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Indoor air quality in urban residential: Current status, regulation and future research for Indonesia

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ABSTRACT

Modern society spends more time indoors, which has led to the hypothesis that indoor exposure can better represent the effects of air pollution at the individual level. Studies on the landscape of urban residential indoor air quality have never been carried out nationally in Indonesia. After 70 years of commitment to standardize the health aspects of the home in Indonesia, this study intends to make a chronological reflection on the Indonesian government's policy in residential indoor air quality. This study raised and analyzed several questions in the national and local context from the previous research. The government's various policies and regulations are chronologically listed to see the development and look for regulatory or implementation gaps. The indicators of insufficient ventilation and indoor air quality in much Indonesian urban housing have been shown in previous studies, encouraging this study to be necessary. This study used a chronological review using national and international journals. Previous studies have shown possibilities to estimate the landscape of indoor pollution exposure effectively using a socio-economic approach as a part. The latest national housing survey results can be used as references to discover the housing landscape status in Indonesia for further research suggestions.

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1. INTRODUCTION

People in modern societies spend 80%-90% of their time doing activities indoors [1]. The ratio of indoor air pollution is up to two to five times that of outdoor air, and in some cases, it can be up to 100 times [2]. This fact raises the hypothesis that indoor exposure studies can better represent the effects of air pollution at the individual level [3].

The influence of policy on development shows that houses with high airtightness standards can trap indoor air pollutants. However, it is beneficial to save energy [2], [4]. Permission for the development of synthetic materials also affects the health of residents [2], [4]. Studies in Europe indicate housing with higher built quality as an effective way to correct environmental exposure across Europe [5]. Regulation and social inequality become health inequalities through the quality of housing conditions, as leveraging factors for indoor air pollution exposure [6]. Policies on the built environment can cause undesirable things, which can have consequences on the health of residents due to the dichotomy in the process of policy creation between indoor air quality and another aspect, such as cost of energy [7]–[12].

Research in Jakarta, Indonesia, shows that the average ambient air quality in primary school area in West Jakarta is above the quality standard, reaching 83.1 µg/m3 [13]. The results of monitoring of five city air quality monitoring stations (SPKU) show that the annual concentration of $PM_{2.5}$ DKI Jakarta exceeds the quality standard, and there are 51% "unhealthy" days in 2018 and 48% in 2019 [14]. Research in housing around Jakarta, in Bekasi, Indonesia, shows that the average concentration of $PM_{2.5}$ in residential houses is already two times the quality standard, 70 µg/m3. The study indicates that improper home ventilation is twice as likely to develop symptoms of acute respiratory infection (ARI) in children under five, including pneumonia, which can lead to death [7]. Other studies on apartments and residents in Surabaya show that the Formaldehyde and total volatile organic compounds (TVOC) content in many units have exceeded quality standards and pose a health risk. Another conclusion shows that high humidity and hot air temperature allow fungi to thrive in 40% of companies [8], [9]. Several studies which have been conducted in the last few years have prompted this research to conduct a study of the current status of residential indoor air quality (IAQ) in Indonesia. Several studies showed improvements due to the development of research-based regulations [10], [11], [15], also encourage this article to study the chronological regulation policy of residential IAQ in Indonesia.

2. RESEARCH METHOD

This research used a snowball and chronological literature review of 30 articles from national and international previous studies, mainly focusing on the last ten years, covered in Scopus, and significant international studies with a sizable sample. This study gathered the national current status data from the latest national housing survey and the chronological government policy in the last 20 years. This article compared the government regulations and standards regarding indoor air quality from time to time.

This study reviews the data in the latest national housing survey results to understand and raise a question and suggestion for future research suggestion based on the current status. Since the condition of the latest national housing survey was related to economic status, affordability, ownership, self-assisted behavior; a large sample of residential IAQ studies with socio-economic status (SES) as a part was taken from the national and international journal and used as references to suggest the future research focus in Indonesia [16]–[22].

