. Overall, the pattern is the same as the pattern in the whole apartment data. However, the opening durations are different in each pattern. On average, the opening durations are 4.9 hours for pattern 1 (opened in the morning only), 0.6 hours for pattern 2 (closed windows), 7.7 hours for pattern 3 (opened morning and evening, closed afternoon), 20.4 hours for pattern 4 (frequently opened), and 10.2 hours for pattern 5 (opened daytime). The least applied window-opening pattern in the bedroom is pattern 4, only 9.8%. Whereas the respondents apply patterns 1, 2, 3, and 5, ±20% equally.

The opening patterns in the apartment living room are the same as all data and bedroom analysis results, only different in duration (Figure 4.12). In the living room, the windows opening durations are 5.2 hours (pattern 1), 0.7 hours (pattern 2), 5.0 hours (pattern 3), 18.1 hours (pattern 4), and 11.4 hours (pattern 5). Overall, the respondents tend to open their windows in the living room only in the morning (28.8%) and in the daytime (25%). Compared to the bedroom, in the living room, people tend to open their windows, in the morning and evening (pattern 3), at precisely 6 am and 6 pm, which leads to shorter opening duration. In contrast, apartment respondents tend to open windows slightly more in the bedroom compared to the living room. This tendency was also applied to the frequently open situation. Bedrooms tend to be open longer than apartments, 20.4 / 18.1 hours, respectively.

Based on this comparison, window opening patterns in the apartment are relatively the same between bedroom, living room, and one unit data. However, in the living room, people tend only to open windows in the morning. Whereas opening windows in the morning and evening but closing them in the afternoon tends to be applied more in the apartment bedroom. Overall, apartment respondents rarely open their windows; only 9-11% of people open them for over 12 hours.

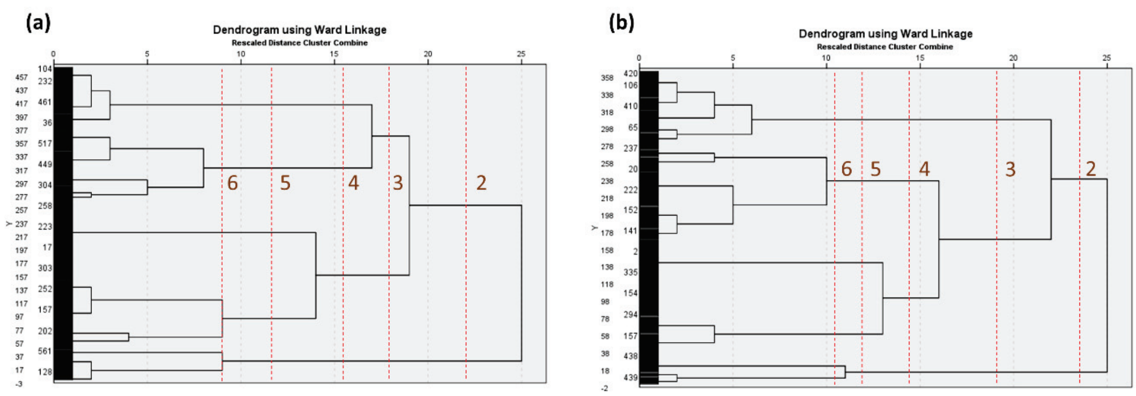


Figure 4.10 Hierarchical cluster analysis dendrogram of daily windows-opening pattern in apartments (a) bedroom and (b) living room

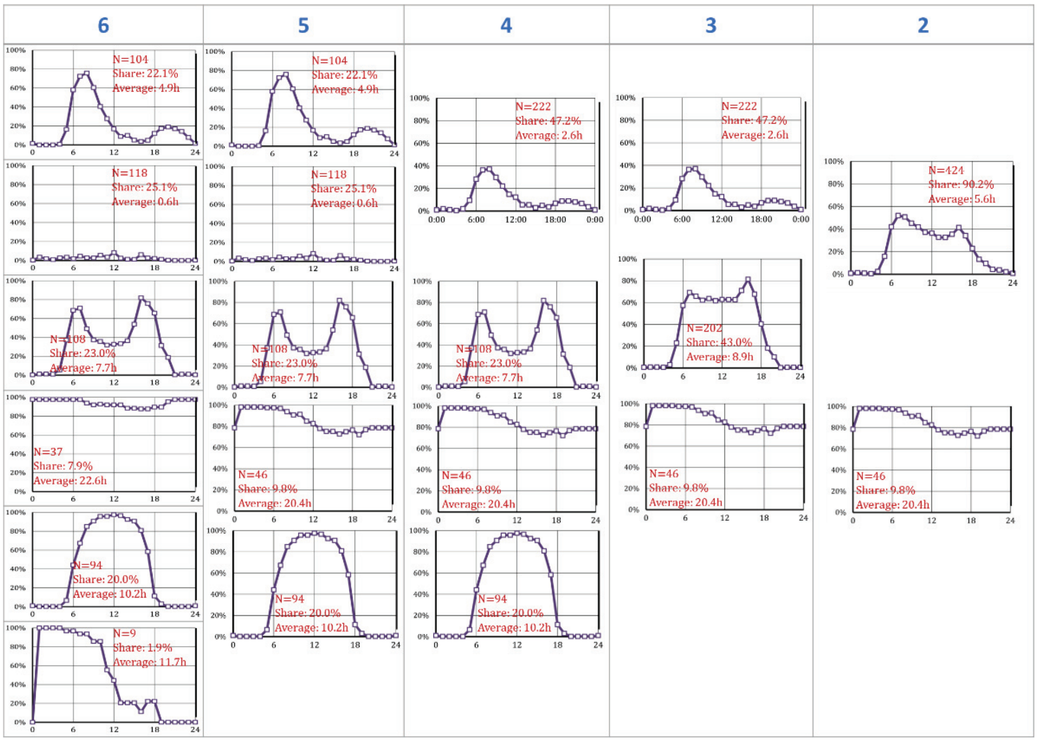


Figure 4.11 Groups of windows-opening pattern based on the number of clusters in apartments bedroom

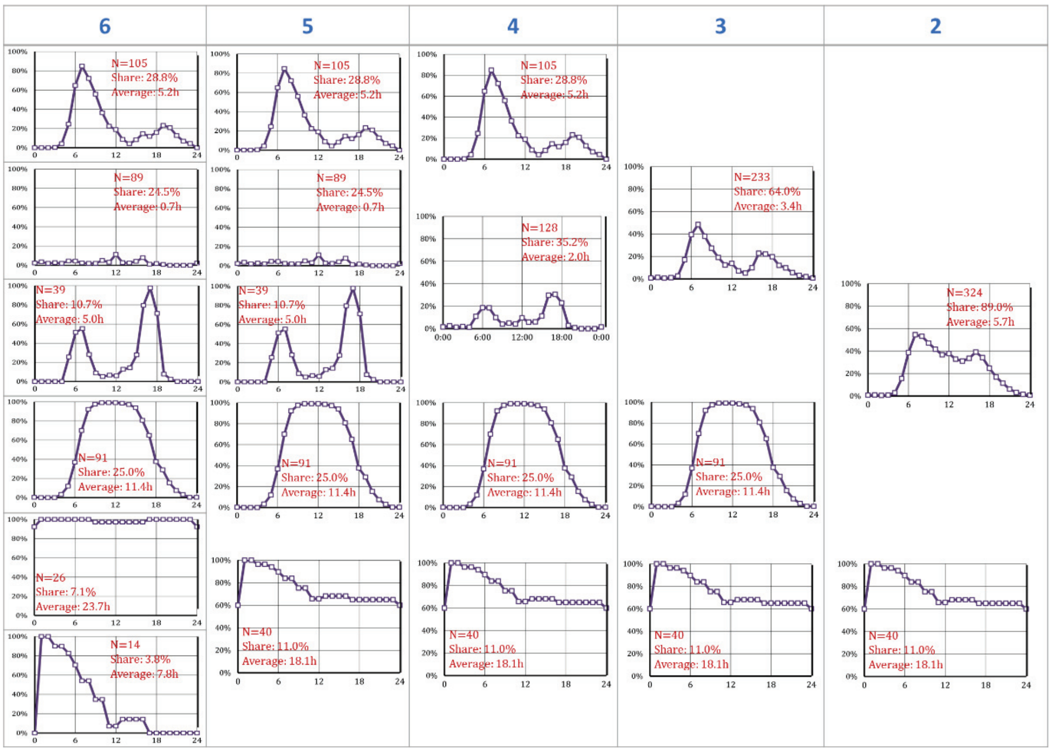


Figure 4.12 Groups of windows-opening pattern based on the number of clusters in apartments living room

Figure 4.13 depicts the hierarchical cluster analysis dendrogram of windows opening in the bedroom and living of Kampong. In the bedroom, the closeness of the cluster was distanced in the beginning and was closed in the end. In contrast, in the living room, the closeness was distant in the end and quite close in the beginning (clusters 5 and 4). This might indicate that the opening pattern can differ between Kampong's bedroom and the living room. However, cluster 3 is selected to represent the window opening pattern in Kampong both for the bedroom and living room, similar to the combined data.

The overall window opening patterns in the Kampong bedroom are expressed in Figure 4.14. Three patterns are selected to explain the opening patterns in the bedroom. The two patterns were relatively the same with all kampong data, but one pattern was different. The first pattern only appeared in the bedroom, where respondents tended to open windows in the morning (around 6 am) for an average of 2.3 hours (16.8%). The second pattern is where they opened windows only during the daytime, for an average of 13.1 hours. Lastly, pattern 3 is always open windows (average 24 hours). Most respondents in Kampong opened their bedroom windows during the daytime (pattern 2), 66.8%. In comparison, 16.8% and 16.3% opened their windows by patterns 1 and 3, respectively.

In the living room, the opening pattern was similar to the pattern of all the kampong data (Figure 4.15). However, in pattern 1 (open in the morning and evening but closed in the afternoon), in the living room, morning and evening tend to open in the same percentage, and in the afternoon, the windows are closed at noon. In comparison, in all data, the morning opening tends to have a higher percentage than the evening one, and windows are closed at 2 pm. Furthermore, people tend to always open windows (pattern 3) less in the living room compared to the bedroom, 10.6% and 16.3%, respectively. People also tend to open more in the evening in the living room compared to in the bedroom. However, most people preferred to open their windows during the daytime, both in the living room and bedroom, 69.1% and 66.8%, respectively.

Overall, the apartment showed more window-opening patterns compared to Kampong, but the tendency to open windows longer is higher in Kampong. In Kampong, most respondents (60%) tend to open their windows during the daytime for 13 hours on average, both in the living room and bedroom. Whereas, in the apartment's bedroom and living room, only ±10% of the respondents opened their windows for more than 12 hours, and ±25% opened their windows for less than one hour.

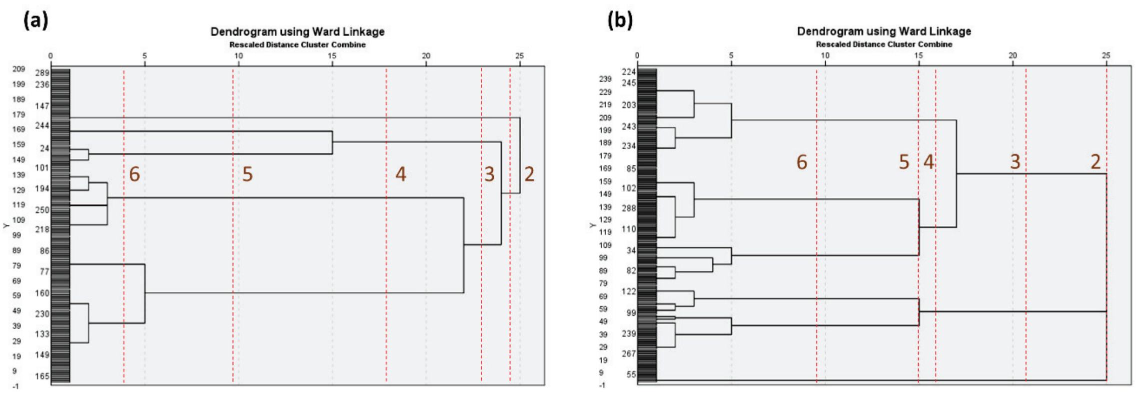


Figure 4.13 Hierarchical cluster analysis dendrogram of daily windows-opening pattern in Kampongs (a) bedroom and (b) living room

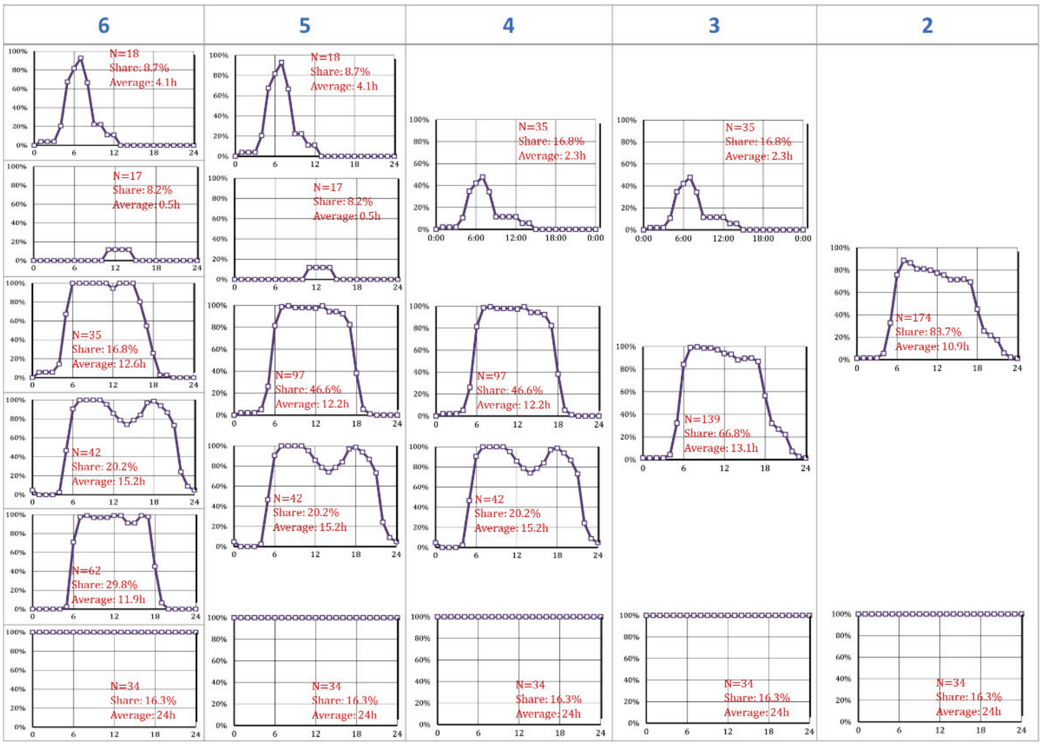


Figure 4.14 Groups of windows-opening pattern based on the number of clusters in Kampong bedroom

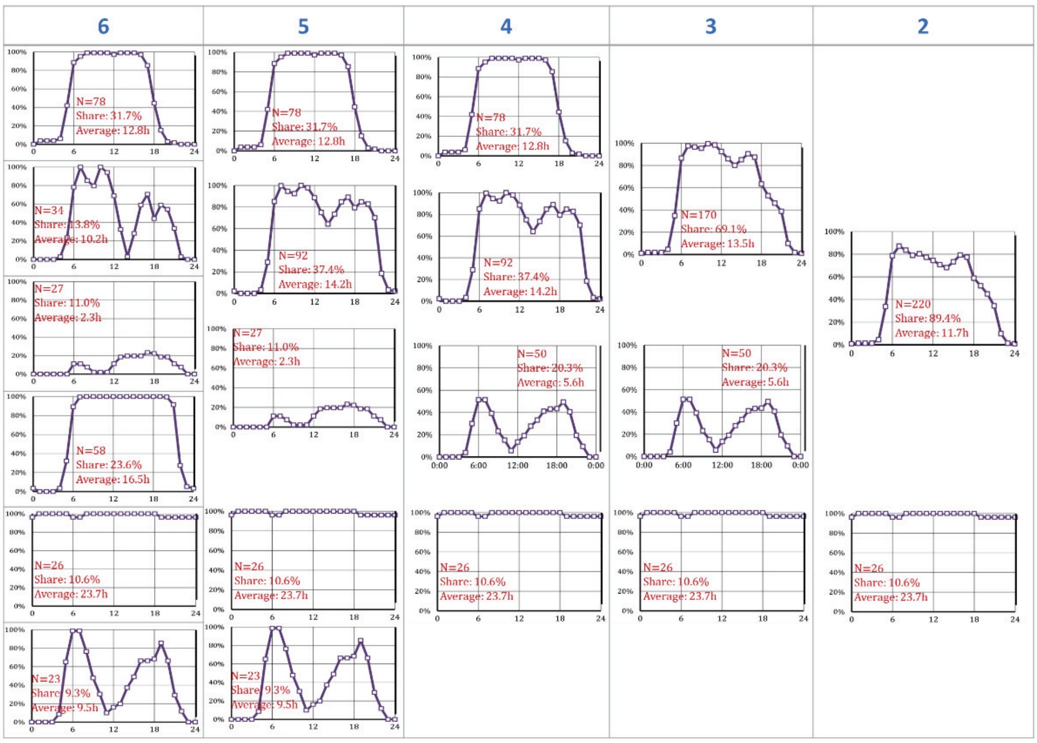


Figure 4.15 Groups of windows-opening pattern based on the number of clusters in apartments living room

4.5.3 Windows-opening pattern and IAQ

Furthermore, we compared and analyzed the differences in the mean value of formaldehyde and TVOCs, respectively, between selected five window-opening patterns in each apartment location (Figure 4.16) to find the correlation between windows-opening behavior and IAQ. Initially, the opening patterns were arranged based on cluster analysis results (Pattern 1-2-3-4-5), as shown in Figure 4.16. However, the following analysis arranged the five window opening patterns based on the opening duration from the least to longer (Pattern 2-1-3-5-4), respectively. The field measurements were done in separate locations, the living room and bedroom, and an average of all six-day measurements is considered as the average concentration of the unit (all data). Therefore, formaldehyde and TVOC concentrations correlated with the windows-opening pattern were also separated based on the measurement location.

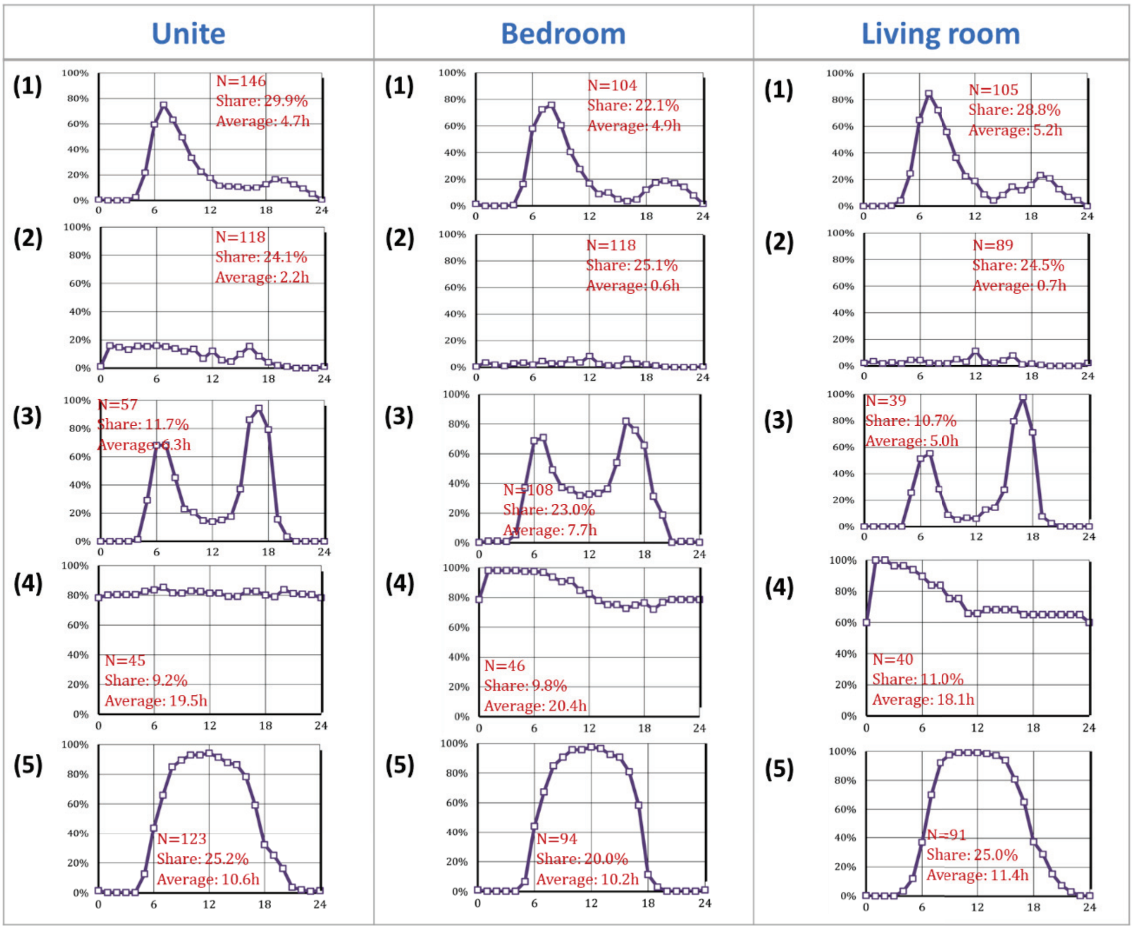


Figure 4.16 Comparison of windows-opening patterns (1-5) in apartment between combined, bedroom, and living room data

Figure 4.17 explains the concentrations of formaldehyde and TVOC (mean and maximum value) based on the windows-opening pattern in the unit, bedroom, and living room. In the unit's mean and maximum values of formaldehyde, opening windows in the morning only showed the highest concentration, 0.098 and 0.265 ppm, respectively. However, this window opening pattern showed the lowest mean and maximum value of TVOCs concentration in the unit, 74.7 and 628.3 μg/m^3 (Figure 4.17a). A similar tendency was also seen in the bedroom's TVOC and maximum value of formaldehyde, except in the mean value of formaldehyde, not opening windows in the bedroom led to the highest concentration, 0.097 ppm (Figure 4.17b). In contrast, the concentrations of formaldehyde and TVOC were the highest when the respondents opened their windows in the morning, closed them in the afternoon, and open again in the evening (Figure 4.17c). The most prolonged opening duration in the apartment living room showed the lowest concentration of mean formaldehyde (0.051 ppm). However, the same tendency was not seen in the TVOC and formaldehyde maximum value. Overall, based on these results, a longer opening duration does not indicate better air quality either. Further analysis is needed to understand further, but climatic conditions and outdoor pollution can be possible factors.

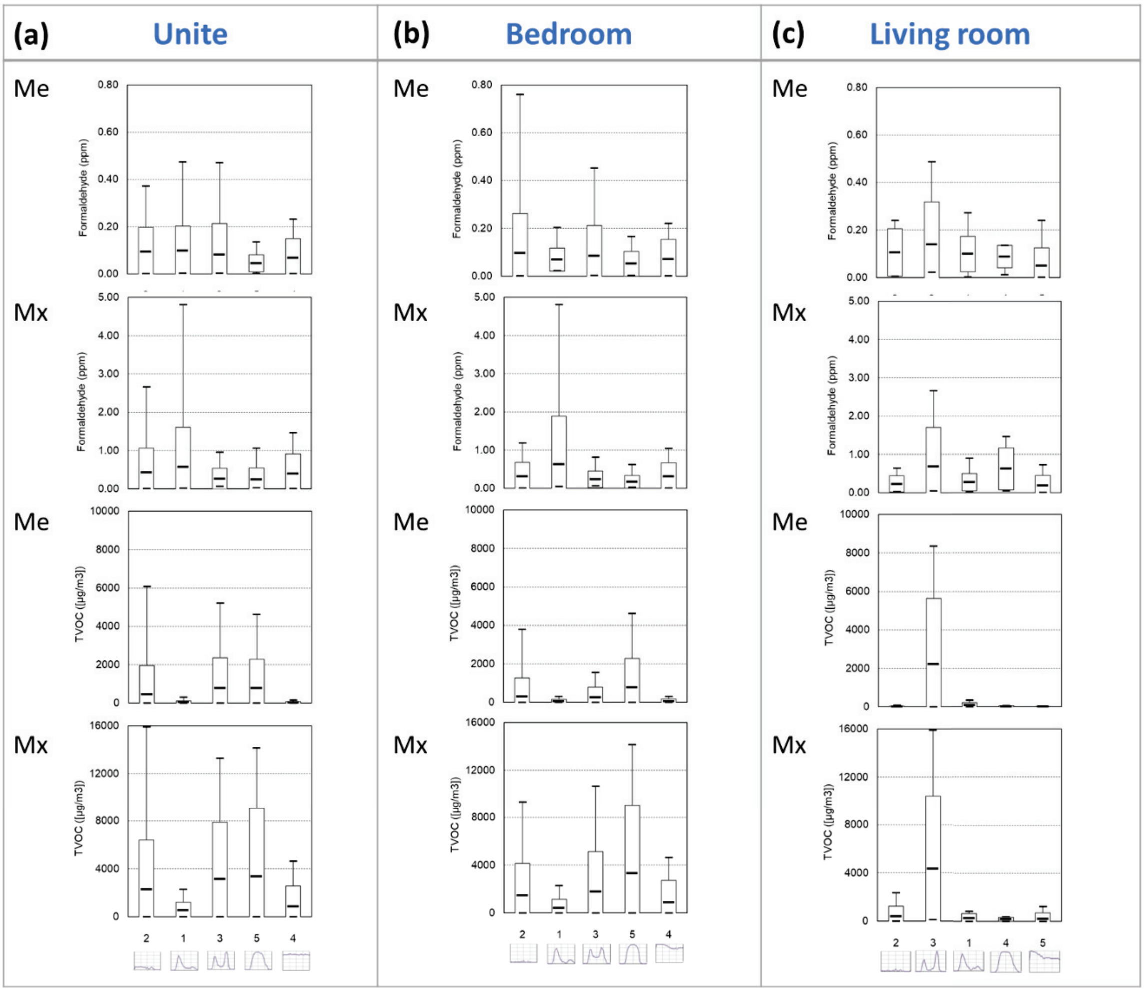


Figure 4.17 Statistical comparison of window-opening pattern formaldehyde and TVOC concentrations in the apartments (a) unit, (b) bedroom and (c) living room

The previous five pattern comparison did not show a significant difference. Therefore, to compare the window opening patterns in apartments and Kampong and differentiate further the opening pattern, the number of patterns was reduced from five to only three patterns in apartments. The results from cluster analysis were in order based on the opening duration, from the shorter to the longest. Figure 4.18 shows the window-opening patterns of apartments compared to Kampong. The apartments' opening patterns are relatively the same: open in the morning only, open during the daytime, and open all day. Whereas in Kampong, the bedroom and living room have different patterns. In addition, the opening durations in Kampong are longer compared to the apartments, even though the patterns are the same.

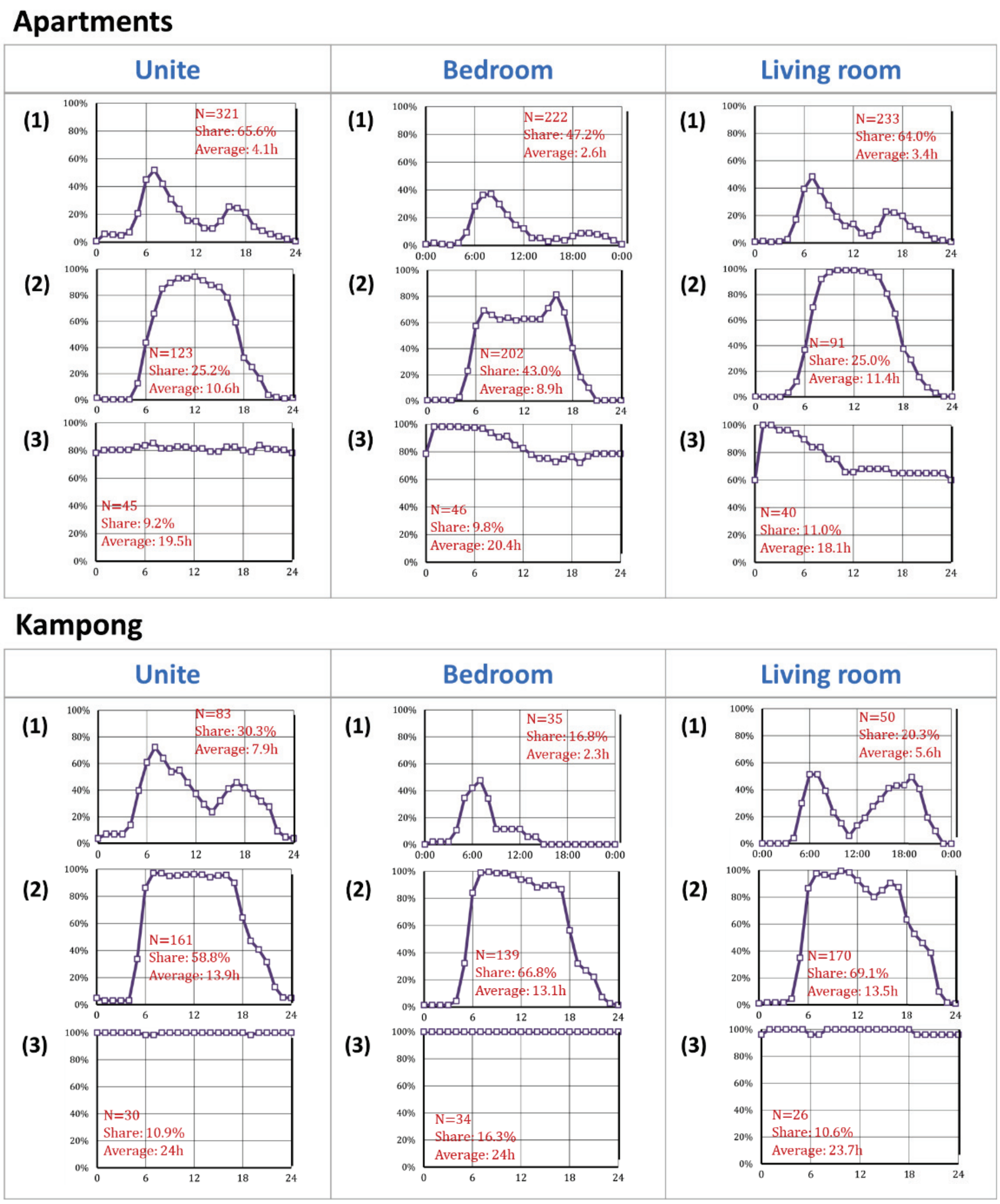


Figure 4.18 Comparison of windows-opening patterns (1-3) between combined, bedroom, and living room data in the apartments and Kampongs

The comparison of IAQ concentration and window opening pattern in apartments and Kampong is explained in Figure 4.19 In apartments united data (Figure 4.19a), no clear tendencies can be seen, pattern 3 showed the lowest concentration of TVOC, but Pattern 2 had more concentration than Pattern 1. Whereas pattern 2 showed the lowest concentration of formaldehyde compared to other patterns. A similar trend can be seen in apartment bedroom TVOC and maximum formaldehyde in the living room. In the mean value of formaldehyde in the apartment's living room and bedroom, the average concentration decreased the longer the opening duration (Figure 4.19b and 4.19c). In contrast, opening patterns showed an increased tendency in the mean value of TVOC in Kampong's united and living room data (Figure 4.19d and 4.19f). The longer they open windows, the higher the average TVOC concentrations. In addition, like the bedroom in apartments, longer opening duration tends to decrease the concentration of formaldehyde in Kampong (Figure 4.19e). However, this tendency was not only in the mean value but also in the maximum value of formaldehyde.

