Factors Affecting Indoor Air against the Transmission Risk of Coronavirus Disease 2019: Systematic Review and Policy Analysis

Mustika Marwah¹, Bambang Wispriyono², Dewi Susanna³, Aria Kusuma³

¹Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Jakarta, Indonesia; ²Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, Indonesia; ³Health Policy Agency, Ministry of Health, Republic of Indonesia, Jakarta, Indonesia

Abstract

**BACKGROUND:** Coronavirus disease 2019 (COVID-19) is thought to be transmitted primarily through droplets and contaminated surfaces through aerosols. Therefore, this study aims to identify the risk of COVID-19 agents in aerosol form and how indoor air control technique plays a role in the risk of disease transmission. It also examines the existing policies as administrative controls in managing the risk of COVID-19 transmission through indoor air control techniques.

**AIM:** This is a systematic review and policy study carried out in line with the preferred reporting item for systematic review and meta-analysis guidelines using ProQuest, PubMed, ScienceDirect, and Scopus databases. Furthermore, the search strategy was carried out using keywords with the Boolean AND and OR operations, namely, “COVID-19 AND (Transmission OR Spread) AND (aerosol OR airborne OR microdroplet) AND (Indoor OR Indoor Air OR Ventilation).”

**METHODS:** The search strategy was carried out using keywords with the Boolean AND and OR operations, namely, “COVID-19 AND (Transmission OR Spread) AND (aerosol OR airborne OR microdroplet) AND (Indoor OR Indoor Air OR Ventilation).”

**RESULTS:** In the policy review, the analysis unit was obtained from the official websites of the Indonesian Government and World Health Organization in the form of regulations, recommendations, guidelines, or other protocols that regulate indoor activities during the pandemic. There is a risk of COVID-19 agents from aerosols in indoor air. Meanwhile, the control of indoor air techniques plays a role in reducing the risk of transmission through aerosols by (1) increasing the exchange of indoor with outdoor air, (2) using air purifiers, and (3) paying attention to the layout of ventilation devices, airflow direction and distribution, as well as the flow of clean and dirty air in a room.

**CONCLUSION:** Based on the results, the existing policies are still minimal in preventing transmission risk through indoor aerosols; hence, policy development is needed.

Introduction

In December 2019, a new disease caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) virus was confirmed in Wuhan, China. It was named Novel Coronavirus Disease 2019 (COVID-19) and causes severe acute respiratory syndrome. Furthermore, the World Health Organization (WHO) [1] declared COVID-19 outbreak a global pandemic on March 11, 2020. The number of cases reached 445.6 million on March 6, 2022, with a death toll of 6 million worldwide, while cases in Indonesia reached 5.7 million with 150,172 deaths [2].

Given the pandemic conditions, the public health system and service facilities faced enormous challenges in the management of these non-natural disasters. The public health system plays a role in responding to non-natural disasters, implementing comprehensive and non-comprehensive planning, as well as coordinating pandemic management and policy making [3]. Meanwhile, health-care facilities are at the forefront of conducting disease tests, tracing close contacts, and treating COVID-19 patients. However, the unprecedented pandemic conditions in the modern era have created a real gap in the preparedness of public health systems and health-care facilities [4]. Besides, the pandemic condition also has the risk of causing social and economic problems. This resultantly affects economic activities, thereby triggering an increase in inequality and poverty globally [5].

To prevent the spread of COVID-19 and to keep the economy moving, the Indonesian Government implemented partial social restrictions [6], [7]. In practice, the public is allowed to carry out shopping, visit offices, and recreational activities while still complying with the health protocols. However, despite the adherence to the health protocols, the number of new cases from July 2020 to January 2021 continues to increase [8].

SARS-CoV-2 was thought to be transmitted primarily through droplets and close contact with infected individuals. However, the mode was not the absolute transmission mechanism [9]. This is supported by various studies which reported that SARS-CoV-2 is transmitted through aerosols, namely, microdroplets measuring ≤5 µm and survives in the air for several hours [10]. Transmission through aerosols is also at risk of being the most dominant route [11].
According to the WHO [12], COVID-19 has a higher risk in closed, confined, and poorly ventilated environments. Furthermore, Nishiura et al. [13] stated that the transmission of COVID-19 has higher risk in a closed environment than in the open. Therefore, there is a need to review the factors that affect indoor air as a risk factor for transmission media. This study aims to examine the factors that influence indoor air for transmission risk by examining control techniques through systematic studies and administrative controls related to indoor activities during the pandemic through policy studies. The policies studied in this study are policies that aim to control COVID-19 by regulating air circulation in the room and can be accessed online.

Methods

**Identification of analysis units**

This study used a qualitative approach with two methods, namely, systematic and policy studies. A systematic review was conducted to assess the risk of COVID-19 transmission through aerosol and indoor air control techniques. Meanwhile, the policy review was conducted to examine the administrative control of indoor activities during the pandemic. The systematic review used the stream preferred reporting item for systematic review and meta-analysis (PRISMA) [14], [15], [16] while the policy review was carried out using a literature review approach [14], [15].