3. RESULTS AND DISCUSSION

In general, the data shows the aspect of air circulation or the physical condition of the dwelling, the construction behavior, and ownership status. In general, the air circulation of shared space in the residential is still mostly not following the Health Ministry of Indonesia's standards. National housing survey data also shows that the existence of socio-economic conditions related to houses in the form of strong ownership status is an indicator of difficulties to buy a house from the market stock. This situation leads to self-built house behavior, which most likely means that the owner does not hire the professional services of a contractor or architect.

3.1. Current IAQ in residential status

A healthy home must have an adequate air ventilation system so that air circulation becomes smooth and the air becomes fresh [19]. Adequate air circulation is essential in maintaining air quality in the house [3], [11], [12]. Good air quality is the continuous flow or change of air through the rooms in a house to make the occupants healthy. Figure 1 indicates that the condition of housing nationally shows that most households have a place with a bedroom with sufficient air circulation of 90.62%, followed by space with enough other circulation starting from the highest to the lowest, namely a mixed room of 70.77%, a living room of 57.41%, the family room 33.34%, and the dining room 22.49%. This shows that there are still many rooms in the house that do not have sufficient air circulation. This is indicated by the low percentage of adequate air circulation from the dining room and family, which is still below 40%.

The survey data for residential natural light conditions in Indonesia are similar to air circulation. This survey uses Ministerial Health Decree in 1999 concerning Housing Health Requirements. This natural light from sunlight can also clean and warm the room so that the room is not damp and can minimize the emergence of germs [23]. Figure 2 shows that almost all households own a house with adequate light bedroom and it is 86.94%, followed by space with sufficient light others ranging from the highest to the lowest, namely the mixed space of 67.57%, living room by 55.28%, family room by 31.63%, and dining room by 21.44%. This shows that many rooms in the house do not yet have adequate lightings, such as the dining room and family room. This is demonstrated by the low proportion of sufficient light from the dining room and family, which is still below 35%.

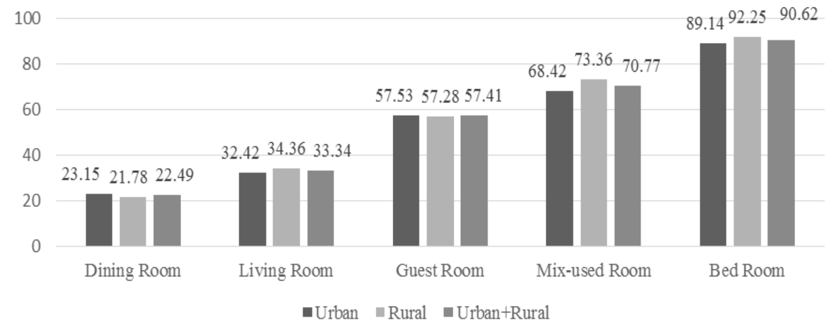

Figure 1. Percentage of sufficient air circulation by type of room in the residential, 2016 [19]

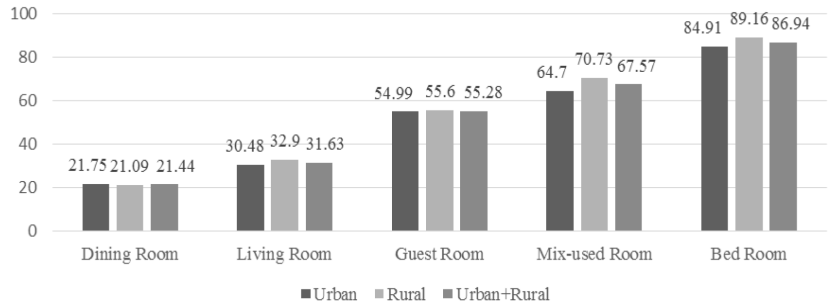

Figure 2. Percentage of sufficient sunlight by type of room in the residential, 2016 [19]

The urban and rural aggregations show moderately lit homes in rural areas tend to have a slightly higher percentage than urban areas such as bedrooms (89.16% versus 84.91%), mixed rooms (70.73% versus 64.70%), living rooms (55.60% versus 54.99%), and family rooms (32.90% versus 30.48%). A different pattern occurs in the dining room (21.75% is compared to 21.09%) that there is lighter in urban homes with the percentage is higher than in rural areas.