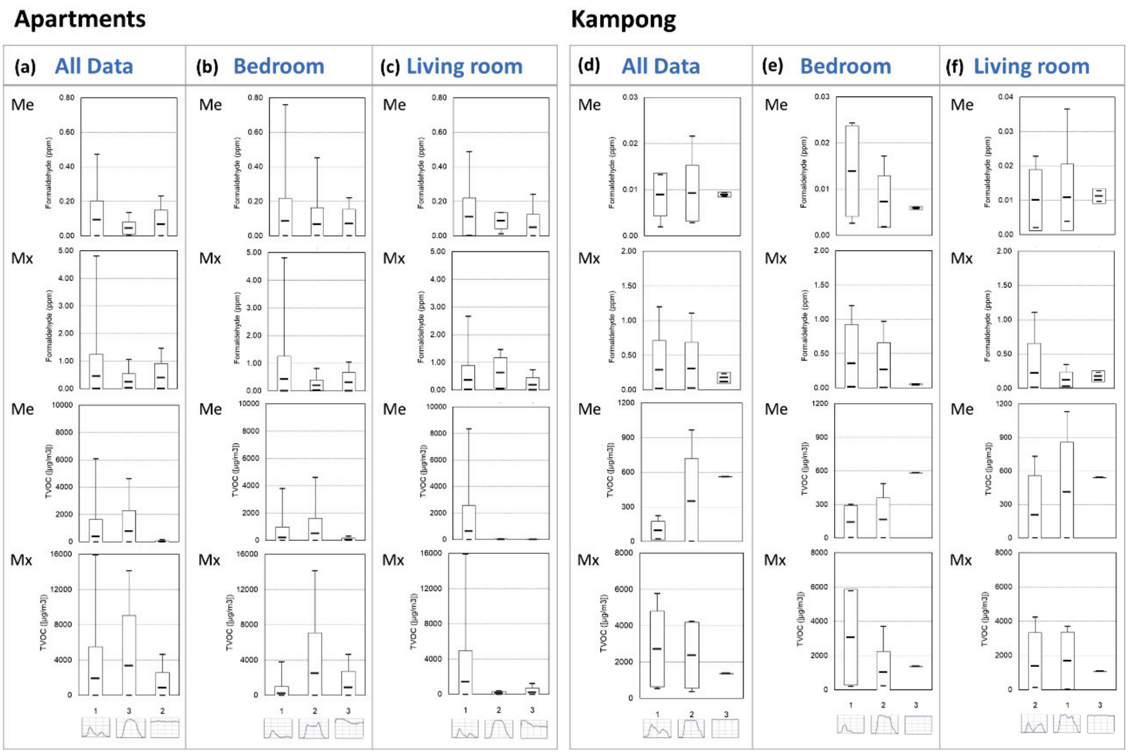


Figure 4.19 Statistical comparison of window-opening pattern formaldehyde and TVOC concentrations in the unite, bedroom and living room of apartment and Kampong.

Furthermore, continuous-measurement results during brief measurement showed possible exposure pattern in some locations. These patterns are different in every unit and only showed in 16% of all the measurements. However, by analyzing the opening time of the house and the measurement result of the specific house, a few cases showed that when the respondents open their window the concentration of formaldehyde decreased. Figure 4.20 shows several examples of chemical concentrations pattern from the field measurements. Several patterns showed that the concentration of formaldehyde increased during nighttime, while some showed the opposite tendencies. Additionally, in the case where the concentration of formaldehyde / TVOC increases during nighttime, it is recommended to open the windows during nighttime. The finding that there is no significant different and tendency between window opening and opening pattern can be related to the situation where the concentrations of chemical in the field measurement are mostly increasing and decreasing with no specific pattern (84%).

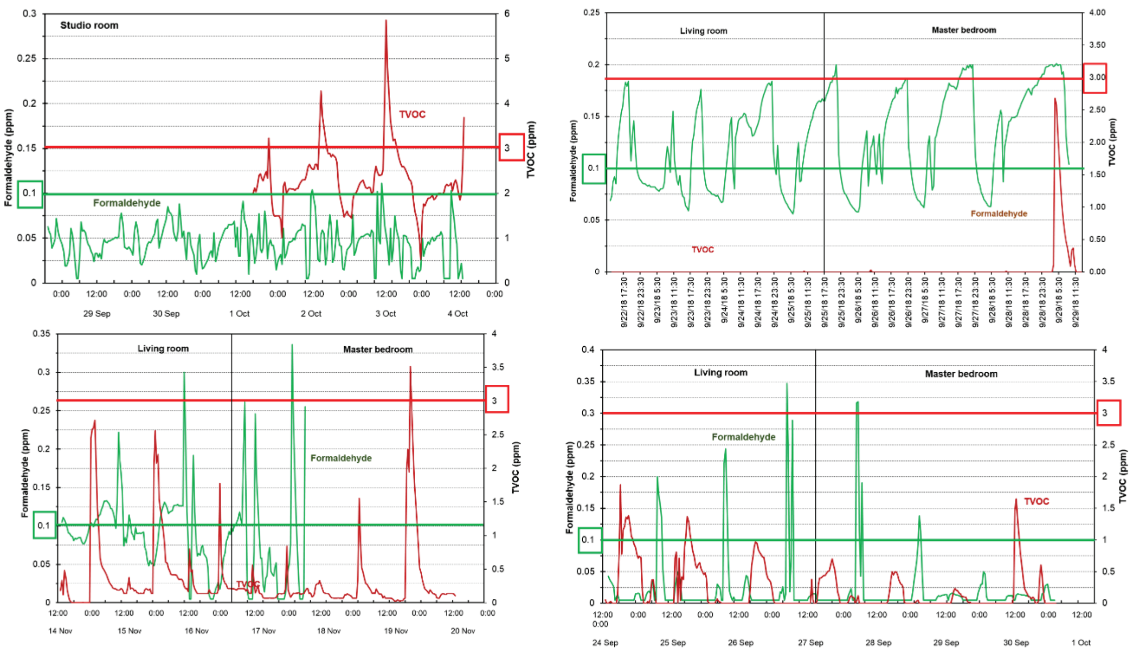


Figure 4.20 Possible pattern of chemical concentrations from continues direct measurement.

4.5 Summary

Further analysis of the household interview data was carried out to find the factors affecting the multiple chemical sensitivity (MCS) risk and SBS in newly constructed high-rise apartments compared to Kampongs. The key findings are summarized as follows:

- In the apartments, MCS risk was generally influenced by allergies and self-reported air quality rates, which were related to the building attributes. The building attributes affected the air quality rates probably due to some emissions from the building materials, such as wallpapers and furniture, which were often perceived as smells by the occupants. The allergies might increase when the occupants clean the rooms and open windows less. The cleaning behaviour significantly increased the duration of opening windows in the apartments.
- In Kampongs, the allergies and self-reported air quality rates were related to dampness, which was the main factor affecting MCS risk. Moreover, older buildings/houses were observed to have more severe dampness problems, possibly causing allergies and decreasing the air quality rates, leading to more MCS risk among the residents.
- Overall, apartment occupants tend to open windows less than in Kampong. In the apartment, people tend to open windows in the morning and only occasionally open their windows in the evening. Whereas in Kampong, people tend to open windows during the daytime for an average of 12 hours.
- There are mainly three window-opening patterns in urban houses, opened all the time (24h), opened during daytime only, and opened in the morning and evening, but closed in the afternoon. The longer the opening durations do not indicate the lower the chemical concentration in both Kampong and apartments. In addition, formaldehyde and TVOC have different tendencies with window opening patterns. In some cases, one pattern will result in a lower concentration of formaldehyde but higher concentrations of TVOC and the other way around. Therefore, further analysis and simulation are recommended to find a suitable opening pattern for improving the IAQ.

5
The Effects of Air Pollution and Dampness on Respiratory Health in Kampong Houses

5.1 Introduction

Many areas in Indonesia's cities still consist of traditional unplanned housing known as Kampungs. These Kampung houses are small, detached dwellings built by non-professional workers in densely populated settlements. While the term "Kampung" can have various interpretations, it generally refers to an urban village. Within Kampungs, the houses vary in size and wealth, often featuring different architectural styles and types (Funo et al., 2018). Moreover, these houses retain characteristics of rural life, such as close family ties, strong social connections leading to a strong sense of ownership, and an informal and irregular building environment. (Parisi et al., 2021). As a result, Kampungs have a distinct urban microclimate with higher relative humidity (RH) compared to other urban areas, particularly during the dry season, with measurements ranging from 74% to 91% in Bandung (Paramita & Suparta, 2019). The prevalence of dampness and mold is common in Kampungs, especially during the rainy season and floods, which can contribute to adverse health effects, particularly respiratory diseases among the residents. In line with the previous chapter, this section focuses on conducting a thorough survey and analysis of Kampungs.

The main objective is to evaluate the residents' health status, particularly respiratory health, and their living environment in these densely populated and unplanned houses, where concerns regarding dampness and respiratory health issues are prevalent. The study involves statistical analysis to examine the correlation between the living environment in Kampungs (such as dampness, mold, and air quality) and respiratory health conditions. The chapter begins by presenting the results of field measurements and assessing the respiratory health of the occupants to determine the current condition (sections 5.3-5.6). Subsequently, it analyzes the factors that influence respiratory health and explores the relationship between physical environments and behavior in sections 5.7 and 5.8.

5.2 Case study Kampong in Bandung

Bandung has undergone a significant transformation, growing from a small-sized city to a sprawling and populous urban center. This expansion has led to the development of residential areas, businesses, and basic infrastructure, contributing to the city's economic activities (Tarigan et al., 2016). Currently, Bandung ranks as the third-largest city in Indonesia and is home to 121 neighborhoods categorized as Kampungs. However, the lack of adequate urban infrastructure has resulted in highly dense Kampungs with irregular grid patterns and disorderly neighborhoods. Bandung has also experienced rising average temperatures, the urban heat island phenomenon, and elevated humidity levels (Paramita & Fukuda, 2013; Paramita & Suparta, 2019). In comparison to Jakarta and Surabaya, the two largest cities in Indonesia, Bandung has seen fewer Kampung Improvement Programs (KIP) implemented. ("Indonesia's Kampung Improvement Program: Policy Issues and Local Impacts for Secondary Cities," 1989). Given these conditions, it is crucial to investigate Bandung as a study area where issues of dampness and indoor air quality (IAQ) may arise in unplanned Kampung houses.

Bandung, the provincial capital city of West Java, is renowned for its high population density within Indonesia (Bandung, 2016). The study area selected for the case study is Kampung Pasteur, a typical Kampung neighborhood located in the center of Bandung (Figure 5.1). This neighborhood encompasses 360 households and is situated near the main street, within the business district that features a large shopping mall and traditional market in close proximity. The roads in Kampung Pasteur are narrow, allowing only one motorcycle to pass at a time (Figure 5.2). The total area of the neighborhood is 5.3 hectares and is divided into six sub-neighborhoods known as RTs (Figure 5.1). After obtaining consent from the head of the neighborhood association, field measurements and interviews were conducted during both the dry season (September-November 2018) and the rainy season (March-April 2019). Additionally, a second set of field measurements focusing on Particulate Matter (PM) and Total Suspended Particulate (TSP) was carried out during the subsequent dry season (September-November 2019) based on the results from the initial measurement.

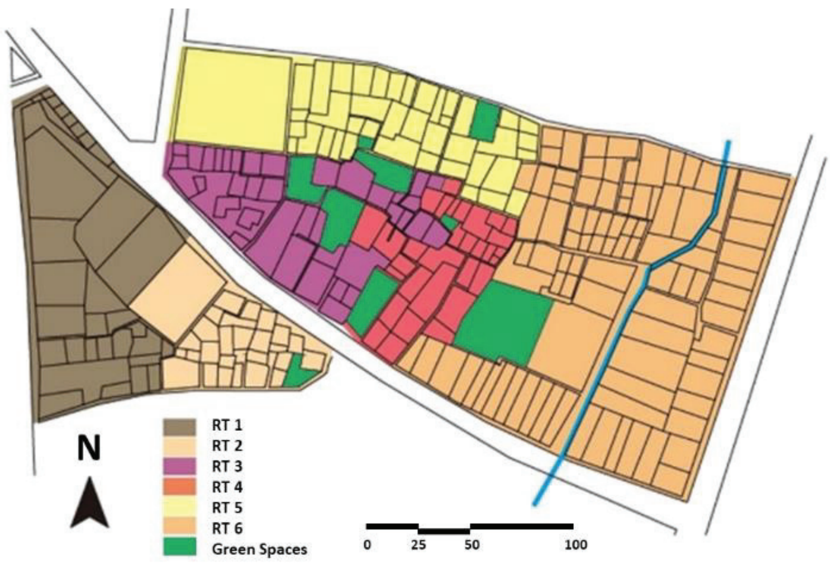


Figure 5.1 Layout and the zone of the Kampung study area

Figure 5.2 Outdoor and indoor views of Kampong case study area

5.3 Methods

Previous research on indoor air quality (IAQ) and dampness has primarily focused on regions in the global north and countries with four distinct seasons, which have different climate characteristics compared to tropical regions (Bai et al., 2021; BRE, 2007; WHO, 2009). The limited of studies addressing this topic in tropical areas, and the few available studies have primarily examined non-residential buildings like schools and offices, often with children as the primary sample group (Fu et al., 2020; Norbäck et al., 2017, 2021; Yap et al., 2009; Zuraimi & Tham, 2008). Some studies that explored the health and housing aspects in the tropics relied on self-reported information (Tham et al., 2007), while others only assessed the current indoor environment conditions of schoolchildren's houses (J. Hu et al., 2020). In contrast, this study employs a combination of objective measurements and self-reported surveys to evaluate dampness in health-related epidemiological investigations (Manivannan et al., 2017) and to explore the factors influencing respiratory health in both children and adults. A total of 599 respondents, 333 during the dry season and 266 during the rainy season, were interviewed. Additionally, 102 samples were randomly selected for field measurements of mold risk, air temperature (AT), and relative humidity (RH), while 38 houses were chosen for measuring Total Suspended Particulate (TSP) and $PM_{2.5}$ levels (Table 5.1).

Table 5.1 Sample size of the study (H. Sani et al., 2022)

Samples		Dry season (Sept – Nov 2018)	Rainy season (Mar - Apr 2019)	Dry season (Sept – Nov 2019)	Total
Questionnaires	ATS-DLD-78	333	266	-	599
Measurements	Mold risk	34	34	34	102
	TSP and $PM_{2.5}$			38	38

5.3.1 Questionnaire survey: household attributes and self-reported health

The interviews were conducted face-to-face using a questionnaire based on the American Thoracic Society-Division of Lung Diseases (ATS-DLD-78) (Ferris, 1978). The ATS-DLD questionnaire has been widely utilized in previous research to investigate respiratory health in general (Enright et al., 1994; Langkulsen et al., 2006; Nkosi & Voyi, 2016). In addition, personal information, occupational history, details about the building characteristics, cleaning practices, window-opening behavior, and tobacco smoking habits were included in the questionnaire (Table 5.2). Moreover, information regarding interior features such as envelope features and ventilation conditions was also recorded. Participants were asked to report their health symptoms, including cough, phlegm, wheezing, breathlessness, chest colds, and chest illnesses, using yes/no questions. The survey was conducted with two target groups: children under 15 years old and adults aged 15 years and above. The questionnaire contained slight variations between these two groups, with additional questions about allergies for children and questions about work history and smoking habits for adults.

Table 5.2 Questions interviewed for household in Kampung (H. Sani et al., 2022)

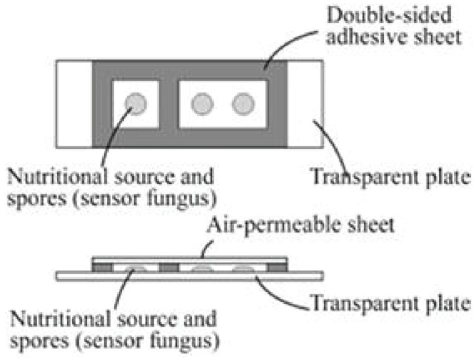
Questionnaire	**Factors / scales**	**Details**
House's and respondent's information	Personal attributes	Age, gender, occupation, asthma (past/present), eczema (past/present), allergic symptoms (past/present), stress level (10-point scale), other diseases
	Household attributes	Established year, living duration, cleaning habits, furniture conditions, household income
	Indoor air quality	Smell sensation (past/present), humidity sensation (10-point scale), mold and water leakage occurrence (past/present), mite observation (past/present), air quality sensation (indoor and outdoor, 10-point scale)
	Detailed cooling behavior	Windows-opening behavior, AC and fan availability and usage

5.3.2 Field measurement: indoor and outdoor air quality

A variety of sensors equipped with data loggers were placed in the dwelling units to gather information on air pollution and mold conditions (Table 5.3). Mold risk measurements were conducted in the master bedroom, approximately 10 cm above the floor, during both the dry and rainy seasons (Figure 5.3b). To predict fungal contamination, a fungal risk detector developed by Abe (1993) was utilized. This device contained dried fungal spores that have varying sensitivities to relative humidity (RH), including moderately *xerophilic Eurotium herbariorum J-183*, strongly *xerophilic Aspergillus penicillioides K-712*, and *hydrophilic Alternaria alternate S-78*, along with nutrients. The measurement process involved exposing the fungal risk detector to the surrounding environment for a period ranging from two days to four weeks, followed by storing the detector in a container with silica gel to prevent hyphae growth. The sample was then sent to a laboratory in Japan for mold prediction. The length of hyphae in each sensor determined the response unit, ru (Abe, 2010, 2012). The fungal index, as defined by Abe (1993), quantified the potential for mold growth in the assessed environment. Similar to a previous study (Hildebrandt et al., 2019), this index was considered valuable for evaluating microclimates in buildings where mold growth could occur. Air temperature (AT) and relative humidity (RH) were simultaneously measured using a sensor (T&D 72ui, 72wf & 73u) at five-minute intervals over a period of seven days. Additionally, a digital dust meter (SIBATA, LR-5R) was deployed to measure Total Suspended Particulate (TSP) and $PM_{2.5}$ levels at a height of 1.1 m above the floor in both the indoor (bedroom) and proximate outdoor environments. Measurements were taken continuously for 24 hours, with a one-minute interval (Figure 5.3a, c). This device employed a dust indicator based on light scattering methods, enabling the calculation of particles and fumes and outputting the average particle size in the air using a specific sensor for particle size (Chicea et al., 2021). Whereas it was suitable for prolonged measurement in a specific location (Sinclair, 1953). In addition, the outdoor measurements were recorded in front of the house at a sheltered area facing the front alley setting.

Table 5.3 Description of the instruments for field measurement (H. Sani et al., 2022)

Measured variable	Instrument model	Accuracy
Air temperature, relative humidity	T&D TR-72Ui	Accuracy: ±0.3℃, ±5%RH Resolution: 0.1℃, 1%RH Range: 0~50℃, 10~95％
Air temperature, relative humidity, air pressure	T&D TR-73U	Accuracy: ±0.3℃, ±5%RH Resolution: 0.1℃, 1%RH, 1 hpa Range: 0~50℃, 10~95％, 750~1100 hpa
TSP, $PM_{2.5}$	SIBATA LD-5R cyclone granulator for $PM_{2.5}$	Accuracy: ±10% (relative to standard particles) Range: 0.001~10.000mg/㎥ (for standard particles)
Mold risk	Fungal risk detector	The error range for mold index measurement at constant temperature and humidity is a few percent (up to 20 percent). Measurable range: fangal index from 8 to 70.5 for one week



Source: Abe (Abe, 2012)

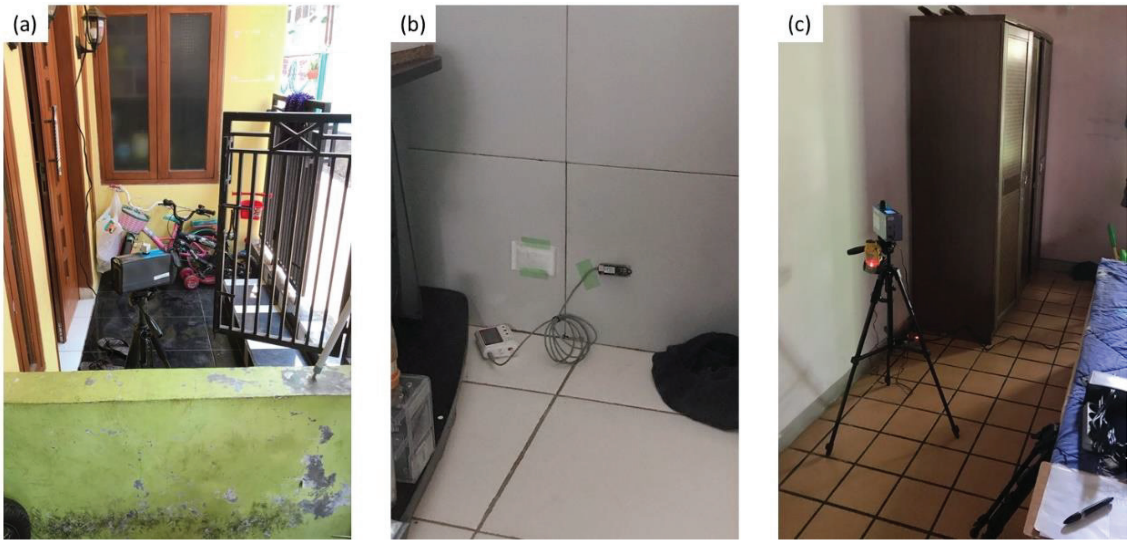


Figure 5.3 Measurement setting in the case study area, (a) PM2.5 and TSP sensor installed outdoor, (b) fungal risk detector for mold risk measurement, and (c) PM2.5 and TSP sensor installed indoor. (H. Sani et al., 2022)

5.3.3 Statistical analysis

Using the data gathered from the questionnaire survey, a path analysis was carried out to comprehend the causal structure impacting persistent cough among people of Kampong, Bandung. The dependent or objective variable was determined to be the self-reported symptoms of respiratory illness. A statistical technique called path analysis demonstrates the mathematical connections between variables, enabling a thorough evaluation of the interrelationships between variables (Olobatuyi, 2006). Various models are employed in path analysis to depict the relationships between variables, guided by the researcher's hypothesis. The parameters used to describe the amounts of variances include direct and indirect relationships among variables. In this study, the path analysis model's hypothesis variables were first determined using a linear regression analysis. The regression analysis progressed from the dependent variable (downstream) to the explanatory variables (upstream). Subsequently, the path analysis was conducted based on the linear regression results. The best-fit model was determined through trial and error, considering indicators such as CFI (>0.8), RMSAE (<0.05), and chi-square values of the model. All statistical analyses were carried out using the SPSS program.

5.4 Household survey

In Table 5.4, it can be observed that the average age of the respondents was 36.3 years, with 17.9% of the respondents being children aged 14 years and below. Among the children group, male respondents were slightly more prevalent (52.3%) compared to females (47.7%), while in the adult group, female respondents (54.5%) outnumbered males (44.7%). Whereas 56.3% of the respondents belonged to the income group of US$150-450.

Regarding window opening behavior, it was found that respondents tended to open windows for around nine hours in the bedroom and 12 hours in the living room, particularly during the daytime. During the dry season, approximately 69% of the respondents (32% active smokers, 37% passive smokers) were exposed to Environmental Tobacco Smoke (ETS). This exposure increased during the rainy season, with over 98% of respondents (50% active smokers, 48% passive smokers) being exposed to ETS. The type of smoke breathed is the major distinction between active and passive smoking. Active smoking refers to inhaling the mainstream smoke (MSS) produced during a puff, while passive smoking occurs when a person inhales the smoke generated by a lit cigarette between two puffs (SSS) or the smoke exhaled by an active smoker (EXS) (Schramm et al., 2014). Children often experience passive smoking when there is an adult smoker in their vicinity, which is a common practice in Southeast Asia where the smoking rate is 29% (*Smoking Rates by Country 2022*, n.d.).

Table 5.4 Profile of respondents (H. Sani et al., 2022)

			Whole n=599	Child n=101	Adult n=497	Dry season n=333	Rainy season n=266
Personal attributes	Age	Years [mean]	36.3	6.9	42.4	35.9	36.9
	Duration	Years [mean]	26.4	22.9	26.8	28.3	23.6
	Gender [%]	Male/ Female	45.8/53.5	52.3/47.7	44.7/54.5	45.1/53.6	46.7/53.3
	Income (US$) [%]	< 150	27.9	23.1	28.8	34.9	18.8
		150-450	56.3	60.0	55.7	48.3	67.0
		450-750	10.3	9.2	10.4	8.8	12.2
		> 750	5.5	7.7	5.1	8.0	2.0
	Occupation [%]	Government	0.9		1.1	0.9	
		Private	18.9		21.6	18.9	
		Entrepreneur	15.5		18.3	15.5	
		Student	20.1	81.6	10.6	20.1	
		Housewife	26.9		31.1	26.9	
		Retired	6.5		7.7	6.5	
		Other	10.5	18.4	9.2	10.5	
	Worked for a year or more in dusty job	[%]	39.9		39.9	29.1	49.0
	Exposed to gas or chemical fumes in work	[%]	19.7		19.7	16.9	22.3
Behavior	Window opening in bedroom	Hours (Average)	9.0	8.3	9.1	8.6	9.6
	Window opening in living room	Hours (Average)	12.1	13.5	11.8	13.8	9.0

	Smoking behavior [%]	Active	39.6		39.6	31.9	50.0
		Passive	41.2		41.2	36.5	47.1
	Frequency of cleaning rooms [%]	Every day	90.8	92.6	90.5	87.3	96.6
		Several times per week	5.3	2.5	5.8	7.9	1.0
		Every week	0.8	1.2	0.7	1.2	0.0
		2-3 times per month	1.7	2.5	1.5	2.7	0.0
		Once per month or less	1.5	1.2	1.5	0.9	2.5
	Frequency of cleaning bathroom [%]	Every day	63.2	72.7	62.3	62.2	64.0
		Several times per week	25.9	27.3	25.8	20.5	30.0
		Every week	8.6		9.5	12.8	5.4
		2-3 times per month	1.1		1.2	2.6	
		Once per month or less	1.1		1.2	1.9	0.5
Health	Asthma	[%]	13.8	15.7	13.5	13.8	
	Hay fever	[%]	30.8	20.7	33.0	30.8	
	Eczema	[%]	13.5	10.9	14.1	13.5	
	Allergy	[%]	13.6	9.4	14.4	13.6	
	Disease	[%]	18.0	1.8	21.6	18.0	
	Health change	[%]	4.3	0.0	5.2	4.3	
	Stress	[mean: 0 = no stress, 10 = very stressful]	1.5	0.4	1.8	1.5	

Referring to Table 5.5, there were 266 participants in the rainy season and 333 in the dry season. Indicating their comparability, the two samples showed no discernible differences in terms of gender, age, or building age. The average age of the buildings in the overall sample was 40.7 years, and 36.5% of the homes were older than 50 years. Notably, 32% of homes lacked windows in the living room and about 25% of homes lacked windows in the master bedroom. Additionally, the vast majority (91.5%) of homes in urban Kampung areas have switched from utilizing solid fuel to gas stoves as their main source of cooking energy.

Dampness was prevalent in the Kampung dwellings, with visible mold observed in 48.9% of the dwellings and 64% of dwellings in the children group indicating the presence of mold. Around 18% of houses reported mite problems, while water leakage (59.9%) as well as odor and smell issues (60.6%) were commonly reported, particularly during the rainy season. In terms of indoor air quality (IAQ), 15.3% of adult respondents and 18.7% of children thought that IAQ was generally 'dirty', while approximately 19.3% of adults and 12% of children perceived outdoor air quality (OAQ) as 'dirty'. Furthermore, about 10.1% of the respondents said that they were irritated by outdoor air pollution.

Table 5.5 Overview of building attributes, interior sources and perceived indoor air quality levels (H. Sani et al., 2022)

			Whole n=599	Child n=101	Adult n=498	Dry season n=333	Rainy season n=266
Building attributes	Building age	Average age [a] [years]	40.7	39.7	40.8	39.0	41.9
	No. of windows in master bedroom [%]	0	24.8	20.9	25.6	29.9	16.8
		1	51.6	58.2	50.3	48.0	57.1
		>1	23.6	20.9	24.1	22.0	26.1
	No. of windows in	0	32.1	34.4	31.7	37.6	22.5

	living room [%]	1	38.3	46.9	36.6	41.6	32.4
		>1	29.6	18.8	31.7	20.4	43.0
	HVAC system [%]	AC	6.7	8.7	6.4	4.7	10.6
		Fan in bedroom	65.7	66.7	65.6	65.7	
		Ceiling / stand fan	47.3	45.7	47.7	47.3	
		Exhaust fan	17.9	27.3	19.7	17.9	
	Number of furniture in living room [%]	0	4.3	2.0	4.8	4.3	
		1-5	86.2	88.2	85.7	86.2	
		>5	9.6	9.8	9.5	9.6	
	Number of furniture in bedroom [%]	0	1.1	2.2	0.9	1.1	
		1-5	90.6	84.4	91.9	90.6	
		>5	8.2	13.3	7.2	8.2	
	Vehicle frequency [%]	Constantly	22.7		22.7	13.0	31.9
		Frequency	46.0		46.0	56.7	39.3
		Seldom	29.1		29.1	27.9	27.4
		never	2.2		2.2	2.3	1.5
	Gas stove usage [%]		91.5		91.5	91.5	
Dampness	Visual mold	[%]	49.8	64.0	47.3	55.9	39.2
	Mite	[%]	17.9	23.8	16.9	19.9	15.0
	Water leakage	[%]	53.7	58.4	52.8	50.2	59.9
	Smell / Odor	[%]	47.8	57.5	46.1	39.8	60.6
	Humidity [%]	0-3: (rather) dry	21.6	19.4	22.0	21.4	22.1
		4-6: neutral	46.6	43.1	47.2	44.3	50.3
		7-10: (rather) humid	31.7	37.5	30.8	34.3	27.7
Perceived IAQ	IAQ [%]	0-3: (rather) clean	38.2	34.7	38.7	35.6	42.3
		4-6: neutral	46.1	46.7	45.9	47.1	44.4
		7-10: (rather) dirty	15.8	18.7	15.3	17.3	13.3
	OAQ [%]	0-3: (rather) clean	30.2	24.0	31.2	28.0	33.8
		4-6: neutral	50.4	57.3	49.2	49.7	51.5
		7-10: (rather) dirty	19.2	12.0	19.3	22.0	9.1
	Annoyance from outdoor air pollution [%]	0-3: not annoyed	63.8		63.8	57.6	69.4
		4-6: neutral	26.0		26.0	34.3	18.7
		7-10: annoyed	10.1		10.1	8.1	11.9

5.5 Self-reported Respiratory health

The ATS-DLD-78 questionnaire was used to assess the severity of respiratory health symptoms, including asthma, persistent cough, and persistent phlegm. Comparisons were done for various seasons and ages, because the survey were done in different seasons and the questionnaire forms for children and adults were initially built differently in the ATS-DLD-78, specifically adults (>15 years old) and children (14 years old), respectively. Figure 5.4 demonstrates that, aside from asthma, children generally displayed a higher percentage of severe symptoms (i.e., sickness) during the dry season. During this season, the percentages of sickness and certain symptoms among children were as follows: 19.2% for asthma, 24.4% for cough, and 17.0% for phlegm. However, the incidence rates increased in the rainy season, particularly for persistent cough and phlegm, with rates of 13.0% for asthma, 41.3% for cough, and 22.2% for phlegm. Among adult respondents, the highest percentage was found to be for persistent cough, with rates of 23.8% in the dry season and 27.1% in the rainy season.