All analysis units were obtained through an online search, for the systematic study, the sources include ProQuest, PubMed, ScienceDirect, and Scopus databases. The search strategy was carried out using keywords Boolean AND and OR operations, namely, “COVID-19 AND (Transmission OR Spread) AND (aerosol OR airborne OR microdroplet) AND (Indoor OR Indoor Air OR Ventilation)” by utilizing advanced search features on each database. Meanwhile, the literature type selected was only non-reviewed research articles published between November 2020 and April 2021. In the policy studies, the analysis units were obtained from the official websites of the Indonesian Government and WHO in the form of regulations, recommendations, guidelines, and other protocols governing indoor activities during the pandemic. In addition, several COVID-19 control guidelines that regulate indoor air circulation in Singapore, England, the State of North California, and Daerah Khusus Ibukota (DKI) Jakarta Province also reviewed in this study.

**Data analysis**

The data analysis process consists of a general description, as well as identification of literature and policies, and a synthesis process where the results of literary works are summarized. Furthermore, the synthesis process was carried out in several stages. The first stage involves the search for similarities (compare) and differences (contrast); meanwhile, the next process is to criticize the gaps in the literature that were collected and linked to the theory described in the literature review (criticize) to make conclusions (summarize). These studies were only analyzed to make a synthesis and conclusion.

**Results**

**Systematic study**

The analysis units of the systematic study include 12 kinds of literatures from various countries. Meanwhile, the study design used consisted of modeling, experimentation, and epidemiological investigations. However, one study used only two methods, namely,
experimental and epidemiological investigations. In total, 26 variables were found. The number of each literature and description of the characteristics are listed in Table 2.
Although all units selected in the systematic review were assessed according to the PICO approach, not all analysis units directly account for the potential presence of aerosolized COVID-19 agents which were described in three literatures. Furthermore, the role of indoor air control technique as an intervention against the risk of COVID-19 transmission in the analysis unit was carried out through several variables, namely, the ventilation, airflow rate, direction and distribution, temperature, as well as relative humidity.

The risk of aerosolized SARS-CoV-2 transmission was described in each literature, as the control technique influences indoor air. Airflow direction and distribution play a role in the spread of indoor aerosolized SARS-CoV-2 [17, 18, 19, 20, 21, 22, 23, 24]. Furthermore, ventilation rates play a role in changing indoor with outdoor air, thereby reducing aerosol agents [18, 19, 25]. Temperature affects the movement of air particles [18, 19, 23], while relative humidity affects the survival of aerosol in the air [20, 26]. In addition, ventilation type, rate, and temperature affect the airflow direction and distribution [17, 18, 19, 20, 21, 22, 23, 24].

Policy study

The analysis units in the policy review include three Decrees of the Indonesian Ministry of Health, as well as three policies from the WHO in the form of one policy brief, one recommendation, and one guideline. In addition, one guideline each from CDC, British Columbia Center for Disease Control, United Kingdom, the State of North California, and two guidelines from Singapore and four regulations from DKI Jakarta province were reviewed in this study. The overview of the selected policies is presented in Table 1. Based on the analysis units, it was found that the health protocol for indoor activities during the pandemic provides directions for preventing COVID-19 transmission for individuals and environmental settings. In general, the health protocols obtained have similarities for individuals and the environment.

Indonesian Government and WHO policies have promoted six points to prevent COVID-19 transmission for individuals and in the communities as well as: (1) Hand hygiene with soap or hand Cuci Tangan Pakai Sabun and/or using hand sanitizers, (2) wearing mask, (3) implementing cough etiquette, and (4) keeping social distance. Preventive actions based on the environmental arrangement include (1) providing hand hygiene facility, (2) regularly disinfecting facilities, (3) setting physical distancing, (4) forming a COVID-19 transmission prevention team, (5) recommending online activities, and (6) regulating and monitoring indoor air. However, the health protocols made by the Indonesian government have not regulated the exchange of indoor with outdoor air, the position of clean and dirty air areas, and air recirculation [27, 28, 29, 30, 31, 32].
Table 2: Characteristics overview of a systematic study