Proof of property ownership, such as self-ownership freehold title certificates, tend to be lower than in urban and rural areas, namely 60.82% compared to 39.18%. It is shown in Figure 3. This shows several indicators, namely, the public awareness of secure tenure in rural areas is lower than in urban areas or an indication of the high cost of legalization due to high property prices.

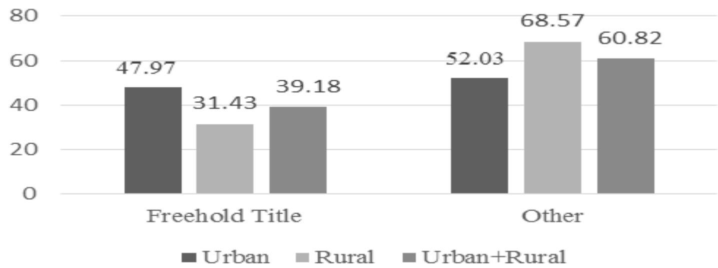

Figure 3. Percentage of self owned freehold title and other legal proof of the residential, 2016 [19]

To find out the level of housing demand, a national survey is conducted on the main reasons households occupy the house, not their own. Based on the main reason that families occupy a home that is not their own, starting from the highest to the lowest percentage is around 63.73% of households occupy the reason because they do not have their own house, 16.98% of households are close to their workplace stairs because they are close to the family, 9.62% of homes for other reasons, and 1.14% of households said that the transportation facilities are better as shown in Figure 4.

The reason for being close to the workplace, better transportation facilities, and other causes is that the percentage is higher in urban areas than in rural areas as shown in Figure 4. This shows that households who live in urban areas tend to live at home instead of owning property to get it more accessible in activities. Meanwhile, not having their own house and being close to family was higher in rural areas than in urban areas. This shows that households who live in rural areas tend to live in homes that do not belong to them for family reasons.

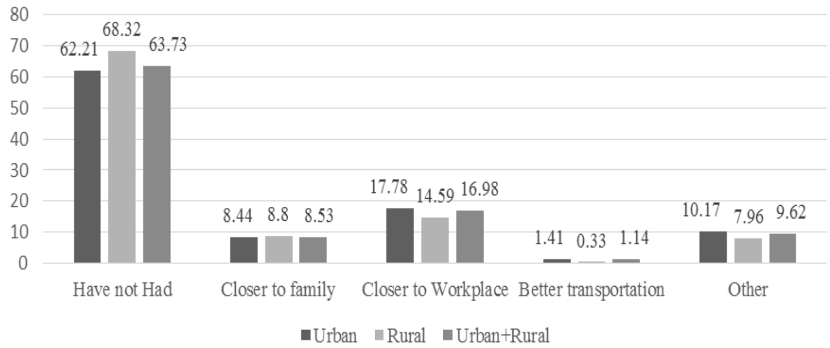

Figure 4. Percentage of households with non-owned residential buildings according to the reasons for living in the house and type of area, 2016 [19]

Based on the data above, there are indications of the issue of economic constraints in house ownership, which in relation to air quality in previous studies might be, have an effect. Figure 5 also shows how the house construction pattern that dominates nationally is to build one's own house, which is also likely to affect the air quality of the house.