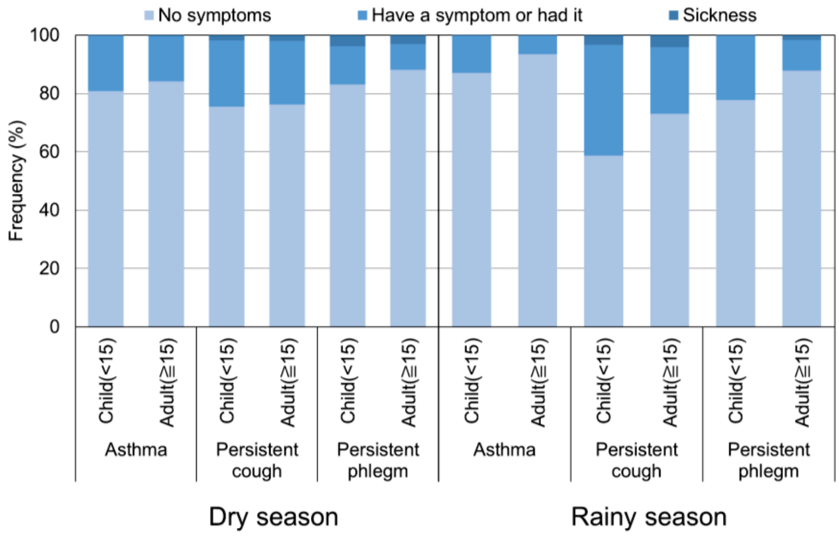


Figure 5.4 Self-reported respiratory health among adults and children in both dry and rainy season (H. Sani et al., 2022)

5.6 Field Measurements

Figure 5.5 depicts the overall results of mold risk measurements in relation to the observed thermal conditions. The mold risk categories range from A (low likelihood of fungal propagation) to D (high likelihood of propagation). During the rainy season of 2019, the mold risk was severe, with 97% of houses experiencing a high risk of mold propagation. In the dry season of 2018, 67% of houses were exposed to a high risk of mold. However, in the dry season of 2019, due to unusually low humidity (average 65%), 91% of houses showed no possibility of mold propagation. Mold risk typically becomes evident when the relative humidity exceeds 70% and the air temperature falls below 27°C. Interestingly, during dry season 2018, even when indoor relative humidity exceeded 70% and indoor air temperature was averagely higher (>26ºC), often exceeded the above threshold point of temperature, the measured mold indexes exhibited minimal variations. This suggests that other factors such as surface material properties and dampness conditions play a role in mold growth.

Furthermore, the interrelationship between the thermal conditions in the kampong environment and mold risk was explored using a psychrometric graph. The graph represents air temperature on the horizontal axis, its precise water vapor content in the air (humidity ratio or specific humidity) on the vertical axis, and relative humidity (RH) through curved lines (Lechner, 2015). The psychrometric graph has two boundaries or limits: the lower part represents dehydrated air, while the upper part represents air saturated with water vapor (100% RH) (Lechner, 2015). Figure 5.6 displays the mold indices and psychrometric graphs for three separate measurement times from Kampong. Although the air temperature in Kampong did not significantly differ between the dry and rainy seasons, ranging from 22-28 ºC, there were notable differences in relative humidity. In the rainy season, relative humidity ranged from 70% to 100%, which could contribute to higher mold indexes in kampong houses.

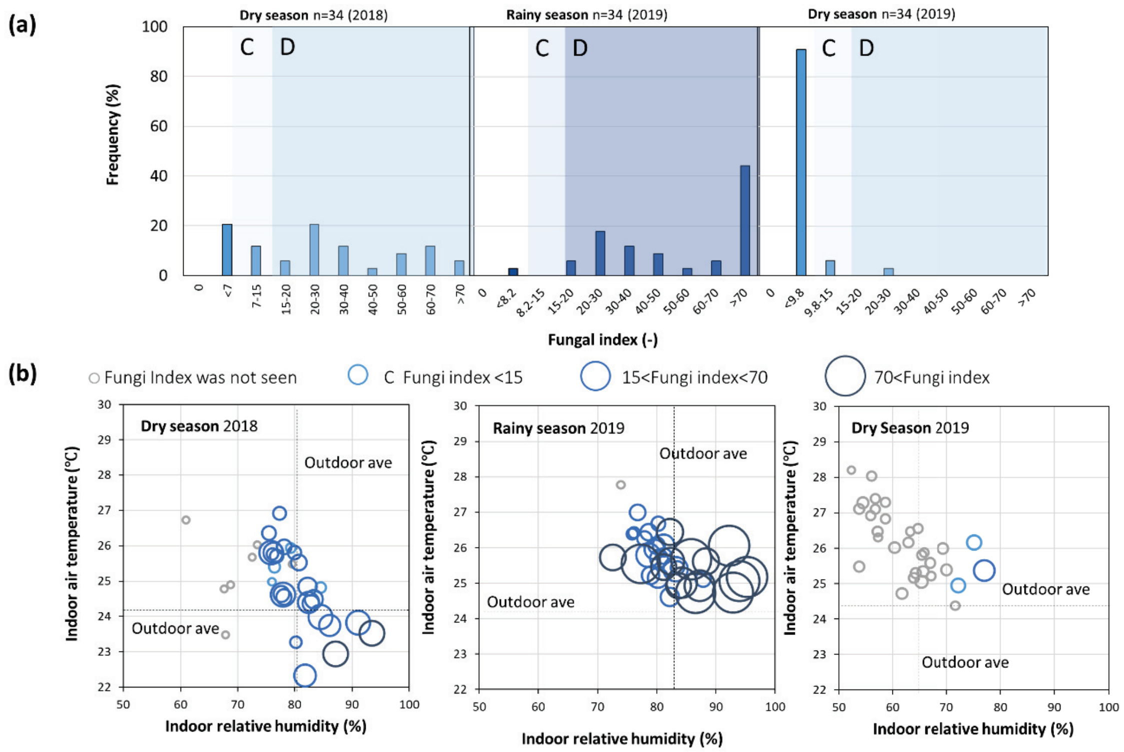


Figure 5.5 (a) Measured fungal indexes in Kampung houses (b) Relationship between thermal conditions and mold risk. (H. Sani et al., 2022)

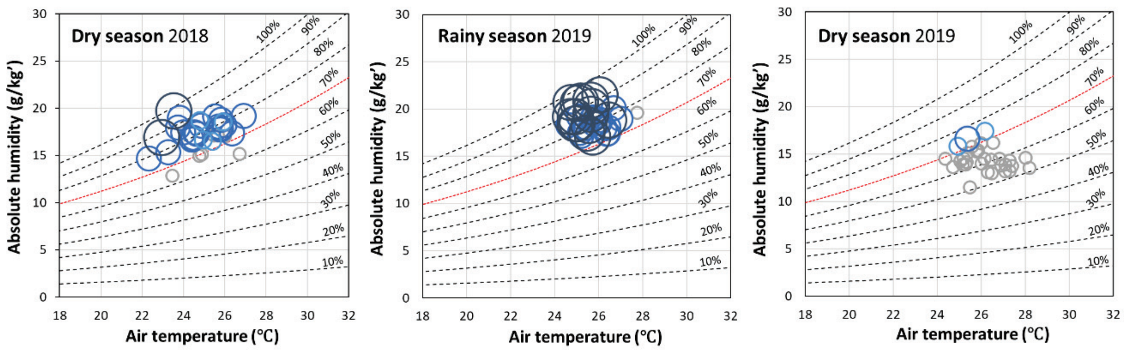


Figure 5.6 Measured fungal indexes in psychrometric charts (indoor thermal conditions) (H. Sani et al., 2022)

Figure 5.7 displays the locations of the surveyed households and the measured air sampling locations. The color circles represent concentrations of Total Suspended Particulate (TSP) and $PM_{2.5}$, with darker colors indicating higher concentrations. It can be observed that TSP and $PM_{2.5}$ are spread throughout the entire kampong area in high proportions. However, it is possible that particles from the nearby road were dispersed by the wind, resulting in higher concentrations elsewhere in several locations rather than being specifically close to the road. The average indoor and outdoor particle concentrations over a 24-hour period are shown for each residence in Figure 5.8. As demonstrated, the indoor concentrations of TSP and $PM_{2.5}$ generally corresponded with outdoor concentrations, with some exceptions where indoor concentrations significantly exceeded outdoor levels. Similar findings were reported in a field measurement conducted by Lueker et al. (2020), in slum tenements of Dharavi, Mumbai, India, where indoor and outdoor $PM_{2.5}$ concentrations were correlated, except for occasional spikes induced by indoor cooking. The average indoor TSP concentration in this study was measured at 70.5 g/m^3, with almost 65% of the dwellings exceeding the WHO limit (24-hour PM_{10}) for outdoor TSP concentrations (50 g/m^3) (Figure 5.8a2). Additionally, the average interior $PM_{2.5}$ concentration was measured at 61.9 g/m^3, with around 87% of the homes above the recommended $PM_{2.5}$ threshold concentration of 25 g/m^3 (Figure 5.8b1), indicating significant indoor pollution. It's interesting to note that for 58% of the homes, the average outside $PM_{2.5}$ concentration was higher than the indoor concentration (Figure 5.8b-3). TSP, on the other hand, had an average outdoor concentration that was 47% greater than the average interior TSP concentration. These findings can be attributed to emissions from diesel engines and hydrocarbons, particularly from 2-stroke motorcycles, as well as air pollution such as haze from open burning.

Figure 5.7 The measurement distribution of (a) TSP and (b) $PM_{2.5}$ outdoor mean concentration

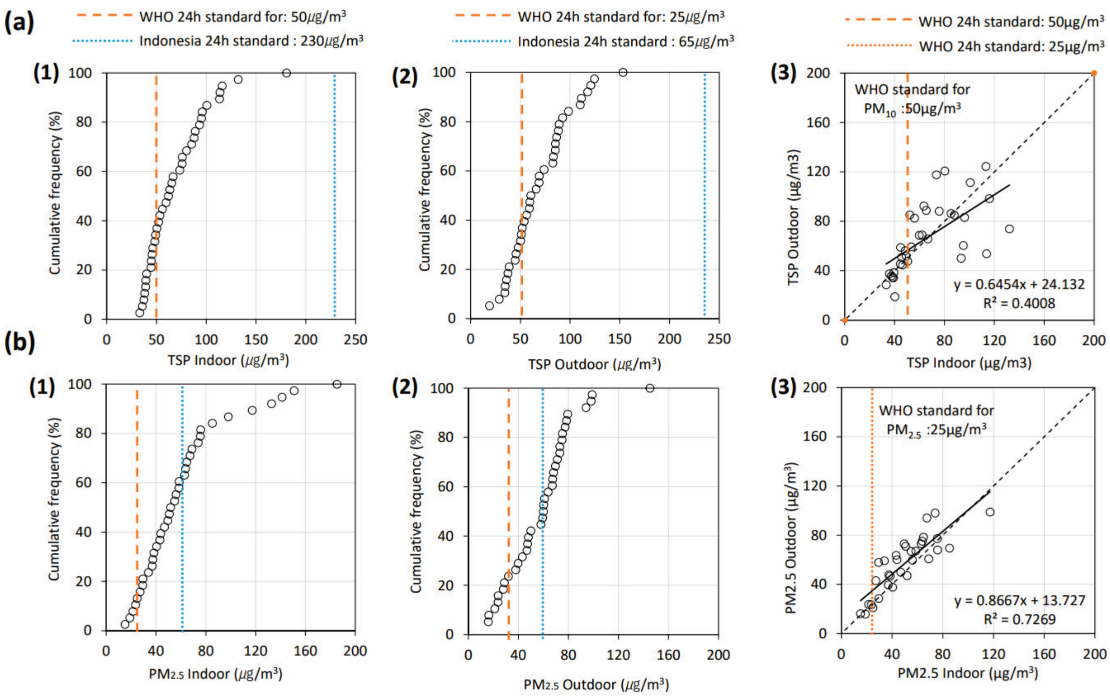


Figure 5.8 Cumulative frequency of (a) TSP and (b) PM2.5; (1) Indoor, (2) outdoor and (3) association between indoor and outdoor (H. Sani et al., 2022)

5.7 Factor impacting occupant respiratory health symptoms

5.7.1 Logistic regression analysis

Logistic regression analysis was applied to the questionnaire data in order to find the factors causing the respiratory health symptoms in Kampong, for both respondents under 15 years old age (n=101) and above 15 years old and over (n=479). IBM SPSS statistics 23 was utilized for the analysis. In addition to Crude's unadjusted analysis, the analysis was adjusted by gender and income variables, for respondents under 15 years old, while for those above 15 years old and over, it was adjusted for age, gender, and income. Additionally, the results were further stratified by age groups, with each group covering a 15-year span (0-15 / 16-30 / 31-45 / 46-60 / 60+). The odds ratios (ORs) were calculated for each step up in the age classification. The odds ratios (ORs) were calculated for each step up in the age classification. Furthermore, the ORs for window opening time were measured for every 6-hour interval. The ORs for the levels of "stress," "humidity," "IAQ" (Indoor Air Quality), and "OAQ" (Outdoor Air Quality), as well as "Annoyance by outdoor air pollution," were categorized into three levels: 0-3, 4-6, and 7-10.

Table 6.2 presents the findings of the analysis conducted for respondents under 15 years old. Regarding personal attributes, income level showed a significant effect on persistent cough symptoms ($p<0.05$), in both the unadjusted analysis (OR: 0.31) and the adjusted analysis (OR: 0.29). The findings show that when the income level of the occupant rises, the prevalence of persistent cough symptoms declines, indicating further analysis necessary to understand the connection between income level and respiratory health in Kampong house. Another interesting result is that asthma symptoms were more likely to occur when windows in the living room were opened (OR: 2.87), in every increase of opening duration for 6 hours the symptoms of asthma increased by 2.87 times. On the other hand, the number of windows in master bedroom showed a significant correlation with persistent cough ($p<0.01$) and phlegm symptoms ($p<0.05$). The likelihood of developing symptoms was shown to be reduced in bedrooms with windows, OR: 0.15 (persistent cough) and 0.10 (persistent phlegm). Additionally, the "IAQ" (Indoor Air Quality) environment rating had an odds ratio of 5.46, indicating that a higher rating for indoor air quality is linked to an increased occurrence of asthma symptoms. In every three rates increase of the IAQ the asthma symptoms increased by 5.46 times, prompting the need to further investigate the impact of personal IAQ rate on these outcomes.

Following that, Table 6.3 presents the findings specifically focused on adults or those above 15 years old and over. In the adjusted analysis concerning personal attributes, several associations were observed. There was a connection between persistent cough symptoms and "age" (OR: 1.46), suggesting that the likelihood of persistent cough symptoms increases 1.46 times every 15 years additional age. Similarly, it was discovered that persistent phlegm symptoms were related to "gender" (OR: 2.18), suggesting that male respondents may be more prone to these symptoms by 2.18 times compared to female. Same as those under 15 years old, the symptoms of asthma for adults also related to the windows opening duration in living room (OR: 1.31). History of health factors (asthma, allergy and stress) were found be correlated with all three symptoms as expected. Additionally, passive smoking was also linked to asthma and phlegm. Asthma was significantly correlated with passive smoking, both in unadjusted (OR: 2.44) and adjusted (OR:3.52), indicating passive smoking exposure increased the risk of asthma by 2-3 times for adults. Whereas phlegm risk was increased 1.90 times when there is passive smoking exposure. In dampness, smell occurrence was found to increase the risk of cough (OR: 1.97) and phlegm (OR: 2.18) in adult respondents.

Table 5.6 Odds ratios with 95% confidence intervals of questionnaire variables for respiratory health among those under 15 years old

		Asthma		Cough		Phlegm	
		OR	95%CI	OR	95%CI	OR	95%CI
Personal attributes	Age (0-15,15-30,31-45,46-60,60<)						
	Adjusted[a]						
	Gender (male/female)	0.52	(0.13 - 2.05)	1.09	(0.33 - 3.64)	1.18	(0.42 - 3.31)
	Adjusted[a]	0.79	(0.18 - 3.48)	2.8	(0.57 - 13.66)	3.54	(0.63 - 19.95)
	Income (<150,150-450,450-750,750<, US$)	1.28	(0.60 - 2.74)	0.31	(0.11 - 0.89)*	0.51	(0.18 - 1.41)
	Adjusted[a]	1.23	(0.57 - 2.67)	0.29	(0.09 - 0.99)*	0.63	(0.23 - 1.74)
	Work in dusty job (YES/NO)						
	Adjusted[a]						
	Exposed to gas or chemical fumes (YES/NO)						
	Adjusted[a]						
Behavior	Window opening in bedroom (6h)	0.63	(0.30 - 1.34)	0.95	(0.54 - 1.69)	1.02	(0.50 - 2.05)
	Adjusted[a]	0.75	(0.38 - 1.50)	0.39	(0.12 - 1.26)	0.81	(0.34 - 1.94)
	Window opening in living room (6h)	1.07	(0.8 - 1.43)	0.99	(0.73 - 1.35)	0.87	(0.53 - 1.41)
	Adjusted[a]	2.87	(1.18 - 6.98)*	1.22	(0.58 - 2.58)	1.13	(0.50 - 2.54)
	Smoking active (YES/NO)						
	Adjusted[a]						
	Smoking passive (YES/NO)						
	Adjusted[a]						
	Clean room (2-3times per month/every week/several time per week/everyday)	1.32	(0.64 - 2.69)				
	Adjusted[a]	1.26	(0.59 - 2.68)				
	Clean bath (2-3times per month/every week/several time per week/everyday)	2.50	(0.17 - 37.26)			1.78	(0.14 - 23.40)
	Adjusted[a]					0.69	(0.03 - 17.80)
Health	Asthma (YES/NO)	21.67	(3.4 - 137.99)**	4.44	(0.80 - 24.53)	1.42	(0.24 - 8.37)
	Adjusted[a]	45.25	(3.11 - 659.35)**	3.29	(0.17 - 63.59)	23.93	(0.81 - 703.39)
	Eczema (YES/NO)			1	(0.10 - 9.75)	0.67	(0.07 - 6.38)
	Adjusted[a]			1.12	(0.06 - 20.12)	1.38	(0.10 - 19.59)
	Allergy (YES/NO)			3.81	(0.54 - 27.08)	6.33	(0.92 - 43.68)
	Adjusted[a]			38.6	(0.66 - 2263.56)	4.70	(0.19 - 115.6)
	Stress (0-3,4-6,7-10)						
	Adjusted[a]						
Building attributes	Age of building (10years)	0.28	(0.09 - 0.91)*	1.06	(0.58 - 1.93)	0.83	(0.45 - 1.52)
	Adjusted[a]	0.59	(0.31 - 1.12)	0.77	(0.36 - 1.65)	1.03	(0.68 - 1.57)
	No. of windows in master bedroom (1 or more/NO)	2.16	(0.24 - 19.38)	0.15	(0.03 - 0.66)**	1.09	(0.25 - 4.72)
	Adjusted[a]	1.16	(0.10 - 12.89)	1.34	(0.18 - 9.82)	0.10	(0.01 - 0.76)*
	No. of windows in living room (1 or more/NO)	4.57	(0.52 - 39.95)	0.63	(0.15 - 2.61)	0.84	(0.23 - 2.99)
	Adjusted[a]	2.85	(0.30 - 27.24)	0.64	(0.10 - 4.22)	0.44	(0.07 - 2.91)
	HVAC system (YES/NO)	10.29	(1.45 - 72.81)*	5.00	(0.63 - 39.79)	4.80	(0.6 - 38.23)
	Adjusted[a]	5.16	(0.50 - 53.15)	21.84	(0.61 - 783.17)		(-)
	Ceiling / stand fan (YES/NO)	1.83	(0.36 - 9.35)	2.03	(0.30 - 13.51)	0.28	(0.03 - 2.69)
	Adjusted[a]	0.94	(0.16 - 5.51)	0.37	(0.02 - 7.48)		(-)
	Exhaust fan (YES/NO)	0.83	(0.08 - 9.25)	0.83	(0.08 - 9.25)	0.67	(0.06 - 7.25)
	Adjusted[a]	0.43	(0.03 - 5.77)			4.00	(0.10 - 163.94)
	Vehicle frequency (Never / seldom / frequency / constantly)						
	Adjusted[a]						
Dampness	Visual mold (YES/NO)	5.62	(0.66 - 47.82)	1.62	(0.38 - 6.81)	1.39	(0.42 - 4.64)
	Adjusted[a]	4.80	(0.46 - 49.8)	2.16	(0.32 - 14.53)	3.1	(0.33 - 29.17)
	Mite (YES/NO)		(-)	2.2	(0.59 - 8.12)	3.26	(0.97 - 10.97)
	Adjusted[a]		(-)	2.87	(0.49 - 16.6)	0.99	(0.17 - 5.82)
	Water leakage (YES/NO)	0.36	(0.09 - 1.44)	3.75	(0.74 - 18.98)	1.17	(0.37 - 3.71)
	Adjusted[a]	0.38	(0.09 - 1.70)	1.87	(0.36 - 9.69)	6.45	(0.67 - 61.83)
	Smell / Odor (YES/NO)	0.92	(0.24 - 3.59)	1.82	(0.47 - 6.99)	3.25	(0.91 - 11.66)
	Adjusted[a]	0.78	(0.17 - 3.51)	2.15	(0.43 - 10.62)	1.45	(0.29 - 7.29)
	Humidity (0-3,4-6,7-10)	0.82	(0.31 - 2.21)	2.02	(0.85 - 4.84)	1.95	(0.73 - 5.19)
	Adjusted[a]	1.08	(0.37 - 3.18)	2.53	(0.78 - 8.21)	2.06	(0.64 - 6.65)
Perceived IAQ	IAQ (0-3,4-6,7-10)	2.84	(0.96 - 8.47)	1.27	(0.58 - 2.79)	2.59	(0.97 - 6.95)
	Adjusted[a]	5.46	(1.16 - 25.62)*	1.13	(0.37 - 3.45)	3.18	(0.85 - 11.95)
	OAQ (0-3,4-6,7-10)	1.84	(0.63 - 5.39)	0.76	(0.33 - 1.76)	1.08	(0.42 - 2.80)
	Adjusted[a]	2.79	(0.57 - 13.66)	0.71	(0.2 - 2.51)	0.84	(0.23 - 3.08)
	Annoyance by outdoor air pollution (0-3,4-6,7-10)						
	Adjusted[a]						

[a] Adjusted for Age, Gender, and Income variables

Table 5.7 Odds ratios with 95% confidence intervals of questionnaire variables for respiratory health among those of 15 years old and over.

		Asthma		Cough		Phlegm	
		OR	95%CI	OR	95%CI	OR	95%CI
Personal attributes	Age (0-15,15-30,31-45,46-60,60<)	0.96	(0.71 - 1.28)	1.35	(1.06 - 1.73)*	1.14	(0.84 - 1.55)
	Adjusted[a]	1.03	(0.73 - 1.45)	1.46	(1.11 - 1.93)**	1.23	(0.86 - 1.76)
	Gender (male/female)	0.56	(0.30 - 1.05)	1.24	(0.68 - 2.29)	0.97	(0.62 - 1.53)
	Adjusted[a]	0.71	(0.33 - 1.51)	1.00	(0.56 - 1.78)	2.18	(1.01 - 4.73)*
	Income (<150,150-450,450-750,750<, US$)	1.03	(0.68 - 1.55)	0.76	(0.54 - 1.07)	0.64	(0.39 - 1.06)
	Adjusted[a]	1.17	(0.76 - 1.8)	0.84	(0.58 - 1.22)	0.64	(0.37 - 1.11)
	Work in dusty job (YES/NO)	1.20	(0.53 - 2.73)	1.58	(0.71 - 3.52)	1.45	(0.79 - 2.68)
	Adjusted[a]	0.66	(0.21 - 2.04)	1.19	(0.51 - 2.78)	1.1	(0.4 - 3.06)
	Exposed to gas or chemical fumes (YES/NO)	1.23	(0.43 - 3.55)	2.77	(1.12 - 6.88)*	2.32	(1.10 - 4.87)*
	Adjusted[a]	1.75	(0.47 - 6.43)	2.44	(0.90 - 6.62)	2.32	(0.76 - 7.08)
Behavior	Window opening in bedroom (6h)	0.96	(0.68 - 1.36)	1.05	(0.81 - 1.37)	1.03	(0.71 - 1.49)
	Adjusted[a]	1.26	(0.91 - 1.73)	1.06	(0.82 - 1.37)	0.89	(0.62 - 1.28)
	Window opening in living room (6h)	1.31	(1.01 - 1.72)*	1.05	(0.85 - 1.30)	0.96	(0.70 - 1.33)
	Adjusted[a]	1.16	(0.85 - 1.57)	1.23	(0.95 - 1.59)	1.1	(0.75 - 1.61)
	Smoking active (YES/NO)	1.04	(0.53 - 2.05)	1.27	(0.65 - 2.47)	1.01	(0.61 - 1.67)
	Adjusted[a]	1.48	(0.54 - 4.06)	1.07	(0.49 - 2.35)	1.00	(0.37 - 2.65)
	Smoking passive (YES/NO)	2.44	(1.23 - 4.83)**	1.62	(0.84 - 3.10)	1.90	(1.14 - 3.17)**
	Adjusted[a]	3.52	(1.46 - 8.47)**	1.94	(1.00 - 3.79)	1.39	(0.61 - 3.19)
	Clean room (2-3times per month/every week/several time per week/everyday)	1.35	(0.97 - 1.87)	1.05	(0.76 - 1.44)	1.09	(0.73 - 1.63)
	Adjusted[a]	1.38	(0.98 - 1.95)	0.93	(0.65 - 1.35)	1.11	(0.73 - 1.68)
	Clean bath (2-3times per month/every week/several time per week/everyday)	1.04	(0.67 - 1.62)	0.98	(0.71 - 1.36)	1.09	(0.71 - 1.68)
	Adjusted[a]	1.05	(0.60 - 1.84)	0.89	(0.58 - 1.36)	1.02	(0.59 - 1.75)
Health	Asthma (YES/NO)	25.29	(10.8 - 59.23)**	1.71	(0.65 - 4.52)	1.6	(0.74 - 3.48)
	Adjusted[a]	32.15	(10.69 - 96.72)**	1.35	(0.55 - 3.31)	1.24	(0.37 - 4.10)
	Eczema (YES/NO)	0.60	(0.20 - 1.80)	1.54	(0.59 - 4.04)	1.69	(0.80 - 3.58)
	Adjusted[a]	0.46	(0.12 - 1.69)	1.47	(0.60 - 3.56)	1.75	(0.56 - 5.52)
	Allergy (YES/NO)	2.58	(1.16 - 5.71)*	3.85	(1.63 - 9.12)**	1.99	(0.95 - 4.19)
	Adjusted[a]	1.71	(0.61 - 4.77)	1.86	(0.77 - 4.51)	2.67	(0.91 - 7.80)
	Stress (0-3,4-6,7-10)	1.76	(1.02 - 3.06)*	2.03	(1.23 - 3.36)**	1.96	(1.06 - 3.62)*
	Adjusted[a]	1.47	(0.77 - 2.82)	1.82	(1.03 - 3.21)*	1.94	(0.97 - 3.87)
Building attributes	Age of building (10years)	1.09	(0.78 - 1.52)	0.95	(0.74 - 1.21)	1.25	(0.89 - 1.75)
	Adjusted[a]	1.10	(0.87 - 1.39)	0.97	(0.80 - 1.16)	1.2	(0.93 - 1.54)
	No. of windows in master bedroom (1 or more/NO)	0.78	(0.37 - 1.63)	1.04	(0.44 - 2.42)	1.13	(0.61 - 2.07)
	Adjusted[a]	1.28	(0.49 - 3.36)	1.11	(0.52 - 2.36)	1.00	(0.34 - 2.95)
	No. of windows in living room (1 or more/NO)	1.26	(0.61 - 2.63)	0.5	(0.23 - 1.07)	0.77	(0.44 - 1.36)
	Adjusted[a]	1.58	(0.66 - 3.81)	0.49	(0.25 - 0.98)*	0.25	(0.09 - 0.68)**
	HVAC system (YES/NO)	1.76	(0.47 - 6.55)			1.41	(0.43 - 4.62)
	Adjusted[a]	1.30	(0.25 - 6.81)	1.98	(0.50 - 7.86)		
	Ceiling / stand fan (YES/NO)	1.03	(0.5 - 2.13)	0.49	(0.20 - 1.21)	1.83	(0.95 - 3.53)
	Adjusted[a]	0.98	(0.41 - 2.31)	2.13	(0.95 - 4.76)	0.44	(0.15 - 1.28)
	Exhaust fan (YES/NO)	0.92	(0.32 - 2.65)	0.5	(0.11 - 2.32)	0.60	(0.21 - 1.68)
	Adjusted[a]	1.36	(0.37 - 5.01)	0.57	(0.14 - 2.27)	1.24	(0.22 - 6.88)
	Vehicle frequency (Never / seldom / frequency / constantly)	1.24	(0.88 - 1.77)	1.24	(0.94 - 1.65)	1.22	(0.84 - 1.76)
	Adjusted[a]	1.01	(0.64 - 1.61)	1.03	(0.70 - 1.50)	0.90	(0.56 - 1.42)
Dampness	Visual mold (YES/NO)	1.55	(0.84 - 2.84)	1.21	(0.63 - 2.31)	0.86	(0.53 - 1.41)
	Adjusted[a]	1.57	(0.74 - 3.34)	1.09	(0.60 - 1.95)	2.17	(0.96 - 4.90)
	Mite (YES/NO)	1.44	(0.69 - 3.02)	2.38	(1.18 - 4.82)*	1.87	(1.06 - 3.32)*
	Adjusted[a]	1.2	(0.45 - 3.17)	1.89	(0.89 - 4.03)	3.89	(1.61 - 9.43)**
	Water leakage (YES/NO)	0.99	(0.54 - 1.81)	1.32	(0.69 - 2.52)	1.32	(0.81 - 2.15)
	Adjusted[a]	1.13	(0.53 - 2.43)	0.96	(0.53 - 1.75)	1.05	(0.48 - 2.32)
	Smell / Odor (YES/NO)	0.75	(0.40 - 1.42)	1.97	(1.03 - 3.79)*	1.36	(0.83 - 2.22)
	Adjusted[a]	1.02	(0.48 - 2.18)	1.35	(0.75 - 2.43)	2.18	(1.00 - 4.75)*
	Humidity (0-3,4-6,7-10)	1.05	(0.69 - 1.62)	0.99	(0.71 - 1.40)	1.03	(0.66 - 1.63)
	Adjusted[a]	0.80	(0.48 - 1.35)	1.03	(0.68 - 1.56)	1.11	(0.64 - 1.93)
Perceived IAQ	IAQ (0-3,4-6,7-10)	1.00	(0.65 - 1.53)	1.00	(0.72 - 1.40)	0.92	(0.58 - 1.46)
	Adjusted[a]	0.79	(0.47 - 1.34)	0.82	(0.54 - 1.24)	0.88	(0.50 - 1.55)
	OAQ (0-3,4-6,7-10)	1.15	(0.76 - 1.76)	0.98	(0.70 - 1.37)	0.72	(0.45 - 1.15)
	Adjusted[a]	0.96	(0.58 - 1.6)	0.84	(0.56 - 1.28)	0.54	(0.31 - 0.96)*
	Annoyance by outdoor air pollution (0-3,4-6,7-10)	1.37	(0.86 - 2.2)	1.31	(0.90 - 1.90)	1.35	(0.84 - 2.18)
	Adjusted[a]	0.97	(0.53 - 1.75)	1.26	(0.78 - 2.04)	1.22	(0.66 - 2.27)

[a] Adjusted for Age, Gender, and Income variables

5.7.2 Path analysis

The IBM AMOS software was utilized to conduct path analysis and determine the factors impacting respiratory health issues of the occupants. Due to its highest prevalence among the self-reported respiratory health complaints in this investigation, the persistent cough was chosen as the major dependent variable for the path analysis in this study (see Figure 5.4). An explanatory variable's effects on the dependent variable are examined in three categories in a path analysis: direct effect, indirect effect, and total effect. The direct effect indicates the measure of changes in the independent variable due to a unit change in a dependent variable. The indirect effect quantifies the predicted changes in the dependent variable through intermediate variables when the independent variable changes by one unit. It can be calculated by multiplying path coefficients that construct the causal path. The total effect is the addition of direct effect and indirect effect (Olobatuyi, 2006).

Figure 5.9 displays the outcomes of the path analysis for children under the age of 15 who have persistent cough symptoms. The model's fit statistics are reported as follows: CFI = 0.855, NFI = 0.572, and RMSEA = 0.042, indicating a moderate fit. The R-squared value for persistent cough symptoms is 0.36, meaning that this diagram can account for 36% of the factors associated with persistent cough symptoms among individuals under the age of 15. The analysis reveals that "allergies" had the highest total effect (0.357), followed by "humidity" (0.262), "income" (-0.217), "smell" (0.203), "mite" (0.191), and "window opening in bedroom" (-0.136).

In this survey, it was discovered that among individuals under 15 with allergy symptoms frequently experienced persistent cough symptoms (Figure 5.9 and Table 5.6). This suggests that pre-existing health conditions have a significant impact on cough symptoms. The presence of mold (0.061) and mites (0.211) in the home can result in allergic conditions (Gent et al., 2012). Perceived mold occurrence affects the perception of mite occurrence (0.289). Therefore, it is believed that mold occurrence is considered a key factor influencing the symptoms of cough in children. The likelihood of mold occurrence, in turn, is influenced by perceived outdoor air quality rates (0.328) and perceived water leakage (0.203). Table 5.7a demonstrates a significant association between perceived water leakage and mold occurrence in houses, suggesting that water leakage may be one of the underlying causes of children's cough symptoms, even if it does not directly trigger the symptoms (Table 5.7b).

Furthermore, it was found that among individuals under 15 years old, humidity levels had a direct impact on cough symptoms (0.262). These results align with the earlier findings that children face higher health risks during the humid rainy season (see Figure 5.4). Additionally, the findings demonstrate that window opening behavior had an impact on indoor humidity levels, particularly in the master bedroom, with a total effect of -0.325, showing that the more frequently a household opens its windows, the less humid the space is. Improved ventilation is known to enhance the removal of air pollutants and moisture. Similar results were reported by Fabi et al. (2012), where window-opening behavior significantly impacted indoor environmental conditions. Although they are not included in the path model, window opening time in the living room had a positive association on the occurrences of mold and mite, respectively. This suggests that the likelihood of noticing the presence of mold and mites in a living room would increase if households opened windows more frequently. On the other hand, window-opening in the bedroom showed a negative effect on mite occurrence with a total effect of -0.264. This phenomenon might be related to indoor moisture sources. In kampongs, bathrooms and kitchens, which are major sources of indoor moisture, are typically attached to the living room. Therefore, opening windows and internal doors can increase indoor humidity levels. While the perceived OAQ rate directly influences mold occurrence (0.328), the OAQ is also one of the key elements indirectly causing the persistent cough. Overall, the findings imply that, in addition to allergy-related preconditions, indoor environmental factors like excessive indoor humidity, odor, and perceived mite and mold growth were the main contributors to children's persistent cough symptoms. Moreover, water leakage in houses may be a root cause of mold and, consequently, children's persistent cough.

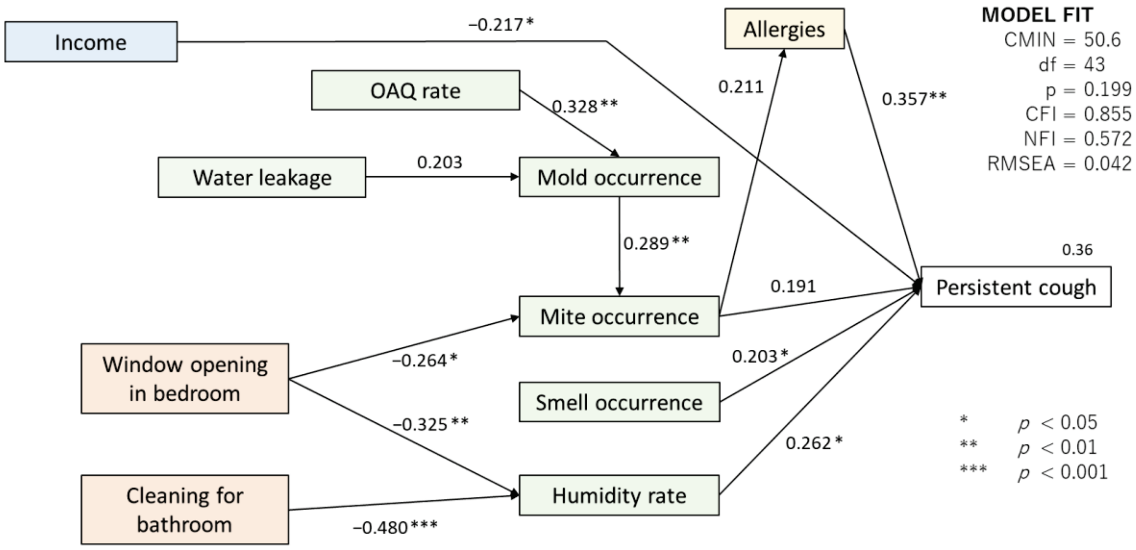


Figure 5.9 Path diagrams for persistent cough among those under 15 years old (H. Sani et al., 2022)

Table 5.8 Standardized total effect, direct effect, and indirect effect of path diagram for persistent cough among those under 15 years old

Dependent Variables	Independent Variables	Total effect	Direct effect	Indirect effect
Persistent cough	Allergic	0.357	0.357	
	Humidity Rate	0.262	0.262	
	Smell occurrence	0.203	0.203	
	Mite Occurrence	0.266	0.191	0.075
	Income	-0.217	-0.217	
	Windows opening bedroom	-0.155		-0.155
	Cleaning bathroom	-0.126		-0.126
	Windows opening living room	0.026		0.026
	Outdoor air quality rate	0.023		0.023
Allergic	Mold occurrence	0.059		0.059
	Windows opening Bedroom	-0.055		-0.055
	Windows opening living room	0.021		0.021
	Mite occurrence	0.211	0.211	
	Outdoor air quality rate	0.019		0.019
Humidity rate	Cleaning bathroom	-0.481	-0.481	
	Windows opening bedroom	-0.325	-0.325	
Mite occurrence	Mold occurrence	0.278	0.278	
	Windows opening bedroom	-0.263	-0.263	
	Windows opening living room	0.099		0.099

	Outdoor air quality rate	0.088		0.088
Mold occurrence	Windows opening living room	0.355	0.355	
	Outdoor air quality rate	0.315	0.315	

Table 5.9 Associations between (a) water leakage and mold growth, and (b) mold growth and persistent cough for all samples (H. Sani et al., 2022)

(a)

Water leakage	Mold growth		Sig.
	Yes	No	
Yes	160 (60.6%)	104 (39.4%)	0.000
No	98 (39.2%)	152 (60.8%)	

(b)

Mold growth	Persistent cough			Sig.
	No symptoms	Have a symptom of had it	Sickness	
Yes	166 (77.2%)	46 (21.3%)	3 (1.4%)	0.696
No	155 (73.5%)	49 (23.2%)	7 (3.3%)	

Figure 5.10 illustrates the path diagram results for individuals aged 15 and above. The R-squared value for cough symptoms is 0.05, meaning that only 5% of all chronic cough symptoms are explained by the diagram. However, the conformance value was reported with a sufficient fit (CFI = 0.931, NFI = 0.750, and RMSEA = 0.026). This is likely can be explained by the fact that the percentage of people aged 15 and older who had a persistent cough was lower than it was for children. Figure 5.10 demonstrates that "Sick Building Syndrome (SBS)" (0.210), followed by "smoking (including active and passive smoking)" (0.097), has a significant impact on the persistent cough in people aged 15 and older. The "SBS" in this study reveals if the inhabitants' health problems worsened while they were living in their homes due to unidentified factors. These building-related health issues are directly influenced by perceived outdoor air quality, which is likely associated with vehicle frequency, with a total effect of 0.152 (Table 5.8). This suggests that traffic-related air pollution can degrade outdoor air quality.

In addition to being influenced by vehicle frequency, perceived OAQ rate was also shown to be influenced by smoking (0.121), as shown in Figure 5.10 and Table 5.8. Smoking behaviors, including active and passive, are substantially correlated with gender (-0.445), AC ownership (-0.067), and exposure to chemicals and dust (0.213) at work (0.088). These exposures are gender-associated, with males being predominant. Ownership of air conditioning is negatively related to smoking habits, indicating that households with air conditioning tend to have a lower probability of smoking indoors. This is likely because other household members refrain from smoking when the air conditioning is in operation. Figure 5.10 demonstrates that smoking habits, in addition to having a direct impact on chronic cough, have an impact on SBS in those aged 15 and older. Table 5.9 provides a summary of the detailed correlations between smoking and persistent cough. Although the multiple correlation coefficient is small, it can be concluded that smoking behaviors and the deteriorated OAQ, which is mostly brought on by air pollution related to traffic, may have an impact on the symptoms of chronic cough in those aged 15 and older.

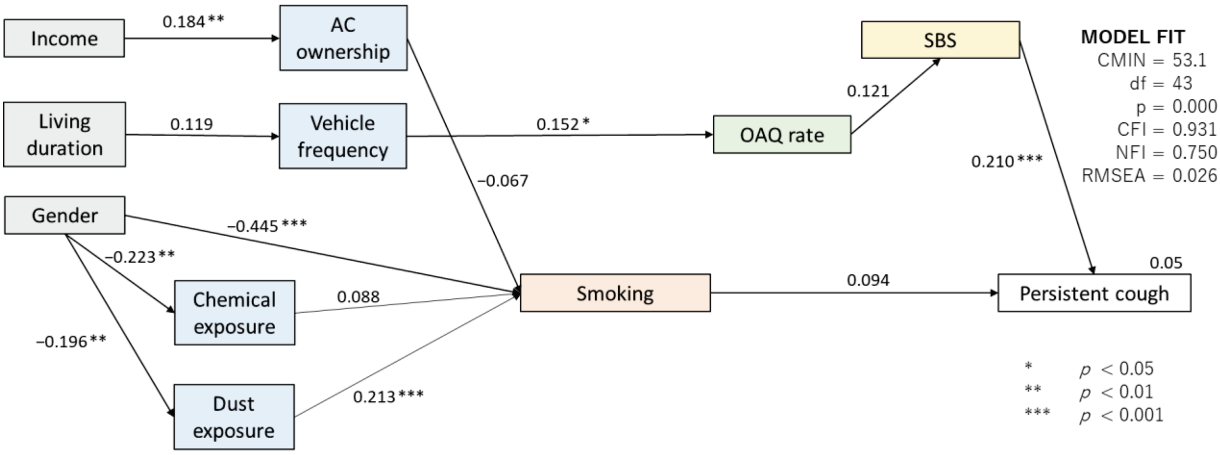


Figure 5.10 Path diagrams for persistent cough among those of 15 years old and over (H. Sani et al., 2022)

Table 5.10 Standardized total effect, direct effect, and indirect effect of path diagram for persistent cough among those of 15 years old and over.

Dependent Variables	Independent Variables	Total effect	Direct effect	Indirect effect
Persistent cough	Health change	0.242	0.242	
	Outdoor air quality rate	0.039		0.039
	Passive smoking	0.155	0.151	0.005
	Cleaning room	0.007		0.007
	Vehicle's frequency	0.006		0.006
	Gender	-0.027		-0.027
	Dust exposure at workplace	0.048		0.048
	Chemical exposure at workplace	0.028		0.028
	AC ownership	-0.020		-0.020
	Number of bedrooms	0.001		0.001
	Living duration	0.001		0.001
	Income	-0.003		-0.003
Health change	Outdoor air quality rate	0.161	0.161	
	Passive smoking	0.020		0.020
	Cleaning room	0.027		0.027
	Vehicle's frequency	0.023		0.023
	Gender	-0.003		-0.003
	Dust exposure at workplace	0.006		0.006
	Chemical exposure at workplace	0.003		0.003
	AC ownership	-0.002		-0.002
	Number of bedrooms	0.006		0.006
	Living duration	0.003		0.003
Outdoor air quality rate	Passive smoking	0.121	0.121	
	Cleaning room	0.167	0.167	
	Vehicle's frequency	0.142	0.166	-0.025
	Gender	-0.021		-0.021
	Dust exposure at workplace	0.037		0.037

	Chemical exposure at workplace	0.022		0.022
	AC ownership	-0.015		-0.015
	Number of bedrooms	0.035		0.035
	Living duration	0.020		0.020
	Income	-0.002		-0.002
Passive smoking	Gender	-0.175	-0.175	
	Dust exposure at workplace	0.306	0.306	
	Chemical exposure at workplace	0.179	0.179	
	AC ownership	-0.126	-0.126	
	Income	-0.019		-0.019
Cleaning room	Vehicle's frequency	-0.147	-0.147	
	Number of bedrooms	0.209	0.209	
	Living duration	-0.021		-0.021
Vehicle's frequency	Living duration	0.141	0.141	
AC ownership	Income	0.155	0.155	

Table 5.11 Associations between smoking habits and persistent cough among 15 years old and over (H. Sani et al., 2022)

Gender	Smoking habits	Persistent cough			Sig.
		No symptoms	Have a symptom of had it	Sickness	
Male	Active	53 (76.8%)	16 (23.2%)	0 (0%)	0.775
	Passive	10 (71.4%)	4 (28.6%)	0 (0%)	0.437
	None	22 (81.5%)	5 (18.5%)	0 (0%)	-
Female	Active	23 (76.7%)	7 (23.3%)	0 (0%)	0.703
	Passive	19 (70.4%)	8 (29.6%)	0 (0%)	0.891
	None	68 (75.6%)	22 (24.4%)	0 (0%)	-

5.8 Window-opening behavior in Kampong houses

As previously mentioned, the behavior of opening windows had an indirect impact on persistent coughing in children living in Kampungs (refer to Figure 5.9). Nevertheless, depending on the room, both positive and negative correlation were observed. Opening the window in the living room had a positive effect on the persistent cough, but the bedroom window had the opposite effect. Figure 5.11 presents the results of Indoor Air Quality (IAQ) measurements analyzed according to different window-opening patterns: Pattern 1 (open for 24 hours), Pattern 2 (open during daytime for 12.6 hours), and Pattern 3 (open for less than one hour or no windows). These patterns were observed in both the living room and the bedroom among households with children.

As shown in Figure 5.11a, when examining indoor/outdoor $PM_{2.5}$ levels in the living room, it was found that longer window-opening durations led to higher average concentrations of $PM_{2.5}$ (61.9 μg/m^3 in Pattern 1, 48.0 μg/m^3 in Pattern 2, and 29.3 μg/m^3 in Pattern 3). This demonstrates that the primary outside sources of $PM_{2.5}$ in the living room are likely outdoor sources such as air pollution from traffic, which entered the room through open windows. Contrarily, Pattern 1 in the bedroom exhibits the lowest average $PM_{2.5}$ concentration (50 g/m^3) in comparison to the other patterns (54.9 g/m^3 for Pattern 2 and 51.2 g/m^3 for Pattern 3). The maximum $PM_{2.5}$ values for Patterns 2 and 3 (117.2 g/m^3 and 141.2 g/m^3, respectively) are more than twice as high as those for Pattern 1 (58.6 g/m^3). This indicates that opening windows in the bedroom helped reduce the $PM_{2.5}$ concentration in the room. The location of the rooms could be a potential factor influencing these results; bedrooms are typically situated deeper within the house, while the living room is closer to the front road (Funo et al., 2018). According to Funo et al. (2018), Kampong houses often have a narrow frontage and a tiny terrace next to the road, which allows air pollutants from the road to easily enter the living room. Therefore, when designing and arranging rooms in Kampong houses, consideration should be given to minimize exposure to air pollution from traffic. Additionally, it is crucial to control the traffic within densely populated Kampong neighborhoods.

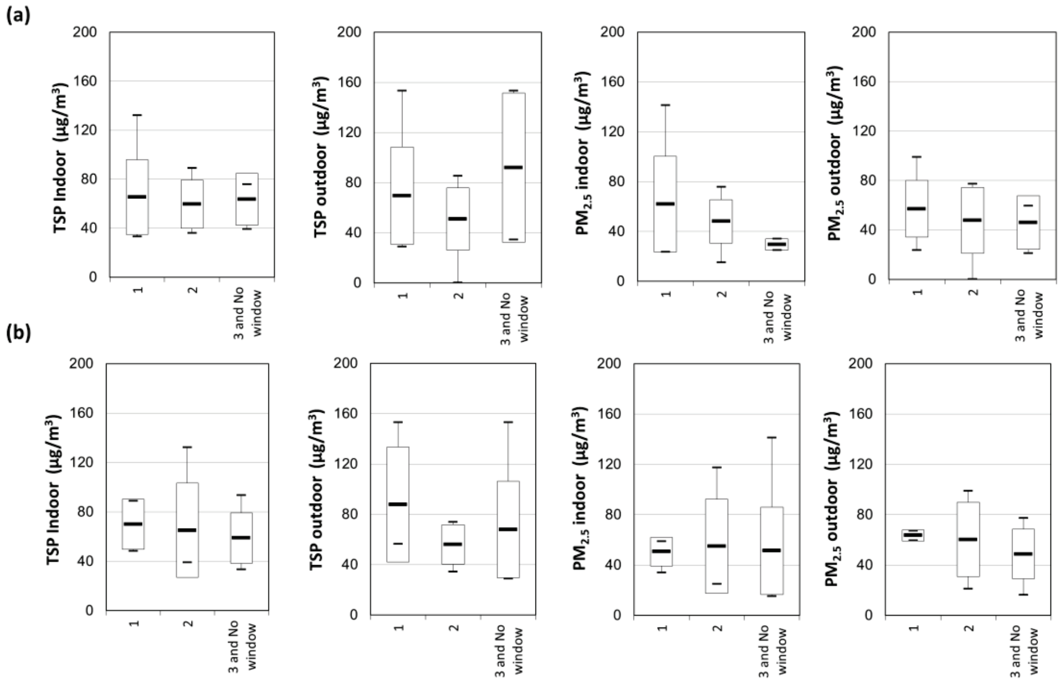


Figure 5.11 Indoor and outdoor TSP and $PM_{2.5}$ concentration based on windows-opening pattern in (a) living room and (b) bedroom (H. Sani et al., 2022)

5.9 Summary

This chapter presented the findings derived from field measurements and surveys conducted on a typical traditional unplanned neighborhood, Kampung, located in Bandung, Indonesia. The assessment of indoor mold risk severity and its effects on occupants' respiratory health were the main concerns. This study's main findings can be summed up as follows:

- Regardless of the dry or wet seasons, children consistently exhibited higher respiratory health issues symptoms. During the rainy season, children were shown to experience more than 40% of the symptoms of a persistent cough, whereas the prevalence among adults was 27%.
- It was observed that Kampung houses were at a significant risk of mold. In the wet season, mold growth was highly likely in more than 97% of the homes. Even in the dry season, the outdoor RH can reach up to 80% on average, 79% of homes were at risk for mold growth, and 68% having a high possibility of mold propagation. During the wet season, the outdoor RH averaged 83% whereas the comparable inside RH averaged 82%. Additionally, water leakages were reported by 50% and 60% of respondents during the dry and rainy seasons, respectively.

- Indoor total suspended particulate (TSP) and $PM_{2.5}$ concentrations exceeded the standards set by the World Health Organization (WHO) in more than 50% of the Kampung houses. Approximately 66% of dwellings had outside $PM_{2.5}$ mean concentrations that were higher than their indoor mean concentrations, showing that Kampungs' poor indoor air quality was a result of outdoor air pollution.
- Opening the bedroom windows had a negative effect on mite occurrence and humidity levels. Additionally, a longer period of opening windows in the bedroom associated with a lower concentration of $PM_{2.5}$, but a longer period of opening windows in the living room revealed a higher concentration of $PM_{2.5}$.

6 Possible Sources of IAQ problems in Apartments: Detailed Measurement

6.1 Introduction

As mentioned in Chapter 3 detailed IAQ measurements are necessary for characterizing the indoor VOCs and identifying the exact pollution sources. Every house would have different indoor environments; thus, it is essential to investigate details of interior conditions, including furniture used, choices of paint, and flooring materials. Therefore, follow-up detailed measurement result to find the possible source of the IAQ problem in the apartment is discussed in this chapter. The detail measurement was focused on the apartment units where the concentrations of chemicals, formaldehyde and TVOCs are higher and more alarming to the health of the occupants.

6.2 Methods

In the previous preliminary IAQ measurements, 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. In addition, it was found that apartment houses tend to be exposed to higher concentrations of formaldehyde and TVOCs. Therefore, in the following measurement, a diffusive sampler, DSD-DNPH passive gas tube, was selected to investigate further the possible sources of IAQ problems, especially in the apartment. Furthermore, ADSEC (Advanced Diffusive Sampling Emission Cell) is applied to measure formaldehyde and VOCs emission rates from specific material and building attributes directly in the apartment unit. The samples are collected in the center of the room at a height of about 1.5 m following the EU guideline (ECA 1995) and in the possible exposure source for 24 hours sampling duration, where the collected samples will be analyzed in the chemical laboratory of UPI (*Universitas Pendidikan Indonesia*) with Gas Chromatography-Mass Spectrometry (GCMS).

6.2.1 Brief measurement and air sampling

Detail measurement began with a short investigation by using the direct reading measurement devices similar to the previous investigation, FMM-MD, Shinyei Technology (formaldehyde) and ToxiRAE Pro, RAE Systems (TVOCs) (See Chapter 3) to find units with a high concentration of IAQ problems. The WHO and Indonesian standards for formaldehyde are the parameters for high concentration units' selection, 0.08 and 0.1 ppm, respectively. In TVOC, the parameter is based on the Indonesian standard for VOCs, 430 μg/m^3 for 30 minutes. A brief measurement was done for 24 hours in each room. Furthermore, selected units were sampled with Supelco DSD-DNPH (Diffusive Sampling Device 2-4-Dinitrophenylhydrazine) (Figure 6.1) for formaldehyde and Sibata passive gas tube for organic solvents (VOCs) (Figure 6.2), together with the AT and RH. In the detail measurement, outdoor air quality was also measured with the same sampling devices at the same time as indoor air detailed measurements. Table 6.1 shows the overall instrument for the brief and detail measurement.

Table 6.1 Instruments for brief and detailed field measurements

	Measured variable	Instrument model	Accuracy
Brief Measurement	Air temperature, relative humidity	T&D TR-72Ui	Accuracy: ±0.3°C, ±5%RH Unit:0.1°C,1%RH Rang:0~50°C,10~95%
	Formaldehyde, Air temperature, relative humidity	Shinyei technology FMM-MD	Accuracy: ±10% at 2ppm, over a 25-70% RH ±0.4°C, ±3%RH Unit: ppb or μg/m^3, Range: 20-1000 ppb
	TVOC	ToxiRAE Pro, RAE system	Accuracy: ±3% at the calibration point Unit: ppm, Range: 0-2000 ppm
	Formaldehyde, Air temperature, relative humidity	Formaldemeter™ htV-M, PPM Technology	Accuracy: ±10% at 40, 80, 160ppb, under AT 25°C & 50% RH Unit: ppm or μg/m^3, Range: 0 – 10 ppm
Detail Measurement	Air temperature, relative humidity	T&D TR-72Ui	Accuracy: ±0.3°C, ±5%RH Unit:0.1°C,1%RH Rang:0~50°C,10~95%
	Formaldehyde	DSD-DNPH (2-4-Dinitrophenyl-hydrazine), Supelco.	Reliable quantitation limit: 0.58 ppb, 0.70 μg/m^3 Detection limit: 0.17 ppb, 0.21 μg/m^3 Precision: ±14.8-22.0% Solvent: Acetonitrile Analysis: GC-MS or HPLC (Eide, 2005)
	VOCs	Passive Gas Tube (for Organic Solvents), Shibata	Adsorbent: Coconut shell activated carbon (about mesh of 20 to 40) 200 mg. Solvent: Carbon disulfide Analysis: GC-MS

Figures 6.1 and 6.2 illustrate the passive sampling used in the detailed measurement. The size of this sampling device was relatively small and thus could be placed anywhere without disturbing the respondents’ activities in the room. The sampling process followed the OSHA (Occupational Safety and Health Administration) 1007 (Eide, 2005) for formaldehyde and passive gas tube guideline from Shibata. Before the sampling began, the room was ventilated for 30 minutes by opening the windows and door. Similarly, with brief measurements, the detailed sampling was done for 24 hours. The sampling starts when the sampler is removed from the aluminized container. After the measurement, the samples should be put in the original aluminized container and kept in the fridge before being transferred to the laboratory for preparation and analysis. In addition, another measurement setting for specific material emission was done in several possible locations with ADSEC. The sampler was inserted into the cup by the hole on top of it, as indicated in Figure 6.3a. In this study, a custom spring holder supported by a tripod was applied to hold the cup on the vertical surface (wallpaper, wallboard, and wall) (Figure 6.3b).

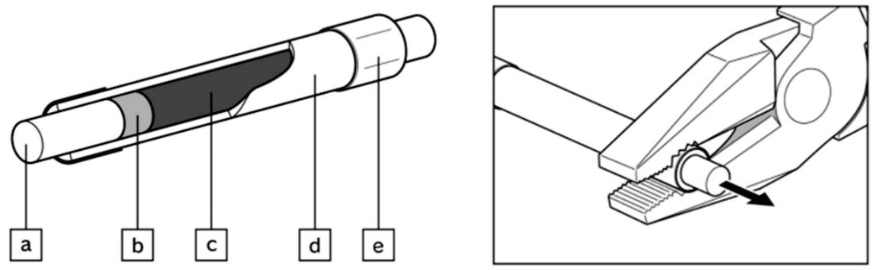


Figure 6.1 Passive gas tube for organic solvent, Sibata Source: Sibata operation manual

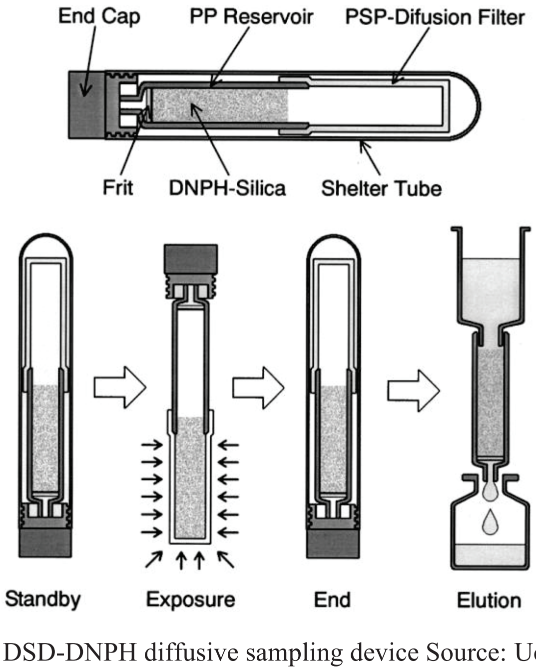


Figure 6.2 Supelco DSD-DNPH diffusive sampling device Source: Uchiyama et al., 2004

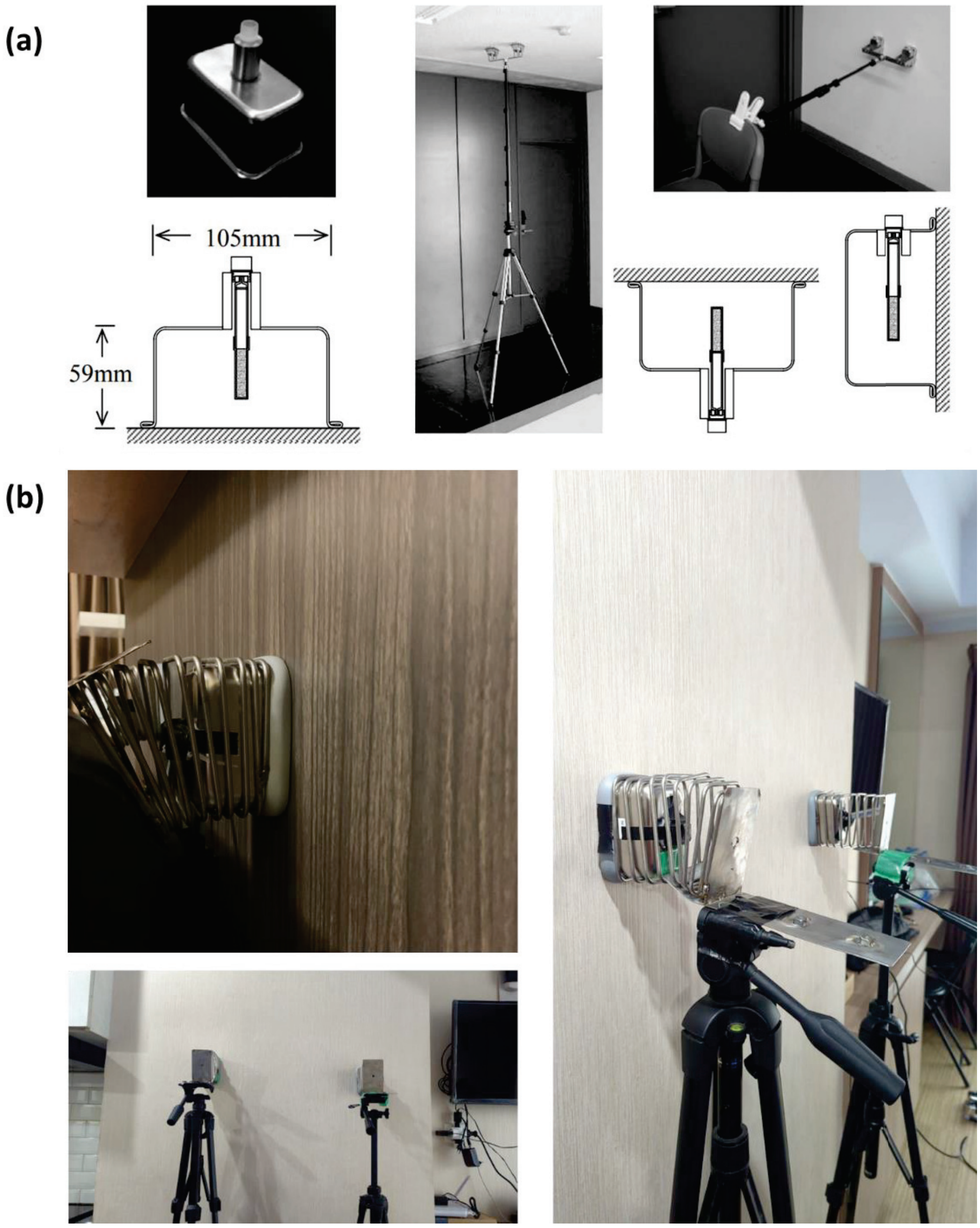


Figure 6.3 Detail measurement setting construction (a) Aldehyde-ADSEC (Matsumoto et al., 2002) (b) measuring cup in apartments

6.2.2 Sample preparation

DSD-DNPH samples were prepared by removing the sample from the white translucent part and diluted with 1 mL standard acetonitrile into a 4 mL vial. From 1 mL of the total solution, only 0.4 μL is injected into the GC-MS analysis. In this analysis, GC-MS is selected to investigate the other possible compounds in the room other than formaldehyde (Eide, 2005). On the other hand, technical tools are necessary to prepare the Shibata passive gas tube. After removing the sample from the aluminum bag, transfer all the active carbon to a Bayer bottle by picking up the aluminum ring of the sample. The extracted active carbon is then diluted by 1 mL of carbon disulfide and shaken using a shaking unit for 1 hour before being ready for GC-MS analysis. Similarly, with DSD-DNPH, the injected sample for the passive gas tube is only

0.4 μL also.