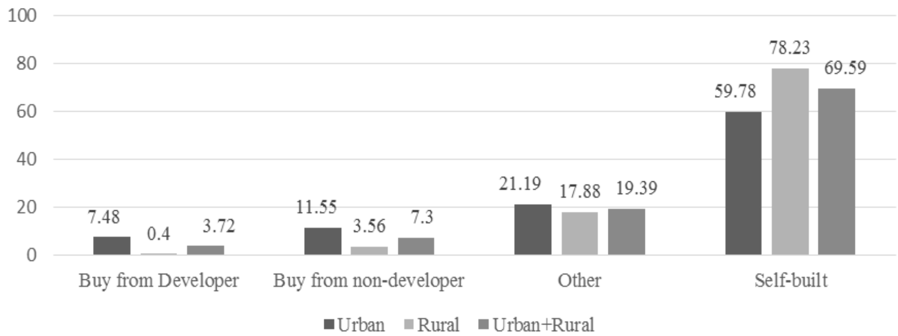

Figure 5. Percentage of households with owned residential buildings according to how to obtain, 2016 [19]

3.2. IAQ in residential regulation

Table 1 (see in Appendix) shows that all the stakeholder of housing in Indonesia has their concern about IAQ in residential since 1950, which coincided with the National Congress of Healthy Public Housing. After that year, there was another Congress of Healthy Public Housing but the standard, guideline, and manifesto cannot be found. Almost 50 years after the congress, The Government of Indonesia, through its Health Ministry set the standard to start to regulate residential indoor air quality IAQ as shown in Table 1 (see in Appendix).

After the stagnation of the policy for the last 20 years, there has been an increase in regulations and policies. Progress has also occurred in the previous ten years in which there are procedures for monitoring air quality in residential spaces. However, no studies show the effectiveness and implementation of policies whose research is rarely heard by urban residents compared to ambient air quality in cities. 2011 compared to the 2009 regulations, there have been significant changes such as lower humidity standards and PM_{10}. New standards have also emerged, such as special ventilation for kitchen spaces, $PM_{2.5}$, and suggestions for smoking outside the home. However, Hildebrandt in 2019 still said exposure to tobacco smoke in residential areas in the city of Surabaya had worsened air quality in residential spaces, which shows that after almost ten years, the policy has not been able to show changes in society [18].

3.3. Current IAQ urban residential status studies in Indonesia

Table 2 shows that the most recent studies on indoor air quality in housing in Indonesia on a reasonably large scale are dominated by studies on apartment buildings. Several studies in collaboration with foreign parties have been able to produce studies with a sample size of more than 100. This shows the high cost of conducting indoor air quality studies so that in this case government intervention is needed to support the creation of reliable indoor air quality research.

These recent studies indicate a research focus on tall buildings. Some of researchs shows an effort to get a landscape picture of indoor air quality in two types of housing and environment [25], [26]. Archetype structures can help analyze and predict future exposure to pollution in social housing type [8] residences area that have high population density [25], and residences with young children [26] . However, there is still a gap of information of the building with IAQ monitoring equipment. Other aspects besides the building archetype are still needed to complete the simulation parameters information about social, economic, and cultural behavior, or more specifically, the air-related behaviour of the occupants. The national housing and settlement census indicated a problem with socio-economic and occupant behavior. Therefore an idea about an initial road map to predict air quality in urban residential spaces of Indonesia is proposed in this article.