6.2.3 Instrumental analysis

The analyses were performed using a Shimadzu GCMS-QP2010 system (Shimadzu Corporation, Japan). Table 6.2 explains the overall setting of the instruments. Both analyses for formaldehyde and VOC were done with 0.4 μL injection in splitless mode, which is suitable for higher boiling temperature compounds with a low analyte concentration. The carrier gas is Helium, with pressure flow control for formaldehyde and linear velocity flow control mode for VOCs. The Rtx-5MS column was used for the separation of both analyses. In the formaldehyde analysis, the oven temperature was programmed at 250 ^{O}C, starting from 50 ^{O}C (2 min holds) to 120 ^{O}C at a rate of 10 ^{O}C/min, and continued to 300 ^{O}C at the same rate. Whereas, for VOC analysis, the oven temperature was 200 ^{O}C, starting from 45 ^{O}C (1 min hold) and going to 220 ^{O}C at a rate of 12 ^{O}C/min.

Table 6.2 GC-MS instrument setting for sample analysis

Analysis Setting	Formaldehyde (DSD-DNPH)	VOCs (Passive gas tube)
Column oven temperature	50 ^{O}C	45 ^{O}C
Injection temperature	250 ^{O}C	200 ^{O}C
Injection mode	Splitless	Splitless
Sampling time	0 min	0 min
Flow control mode	Pressure	Linear Velocity
Pressure	70 kPa	51.6 kPa
Total flow	126.7 mL/min	104.1 mL/min
Column flow	1.22 mL/min	1.0 mL/min
Linear velocity	40.1 cm/sec	36.2 cm/sec
Purge flow	3.0 mL/min	3.0 mL/min
Split ratio	100	100
High pressure injection	Off	Off
Carrier gas	Helium	Helium
Oven temperature program	50 ^{O}C (hold 2 min) 120 ^{O}C (no hold, 10 ^{O}C /min) 300 ^{O}C (no hold, 10 ^{O}C /min)	45 ^{O}C (hold 1 min) 220 ^{O}C (no hold, 12 ^{O}C /min)
Ion source temperature	200 ^{O}C	200 ^{O}C
Interface temperature	560 ^{O}C	180 ^{O}C
Solvent cut time	0 min	0 min
Detector gain mode	Absolute	Absolute
Detector gain	0.80 kV	0.80 kV
Threshold	0	0
Column	RTX 5MS	RTX 5MS
Total time	27 min	15.58 min

In this study, besides formaldehyde, VOCs are also investigated in detail measurement. Based on the investigation, there are several VOCs shown and analysed further, which are Toluene, Methanol, Ethanol, Benzene, Hexane, and 2-Ethylhexyl acrylate. The total area results from the GCMS analysis are calculated and calibrated based on the calibration curve for each compound (Figure 6.4). The calibration curve was made by diluting the standard solution of each compound with a solvent with a particular ratio to reach a specific concentration. For example, 20 µg/ml formaldehyde was made by diluting 0.2 ml of 100 µg/ml standard formaldehyde and 0.8 ml of acetonitrile. In the case of other compounds besides formaldehyde, the solvent for the standard solution is carbon disulfide. After calibrating the area from GCMS to microgram (µg), the results are calculated to find the compound's room concentration by volume (ppm) based on molecular weight and concentration by weight.

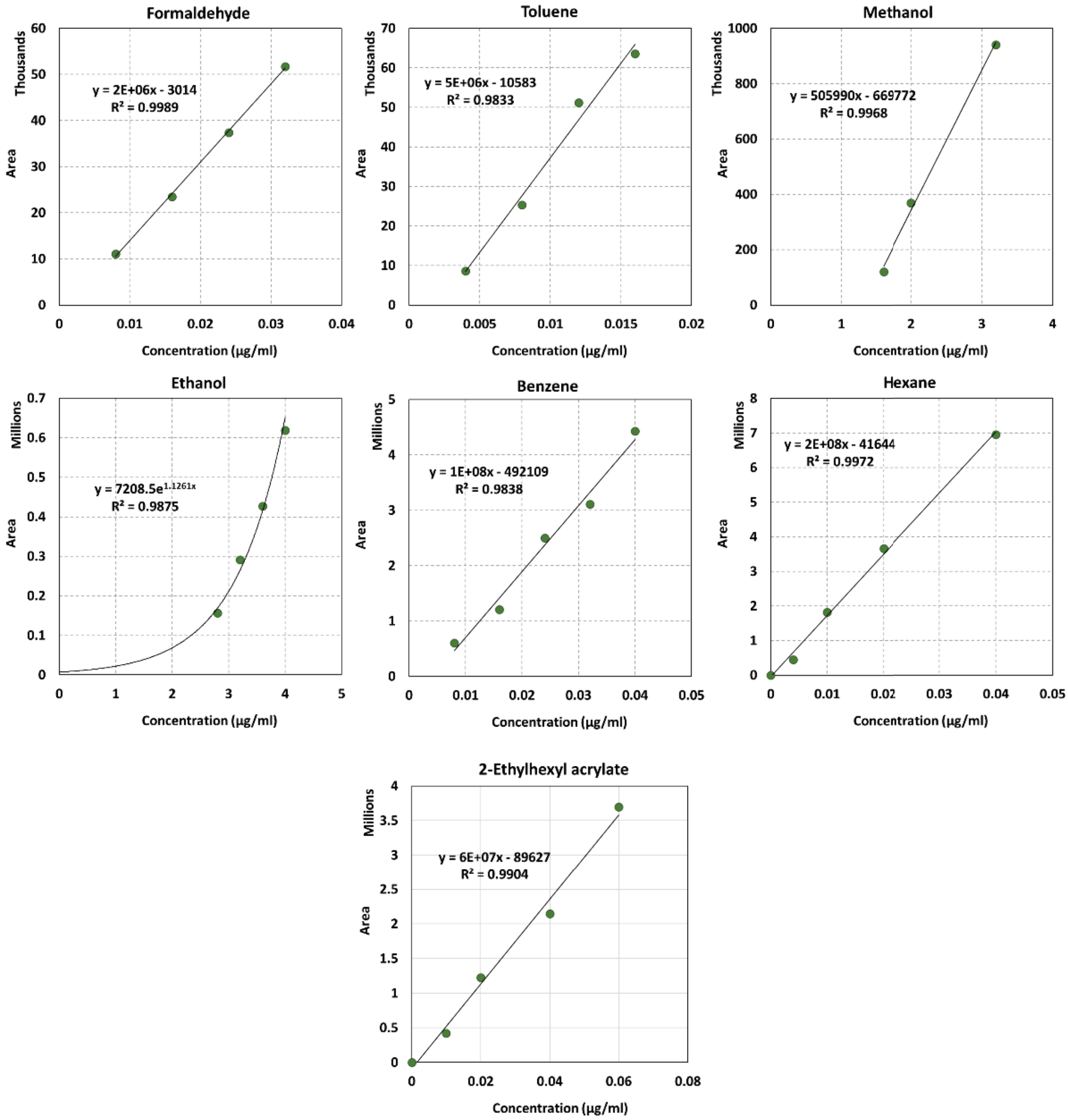


Figure 6.4 Calibration curves for each compound analyzed in detail measurement

Equation 6.1 calculates the concentration by volume (C_V) (ppm), where M_r is molecular weight (30.0 for formaldehyde), V_M is 24.46 at NTP, and C_M is concentration by weight. Whereas the concentration by weight should be calculated with Equation 6.2, where M is microgram per sample, *1000* is a conversion factor to convert the sampling rate mL/min to L/min, t is the sampling time, R_{SS} is the sampling rate the sampling site, and E_E is extraction efficiency, in decimal form. The sampling rate at the sampling site was determined by the temperature at site temperature (T_{SS} in Kelvin), temperature NTP (T_{NTP} =298.2 K), pressure at the sampling site (P_{SS}), pressure NTP (P_{NTP}=760 mmHg), and sampling rate at NTP conditions (R_{NTP}=70.45 mL/min) (Equation 6.3). In this study, AT of the room was measured during the measurement, but not the pressure of the room. Therefore, the pressure was calculated by Equation 6.4, where P_{SS} is the approximate atmospheric pressure (mmHg), E is the sampling site elevation (ft), A is 3.887x10^{-7} mmHg/ft^2, and B is 0.02784 mmHg/ft (Eide, 2005).

$$C_V = \frac{V_M C_M}{M_r} \quad 6.1$$

$$C_M = \frac{M1000}{tR_{SS}E_E} \quad 6.2$$

$$R_{SS} = R_{NTP}\left(\frac{T_{SS}}{T_{NTP}}\right)^{\frac{3}{2}}\left(\frac{P_{NTP}}{P_{SS}}\right) \quad 6.3$$

$$P_{SS} = AE^2 - BE + 760 \quad 6.4$$

In the case of Toluene, Hexane, and Benzene, the calculation of the concentration was using the formula.

$$C = \frac{Wa - Wb}{SRt} \quad 6.5$$

where C is the substance to measure (ppm), Wa is the collected quantity of targeted substance based on the calibration curve (µg/mL), Wb is the blank value (µg/mL), SR is the factor of proportion for each substance (sampling rate) (µg/ppm.min), and t is sampling time (min). The sampling rate values for those compounds are Toluene 0.180 µg/ppm.min, Hexane 0.179 µg/ppm.min, and Benzene 0.178 µg/ppm.min (Shibata, 2016).

Furthermore, the specific material and possible sources measurement by ADSEC device only gave a total concentration of the measured area. Therefore, to calculate the emission rate of the material, the collected amount was divided by the measurement area and the sampling time as, shown in Equation 6.6.

$$EF = \frac{M}{S \times t} \quad 6.6$$

where, EF is the emission rate (µg/m^{2}g), M is the total weight of the substance in the sample (µg), S is the measurement area or the surface covered by the measuring cup (0.005884 m^2), and t is the sampling time (h) (Matsumoto et al., 2002).

6.3 Possible factors and sources of IAQ problems

6.3.1 Selected units for detail measurement

Brief measurements were conducted to enhance the accuracy of the detailed measurements, focusing on selecting units that would provide representative data on the composition, chemical concentration, and emission rate (ER) of suspected materials within the room. Therefore, baselines of 0.1 ppm for formaldehyde and/or 430 µg/m^3 for VOCs are selected as the parameters. As shown in Table 6.3, in Surabaya, from eight measurements, six units are selected for detailed measurement. In Jakarta, seven brief measurements were done where four units showed high concentrations of formaldehyde and VOCs, but one unit was added in the detailed measurements, which made the total measured units for detailed measurements in Jakarta five units. Whereas 14 units of apartments are measured in Bandung, and in total, ten units are measured in detail with a passive sampling device. In addition, there are several cases in Jakarta and Bandung where the detailed measurement and brief measurement are done at the same time to see the different results coming from these two measurement methods.

Table 6.3 Brief measurement results of apartments in all cities

	Apartment	Formaldehyde (ppm)			TVOC (μg/m³)		
		Max	Mean	Min	Max	Mean	Min
Surabaya	Surabaya 1	0.183	0.120	0.093	0.0	0.0	0.0
	Surabaya 2	0.541	0.250	0.055	0.0	0.0	0.0
	Surabaya 3	0.034	0.015	0.009	0.0	0.0	0.0
	Surabaya 4	0.141	0.076	0.063	0.0	0.0	0.0
	Surabaya 5	0.055	0.035	0.020	0.0	0.0	0.0
	Surabaya 6	0.221	0.050	0.049	1545.1	48.3	0.0
	Surabaya 7	0.149	0.109	0.094	264.0	25.9	0.0
	Surabaya 8	0.100	0.064	0.023	680.0	30.5	0.0
Jakarta	Jakarta 1	0.041	0.017	0.010	0.0	0.0	0.0
	Jakarta 2	0.048	0.025	0.014	0.0	0.0	0.0
	Jakarta 3	0.115	0.093	0.081	135.8	2.5	0.0
	Jakarta 4	0.071	0.045	0.033	453.4	147.8	0.0
	Jakarta 5	1.200	0.066	0.000	1139.1	24.2	0.0
	Jakarta 6	0.063	0.051	0.035	0.0	0.0	0.0
	Jakarta 7	0.149	0.033	0.017	1835.8	378.5	0.0
Bandung	Bandung 1	0.026	0.021	0.019	457.1	121.1	0.0
	Bandung 2	0.109	0.048	0.020	1005.7	634.8	0.0
	Bandung 3	0.056	0.026	0.005	601.9	25.0	0.0
	Bandung 4	0.228	0.142	0.056	0.0	0.0	0.0
	Bandung 5	0.194	0.181	0.161	250.3	5.2	0.0
	Bandung 6	0.072	0.043	0.005	0.0	0.0	0.0
	Bandung 7	0.045	0.023	0.018	0.0	0.0	0.0
	Bandung 8	0.195	0.150	0.093	0.0	0.0	0.0
	Bandung 9	0.193	0.097	0.066	1091.7	113.9	0.0
	Bandung 10	0.043	0.027	0.017	5943.0	3527.4	0.0
	Bandung 11	0.058	0.035	0.024	0.0	0.0	0.0
	Bandung 12	0.025	0.019	0.008	0.0	0.0	0.0
	Bandung 13	0.080	0.056	0.043	0.0	0.0	0.0
	Bandung 14	0.040	0.026	0.019	4215.0	900.5	0.0

Overall, the total measured units in brief measurement, detail measurement and detailed measurement for specific materials are shown in Table 6.4. During detailed measurement, two samplers are located in the room, one inside the room and one outside, thus there are in total 42 samples for detailed measurement. In addition, two measurements were also done for the specific material exposure detailed measurement in two selected locations in each unit of apartment, thus there are 36 samples measured with the measuring cup. Therefore, there are 78 samples analyzed for each DHD-DNPH and Shibata passive gas tube.

Table 6.4 Number of samples in the detailed measurement survey

	Measured apartment Jakarta	Measured apartment Bandung	Measured apartment Surabaya	Total
Brief measurement	7	14	8	29
Detailed measurement (Room)	5	10	6	21
Detailed measurement (Specific materials)	5	8	5	18

6.3.2 Compounds identifications

Collected samples analyzed by GCMS methods showed that ranges of compounds vary based on the location of the sampling process. Table 6.4 shows the chemicals identified by GCMS analysis in the DHD-DNPH sample and the number of samples that carried the chemicals. Oxygen is the most commonly detected compound, shown in 48 samples, followed by methanol in 19 samples. However, the main focus compound for the DHD-DNPH sampler is formaldehyde, which is shown in 11 samples in detailed measurements. On the other hand, Shibata passive gas tube sampler helps capture the VOCs concentration in the room, thus more compounds are captured and identified, 40 chemical compounds (Table 6.6). Carbon dioxide and carbon disulfide are the most detected compounds, appearing in more than 26 and 29 samples. In addition, several industrial compounds were identified during the measurement, which are not commonly considered air pollutants in DHD-DNPH and passive gas tubes. Therefore, the most common pollutants are selected for further analysis. In the case of the DHD-DNPH sample, formaldehyde is the focused compound, whereas Toluene, Benzene, Hexane, methanol, ethanol, and 2-Ethylhexyl acrylate are selected for Shibata passive gas tube.

Table 6.5 Compounds detected in GCMS analysis and the number of samples for DSD-DNPH sample

No.	Name of Chemicals	*n*
1	Oxygen	48
2	Methanol	19
3	Cyclopentasiloxane, decamethyl	3
4	3,5-Diisoproxy-1,1,1,7,7,7-Hexamethyl-3,5-Bis	1
5	Cyclohexasiloxane, dodecamethyl	4
6	Cyclohexasiloxane, dodecamethyl	1
7	Tetrahydro Linalool	1
8	Tetradecamethyl cycloheptasiloxane	2
9	Hexadecamethyl cyclooctasiloxane	1
10	Octadecamethyl cyclononasiloxane	1
11	Formaldehyde, (2,4-dinitrophenyl) hydrazone	11
12	Ethanol	4
13	Tetradeuteromethane	12
14	Nickel carbonyl (Ni(CO)4), (T-4)-	1
15	Cyclotrisiloxane, hexamethyl-	1
16	2-Propenoic acid, 2-ethylhexyl ester	2
17	Furan, 2,3-dihydro-	1

18	1,2-Benzenedicarboxylic acid, diethyl ester	2
19	Hydrazine, (2,4-dinitrophenyl	9
20	1,2-Bis(. gamma.-trimethylsilypropoxy)ethane	3
21	p-Dinitrobenzene	2
22	Acetic acid, methyl ester	12
23	Acetic acid, ethyl ester	1
24	Benzenamine, 2,4-dinitro-	1

Table 6.6 Compounds detected in GCMS analysis and the number of samples for Shibata passive gas tube sample

No.	Name of Chemicals	*n*
1	2-Isobutyl-4,4-dimethyl-1,3-dioxane	1
2	(±)-(4.alpha.,5beta)-4-methyl-5-(1-propenyl)-2-Imidazolidi	3
3	(15)N-Ammonium (15)N-thiocyanate	1
4	Butadienyl acetylene	3
5	Dimethylbutadiyne	2
6	2-Butenedinitrile,	1
7	2-Ethylhexyl acrylate	7
8	2-Propenoic acid, 6-methylheptyl ester	2
9	4-Dibenzofurancarboxamide, 8-acetyl-9,9a-dihydro-1,3,7-trihydr	1
10	4H-Pyran-4-one, 2,6-dimethyl	6
11	Oxygen	4
12	Benzene	3
13	Benzyl chloride	1
14	o-Dichlorobenzene	11
15	p-Dichlorobenzene	3
16	Toluene	1
17	n-Butane	3
18	2,2-Dimethylbutane	1
19	Isopentane	1
20	Ammonium Carbamat	11
21	Carbon Dioxide	26
22	Carbonyl Sulfide	29
23	cis-(1S,3R)-Deltamethrinic acid	3
24	Hexanaphthene	1
25	Methylcyclopentane	1
26	Diphenylmaleic anyhydride	2
27	Ethanol	1
28	Formic Acid, ethyl ester	1
29	Furan, 2-3-dihydro	4
30	n-Hexane	2
31	Hydrazine, methyl-, hydrochloride	1
32	Methanol	2
33	MOLYBDENUM, (ETA.6-BENZENE) TRICARBONYL-	1
34	Nickel carbonyl (Ni(CO)4)	1
35	2-Methylpentane	1
36	3-Methylpentane	1
37	Isobutyl chloride	1
38	Pyridine, 3-(1-methyl-2-pyrrolidinyl)-	1
39	Tetradeuteromethane	1
40	Urea	7

6.3.3 Sources identifications

The identified area from the GCMS analysis was calculated to ppm based on the specific formula for each chemical. As mentioned above, the selected compounds are formaldehyde, toluene, benzene, hexane, methanol, ethanol, and 2-Ethylhexyl acrylate. Table 6.7 – 6.13 show the concentration of compounds in the room in a total of 20 locations measured. Each apartment unit has four measurement points: indoor, outdoor, and two-cup measurements. Cup measurements were done in four optional locations: wallpaper (WP), wallboard (WB), floor, and wall. In some cases, two wallpapers or two wallboards in one apartment unit are suspected as the source of air pollution. Therefore, "WP2" and "WB2" sometimes appeared as different wallpaper or wallboards. As shown, many of the samples do not detect the sample, which indicates that the concentration in the sample was not detectable, Limit of Detection (LOD).

Table 6.7 shows the concentration of formaldehyde based on the unit and measurement location. Overall, formaldehyde is detected more in indoor ambient measurements than in cup measurements. In unit number 2, 3, 5, and 6, specific cup measurements in wallpaper, wallboard, and parquet floor did not show any formaldehyde concentration, but in the ambient room, formaldehyde was detected. It was indicated that the possible sources of formaldehyde in that room have yet to be indicated and measured during the detailed measurement. On the other hand, in units 7 and 8, the detailed cup measurement showed an emission from the material, resulting in formaldehyde concentration in the sample. In unit 7, the concentrations of formaldehyde from the measurement cup on the wallpaper and wallboard are 0.165 ppm and 0.121 ppm, respectively, where the formaldehyde concentration in the room is 0.261 ppm. Whereas, in unit 8, formaldehyde concentration in the ambient room was 0.942 ppm, and the suspected sources are the wall boards (0.95 ppm and 0.362 ppm, respectively). The concentration is nearly three times in the ambient room compared to the measuring cup. However, considering the material's surface area and the room's total volume, detailed calculations regarding the emission rate are needed to understand the room's pollutant conditions further. On the other hand, in unit 9, formaldehyde was not detected in the ambient sampling, but in the wallpaper, 0.1 ppm formaldehyde was captured. This indicates that the formaldehyde emitted from the material was exhausted or absorbed before polluting the ambient air. A similar situation can be seen for Toluene concentration in unit 5, where the toluene was detected only on the wallboard-specific measurement (0.008 ppm), but nothing was captured in ambient air measurement. In addition, toluene only appeared in one measurement point (Table 6.8).

Table 6.9 depicts the measurement results for benzene. As shown, only three locations showed benzene concentration, unit 1 in ambient air measurement (0.049 ppm), Unit 16 in floor measurement (0.048 ppm), and Unit 17 in outdoor measurement (0.048 ppm). Similar tendencies can be seen in hexane (Table 6.10), ethanol (Table 6.12), and 2-Ethylhexyl acrylate (Table 6.13), where the measurement either only captured the room ambient or the specific measurements. Hexane was only captured in the indoor ambient measurement of Unit 1 and Unit 2, 0.002 ppm and 0.052 ppm, respectively, and no specific cup material showed a concentration of hexane. At the same time,

Table 6.7 Detail measurement results for formaldehyde in ppm

No.	Apartment	Compound concentration (ppm)							
		Indoor	WP1	WP2	WB1	WB2	Floor	Wall	Outdoor
1	Unit 1	LOD	-	-	-	-	-	-	LOD
2	Unit 2	**0.508**	-	-	-	-	-	-	LOD
3	Unit 3	**0.103**	LOD	-	LOD	-	-	-	LOD
4	Unit 4	LOD	-	-	LOD	-	LOD	-	LOD
5	Unit 5	**0.159**	-	-	LOD	LOD	-	-	LOD
6	Unit 6	**0.328**	LOD	-	LOD	-	LOD	-	LOD
7	Unit 7	**0.261**	**0.165**	-	**0.121**	-	-	-	LOD
8	Unit 8	**0.942**	-	-	**0.095**	**0.362**	-	-	LOD
9	Unit 9	LOD	**0.100**	-	LOD	-	-	-	LOD
10	Unit 10	LOD	LOD	-	LOD	-	-	-	LOD
11	Unit 11	LOD	-	-	LOD	-	-	LOD	LOD
12	Unit 12	LOD	LOD	LOD	-	-	-	LOD	LOD
13	Unit 13	LOD	LOD	-	-	-	-	LOD	LOD
14	Unit 14	LOD	-	-	-	-	LOD	LOD	LOD
15	Unit 15	LOD	-	-	LOD	-	-	LOD	LOD
16	Unit 16	LOD	LOD	-	-	-	LOD	LOD	LOD
17	Unit 17	LOD	-	-	-	-	LOD	LOD	LOD
18	Unit 18	LOD	LOD	-	-	-	LOD	-	LOD
19	Unit 19	LOD	LOD	-	-	-	LOD	-	LOD
20	Unit 20	LOD	-	-	-	-	LOD	LOD	LOD

Table 6.8 Detail measurement results for Toluene in ppm

No.	Apartment	Compound concentration (ppm)							
		Indoor	WP1	WP2	WB1	WB2	Floor	Wall	Outdoor
1	Unit 1	LOD	-	-	-	-	-	-	LOD
2	Unit 2	LOD	-	-	-	-	-	-	LOD
3	Unit 3	LOD	LOD	-	LOD	-	-	-	LOD
4	Unit 4	LOD	-	-	LOD	-	LOD	-	LOD
5	Unit 5	LOD	-	-	**0.008**	LOD	-	-	LOD
6	Unit 6	LOD	LOD	-	LOD	-	LOD	-	LOD
7	Unit 7	LOD	LOD	-	LOD	-	-	-	LOD
8	Unit 8	LOD	-	-	LOD	LOD	-	-	LOD
9	Unit 9	LOD	LOD	-	LOD	-	-	-	LOD
10	Unit 10	LOD	LOD	-	LOD	-	-	-	LOD
11	Unit 11	LOD	-	-	LOD	-	-	LOD	LOD
12	Unit 12	LOD	LOD	LOD	-	-	-	LOD	LOD
13	Unit 13	LOD	LOD	-	-	-	-	LOD	LOD
14	Unit 14	LOD	-	-	-	-	LOD	LOD	LOD
15	Unit 15	LOD	-	-	LOD	-	-	LOD	LOD
16	Unit 16	LOD	LOD	-	-	-	LOD	LOD	LOD
17	Unit 17	LOD	-	-	-	-	LOD	LOD	LOD
18	Unit 18	LOD	LOD	-	-	-	LOD	-	LOD
19	Unit 19	LOD	LOD	-	-	-	LOD	-	LOD
20	Unit 20	LOD	-	-	-	-	LOD	LOD	LOD

Table 6.9 Detail measurement results for Benzene in ppm

No.	Apartment	Compound concentration (ppm)							
		Indoor	WP1	WP2	WB1	WB2	Floor	Wall	Outdoor
1	Unit 1	**0.049**	-	-	-	-	-	-	LOD
2	Unit 2	LOD	-	-	-	-	-	-	LOD
3	Unit 3	LOD	LOD	-	LOD	-	-	-	LOD
4	Unit 4	LOD	-	-	LOD	-	LOD	-	LOD
5	Unit 5	LOD	-	-	LOD	LOD	-	-	LOD
6	Unit 6	LOD	LOD	-	LOD	-	LOD	-	LOD
7	Unit 7	LOD	LOD	-	LOD	-	-	-	LOD
8	Unit 8	LOD	-	-	LOD	LOD	-	-	LOD
9	Unit 9	LOD	LOD	-	LOD	-	-	-	LOD
10	Unit 10	LOD	LOD	-	LOD	-	-	-	LOD
11	Unit 11	LOD	-	-	LOD	-	-	LOD	LOD
12	Unit 12	LOD	LOD	LOD	-	-	-	LOD	LOD
13	Unit 13	LOD	LOD	-	-	-	-	LOD	LOD
14	Unit 14	LOD	-	-	-	-	LOD	LOD	LOD
15	Unit 15	LOD	-	-	LOD	-	-	LOD	LOD
16	Unit 16	LOD	LOD	-	-	-	**0.048**	LOD	LOD
17	Unit 17	LOD	-	-	-	-	LOD	LOD	**0.048**
18	Unit 18	LOD	LOD	-	-	-	LOD	-	LOD
19	Unit 19	LOD	LOD	-	-	-	LOD	-	LOD
20	Unit 20	LOD	-	-	-	-	LOD	LOD	LOD

Table 6.10 Detail measurement results for Hexane in ppm

No.	Apartment	Compound concentration (ppm)							
		Indoor	WP1	WP2	WB1	WB2	Floor	Wall	Outdoor
1	Unit 1	**0.002**	-	-	-	-	-	-	LOD
2	Unit 2	**0.052**	-	-	-	-	-	-	LOD
3	Unit 3	LOD	LOD	-	LOD	-	-	-	LOD
4	Unit 4	LOD	-	-	LOD	-	LOD	-	LOD
5	Unit 5	LOD	-	-	LOD	LOD	-	-	LOD
6	Unit 6	LOD	LOD	-	LOD	-	LOD	-	LOD
7	Unit 7	LOD	LOD	-	LOD	-	-	-	LOD
8	Unit 8	LOD	-	-	LOD	LOD	-	-	LOD
9	Unit 9	LOD	LOD	-	LOD	-	-	-	LOD
10	Unit 10	LOD	LOD	-	LOD	-	-	-	LOD
11	Unit 11	LOD	-	-	LOD	-	-	LOD	LOD
12	Unit 12	LOD	LOD	LOD	-	-	-	LOD	LOD
13	Unit 13	LOD	LOD	-	-	-	-	LOD	LOD
14	Unit 14	LOD	-	-	-	-	LOD	LOD	LOD
15	Unit 15	LOD	-	-	LOD	-	-	LOD	LOD
16	Unit 16	LOD	LOD	-	-	-	LOD	LOD	LOD
17	Unit 17	LOD	-	-	-	-	LOD	LOD	LOD
18	Unit 18	LOD	LOD	-	-	-	LOD	-	LOD
19	Unit 19	LOD	LOD	-	-	-	LOD	-	LOD
20	Unit 20	LOD	-	-	-	-	LOD	LOD	LOD

Table 6.11 Detail measurement results for Methanol in ppm

No.	Apartment	Compound concentration (ppm)							
		Indoor	WP1	WP2	WB1	WB2	Floor	Wall	Outdoor
1	Unit 1	23.02	-	-	-	-	-	-	LOD
2	Unit 2	22.82	-	-	-	-	-	-	LOD
3	Unit 3	LOD	LOD	-	LOD	-	-	-	LOD
4	Unit 4	LOD	-	-	LOD	-	22.67	-	LOD
5	Unit 5	LOD	-	-	LOD	LOD	-	-	LOD
6	Unit 6	LOD	LOD	-	LOD	-	LOD	-	LOD
7	Unit 7	24.97	LOD	-	LOD	-	-	-	LOD
8	Unit 8	LOD	-	-	LOD	LOD	-	-	LOD
9	Unit 9	24.41	24.34	-	LOD	-	-	-	LOD
10	Unit 10	LOD	LOD	-	LOD	-	-	-	LOD
11	Unit 11	LOD	-	-	LOD	-	-	LOD	LOD
12	Unit 12	LOD	LOD	LOD	-	-	-	31.96	24.82
13	Unit 13	LOD	LOD	-	-	-	-	LOD	25.69
14	Unit 14	24.54	-	-	-	-	24.47	24.36	LOD
15	Unit 15	LOD	-	-	24.70	-	-	LOD	24.78
16	Unit 16	LOD	LOD	-	-	-	LOD	LOD	22.63
17	Unit 17	LOD	-	-	-	-	LOD	LOD	22.81
18	Unit 18	LOD	LOD	-	-	-	LOD	-	LOD
19	Unit 19	LOD	23.60	-	-	-	LOD	-	23.10
20	Unit 20	LOD	-	-	-	-	23.20	LOD	22.86

Table 6.12 Detail measurement results for Ethanol in ppm

No.	Apartment	Compound concentration (ppm)							
		Indoor	WP1	WP2	WB1	WB2	Floor	Wall	Outdoor
1	Unit 1	LOD	-	-	-	-	-	-	LOD
2	Unit 2	LOD	-	-	-	-	-	-	LOD
3	Unit 3	LOD	1.31	-	1.30	-	-	-	LOD
4	Unit 4	LOD	-	-	LOD	-	LOD	-	LOD
5	Unit 5	1.30	-	-	1.30	LOD	-	-	LOD
6	Unit 6	LOD	LOD	-	LOD	-	LOD	-	LOD
7	Unit 7	LOD	1.29	-	LOD	-	-	-	LOD
8	Unit 8	LOD	-	-	LOD	LOD	-	-	LOD
9	Unit 9	LOD	LOD	-	LOD	-	-	-	LOD
10	Unit 10	LOD	LOD	-	LOD	-	-	-	LOD
11	Unit 11	LOD	-	-	LOD	-	-	LOD	LOD
12	Unit 12	LOD	LOD	LOD	-	-	-	LOD	LOD
13	Unit 13	LOD	LOD	-	-	-	-	LOD	LOD
14	Unit 14	LOD	-	-	-	-	LOD	LOD	LOD
15	Unit 15	LOD	-	-	LOD	-	-	LOD	LOD
16	Unit 16	LOD	LOD	-	-	-	LOD	LOD	LOD
17	Unit 17	LOD	-	-	-	-	LOD	LOD	LOD
18	Unit 18	LOD	LOD	-	-	-	LOD	-	LOD
19	Unit 19	LOD	LOD	-	-	-	LOD	-	LOD
20	Unit 20	LOD	-	-	-	-	LOD	LOD	LOD

Table 6.13 Detail measurement results for 2-Ethylhexyl acrylate in ppm

No.	Apartment	Compound concentration (ppm)							
		Indoor	WP1	WP2	WB1	WB2	Floor	Wall	Outdoor
1	Unit 1	LOD	-	-	-	-	-	-	LOD
2	Unit 2	LOD	-	-	-	-	-	-	LOD
3	Unit 3	LOD	LOD	-	LOD	-	-	-	LOD
4	Unit 4	LOD	-	-	LOD	-	LOD	-	LOD
5	Unit 5	LOD	-	-	**0.21**	LOD	-	-	LOD
6	Unit 6	**0.21**	LOD	-	LOD	-	LOD	-	LOD
7	Unit 7	LOD	LOD	-	LOD	-	-	-	LOD
8	Unit 8	LOD	-	-	LOD	**0.22**	-	-	LOD
9	Unit 9	LOD	**0.23**	-	**0.21**	-	-	-	LOD
10	Unit 10	LOD	LOD	-	LOD	-	-	-	LOD
11	Unit 11	LOD	-	-	LOD	-	-	LOD	LOD
12	Unit 12	LOD	**0.21**	LOD	-	-	-	LOD	LOD
13	Unit 13	LOD	LOD	-	-	-	-	LOD	LOD
14	Unit 14	LOD	-	-	-	-	LOD	LOD	LOD
15	Unit 15	LOD	-	-	**0.21**	-	-	LOD	LOD
16	Unit 16	LOD	LOD	-	-	-	LOD	LOD	LOD
17	Unit 17	LOD	-	-	-	-	LOD	LOD	LOD
18	Unit 18	LOD	LOD	-	-	-	LOD	-	LOD
19	Unit 19	LOD	LOD	-	-	-	LOD	-	LOD
20	Unit 20	LOD	-	-	-	-	LOD	LOD	LOD

Ethanol and 2-Ethylhexyl acrylate were mostly shown in the wallpaper and wallboard-specific measurement. Whereas, for methanol, in Unit 9 and Unit 14, the specific cup measurement captured emission from wallpaper, floor, and wall, indicating that the possible sources of methanol concentration in the room are from those materials. On the other hand, several materials were found to emit methanol but were not captured in the ambient air sampling. In addition, methanol is primarily found in outdoor air during sampling, especially in Jakarta and Bandung apartments.

Further analysis of the estimated emission rate from each material was conducted based on the total concentration collected by the passive sampler in each specific material measurement. Table 6.14 shows the overall emission rates of each chemical in every specific cup measurement, the parameters to calculate it, and standard emission rates from materials of each compound. In the case of formaldehyde, two locations showed high emission rates, wallboard 2 in unit 8 (329.38 $\mu g/m^2$) and wallpaper in unit 7 (147.79 $\mu g/m^2$). These values are higher than the proposed standard emission rates for formaldehyde, 110.5 $\mu g/m^2$. The ER from the wallpaper in unit 7 was barely below the standard, indicating that the suspected materials from unit 7, wallpaper and wallboard, have extensive possibilities to be the source of formaldehyde in the ambient air of unit 7. Whereas in unit 8, wallboard 2 was likely to be the primary source of formaldehyde in the room, wallboard 1 also emitted formaldehyde (86.16 $\mu g/m^2$) but not as much as wallboard 2. The wallboard in unit 5 emitted toluene but in a relatively low ER (0.06 mg/m^2). Therefore, the compound was not detected in the ambient air sampling. A similar situation was observed in the benzene emission from the floor in unit 16; the ER was relatively small (0.09 mg/m^2), which made the compound only found in the cup measurement but not in the ambient air sampling. A relatively low emission rate also appeared in 2-Ethylhexyl acrylate, where most wallpapers, wallboards, and boards emitted 0.03 mg/m^2, way less than the standard 38 mg/m^2. Methanol and ethanol show high emission rates compared to other compounds, ranging from 23.72 mg/m^2 to 30.80 mg/m^2 for methanol, and from 15.51 mg/m^2 to 17.26 mg/m^2, for ethanol. However, the values are way below the suggested standard for these compounds, 131.20 mg/m^2 for methanol and 1950 mg/m^2 for ethanol.

Table 6.14 Exposure rate (ER) for each compound from materials in the apartments

	Locations	μg	S	time	EF (μg/m^2)	EF (mg/m^2)	Standard
1	**Formaldehyde**						
	Unit 8 (wallboard 1)	12.11	0.01	24.00	86.16	0.09	110.5 (μg)/ 0.09 ppm
	Unit 8 (wallboard 2)	46.28	0.01	24.00	329.38	0.33	
	Unit 9 (wallpaper)	12.80	0.01	24.00	91.12	0.09	
	Unit 7 (Wallboard)	15.22	0.01	24.00	108.36	0.11	
	Unit 7 (wallpaper)	20.72	0.01	24.00	147.49	0.15	
2	**Toluene**						
	Unit 5 (wallboard)	7.83	0.01	24.00	55.75	0.06	375 mg/10 hours or 560 mg STEL
3	**Methanol**						
	Unit 9 (Wallpaper)	3333.2	0.01	24.00	23724.4	23.72	131.20 mg/m^3
	Unit 19 (Wallpaper)	3447.4	0.01	24.00	24537.2	24.54	
	Unit 15 (wallboard)	3343.9	0.01	24.00	23800.6	23.80	
	Unit 4 (floor)	3356.0	0.01	24.00	23886.5	23.89	
	Unit 14 (floor)	3347.5	0.01	24.00	23826.0	23.83	
	Unit 20 (floor)	3391.4	0.01	24.00	24139.0	24.14	
	Unit 12 (wall)	4327.6	0.01	24.00	30802.0	30.80	
	Unit 14 (wall)	3332.6	0.01	24.00	23720.1	23.72	
4	**Benzene**						
	Unit 16 (floor)	12.38	0.01	24.00	88.1	0.09	3.2 mg/m^3
5	**Ethanol**						
	Unit 3 (Wallpaper)	2425.08	0.01	24.00	17260.8	17.26	1000 ppm/ 1950 mg/m^3
	Unit 7 (wallpaper)	2179.63	0.01	24.00	15513.8	15.51	
	Unit 3 (wallboard)	2245.84	0.01	24.00	15985.1	15.99	
	Unit 5 (wallboard)	2339.29	0.01	24.00	16650.3	16.65	
6	**2-Ethylhexyl acrylate**						
	Unit 5 (wallboard)	3.89	0.01	24.00	27.7	0.03	38 mg/m^3
	Unit 8 (wallboard2)	4.12	0.01	24.00	29.3	0.03	
	Unit 9 (wallboard)	3.97	0.01	24.00	28.3	0.03	
	Unit 9 (wallpaper)	4.28	0.01	24.00	30.5	0.03	
	Unit 12 (wallpaper1)	3.95	0.01	24.00	28.1	0.03	
	Unit 15 (board)	3.94	0.01	24.00	28.0	0.03	

Figures 6.5 – 6.8 depict several examples of selected units that show IAQ pollutants in the ambient air and the specific materials. The models represent the actual arrangement of the furniture and finishing interior applications of each unit measured. Most apartments with higher compound concentrations are newly built (2-6 years), with the highest concentrations shown in unit 8 (2 years). In unit 8, the material and furniture are relatively new also, considering the age of the building. Thus, the emission from those materials is high. The situation is worsened by the relatively small size of the room and the ventilation type.

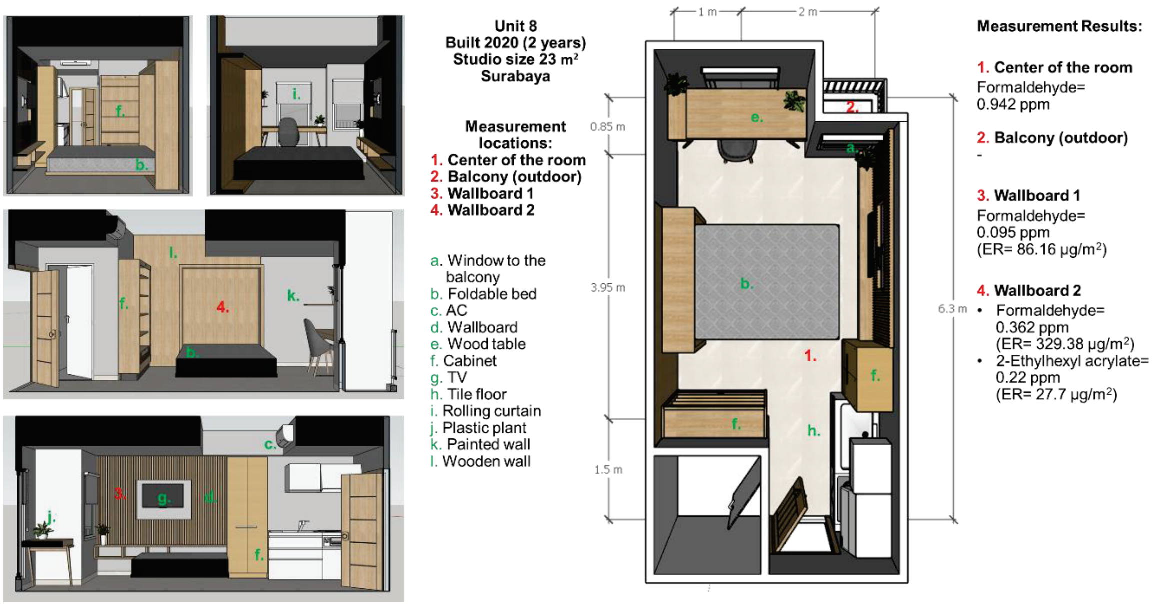


Figure 6.5 Interior, unit information, and detailed measurement result of Unit 8

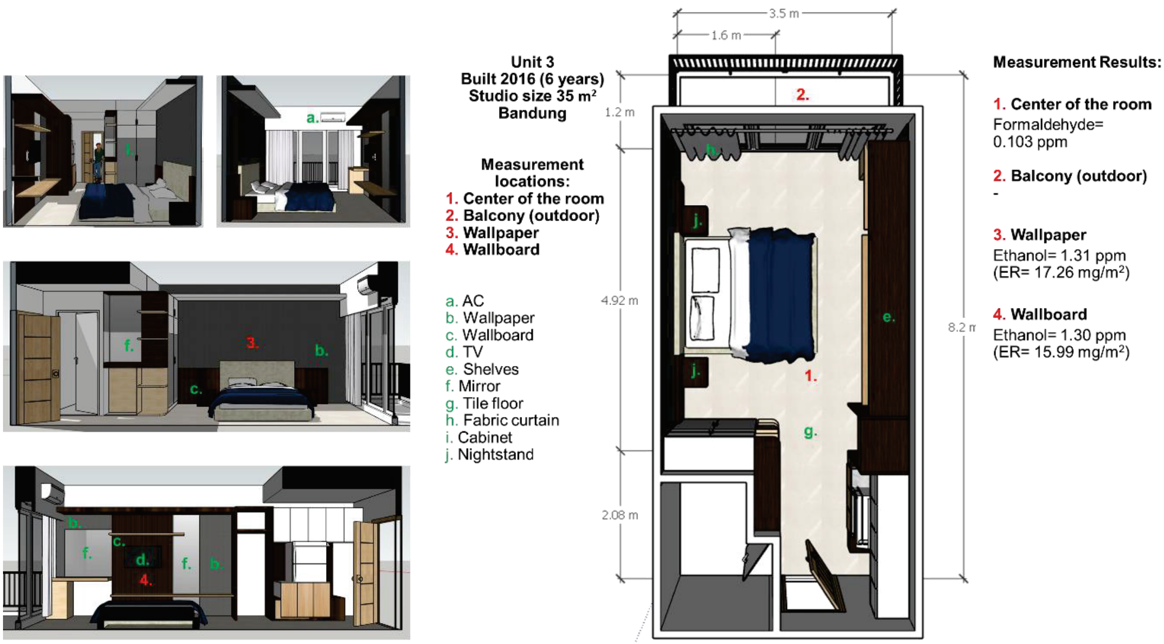


Figure 6.6 Interior, unit information, and detailed measurement result of Unit 3

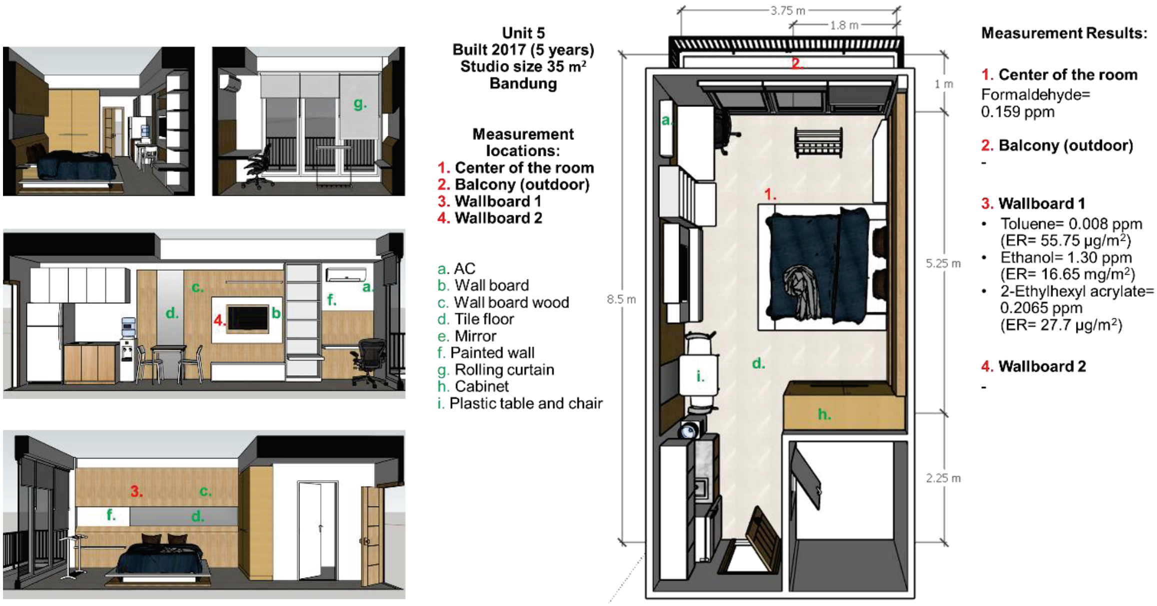


Figure 6.7 Interior, unit information, and detailed measurement result of Unit 5

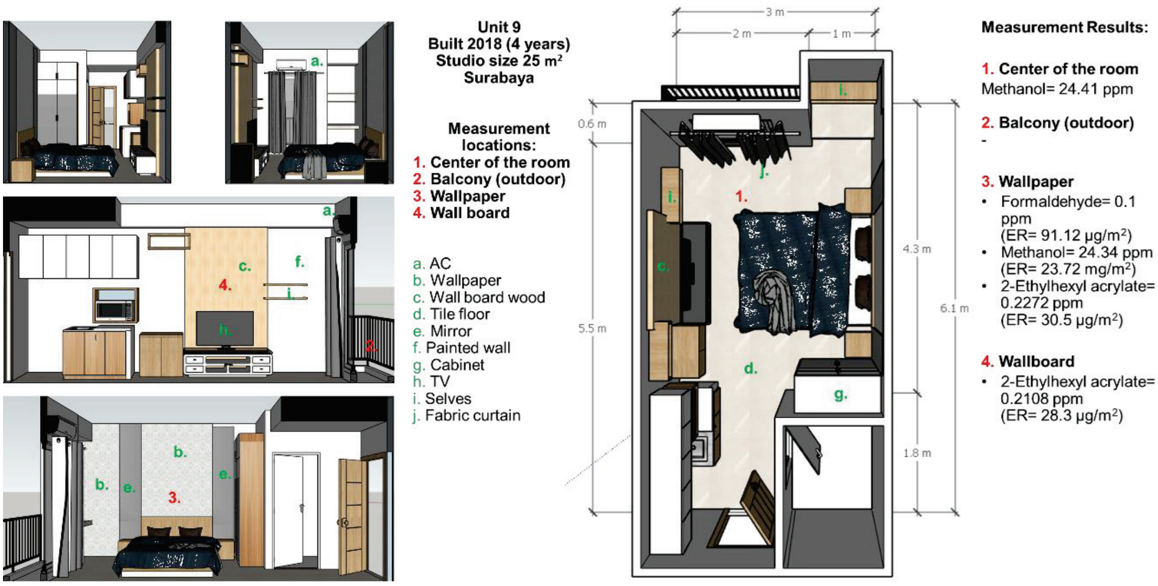


Figure 6.8 Interior, unit information, and detailed measurement result of Unit 9

6.4 Summary

Further detailed and specific measurements in selected high-rise apartments are explained in this chapter. Detailed measurements were done to identify the chemical compounds that pollute the ambient air of the apartment. At the same time, specific cup detailed measurement was performed to find the possible sources of the ambient pollutants. Key findings from this chapter are:

- Detailed measurements captured a wide range of pollutants in the ambient air of the apartment, including the expected compounds like formaldehyde, toluene, benzene, and hexane. At the same time, several industrial compounds have yet to be studied.
- Several units of apartments showed higher and more severe indoor air quality compared to other apartments. Building age, unit size, and the interior condition of the unit are possibly correlated to this condition. The highest concentration of formaldehyde was found in the unit with the smallest room area, the latest to be built, and has many wood-based furniture.
- Specific detailed measurements were found to be an excellent methodology for finding the possible source and emission rates of the air pollutants. Wallpaper and wallboard were found to be the possible source of chemical pollutants in the apartments. Several chemicals were not found in the ambient air, even though they appeared during the cup measurements. It can be related to a relatively low chemical emission rate from the materials and the air change rate of the room, which exhausts the compound before polluting the ambient air.
- The emission rate from formaldehyde in wood-based materials was found to exceed the emission standard for formaldehyde in several unit apartments.

In this investigation, we acknowledge certain limitations related to the detailed material components of the building attributes measured. Currently, the study has focused on identifying potential sources of chemicals in the apartment unit but has not yet covered the specific material and manufacturing processes of the interior attributes. To gain a more comprehensive understanding of chemical exposure in indoor dwellings, further research should encompass information regarding the material used in the wallboard, wallpaper, flooring, and walls applied in the apartment unit, along with their respective manufacturing processes. By doing so, we can better identify potential sources of chemical exposure and assess any associated health risks more effectively.

7
Modification Case and IAQ Study in Apartments

7.1 Introduction

A significant correlation exists between the occupant's behavior and indoor air quality in urban houses. Window opening duration and the number of windows, followed by the availability of AC, fan, and exhaust fan, are several variables that showed a significant relationship with both MCS and IAQ. All those variables are related to the ventilation and air treatment of the house. It is known that improved ventilation is one of the solutions to make a healthy indoor air situation. Therefore, in this chapter, further analysis of the occupant's ventilation behavior and study case a modification is explored to study the effects of improved air circulation by intake and the exhaust fan on IAQ parameters.

7.2 Methods

This chapter discusses the results of a further statistical analysis based on the existing data and field measurement in apartment units before and after a modification project. In the first part, existing data from the previous questionnaire surveys and field measurements in 2017-2019 were further analyzed with principal components and hierarchical clusters analysis. Secondly, the behavior pattern was correlated with the IAQ measurement results to explore the scenario to improve IAQ. Lastly, detailed measurements were conducted in apartments with passive sampling before and after a ventilation modification in the unit to investigate the effect of improved ventilation on IAQ in apartments.

7.2.1 Modification and measurements

The modification project of apartments was done in one of the selected major cities in Indonesia. Between Jakarta, Surabaya, and Bandung, Apartments in Surabaya showed the highest rate of MCS risk and relatively high concentrations of formaldehyde and TVOC. Therefore, Surabaya was selected as the location for the modification project. Three apartments were selected for this project, Gunawangsa Manyar Apartment, Educity Apartment, and Menara Rungkut Apartments. We selected the units with the highest formaldehyde and TVOC concentrations from all the units measured in the first measurements, whereas the MCS risk was also severe.

After getting the acceptance from the respondents and before the first detailed measurement, a brief measurement was done to find the suitable unit with high chemical concentrations. Detail measurement by active sampling and gas chromatography (GS-MS) analysis method was done to further analyze the concentration of formaldehyde and detail compound of TVOC before and after the modification. The sampling and analysis process was done with the help of a sampling and monitoring company, SGS WLN. Active sampling was done with the sampling instrument for eight hours in each location. At the same time, direct reading measurement was also done with FMM-MD, Shinyei Technology (formaldehyde), and ToxiRAE Pro, RAE Systems (TVOC).

In total, four-unit apartments were selected in this study: Unit 1 Apartment Gunawangsa Manyar, Unit 2 Apartment Menara Rungkut (1), Unit 3 Apartment Educity, and Unit 4 Apartment Menara Rungkut (2). One apartment unit was not modified as a controlled unit (unit 1). Furthermore, after the first detailed measurement and obtaining permission from the respondents, the modification project was done by installing the exhaust fan in the living room of the apartment unit (Figure 7.1). The exhaust fan was installed either on the door or the window of the apartment unit facing the balcony/outside (Figure 7.2). 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 was installed on the window in the same direction (Figure 7.2b). All exhaust fans were installed 10 cm from the top of the window/door frame.

Furthermore, the exhaust fan installation study was scheduled for 30 days to understand the modification effects further. At the same time, the second detailed measurement with active sampling was done one week after the modification. Before the second detailed measurement, direct reading devices were installed in the house to continuously monitor the air quality of the unit during the study (30 days). The second measurement was done in a scenario where the exhaust fan was in a working condition with the same eight hours sampling duration. After the second detailed measurement, the occupants were suggested to do their daily activities as usual and turn on the exhaust fan when needed. In addition, all the information regarding the usage of AC, exhaust fan, and window opening was also recorded by the respondents. The data was downloaded and checked every week.

Figure 7.1 Room and door condition (a) before and (b) after the modification (Unit 4)

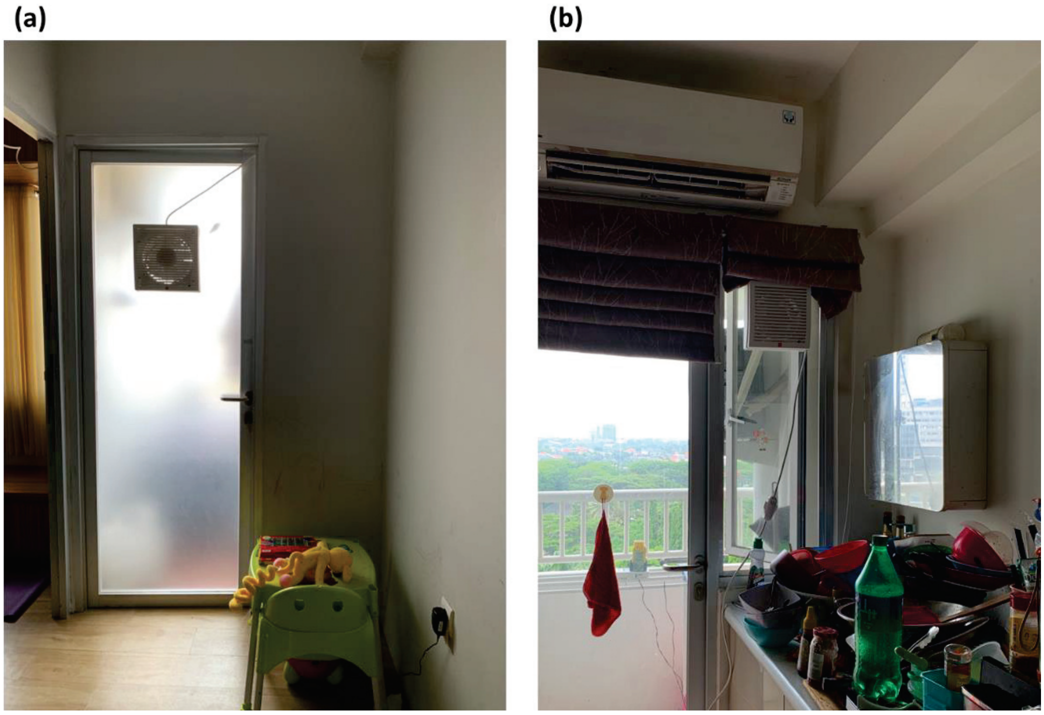


Figure 7.2 Exhaust fan installation on (a) the door and (b) windows of the unit

7.3 Ventilation modification study in apartments

7.3.1 Air change hour in apartment units

In addition, air change per hour (ACH) is also measured to see the house's ventilation rate before the modification, using a CO2 concentration decay method. The measurement was done in all four apartment units selected for modification project in a separate time before the modification. Since the apartment sizes are mostly relatively small and have only one side of ventilation, the measurement in the unit was done once in the center of the room. There are two scenarios measured, open window and closed window, which are done in a separate time. The first scenario, open windows scenario, was done by opening the windows or door that respondents used to open, whereas the second scenario was done with a customarily closed window/door without any additional cover (for example, curtain). The concentration decay method was done by, firstly, CO2 gas was injected into the closed room until reaching a steady level with 2500-3000 ppm concentration. Then, in the interval of 15 seconds, the CO2 concentration decay process and duration were measured. Indoor CO2 concentration was measured using GRAPHTEC Series GL100-WL-CO2 (accuracy ± (5% of reading + 30 ppm) in the range between 0 and 5000 ppm). The equation from Lausmann and Helm (2011) is used to calculate the air change rate.

$$C(t) = (C_0 - C_a)e^{-\lambda t} + C_a \quad 7.7$$

where *C(t)* is the final CO_2 gas concentration (ppm); C_0 is the initial concentration of CO_2 gas (ppm); C_a is the outdoor CO_2 gas concentration (ppm); λ is air change rate (times/hour) and t is time (second).

Figure 7.3a shows the calculation results in opened and closed windows condition. The ACH of unit 1 in apartment Gunawangsa is the highest, 22.13 times per hour, compared to 14.26 times in the Educity apartment and the lowest one, 3.35 times in apartment Menara Rungkut. Indicating that opening windows can result in adequate circulation with high ACH, and there is a possibility that the ACH values are still relatively low even in opened window scenario. On the other hand, in closed window condition (Figure 7.3b), the Educity apartment (Unit 3) shows the lowest ACH by 1.19 times per hour, while in apartment Menara Rungkut (Unit 2 & 4), 2.50 times per hour. Similarly, with open window conditions, apartment Gunawangsa (Unit 1) has the highest ACH in closed window conditions, which is 3.57 times per hour. Therefore, Unit 1 has the most circulated room, whereas Units 2 & 4 were the most airtight room, and Unit 3 was relatively average.