Table 2. Current IAQ urban residential studies in Indonesia

Source	Location	Result
Frimawaty *et al.*[17]	Jakarta (n= 721)	31 out of 721 children under five had pneumonia. Two variables were associated with pneumonia: low maternal education and <10% living room ventilation. Poor air circulation leads to the transmission of pneumonia.
Kubota *et al.*[20]	Apartment and Landed House Jakarta and Surabaya (n= 707 and 125 rooms)	IAQ measurement and interview in 2017-2018 shows 40–50% respondents in the new apartments showed some Multi chemical sensitivity (MCS) risk. Formaldehyde and TVOC level was critical. Higher MCS risk occupants were exposed to the increase of TVOC concentrations in the unit. The most influential factors consecutively are: stress level, gender (females), occupation, window-opening behaviour, cleaning frequency, allergic diseases and air conditioning equipment.
Nurwidyaningrum *et al.* [21]	Apartment Jakarta (n= 45)	Occupant and building managers' involvement play a role to build a healthy lifestyle in the apartment. Furthermore, it can affect the IAQ in the middle-income housing unit. Community engagement program policy in a middle-income housing development regulation needs support from the local government to be implemented. The program plans to cover three aspects -administrative, technical, and ecological- requirements for health sustainability.
Hildebrandt *et al.* [18]	Apartment and Urban Landed Kampong Houses Surabaya (n= 471 and 106 rooms)	The share of occupant with a very suggestive of MCS risk in apartments was twice as in Kampongs (17.6% vs. 6.7%). This study found for both types, that health problem, negative smell or perception of IAQ, and higher level of stress positively correlate with higher degree of MCS. Formaldehyde and TVOC were highly concentrated in the measurement of Apartment IAQ. Prediction of severe fungal problems occurred in Kampongs residential.
Nurwidyaningrum *et al.*[22]	Apartment Jakarta (n= 42)	Structural equation modelling (SEM) analysis, showed that occupants dimension structure was built by the physical and psychological comfort, as well as interact with the healthy life participation and pollution activities. Those factors combination would encourage the change of behaviour relate to IAQ in high rise building. Knowledge about IAQ could increase the occupants dimension impact to IAQ.
Murtyas *et al.* [27]	Banten, Jakarta, West Jawa, Central Jawa, Yogyakarta, and East Java (n= 443)	The results showed economic conditions have significant correlations with health problems. Around 82.5% of respondents that living in rural area felt satisfied with their IAQ. Meanwhile, only 73.7% of respondents that living in the urban kampung area felt satisfied with their IAQ. 58%, 66%, and 41% of respondents that living in urban, rural, urban kampung areas have the opinion that dust is the main air pollution in their area.

3.4. Previous study with socio-economic status (SES) relation to indoor air quality in urban residential

Table 3 shows that the SES relation to IAQ could promote better understanding and bridging the gap between several fields of IAQ related studies. Technical aspect -ventilation, material, and airflow- which are commonly discussed or simulated by the engineer researcher, can have a network of knowledge with the health and behaviour of residents with the socio-economic status as the dependent variable. This table shows the usage of the national survey -housing, health and socio-demographic- in the previous studies. Time series of meteorological and land use data also significantly support the previous IAQ studies for urban residential.

Table 3. Previous study with SES relation to IAQ in urban residential

Source	Location	Method	Findings
Ferguson *et al*.[3]	Cities in US and Europe	Literature review with scoping review. Number of articles: 38, from 1280 identified articles	Education and environmental tobacco smoke (ETS) has a different pattern in each community. Cultural behaviour plays a significant part. There is greater concern about children awareness of ETS exposure nowadays.
Shrubsole *et al*.[11]	UK, Europe, and others	Systematic Literature Review, with PRISMA Methodology for VOC monitoring studies. Number of articles: 71 from 7958 identified articles	Specific volatile organic compounds (VOCs) is better to analyse rather than TVOC for IAQ studies. Controlling the source of VOCs emission is the most crucial strategy, besides still promote low emission labelling and on-site mitigation. Mitigation for good IAQ must include all pollutants encountered from both indoor and outdoor to find the optimal strategies. The older building has a lower VOC concentration, and there is still a gap and needs for further studies concerning SES.
Rosofsky *et al*.[9]	Massachusetts, US	Census data analysis of 3 public datasets (housing, demographic, and meteorological to analyse the air exchange rate equation)	The higher income has a more significant part of the lowest $PM_{2.5}$ exposure than the middle income (23% compared to 7%). Education of the head of house also playing a similar pattern with the household income.
Samoli *et al*.[25]	Lisbon, Barcelona, Paris, Turin, Brussels, Berlin, London, and Athens	Analysis data public from Euro Healthy project, within nine metropolitans in Europe.	Unemployment rate and population density were significant predictors of NO2 exposure.
Stamatelopoulou *et al*.[26]	Athens, Greece	Home measurement and questionnaire (n=13)	No relationship between PM_{10}, $PM_{2.5}$, VOCs and SES (with maternal occupational status as a proxy of household SES)
Kendall *et al*.[28]	UK	Home measurement (n= 3,189 and 11,000 children), part of Nationwide cancer study	A Higher SES home relates to higher radon concentration.
Pinault *et al.* [29]	Toronto, Montreal, and Vancouver, Canada	Canadian census long-form for SES, NO2 exposure from land-use regression (LUR) models. (N>10000 for each city)	The lowest income quintile exposed to higher NO2 concentration.
Yao et al. [30]	US	Self-reported home exposure, study questionnaire (n=2,891)	Exposure to ETS associated with lower SES
Brown *et al*.[10]	France	Home measurement and questionnaire (n= 567)	Higher SES and lower density occupant experienced lower $PM_{2.5}$ concentration.
Raisamo *et al*.[31]	Finland	Self-reported home exposure by adolescent (n= 72726)	Low SES group reduction to ETS exposure among children is the smallest. ETS significance association for only specific cohort age (16-18 years old)
Shrubsole *et al*.[32]	UK	The study used a literature review with a holistic framework of health and well-being.	A policy can lead to unintended consequences for occupant health—the complexity of increased dwelling airtightness policy impact. Housing shortage which leads to overcrowding, will have long-term socio-economic well-being and status.