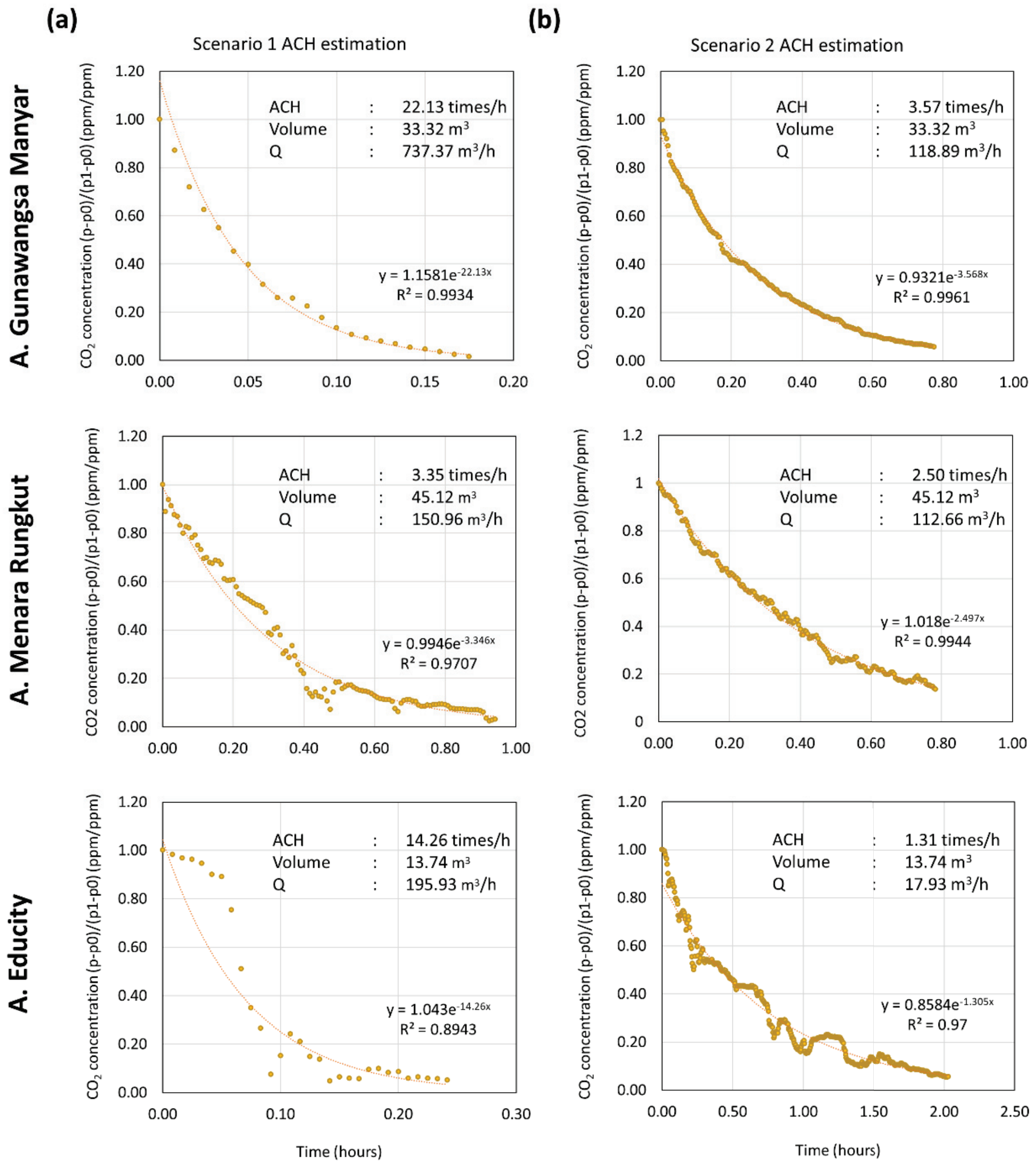


Figure 7.3 Results of ACH calculation using CO_2 decay method for (a) opened windows and (b) closed windows conditions. (H. A. Sani et al., 2021)

Table 7.1 Air change hour measurement results of the apartment units (H. A. Sani et al., 2021)

	ACH (times/h)	Volume (m^3)	Q (m^3/h)
Phase 1 (open window condition)			
Unit 1 (apartment Gunawangasa 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 Gunawangasa 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

In Unit 1, ACH increased six times in the opened-windows scenario compared to the closed-windows scenario. In comparison, Unit 3's ACH increased nearly 12 times in opened windows. This value is double that in Unit 1, even though the ACH was lower compared to Unit 1 in opened windows scenario, 14.26 and 22.13 times, respectively. On the other hand, in Units 2 & 4, the ACH increased insignificantly during the open windows scenarios, from 2.5 times/h to 3.35 times/h (Table 7.1).

7.3.2 Modification

Figures 7.4 and 7.5 present the changes in formaldehyde and TVOC concentrations, respectively, before and after installing the exhaust fans in the measured rooms, in which Unit 1 is the control unit without any modifications. As shown, the formaldehyde level 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 decreased significantly from 118.6 μg/m^3 to 11 μg/m^3 after the modification. Similarly, in unit 4, before the measurement, the concentration was 43.4 μg/m^3, and 11 μg/m^3 after the modification. Furthermore, TVOC concentration was reduced, ranging from 24% to 76%, due to the modification. In the control unit, there was a reduction, but not as significant as in other units, especially unit 4. In the other modified units (2 and 3), the decrease was insignificant because concentration before modification was already low. Further observation is needed to understand the effect of the ventilator installation.

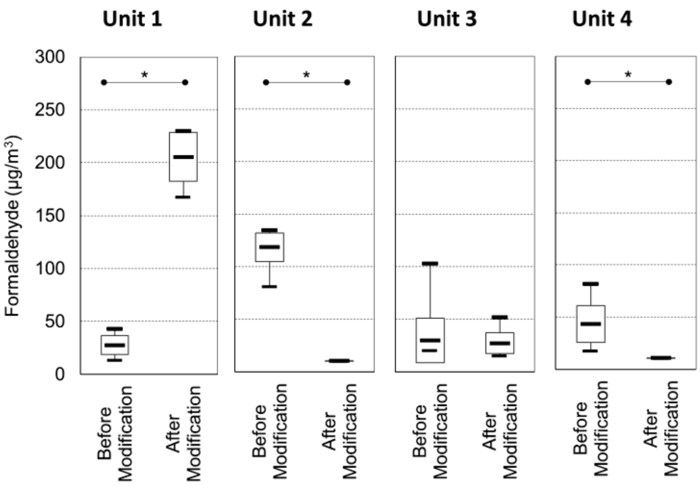


Figure 7.4 Formaldehyde measurement result before and after modification (8 hours sampling)

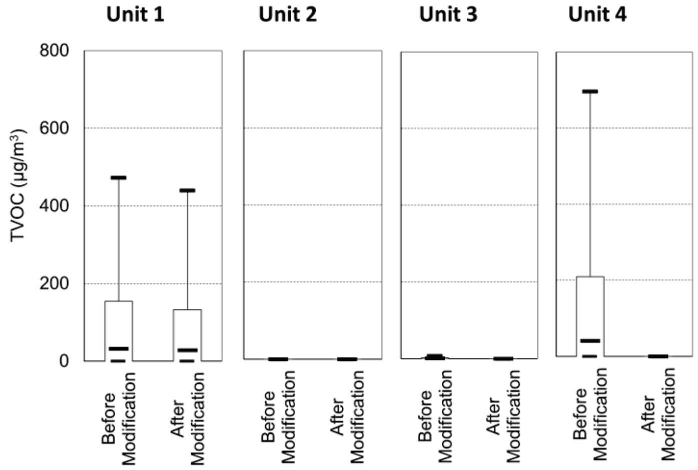


Figure 7.5 TVOC measurement result before and after modification (8 hours sampling)

7.3.3 Follow-up measurement after modification

Furthermore, a follow-up continuous measurement of IAQ (formaldehyde and TVOC) using direct reading devices was done after the modification for a one-month duration. This continuous survey and measurement aim to see the effect of behavioral and usage of heating cooling and ventilator devices in the unit for one month period. Therefore, together with the measurement, occupants were asked to record the AC and ventilator usage. Unfortunately, not all respondents agreed with the measurement due to the duration. Respondents were asked to do their daily activities as usual and motivated to try to turn on the ventilator when it suited them. Besides the ventilator and AC, the occupants recorded detailed window-opening behavior for more than 30 days through an hourly questionnaire marking the opening time. As shown in Table 7.2, respondents in Unit 4 open windows and turn on the ventilator longer compared to respondents in Unit 3, 2.2/1.3 hours, and 6.1/2.8 hours, respectively. On the other hand, Unit 3 showed fully 24 hours AC usage, whereas Unit 4 AC was turned on for 12.3 hours average daily.

Figure 7.6 shows the overall formaldehyde and TVOC temporal changes during this measurement. The recorded daily data was converted to weekly data to see the weekly tendency of the indoor chemical concentration in the unit. As shown, formaldehyde concentration tends to decrease over time, especially in unit 3 (apartment Educity) (Figure 7.6a). However, a similar tendency was not observed in Unit 2, where the formaldehyde concentration increased and then decreased over time. In contrast, the same as formaldehyde in Unit 2, the concentration of TVOC tends to increase and decrease over time in Unit 2 and Unit 3.

In addition, a comparison was made to see the effects of recorded HVAC data on the measured IAQ parameters due to the unclear relationship found in the overall weekly concentration. The IAQ concentration was categorized into two groups (on/open and off/closed) following the AC & ventilator usage and window opening data. However, the AC usage data was not analyzed because the AC unit was always turned on in Unit 3; the data was only analyzed in Unit 2. The installation of ventilation and window opening improves the IAQ concentrations, especially in maximum value in unit 3, based on the results of the follow-up measurement shown in Figure 7.7, where window opening behavior showed a lower level of formaldehyde and TVOC. At the same time, in formaldehyde, the maximum value was relatively lower in opened windows and ventilated time, but the mean value was relatively the same. A similar tendency was also found in the formaldehyde concentration in Unit 2. 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 (figure. 7.8a-b). However, this result showed that the IAQ concentration level might decrease by improving the room's air ventilation. However, there is a possibility that the indoor source is still contaminating the air. Therefore, creating an improvement strategy based on the primary source of the high formaldehyde and TVOC levels is essential to better indoor air quality.

Table 7.2 AC, ventilator, and window opening during the follow-up measurement.

	Total Days	Total on/open	Average on/open daily
Unit 3			
Windows	31	40 h	1.3 h
Ventilator	31	88 h	2.8 h
AC	31	744 h	24.0 h
Unit 4			
Windows	41	90 h	2.2 h
Ventilator	41	249 h	6.1 h
AC	41	505 h	12.3 h

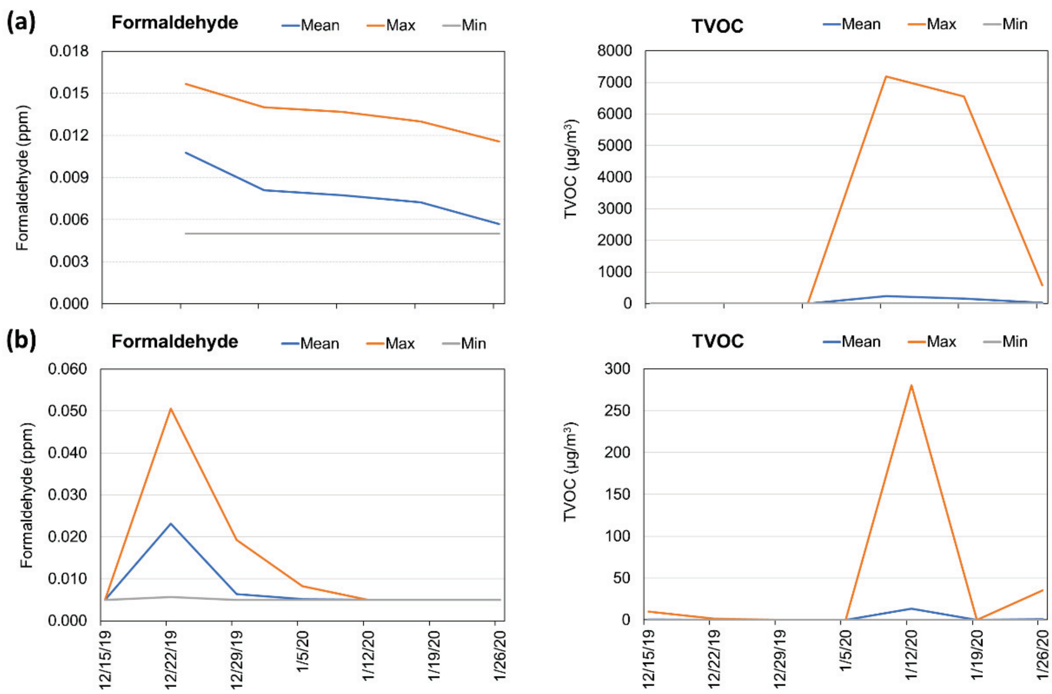


Figure 7.6 Follow-up measurement results temporal variation of weekly concentration of formaldehyde and TVOC at (a) Unit 3 and (b) Unit 2

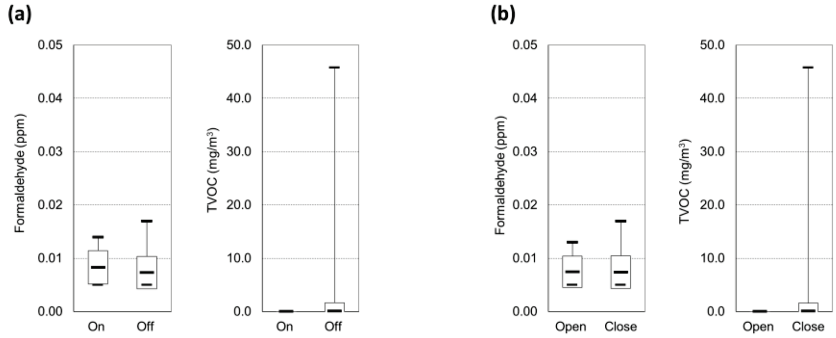


Figure 7.7 IAQ concentration based on (a) the ventilator usage and (b) window-opening condition in Educity apartment (Unit 3)

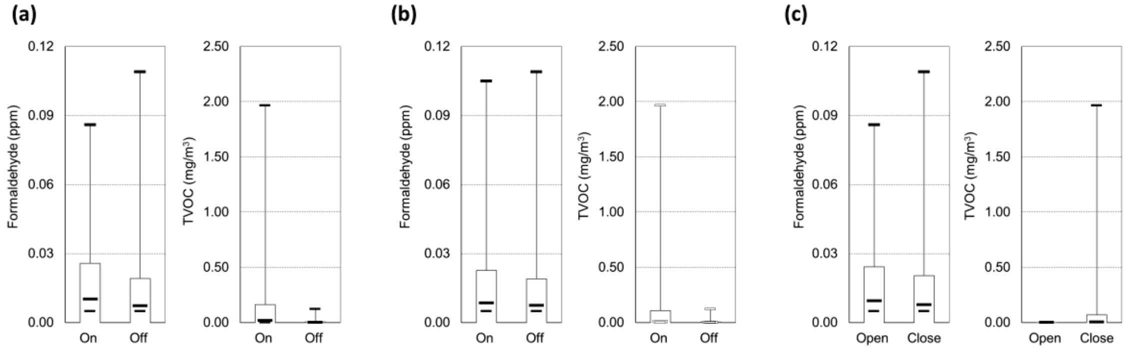


Figure 7.8 IAQ concentration based on (a) the ventilator usage, (b) AC usage, and (c) window-opening condition in Menara Rungkut apartment (Unit 2)

7.4 Summary

This chapter further analyses the occupant's behavior and apartment building attributes with statistical analysis and modification case study. The statistical analysis was done to find a specific (window-opening) behavior pattern that could probably improve the IAQ. At the same time, a modification case was done to explore the effect of improved ventilation on IAQ and health in apartments. Several key findings in this chapter are below.

- In a further detailed measurement, ACH in the apartments increased significantly when the windows or ventilation were opened compared to closed conditions. However, in some cases, there is also a condition where the ACH would not increase significantly. This could be related to the design and wind direction around the room during the ACH measurement, and further study is needed to understand this condition.
- The modifications, exhaust fan installation, to improve the ventilation rate in apartments were found to reduce the concentration of formaldehyde and TVOC effectively. However, in several scenarios, the usage of a ventilator and AC tends to increase the formaldehyde concentration in the apartments. Therefore, further study is needed to understand and combine the ventilation behavior and technology to improve the IAQ of the room.

8 Conclusions

The main objective of this thesis is to provide fundamental and comprehensive data and information on indoor air quality and health in urban houses in Indonesia, which help develop recommendation strategies to improve building performance in IAQ and its health effects. First, this study aims to understand the existing IAQ and health conditions of occupants and their living environments in urban areas. Second, this study investigated the unique environmental condition of the traditional landed houses, Kampong, in urban settings of developing countries as compared to the newly built apartments. Third, the interrelationship of each factor that affects the multiple chemical sensitivities of the occupants of urban houses was analyzed through structural equation modeling. Fourth, potential building attributes and behavioral factors were analyzed to propose suitable materials and measures for the occupants that can be applied to their houses.

6.1 Key findings and conclusions

Review of indoor air quality and sick building syndrome in urban houses

The review mainly focused on the development of knowledge and understanding of indoor air quality and health, especially sick building syndrome in urban houses in developing countries. The study shows that there is a shift in developing countries regarding IAQ problems, which has not yet been studied. Previous studies mostly focused on the IAQ problems related to solid fuels during cooking in houses in developing countries. However, nowadays, due to population growth and urbanization, people moved from solid fuel to gas stoves. Additionally, the majority of residential buildings in urban houses are apartment buildings (vertical houses) and traditional landed houses, Kampong. Due to the lack of standards in the development process, both Kampong and Apartment are prone to IAQ problems and SBS. Recent studies about SBS in developing countries, especially Indonesia, mostly are focused on office and factory building. There are several standards from the government regarding IAQ, formaldehyde and TVOC, but the application of this standard has not been studied. Therefore, study and investigation are necessary to be carried out in those urban houses of developing countries. Building identifications, user interviews and potential threat analysis are necessary to understand the current indoor air quality and health conditions in urban houses of developing countries.

Indoor Air Quality and Health in Existing Newly Constructed High-rise Apartments of Indonesia

The development of urban houses in Indonesia is mostly located in major cities, including Surabaya, Jakarta and Bandung. Field measurement and questionnaire surveys were carried out in apartments in those three cities and Kampong in Surabaya. The key results are as follows.

- Personal attributes related to behavior and socioeconomic of people in Kampong and apartments are significantly different, especially in living duration in the present house, passive smoking behavior, and window opening behavior. Whereas in building attributes, most apartment houses use AC as their cooling system, whereas in Kampong, most people use a fan. The age of the building, mold occurrence and water leakage were more in Kampong compared to the apartment.
- The percentage of MCS risk in apartments was found to be double that in Kampong (42.5/21.9%). Additionally, around 20% of the apartment unit exceeds the WHO standard for formaldehyde in mean value and 60% in maximum value. Even though the percentage of kampong houses exceeding the standard is higher compared to apartments, the overall concentrations of TVOC are higher in apartments. Furthermore, the higher concentration of chemical exposure was found increased the risk of MCS, especially in newly built apartment buildings.
- Personal MCS rates of the respondents in apartments are significantly correlated with their personal rate of indoor and outdoor air quality. Additionally, in newer buildings, a smaller number of windows in bedrooms and usage of AC were found to increase the personal MCS in apartments. Whereas in Kampong, a higher number of windows in the living room and bedroom, more cleaning frequency, and more income are associated with more personal MCS rates.
- Formaldehyde and TVOC concentrations were found to be significantly correlated with the availability of exhaust fan, water leakage, mold and smell occurrence in the dwelling, both in Kampong and apartment. Moreover, in Kampong, longer window opening duration in the bedroom was correlated with a higher mean value of TVOC and a lower mean value of formaldehyde. In Apartments, longer window opening duration in bedrooms significantly correlates to a lower mean value of TVOC. A higher number of furniture and interior conditions are significantly correlated with higher formaldehyde and TVOC, especially wallpaper usage.

Factors Affecting MCS Risk in Newly Constructed High-rise Apartments

Structural equation modeling analysis was applied to understand the interrelationship of the variables affecting multiple chemical sensitivity (MCS). Following the previous analysis, the models were separated between kampong and apartments. The key results are as follows.

- The SEM model of apartments represents the interrelationship of variables affecting MCS for 59% of the whole respondents. Personal air quality rates and allergies symptoms were found to directly affect personal MCS rates. A higher number of furniture, smell occurrence, and wallpaper usage increased the personal air quality. Additionally, the more frequently occupants clean, the more possibility of allergy symptoms. However, when they opened windows, the risk of allergies was reduced.
- 93% of self-assessed MCS risk of people in Kampong are represented by the model. The most significant variable affecting MCS risk in Kampong is self-reported allergies,

which correlated with dampness. The dampness variable only appeared in the model of Kampong. Dampness, which is affected by building age, modifications and living duration, is affecting both personal rates of air quality and self-reported allergies. Cleaning behavior also appeared in the model affecting personal air quality rate, but relatively insignificant.

- There are three basic window opening patterns in apartments and Kampong houses, open 24 hours, open during daytime only, and open morning and evening but closed during the daytime. However, no clear correlation was found between the opening durations/patterns and the concentration of chemicals in the room. These conditions might be related to the fact that only 16% of the measurement results from the units showed some pattern in chemical concentrations, whereas the rest (84%) are random. Therefore, one window opening pattern could not be correlated with the concentration of chemicals.

The Effects of Air Pollution and Dampness on Respiratory Health in Kampong Houses

Kampong was found to have different air quality and health problems from the previous results. Therefore, the typical Kampong area in Bandung is selected as the case study for further measurement and survey regarding air pollution, dampness and respiratory health. The key results are as follows.

- The average age of the building in Kampong Pasteur is 40.7 years, where most houses use a fan as their cooling system, and respondents tend to open windows more in the living room compared to the bedroom. Additionally, around 50% of the houses in Kampong are reported to have mold, water leakage, and smell occurrence during the survey. On the surrounding environment of the houses, 68% of the respondents reported that vehicles are frequently and constantly crossing the narrow alleys in Kampong.
- Comparing children and adult respondents, it was found that children tend to open windows more in the living room compared to adults, where adults tend to open windows more in the master bedroom. Additionally, most children are students; thus, no exposure to the working locations or smoking behavior was recorded.
- Overall, respondents under 15 years old are showing a higher percentage of self-reported respiratory health problems compared to those above 15 years old and more, especially in rainy seasons (41.3/27.1%). Whereas 97% of the houses show a high likelihood of propagation of mold in rainy seasons. However, the risk of mold is highly related to the relative humidity (>70%), which in several conditions also showed in dry seasons. Additionally, particle concentrations were found to be higher in outdoor environments compared to indoor environments, whereas more than 65% of the houses exceeded the WHO standards for $PM_{2.5}$ and TSP both in indoor and outdoor settings.
- Additionally, the risk of self-reported asthma in children was found to increase when the respondents opened windows in the living room longer. While in adult respondents, passive smoking conditions, smell occurrence, and exposure to gas or chemical fumes were possible causes of self-reported respiratory health problems.
- Self-reported persistent cough in children was found to be directly affected by self-reported allergies, humidity rates and mite occurrence. Other indirect factors affecting those variables are window opening durations in the bedroom, bathroom cleaning frequency, mold occurrence, water leakage and OAQ rates. Whereas, in adults, smoking behavior and self-reported SBS are the direct variables affecting self-reported persistent cough, followed by personal OAQ rates, AC ownership, vehicle frequency, chemicals

& dust exposures, gender, living durations and income.

- It was found based on the comparison between measurement results of $PM_{2.5}$ and window-opening behaviors. Occupants are suggested to open windows more in the master bedroom and less in the living room.

Possible Sources of IAQ problems in Apartments: Detail Measurement

Detailed measurements were done to investigate the possible sources of chemical exposure in selected apartment units in three major cities of Indonesia. This measurement follows the previous results assuming that interior elements are the most possible cause of high formaldehyde and TVOC concentration. The key results are as follows.

- A total of 21 rooms were measured with a passive sampling device and analyzed with GCMS analysis. Seven compounds were selected as the focus from around 60 chemical compounds. Several compounds were found both in the ambient air and specific possible sources: wallpaper, wallboard, floor, and wall. However, most measurements showed conditions where the compounds were found only in ambient air or specific possible sources.
- In 25% of the locations, several possible sources of chemical compounds were identified. Wallpaper and wallboards are found to be possible sources of chemical exposure in the indoor environment of apartments.
- Exposure rates of several materials were found to be relatively small and below the standards. Therefore, in most cases, the concentrations were found only in the specific materials but not in the ambient air. Based on previous research (Matsumoto et al., 2002), air circulation and air change hours in the room can be one of the possible causes of this condition. Further analysis and measurement are needed to understand the specific settings of the room, which caused the concentrations to dilute.
- Additionally, based on the finding that the interior attributes could be the possible sources of chemical pollution in the indoor air, information regarding the materials and manufacturing process of several specific interior attributes should be studied further to improve the air quality in the apartment units.

Modification Case and IAQ Study in Apartments

The effects of ventilation on chemical concentrations are evaluated by a modification project in several selected apartment units in Surabaya. Additionally, the ventilator and AC usage, together with the window opening, are observed for more than 30 days after the modification project to see the long-time effect. The key results are as follows.

- The air change hours of selected typical apartment units in Surabaya range from 1.31 to 3.57 times per hour in a closed-windows setting, whereas in an opened-windows setting, it ranges from 3.35 to 22.13 times per hour.
- The installation of ventilators in apartment units was found to reduce the concentration of formaldehyde and TVOC, based on the modification case done in 3 units of apartments in Surabaya. However, in the long-term use of ventilators, there are cases where the concentration of formaldehyde was higher when the respondents turned on the ventilator, which indicates that the source of chemicals could be not only from the building attributes emissions but also the activities in the house. Further analysis of these conditions is needed to understand how to improve IAQ in apartment units.

Final conclusions

Based on previous key findings and summaries, the conclusions of this study are as follows:

- This study provides valuable information to reveal the current conditions of IAQ and health in urban houses in Indonesia through the cross-sectional survey among a relatively large number of samples. It is found that the self-reported SBS represented by MCS and measured indoor air pollutants in apartments are quite severe in Indonesia compared to other countries, especially developed countries. Nevertheless, in Kampong, dampness and respiratory health problems were found to be a concerning matter, especially for young occupants less than 15 years old.
- In the case of multiple chemicals sensitivity (MCS), respondents' perceptions in apartments are likely to be affected by the behavioral and building attributes related to chemical contaminants. Whereas in Kampong, self-reported MCS was highly affected by building attributes and dampness factors related to biological contaminants. These different conditions are supported by the results of field measurements where in apartments, the concentrations of chemicals (formaldehyde and TVOC) are higher compared to Kampong, while in Kampong, the mold risk measurements showed a higher risk compared to apartments.
- In Kampong, the respiratory health respondents under 15 years old are highly affected by the air quality conditions, specifically dampness, cleaning, and opening windows behavior. Whereas those above 15 years old and over are more likely affected by smoking behavior, working environments, and their perception of outdoor air quality. Additionally, the concentration of $PM_{2.5}$ was found to be worse outside of the house compared to indoors, which makes opening windows in the living room could let the pollutants enter the house. Therefore, opening windows in the master bedroom is more efficient for Kampong houses.
- To prevent exposure to traffic-related air pollution, it was advised that Kampong dwellings' room layouts and window designs be taken into account. Furthermore, implementing effective traffic control measures within the Kampong neighborhood could help decrease internal air pollution caused by traffic. To further avoid children's respiratory issues, a public policy prohibiting smoking indoors with children should be taken into consideration.
- The emission from materials and furniture in the urban houses of Indonesia was found to be concerning and polluting the ambient air. However, improvements in air change rate and ventilation are found to decrease the chemical concentration in the ambient room. Even though this study only focused on Indonesia, the results can be applied to other similar newly constructed houses in developing countries with similarities in socio-economic conditions.
- Sick Building Syndrome (SBS) caused by chemical exposure is increasingly prevalent in developing Asian regions like Indonesia, mainly due to the widespread use of air-conditioning. While Indonesia has some existing regulations concerning Volatile Organic Compounds (VOCs) and ventilation, they are currently not obligatory and may not be consistently implemented in construction projects. Drawing from the lessons learned in developed countries facing similar issues, it is anticipated that SBS problems in developing countries will worsen unless strict mandatory regulations regarding building materials and ventilation are introduced in the near future.

6.2 Recommendations

Indonesia, as a growing county, having two types of urban houses is a condition that necessary in the process of development. However, as discussed previously, each type of urban houses has their own indoor air and health problems. The current conditions of Kampong and apartments are in need of improvement. Based on the results of this study, there are several recommendations proposed to improve the indoor air quality of urban houses in Indonesia as follow.

Kampongs

Dampness related to water leakage, humidity, and mold, worsened by $PM_{2.5}$ concentration both in indoor and outdoor are the main problem in Kampong. These conditions can be improved by the building attributes and occupants' behavior. Water leakage can be reduced by improvement in the roof conditions in Kampong, where there is no separation or plafond after the roof tile in most kampong houses, especially in service areas. Additional plafond and waterproof coating would prevent the water drop inside the house. Application of a filter such as breath-able curtain in the windows of living room could reduce the risk of $PM_{2.5}$ entering the indoor ambient air when the occupants open their windows. At the same time, usage of ventilator or exhaust fan, can be one solution to increase the air circulation in Kampong houses. Additionally, occupants should consider the vehicles frequency and the activities outside the house when they open windows, such time when there are high frequency and activities, it is better to close the windows in living room and open the windows in bedroom instead. Furthermore, people living in Kampong need to be informed and educated about the danger of old buildings with low design quality and the need of maintaining the health of the building for a comfortable living.

Additionally, narrow alleys like the one in Kampong are prompt to air quality problems. Therefore, as mentioned in conclusion, the government, and people in charge in Kampong, such as the head of the kampong, should regulate the traffic situations inside of kampong narrow alleys. This regulation can be applied and initiated in a specific Kampong. In a higher level, such as city level and national level, the government should regulate the maximum age of a building which is safe, and indicate the necessity of modification, improvements, and maintenance of the building during certain age and conditions.

Apartments

Chemical contaminants, limited room area and ventilation are the main indoor air problem in apartments. It was found that material such as processed wood board and wallpaper are the possible attributes that emitted chemical pollutants. Therefore, the usage of these materials should be considered and tested before the occupants live in the unit. It is necessary to have a break period to let all the chemical compounds are reduced after the installation or the construction process. Ventilation rates of the units in apartments should be increased by opening more windows or installing a ventilator/exhaust fan in the unit. Additionally, for limited spaces in apartments, reducing the number of furniture is also recommended to maximize the circulations and minimize the risk of emissions from furniture gathered in a stuffed room. There should be a separate area for cooking and service in the apartment unit, which minimizes the air pollutant from the cooking and cleaning activities. In most apartment units, kitchen would be located close to the entrance of the unit and far from the windows area, which indicates the need of a systemize exhaust that can dilute and bring the air from the inside to the outside area in a more efficient way. A pipe system with an exhaust fan connecting the service area to the outside windows side can be a recommended solution. Additionally, based on the results of SEM modelling, respondents should open their windows when they clean the units, especially when they use a cleaner witch contains chemicals.

Furthermore, the current result from this study indicates the need of a detailed nationwide survey of IAQ and SBS in a residential building in Indonesia. Similar nationwide surveys were done in several countries before, like Japan, Korea, and China. By doing so, those countries made regulations regarding the emission rates, possible sources and conditions that can increase the risk of SBS in building. The government should regulate the emission rate from several interior attributes materials which can prevent the air pollution inside the building where the materials will be used and exposed to the occupants. Additionally, the regulation should follow the construction process from the design stage to the completed construction stage, to check the emission rate and chemical pollutants in the building before occupants are allowed to move in. These regulations should also be followed by the contractor for interior modification, where the emissions from the materials used should be checked before and after the modification.

Improving the indoor air quality and health of the occupants should combine the building conditions and the activities of the occupants. People need to increase their awareness about air quality and their environment. Therefore, understanding the conditions with the highest risk of pollutants is necessary to adjust the occupant's behavior to improve the IAQ and health in kampong and apartments houses.

6.3 Study limitations and further study

The data collected in this research was limited due to the restriction conditions during the COVID-19 pandemic. The current results in Chapter 7 have not clearly identified how to improve the IAQ based on the indoor measurement results due to the limited information. Therefore, in the following study, it is essential to investigate detailed information on interior conditions, including furniture used, choices of paint, and flooring materials of the rooms and buildings. Additionally, the manufacturing and the material used in those indoor attributes should be analyzed as well to find the main cause of chemical emissions. At the same time, the current building quality should be assessed, like the surrounding air quality, air change hours, and infiltration rates of the buildings.

Furthermore, this study focused primarily on health issues potentially associated with chemicals such as formaldehyde and TVOC in newly constructed apartments in Indonesia. However, based on the detailed measurement results, many other chemical compounds were found in the ambient air of urban houses in Indonesia. Future study is required to deal with other IAQ parameters, including CO2, CO, and suspended particulate matter (SPM), among others, both in the new apartments and the traditional Kampong houses. Additionally, the medical conditions of the occupants should be assessed with the help of experts from medical fields.

Another limitation of this study regarding the survey in Kampong is the number of samples. The future study is needed to increase samples and case study cities, making more detailed statistical analyses possible. It is also important to deal with the effects of specific outdoor air pollutants and other IAQ parameters, including CO2 and CO among others in the future study.

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Appendix A

Questionnaire forms

Questionnaire for Indoor Air Quality A fundamental study on indoor air quality in residential buildings in major cities of Indonesia **(For household representative (Ideally, Housewife))**	No **A/B**

I	**IDENTIFICATION [Filled in by investigator]**
1	Area: (*Please circle one of them*) → Jakarta | Bandung | Surabaya
2	What is the date of investigation? (*Write dd/mm/yyyy*) → ..../........../................
3	Category of building? *circle one of them* → **(A)** Rusunami (Subsidized apartment) | (B) Condominium (Non-subsidized apartment)
4	Apartment's name: …………………… Block:……….. No:………… Postal address:................
5	Surveyor: ……………………………… Survey time:……… to …………..
6	Group: ………………………………… Affiliation: (*Please circle one of them*) ITS/UPI/Trisakti/other.......

II	**BACKGROUND FACTORS**
7	How many household members are living in the house? *(in person)*
	7a.How many children (≤15 years)? ......(child/children) 7b. How many elder (≥ 60 years)?..........(person)
8	How long have you been at your present living unit? (*in years*)
9	When was establishment of your building/house? *(Specify)*
10	Please observe the specific materials used for respective building parts

Building parts	Specific materials used (Living room/bedrooms)	Finishing materials (if any) (Living room/bedrooms)
Floor		
Wall		
Door		
Ceiling		
Other, specify….		
Other, specify….		

11 How often do you clean your rooms? *(specify)*

a. Everyday b. Several times per week c. Every week d. 2-3 times per month e. Once per month or less

12 How do you usually clean the rooms? *(Possible to answer more than one)*

a. Swept b. Wiped c. Vacuum cleaner d. Other, specify………………..

13 How often do you clean your bathrooms? *(specify)*

a. Everyday b. Several times per week c. Every week d.2-3 times per month e. Once per month or less

14 How do you usually clean your bathrooms? *(Possible to answer more than one)*

a. Brushed b. Sprayed c. Wiped d. Other, specify…………………

15 Where do you dry your laundries? *(Possible to answer more than one)*

a. Indoor b. Outdoor c. At Veranda d. Other, *specify*……………….

16 How do you dry your laundries? *(Possible to answer more than one)*

a. Under the sun b. Laundry c. Drying machine d. Other, specify…………………..

17 What kinds of bedclothes do you use for the sleep? How do you clean your bedclothes? *[Specify]*

Kinds of bedclothes	How to clean
Cotton	
Silk	
Other, specify….	
Other, specify….	

18 How often do you clean your bedclothes? *(Specify)*

a. Everyday b. Several times per week c. Every week d. 2-3 times per month e. Once per month or less

19 What kinds of bed mattresses do you use for the sleep? How do you clean your bed mattresses? *[Specify]*

Kinds of bed mattresses	How to clean
Kapok	
Spring bed	
Sponge	
Other, specify….	
Other, specify….	

20 How often do you clean your bed mattresses? *(Specify)*

a. Everyday b. several times per week c. Every week d. 2-3 times per month e. Once per month or less

21 How many furniture (bed, desk, cupboard not electronic device/appliances) do you have in the following rooms?

Living room ☐ Unit(s) Main Bedroom ☐ Unit(s)

22 When did you purchase them, respectively? *(Please observe the condition of the furniture; materials, new, etc.)*

Living Room		Main Bedroom	
Furniture	Year	Furniture	Year

23 How much is your total household monthly income on average? (in thousand rupiah) *Please circle one of them*

a. < 1000	b. 1001-2000	c. 2001-4000	d. 4001-6000	e. 6001-8000
f. 8001-10000	g. 10001-12000	h. 12001-14000	i. 14001-16000	j. >16001

24 How many person who has income in your family? *(in person)*

25 How many rooms and what size of your unit apartment? *(Specify)*

Rooms	Size (m2)
Total	Total ....

III INDOOR AIR QUALITY

26 Is there any smell/odor in your house/unit? *Please circle one of them* → Yes | No

27 If yes, please specify place(s) and type of smell (glue, vinegar, ammonia, gasoline, perfume, tobacco smoke, dust, mold, stale)]

Place(s)	Type of smell

28 How do you rate humidity conditions in your house/unit? Very dry 0 1 2 3 4 5 6 7 8 9 10 Very humid

29 Do you see some mold growth in your house/unit? *Please circle one of them* → Yes | No

30	If Yes, where do you find the mold? *(Possible to answer more than one)* a. Master bedroom b. Other bedroom c. Dining room d. Living room e. bathroom f. Toilet g. Kitchen h. Storage i. Other, specify ……………………
31	Is there any water leakage in your house/unit? *Please circle one of them* → Yes | No
32	If yes, please specify place(s) and when it is happened

Place(s)	Month, Year

33	Are you suffered of mite in your house/unit? *Please circle one of them* → Yes | No
34	If Yes, please specify place(s) and when it is happened

Place(s)	Month, Year

35	How do you describe the air quality inside your house?	Very clean	0	1	2	3	4	5	6	7	8	9	10	Very polluted
36	How do you describe the air quality outside your house?	Very clean	0	1	2	3	4	5	6	7	8	9	10	Very polluted
37	Do you have other any indoor air quality problems? *(Specify)*													

IV DETAILED COOLING BEHAVIOUR

38 When do you usually open windows when you stay in the house/unit, during the dry season? *Please draw the line*

Master bedroom   Number of windows: (unit(s))

Weekdays	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	h
Weekends	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	h

39 Living room   Number of windows: (unit(s))

Weekdays	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	h
Weekends	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	h

40 Do you have air-conditioning? *Please circle one of them* → Yes | No

41 If yes, where and how many do you have? *(Specify)*

Air conditioning (AC)	
Location	Number of AC (unit(s))

42 How often do you clean the filter of air-conditioning? *(specify)*

a. Every…..day(s) b. Every….week(s) c. Every…….month(s) d. Never e. Other, specify……........

43 Do you have ceiling/stand fan(s) in your house/unit? *Please circle one of them* → Yes | No

44 If yes, where and how many do you have? *(Specify)*

Ceiling fan	
Location	Number unit(s)

Stand fan	
Location	Number of unit(s)

45 When do you usually use fan(s) when you stay in the house, during the dry season? *Please draw the line*

Master bedroom Number of fans: (unit(s))

Weekdays	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	h
Weekends	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	h

46 Living room Number of fans: (unit(s))

Weekdays	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	h
Weekends	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	h

47 Do you have exhaust fan(s) in your house/unit? *Please circle one of them* → Yes | No

48 If Yes, where and how many do you have? *(Specify)*

Exhaust fan			Cooking fan			
Location	Number (unit(s))	Figure 1	Location	Number (unit(s))	Fig.	Figure 2
						 2b 2a

Note:

In the case of cooking fan (Figure 2), please differentiate;

Cooking exhaust has exhaust piping (Figure 2a) and Cooking filtering does not have any exhaust piping (Figure 2b). Therefore,please take a pictures while opening the shelf above the device to make sure if it is cooking exhaust or only cooking filtering by selecting the Figure above (Figure 2a or 2b).

V PAST/PRESENT DISEASES

49 Month and year of birth: *[Specify]*

50 Your Sex? *Please circle one of them* → Male | Female

51 Relationship to the household head? *Please circle one of them* → Head | Spouse | Child | other..............

52 What is your occupation? *Please circle one of them* →

a. Government b. Private c. Entrepreneur d. Student e. Housewife f. Retired e. Other, *specify*…….

53 Have you ever had asthmatic problems? *Circle one of them* → Yes | No ; If yes, Before | After moving in

54 Have you ever had hay-fever? *Circle one of them* → Yes | No ; If yes, Before | After moving in

55	Have you ever had eczema? *Circle one of them* →	Yes | No ; If yes, Before | After moving in
56	Do you have any other allergic diseases? *Circle one of them* →	Yes | No ; If yes, Before | After moving in
57	If yes, please specify………………………………………....................................	
58	Do you have any other disease? *Circle one of them* → Yes | No ; If yes, specify….....	Before | After moving in
59	Do problems with health get worse when inside of building/unit? *Circle one of them* → Yes | No	
60	Which problems do you experience? *(Please specify)*	

61	Have you been often stressful?	Never	0	1	2	3	4	5	6	7	8	9	10	Very often
62	What do you have stress to? *(Specify)*													
63	How satisfied are you with your living environment?	Very dissatisfied	0	1	2	3	4	5	6	7	8	9	10	Very satisfied
64	If not satisfied, Why? *(Specify)*													

VI CHEMICAL EXPOSURES

The following items ask about your responses to various odors or chemical exposures. Please indicate whether or not these odors or exposures would make you feel sick, for example, you would get a headache, have difficulty thinking, feel weak, have trouble breathing, get an upset stomach, feel dizzy, or something like that. For any exposure that makes you feel sick, on a 0-10 scale rate the severity of your symptoms with that exposure. For exposures that do not bother you, answer "0." Do not leave any items blank. **For each item, circle one number only: [0 = not at all a problem] [5 = moderate symptoms] [10 = disabling symptoms]**

65	Diesel or gas engine exhaust	0	1	2	3	4	5	6	7	8	9	10
66	Tobacco smoke	0	1	2	3	4	5	6	7	8	9	10
67	Insecticide	0	1	2	3	4	5	6	7	8	9	10
68	Gasoline, for example at a service station while filling the gas tank	0	1	2	3	4	5	6	7	8	9	10
69	Paint or paint thinner	0	1	2	3	4	5	6	7	8	9	10
70	Cleaning products such as disinfectants, bleach, bathroom cleansers or floor cleaners	0	1	2	3	4	5	6	7	8	9	10
71	Certain perfumes, air fresheners or other fragrances	0	1	2	3	4	5	6	7	8	9	10
72	Fresh tar or asphalt	0	1	2	3	4	5	6	7	8	9	10
73	Nail polish, nail polish remover, or hairspray	0	1	2	3	4	5	6	7	8	9	10
74	New furnishings such as new carpeting, a new soft plastic shower curtain or the interior of a new car	0	1	2	3	4	5	6	7	8	9	10

75	Name(s) any additional chemical exposures that make you feel ill and score them from 0 to 10: a.………………………………………………………………………	0	1	2	3	4	5	6	7	8	9	10
	b..	0	1	2	3	4	5	6	7	8	9	10
VII	**OTHER EXPOSURES**											
	The following items ask about your responses to a variety of other exposures. As before, please indicate whether these exposures would make you feel sick. Rate these verity of your symptoms on a 0-10 scale. Do not leave any items blank. **For each item, circle one number only:** **[0 = not at all a problem] [5 = moderate symptoms][10 = disabling symptoms]**											
76	Chlorinated tap water	0	1	2	3	4	5	6	7	8	9	10
77	Particular foods, such as candy, pizza, milk, fatty foods, meats, barbecue, onions, garlic, spicy foods, or food additives such as MSG	0	1	2	3	4	5	6	7	8	9	10
78	Unusual cravings, or eating any foods as though you were addicted to them; or feeling ill if you miss a meal	0	1	2	3	4	5	6	7	8	9	10
79	Feeling ill after meals	0	1	2	3	4	5	6	7	8	9	10
80	Caffeine, such as coffee, tea, cola drinks, sprite, fanta or chocolate	0	1	2	3	4	5	6	7	8	9	10
81	Feeling ill if you drink or eat less than your usual amount of coffee, tea, caffeinated soda or chocolate, or miss it all together	0	1	2	3	4	5	6	7	8	9	10
82	Alcoholic beverages in small amounts such as one beer or a glass of wine	0	1	2	3	4	5	6	7	8	9	10
83	Fabrics, metal jewelry, creams, cosmetics, or other items that touch your skin	0	1	2	3	4	5	6	7	8	9	10
84	Being unable to tolerate or having adverse or allergic reactions to any drugs or medications (such as antibiotics, anesthetics, pain relievers, x-ray contrast dye, vaccines or birth control pills), or to an implant, prosthesis, contraceptive chemical or device, or other medical, surgical or dental material or procedure	0	1	2	3	4	5	6	7	8	9	10
85	Problems with any classical allergic reactions (asthma, nasal symptoms, hives, anaphylaxis or eczema) when exposed to allergens such as: tree, grass or weed pollen, dust, mold, animal dander, insect stings or particular foods	0	1	2	3	4	5	6	7	8	9	10
VII I	**SYMPTOMS**											
	The following questions ask about symptoms you may have experienced commonly. Rate the severity of											

	your symptoms on a 0-10 scale. Do not leave any items blank. **For each item, circle one number only:** **[0 = not at all a problem] [5 = moderate symptoms] [10 = disabling symptoms]**	
86	Problems with your muscles or joints, such as pain, aching, cramping, stiffness or weakness?	0 1 2 3 4 5 6 7 8 9 10
87	Problems with burning or irritation of your eyes, or problems with your airway or breathing, such as feeling short of breath, coughing, or having a lot of mucus, post nasal drainage, or respiratory infections?	0 1 2 3 4 5 6 7 8 9 10
88	Problems with your heart or chest, such as a fast or irregular heart rate, skipped beats, your heart pounding, or chest discomfort?	0 1 2 3 4 5 6 7 8 9 10
89	Problems with your stomach or digestive tract, such as abdominal pain or cramping, abdominal swelling or bloating, nausea, diarrhea, or constipation?	0 1 2 3 4 5 6 7 8 9 10
90	Problems with your ability to think, such as difficulty concentrating or remembering things, feeling spacey, or having trouble making decisions?	0 1 2 3 4 5 6 7 8 9 10
91	Problems with your mood, such as feeling tense or nervous, irritable, depressed, having spells of crying or rage, or loss of motivation to do things that used to interest you?	0 1 2 3 4 5 6 7 8 9 10
92	Problems with balance or coordination, with numbness or tingling in your extremities, or with focusing your eyes?	0 1 2 3 4 5 6 7 8 9 10
93	Problems with your head, such as headaches or a feeling of pressure or fullness in your face or head?	0 1 2 3 4 5 6 7 8 9 10
94	Problems with your skin, such as a rash, hives or dry skin?	0 1 2 3 4 5 6 7 8 9 10
95	Problems with your urinary tract or genitals, such as pelvic pain or frequent or urgent urination? (For women: or discomfort or other problems with your menstrual period?)	0 1 2 3 4 5 6 7 8 9 10
96	Problem with your skin such, itching on between the thigh and anus, circle rush and white on skin?	0 1 2 3 4 5 6 7 8 9 10
97	Problem with your skin such itching on between fingers on hand and foot especially on the night	0 1 2 3 4 5 6 7 8 9 10

IX MASKING INDEX

	The following items refer to ongoing exposures you may be having. Circle "0" if the answer is "NO," or if you don't know whether you have the exposure. Circle "1" if the answer is "YES," you do have the exposure. Do not leave any items blank. **Circle "0" or "1" only:**	
98	Do you smoke or dip tobacco once a week or more often?	No:0 Yes:1
99	Do you drink any alcoholic beverages, beer, or wine once a week or more often?	No:0 Yes:1

100	Do you consume any caffeinated beverages once a week or more often?	No:0	Yes:1
101	Do you routinely (once a week or more) use perfume, hairspray, or other scented personal care products?	No:0	Yes:1
102	Has either your home or your workplace been sprayed for insects or fumigated in the past year?	No:0	Yes:1
103	In your current job or hobby, are you routinely (once a week or more) exposed to any chemicals, smoke or fumes?	No:0	Yes:1
104	Other than yourself, does anyone routinely smoke in side your home?	No:0	Yes:1
105	Is either a gas or propane stove used for cooking in your home?	No:0	Yes:1
106	Is a scented fabric softener (liquid or dryer sheet) routinely used in laundering your clothes or bedding?	No:0	Yes:1
107	Do you routinely (once a week or more) take any of the following: steroid pills, such as prednisone; pain medications requiring a prescription; medications for depression, anxiety, or mood disorders; medications for sleep; or recreational or street drugs?	No:0	Yes:1

X IMPACT OF SENSITIVITIES

If you are sensitive to certain chemicals or foods, on a scale of 0-10 rate the degree to which your sensitivities have affected various aspects of your life. If you are not sensitive or if your sensitivities do not affect these aspects of your life, answer "0." Do not leave any items blank. How much have your sensitivities affected:

For each item, circle one number only: [0 = not at all] [5 = moderately] [10 = severely]

108	Your diet?	0 1 2 3 4 5 6 7 8 9 10
109	Your ability to work or go to school?	0 1 2 3 4 5 6 7 8 9 10
110	How you furnish your home?	0 1 2 3 4 5 6 7 8 9 10
111	Your choice of clothing?	0 1 2 3 4 5 6 7 8 9 10
112	Your ability to travel to other cities or drive a car?	0 1 2 3 4 5 6 7 8 9 10
113	Your choice of personal care products, such as deodorants or makeup?	0 1 2 3 4 5 6 7 8 9 10
114	Your ability to be around others and enjoy social activities, for example, going to meetings, church, restaurants, etc.?	0 1 2 3 4 5 6 7 8 9 10
115	Your choice of hobbies or recreation?	0 1 2 3 4 5 6 7 8 9 10
116	Your relationship with your spouse or family?	0 1 2 3 4 5 6 7 8 9 10
117	Your ability to clean your home, iron, mow the lawn, or perform other routine chores?	0 1 2 3 4 5 6 7 8 9 10

XI PICTURES (mold growth observation)

118 Please take a picture in every room! *[Specify]*

- ☐ Elevation
- ☐ Guest room
- ☐ Living Room
- ☐ Master bedroom
- ☐ Bed Room 1
- ☐ Bathroom
- ☐ Water storage
- ☐ kitchen
- ☐ Air-conditioning
- ☐ Ventilator/filtering fan

XIV FURTHER COMMENTS

119 ……
………

120 We are conducting survey on indoor air quality in residential buildings in major cities of Indonesia through interview and measurement. What we did just now is an interview. Measurement survey measures your indoor air quality utilizing small gadgets put in your house/unit within two days up to one week. If possible, can you allow us to do measurement survey in your house/unit? *Please circle one of them* → Yes | No

THANK YOU FOR YOUR COOPERATION

Questionnaire for Indoor Air Quality Biological section (for those 13 years of age and older)		
	COUGH	
1	Do you usually have a cough? (Count a cough with first smoke or on first going out-of-doors. Exclude clearing of throat.)[If no, skip to question 3]	1. Yes ___ 2. No ___
2	Do you usually cough as much as 4 to 6 times a day, 4 or more days out of the week?	1. Yes ___ 2. No ___
3	Do you usually cough at all on getting up, or first thing in the morning?	1. Yes ___ 2. No ___
4	Do you usually cough at all during the rest of the day or at night?	1. Yes ___ 2. No ___
	IF YES TO ANY OF THE ABOVE (1, 2, 3 OR 4), ANSWER THE FOLLOWING: IF NO TO ALL, CHECK DOES NOT APPLY AND SKIP TO 7.	1. Yes ___ 2. No ___
5	Do you usually cough like this on most days for 3 consecutive months or more during the year?	1. Yes ___ 2. No ___ 8. Does not apply __
6	For how many years have you had this cough?	Number of years __ 88. Does not apply __
	PHLEGM	
7	Do you usually bring up phlegm from your chest (Count phlegm with the first smoke or on first going out-of-doors. Exclude phlegm from the nose. Count swallowed phlegm) [If no, skip to 9.]	1. Yes ___ 2. No ___
8	Do you usually bring up phlegm like this as much as twice a day, 4 or more days out of the week?	1. Yes ___ 2. No ___
9	Do you usually bring up phlegm at all on get-ting up or first thing in the morning?	1. Yes ___ 2. No ___
10	Do you usually bring up phlegm at all during the rest of the day or at night?	1. Yes ___ 2. No ___
	IF YES TO ANY OF THE ABOVE (7, 8, 9, OR 10), ANSWER THE FOLLOWING: IF NO TO ALL, CHECK DOES NOT APPLY AND SKIP TO 13.	
11	Do you bring up phlegm like this on most days for 3 consecutive months or more during the year?	1. Yes ___ 2. No ___ 8. Does not apply __
12	For how many years have you had trouble with phlegm?	Number of years __ 88. Does not apply __
13	Have you had periods or episodes of (in- creased*) cough and phelgm lasting for 3 weeks or more each year? *(For individuals who usually have cough and/or phlegm)	1. Yes ___ 2. No ___
	IF YES TO 9A:	
14	B. For how long have you had at least 1 such episode per year?	Number of years __ 88. Does not apply __

	WHEEZING	
15	Does your chest ever sound wheezy or whistling 1. When you have a cold? 2. Occaisonally apart from colds? 3. Most days or nights?	1. Yes ___ 2. No ___ 1. Yes ___ 2. No ___ 1. Yes ___ 2. No ___
	IF YES TO 1, 2, OR 3 IN 15	
16	Have you had 2 or more such episodes? For how many years has this been present?	____________________ Number of years 88. Does not apply __
17	Have you ever had an ATTACK of wheezing or whistling that has made you feel short of breath?	1. Yes ___ 2. No ___
	IF YES TO 11A:	
18	How old were you when you had your first such attack?	_______ Age in years 88. Does not apply __
19	Have you had 2 or more such episodes?	1. Yes ___ 2. No ___ 8. Does not apply __
20	Have you ever required medicine or treatment for the(se) attack(s)?	1. Yes ___ 2. No ___ 8. Does not apply __
	BREATHLESSNESS	
21	If disabled from walking by any condition other than heart or lung disease, please describe and proceed to Question 27	Nature of condition(s) ____________________
22	Are you troubled by shortness of breath when hurrying on the level or walking up a slight hill?	1. Yes ___ 2. No ___
	IF YES TO 22	
23	Do you have to walk slower than people of your age on level because of breathlessness?	1. Yes ___ 2. No ___ 8. Does not apply __
24	Do you ever have to stop for breath when walking at your own pace on the level?	1. Yes ___ 2. No ___ 8. Does not apply __
25	Do you ever have to stop for breath after walking about 100 yards (or after a few minutes) on the level?	8. Does not apply __
26	Are you too breathless to leave the house or breathless on dressing or undressing?	1. Yes ___ 2. No ___ 8. Does not apply __
	CHEST COLDS AND CHEST ILLNESSES	
27	If you get a cold, does it usually go to your chest? (Usually means more than 1/2 the time)	1. Yes ___ 2. No ___ 8. Don't get colds__
28	During the past 3 years, have you had any chest illnesses that have kept you off work, indoors at home, or in bed?	1. Yes ___ 2. No ___
	IF YES TO 28	
29	Did you produce phlegm with any of these chest illnesses?	1. Yes ___ 2. No ___ 8. Does not apply __
30	In the last 3 years, how many such illnesses, with (increased) phlegm, did you have which lasted a week or more?	_____Number of illnesses _______No such illnesses

		________Does not apply
	OCCUPATIONAL HISTORY	
31	Have you ever worked full time (30 hours per week or more) for 6 months or more?	1. Yes ___ 2. No ___
	IF YES to 31:	
32	Have you ever worked for a year or more in any dusty job?	1. Yes ___ 2. No ___ 8. Does not apply ___ Specify job/industry: ________ Total years worked __ Was dust exposure 1. Mild ___ 2. Moderate ___ 3. Severe ___ ?
33	Have you ever been exposed to gas or chemical fumes in your work?	1. Yes ___ 2. No ___ . Does not apply ___ Specify job/industry: _______ Total years worked __ Was dust exposure 1. Mild ___ 2. Moderate ___ 3. Severe ___ ?
34	What has been your usual occupation or job -- the one you have worked at the longest?	1. Job-occupation:___________ 2. Number of years employed in this occupation:________________ 3. Position-job title:_______________ 4. Business, field, or industry: ___________________________
	TOBACCO SMOKING	
35	Have you ever smoked cigarettes? (NO means less than 20 packs of cigarettes or 12 oz. of tobacco in a lifetime or less than 1 cigarette a day for 1 year	1. Yes ___ 2. No ___
	IF YES to 25A:	
36	Do you now smoke cigarettes (as of 1 month ago)?	1. Yes ___ 2. No ___ 8. Does not apply ___
37	C. How old were you when you first started reg-cigarette smoking?	____ Age in Years 8. Does not apply ___
38	D. If you have stopped smoking cigarettes com-pletely, how old were you when you stopped?	____ Age stopped Check if still smoking ___
39	E. How many cigarettes do you smoke per day now?	___ Cigarettes/day 88.Does not apply __
40	F. On the average of the entire time you smoked, how many cigarettes did you smoke per day?	___ Cigarettes/day 88.Does not apply __
41	G. Do or did you inhale the cigarette smoke?	1. Does not apply ___ 2. Not at all ________ 3. Slightly _________ 4. Moderately ______ 5. Deeply _________

Additional Questions		
42	Have you ever told your doctor asthma?	1. Yes ___ 2. No ___
43	At that time your chest ever sound wheezy or whistling that has made you feel short of breath?	1. Yes ___ 2. No ___
44	Have you ever had an asthma attack or in the past two years, or did you get treatment?	1. Yes ___ 2. No ___
45	How much are you annoyed by outdoor air pollution (from traffic, industry, etc) if you keep the windows open	0 1 2 3 4 5 6 7 8 9 1 0 0 Doesn't annoy at all 10 intolerable annoyance
46	How often remove vehicles(e.g.truck/buses)pass your house	Constantly 1 Frequency 2 Seldom 3 Never 4
46	Do people somke regularly in the room where you work	1. Yes ___ 2. No ___
47	How many hours per day are you expand to other people's tobacco smoke?	hours
48	Please provide more information How many hours per day, are you expand to other peoples tobacco smoke in the following locations	At home At workplace In bars, restaurants, cinemas or similar settings elsewhre

Could you cooperate with the survey to measure air quality of the house for a week?	1. Yes ___ 2. No ___
Can we like to enter the room to do actual measurements inside the house?	1. Yes ___ 2. No ___
Do you have a convenient week or something?	1. Yes ___ 2. No ___
Thank you for participating in the research.	

Questionnaire for Indoor Air Quality
For child
Biological section

	COUGH	
1	Do you usually have a cough? (Count a cough with first smoke or on first going out-of-doors. Exclude clearing of throat.)[If no, skip to question 3]	1. Yes ___ 2. No ___
2	Do you usually cough as much as 4 to 6 times a day, 4 or more days out of the week?	1. Yes ___ 2. No ___
3	Do you usually cough at all on getting up, or first thing in the morning?	1. Yes ___ 2. No ___
4	Do you usually cough at all during the rest of the day or at night?	1. Yes ___ 2. No ___
	IF YES TO ANY OF THE ABOVE (1, 2, 3 OR 4), ANSWER THE FOLLOWING: IF NO TO ALL, CHECK DOES NOT APPLY AND SKIP TO 7.	1. Yes ___ 2. No ___
5	Do she/he usually cough like this on most days for 3 consecutive months or more during the year?	1. Yes ___ 2. No ___ 8. Does not apply __
6	For how many years have you had this cough?	Number of years __ 88. Does not apply __
	PHLEGM	
7	Do she/he usually bring up phlegm from your chest (Count phlegm with the first smoke or on first going out-of-doors. Exclude phlegm from the nose. Count swallowed phlegm) [If no, skip to 9.]	1. Yes ___ 2. No ___
8	Do she/he usually bring up phlegm like this as much as twice a day, 4 or more days out of the week?	1. Yes ___ 2. No ___
9	Do she/he usually bring up phlegm at all on get-ting up or first thing in the morning?	1. Yes ___ 2. No ___
10	Do she/he usually bring up phlegm at all during the rest of the day or at night?	1. Yes ___ 2. No ___
	IF YES TO ANY OF THE ABOVE (7, 8, 9, OR 10), ANSWER THE FOLLOWING: IF NO TO ALL, CHECK DOES NOT APPLY AND SKIP TO 13.	
11	Do she/he bring up phlegm like this on most days for 3 consecutive months or more during the year?	1. Yes ___ 2. No ___ 8. Does not apply __
12	For how many years have you had trouble with phlegm?	Number of years __ 88. Does not apply __
13	Has she/he had periods or episodes of (in- creased*) cough and phelgm lasting for 3 weeks or more each year? *(For individuals who usually have cough and/or phlegm)	1. Yes ___ 2. No ___
	IF YES TO 9A:	
14	For how long have she/he had at least 1 such episode per year?	Number of years __ 88. Does not apply __

	WHEEZING	
15	Does she/he chest ever sound wheezy or whistling 1. When you have a cold? 2. Occaisonally apart from colds? 3. Most days or nights?	1. Yes ___ 2. No ___ 1. Yes ___ 2. No ___ 1. Yes ___ 2. No ___
	IF YES TO 1, 2, OR 3 IN 15	
16	Has she/he had 2 or more such episodes? For how many years has this been present?	___________________ Number of years 88. Does not apply __
17	Has she/he ever had an ATTACK of wheezing or whistling that has made you feel short of breath?	1. Yes ___ 2. No ___
	IF YES TO 11A:	
18	How old was she/he when you had your first such attack?	_______ Age in years 88. Does not apply __
19	Has she/he had 2 or more such episodes?	1. Yes ___ 2. No ___ 8. Does not apply __
20	Has she/he ever required medicine or treatment for the(se) attack(s)?	1. Yes ___ 2. No ___ 8. Does not apply __
	ALLERGY	
21	Had a doctor ever said that this child had an allergic reaction to food or medicine?	Food___ Medicine___ Both___ NO___
22	Has a doctor ever said that this child had an allergic reaction to pollen or dust?	1. Yes ___ 2. No ___
23	Has a doctor ever said that this child had an allergic skin reaction to detergents or other chemicals(do not include poison oak or poison ivy)	1. Yes ___ 2. No ___
24	Did this child ever receive allergy shots	1. Yes ___ 2. No ___
	Additional Questions	
25	Have she/he ever told your doctor asthma?	1. Yes ___ 2. No ___
26	At that time she/he chest ever sound wheezy or whistling that has made you feel short of breath?	1. Yes ___ 2. No ___
27	Have she/he ever had an asthma attack or in the past two years, or did you get treatment?	1. Yes ___ 2. No ___
28	Do you have a cat, dog, or dog, or bird living in your home?	No, cat, dog, bird