Table 4 describes that in the developed country, the researcher could study the data of SES, air pollutant, occupant activity, and building type further to predict the future landscape of IAQ in urban residential within a country. This simulation needs comprehensive, accessible, and integrated data that has the same vision of usage. The national survey of housing, health, socio-demographic, occupant activity pattern and cultural behaviour studies will be necessary for future IAQ research in Indonesia.

Table 4. Previous study with modelling to predict the IAQ landscape in urban residential

Source	Location	Method	Findings
Dimitroulopoulou *et al.*[33]	Leicester, UK	This study used probabilistic population exposure with the micro-environment model with a time-activity-location profile.	A novel modelling framework could show different result from each policy intervention alternative. It could be helpful to simulate the policy impact before implementation.
Shrubsole *et al.*[8]	UK and Wales	Building simulation software between $PM_{2.5}$, education, and income, with housing survey data (n= 16,000)	Higher SES experienced lower indoor $PM_{2.5}$ concentration
Hamilton *et al.*[34]	UK	Health impact modelling study using building physics model and health model of the occupant.	The modelling study estimates three scenarios of Quality-Adjusted Life Years (QALYs). It could evaluate the impact of each policy scenario.
Taylor *et al.*[35]	Greater London	Building simulation software using EnergyPlus 8, with two occupant scenario and GIS analysis.	Flats in Central London experienced lower $PM_{2.5}$ concentration compare to a semi-detached and detached house. Exposure for an individual in indoor understands better with simulation than outdoor exposure prediction.
Aerts *et al.* [36]	Belgium	Probabilistic activity model	Occupant pattern behaviour is needed to obtain accurate simulation. The modelling of individual sequences enables the inclusion of highly realistic behaviour in building simulations.
Milner *et al.* [37]		Statistical regression, Microenvironmental model, and computational fluid dynamic (CFD)	More detailed data about occupant behaviour, pollutant source, and moving head will improve the CFD model. The large-scale study will need more detail and time-series data related to the indoor and outdoor air, occupant behaviour, SES, culture, building, and climate.

4. CONCLUSION

Based on the description of the condition of national housing, it has been illustrated the inadequacy of air circulation in housing in Indonesia nationally. The government has made various regulations that are mandatory, but there are still gaps in implementation in the field. Based on the survey data from the national housing, it showed that there were economic issues of the occupant in the reasons for choosing and building their house. The socio-economic status (SES) also described in the survey had a possible relation to the culture of building houses which led to inadequate indoor air quality. This is in line with research in developing countries which shows the relationship between SES and indoor air quality.

From the previous studies in Indonesia, physical condition and human factor determined the IAQ, however, there was still a gap in term of social and economical aspect of occupant. Responding to the reason, the government needed to focus on research of SES relation to IAQ. Previous studies with sizable samples were supported by brands or products with international markets which show this need a lot of financial support. Assessment of IAQ in each SES would help the government of Indonesia to be more familiar with the national landscape of IAQ in residential with lower cost housing. Knowledge of the residential IAQ of every SES will make the government can iterate the result of IAQ studies of each typology of SES to obtain a larger prediction of residential IAQ nationally and the individual national exposure.

In the studies of developed countries, one critical point is building a good base of time series data related to IAQ. The government could support this situation by improving the national survey -housing, health and socio-demographic. Time series data of meteorological, land use and occupant behaviour within the built environment will be valuable. Researchers will access, study, and simulate many models to improve and evaluate policy with IAQ before implementation. This type of research will avoid the creation of policies that could have a negative impact. From the knowledge development together with policy simulation, in the long term, could result in the improvement of the health status of the Indonesian people, reduce the concept of development that damages health, and support human resources development, which could extend the life expectancy and vitality of the older generation the future.

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APPENDIX

Table 1. Policies in Indonesia related to IAQ in residential

Year	Institution	Title and Content	Mandatory/Voluntary/NA
1950	National Congress of Healthy Public Housing [24]	Consensus: residential air ventilation by 10% of the room area	NA
1999	Health Ministry of Indonesia	Regulation No.829/Menkes/SK/VII/1999 Title: Housing Health Regulation Temperature: 18-30 ºC Humidity: 40-70% $PM_{2.5}$: - PM_{10}: 150µg/m^3 Smoking behaviour:- Ventilation area: 10% of total area Kitchen ventilation:- Bedroom density: 4m2/person	Mandatory
2001	Indonesia National Standard (SNI)	Indonesian Standard SNI 03-6572-2001 Fresh Air Standard for residential: With Smoking and Non-smoking room	Mandatory
2004	Indonesia National Standard (SNI)	Indonesian standard SNI 03-1733-2004 Title: Housing environment planning procedures in urban areas Health criteria are achieved by considering the location is not an area that has air pollution above the threshold.	Mandatory

Year	Institution	Title and Content	Mandatory/Voluntary/NA
		The roof cavity space for a residence must have adequate ventilation and natural lighting. In a residential building there is no side clearance, while the rear clearance is determined at least half of the size of the building front demarcation line. Requirement of floor area for adults: 9.6 m2 / person, and air for adults 16-24m3. Child floor area requirements: 4.8m2, with 8-12m3 of air	
2005	Government of Indonesia	Regulation No. 36/2005 Title: Building Determination of building coverage ratio to meet air quality requirements. The certificate of eligibility is valid for 20 (twenty) years for residential houses Single residence and a row residence built by the developer, a certificate of eligibility must be administered by the developer in order to guarantee the proper functioning of the building to the owner and / or user. For a simple single residence or a simple row house, there is no need to extend the certificate of eligibility. What is meant by simple single residence or simple row house in this provision is a non-terraced house with a maximum total floor area of 36 m² and a maximum total land area of 72 m².	Mandatory
2006	Public Works Ministry of Indonesia	Regulation No: 29/PRT/M/2006 Title: Guidelines for Building Technical Requirements Ensuring the fulfilment of adequate air needs, both natural and artificial, to support activities in buildings according to their functions Ensuring the proper operation of air conditioning equipment and equipment; For thermal comfort inside the building, the temperature and humidity must be considered To get the level of temperature and humidity in the room can be done with an air conditioning device Thermal comfort requirements. The roof cavity space for a residence must have adequate ventilation and natural lighting	Mandatory
2011	Health Ministry of Indonesia	Regulation No. 1077/MENKES/PER/V/2011 Title: Housing Health Regulation Temperature: 18-30 ºC Humidity: 40-70% $PM_{2.5}$: 35μg/m^3 PM_{10}: $\leq$70μg/m^3 Smoking behavior: it is advised to not in the house Ventilation area: 10% of total area Kitchen ventilation 40% or with mechanical equipment Bedroom density: -	Mandatory