<table>
<thead>
<tr>
<th>Author</th>
<th>Research title</th>
<th>Publication year</th>
<th>Research location</th>
<th>Study design</th>
<th>Variables</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anas and Heras</td>
<td>The mechanical-effect of moisturization on airborne COVID-19 transmission and its potential use as control technique</td>
<td>2021</td>
<td>Spain</td>
<td>Modeling</td>
<td>Relative humidity</td>
<td>This study considers the absorption time of the COVID-19 agent aerosol with a function of temperature, relative humidity, and water vapor size. It was found that the higher the temperature and relative humidity of the room, the lower the risk of COVID-19 aerosol agents' presence</td>
</tr>
<tr>
<td>Blocken et al.</td>
<td>Ventilation and air cleaning to limit aerosol particle concentration in a gym during the COVID-19 pandemic</td>
<td>2021</td>
<td>Netherlands</td>
<td>Experimental</td>
<td>COVID-19 agent aerosol, ventilation type, ventilation rate</td>
<td>The application of mechanical ventilation with a room cleaning support each other to reduce the risk of COVID-19 agents' presence but cannot replace each other's functions</td>
</tr>
<tr>
<td>Hussein et al.</td>
<td>Indoor model simulation for COVID-19 transport and exposure</td>
<td>2021</td>
<td>-</td>
<td>Modeling</td>
<td>COVID-19 agent aerosol, ventilation rate</td>
<td>The risk of exposure to aerosolized COVID-19 agents for occupants of rooms with low ventilation rates is higher than others with well-ventilated rates</td>
</tr>
<tr>
<td>Kwon et al.</td>
<td>Evidence of long-distance droplet transmission SARS-CoV-2 by direct air flow in a restaurant in Korea</td>
<td>2020</td>
<td>South Korea</td>
<td>Epidemiological investigation</td>
<td>Airflow direction and distribution</td>
<td>Transmission of COVID-19 occurs within a distance of about 2 meters through direct airflow from an infected person</td>
</tr>
<tr>
<td>Li et al.</td>
<td>Effects of ceiling fans on airborne transmission in an air-conditioned space</td>
<td>2021</td>
<td>Singapore</td>
<td>Experimental</td>
<td>Ventilation type, rate, direction, and distribution of airflow, temperature</td>
<td>The movement of particles in the air, including aerosols of COVID-19 agents, is mainly affected by the thermal effects of the indoor environment. The use of mechanical ventilation devices in the form of ceiling fans increases ACH and distributes air particles better in a room thereby reducing the risk of COVID-19 transmission.</td>
</tr>
<tr>
<td>Li et al.</td>
<td>Probable airborne transmission of SARS-CoV-2 in a poorly ventilated restaurant</td>
<td>2021</td>
<td>China</td>
<td>Epidemiological and experimental investigation</td>
<td>Ventilation type and rate of airflow, temperature</td>
<td>COVID-19 outbreak at a restaurant in Guangzhou, China occurred because the room had poor ventilation and was too crowded</td>
</tr>
<tr>
<td>Liu et al.</td>
<td>Simulation-based study of COVID-19 outbreak associated with air-conditioning in a restaurant</td>
<td>2021</td>
<td>United States</td>
<td>Modeling</td>
<td>Airflow direction, distribution, and temperature</td>
<td>The thermal effect affects the movement of air particles in the room and is influenced by the stability of the air hence, mechanical ventilation is needed.</td>
</tr>
<tr>
<td>Nissen et al.</td>
<td>Long-distance airborne dispersion of SARS-CoV-2 in COVID-19 wards</td>
<td>2020</td>
<td>Sweden</td>
<td>Experimental</td>
<td>COVID-19 agent aerosol, airflow direction and distribution, relative humidity</td>
<td>There are aerosols of COVID-19 agents in hospital ventilation systems that manage the transmission at low ventilation rates and relative humidity hence, there is a risk of transmitting disease</td>
</tr>
<tr>
<td>Pease et al.</td>
<td>Investigation of potential aerosol transmission and infectivity of SARS-CoV-2 through central ventilation systems</td>
<td>2021</td>
<td>United States</td>
<td>Modeling</td>
<td>Ventilation rate, direction and distribution of airflow</td>
<td>The use of filters in ventilation devices, alternating indoor with outdoor air, and increasing ACH reduces the risk of COVID-19 transmission</td>
</tr>
<tr>
<td>Tung et al.</td>
<td>Enlightenment of re-entry of the airborne pollutants transmission in buildings</td>
<td>2021</td>
<td>China</td>
<td>Experimental</td>
<td>Airflow direction and distribution</td>
<td>The occurrence of air recirculation occurs due to the low wind speed and the role of the air flow mechanism</td>
</tr>
<tr>
<td>Deng et al.</td>
<td>Control of exhaled SARS-CoV-2-laden Aerosols in the interpersonal breathing microenvironment in a ventilated room with limited space air stability</td>
<td>2021</td>
<td>China</td>
<td>Experimental</td>
<td>Ventilation rate, direction and distribution of airflow, temperature</td>
<td>Room conditions with stable air are riskier than rooms with neutral to unstable air conditions. The recommended use of devices in room conditions with stable air is local ventilation</td>
</tr>
<tr>
<td>Foster and Kinzel</td>
<td>Estimating COVID-19 exposure in a classroom setting; a comparison between mathematical and numerical models</td>
<td>2021</td>
<td>United States</td>
<td>Modeling</td>
<td>Ventilation type, relative humidity</td>
<td>Air in an unventilated room generates a localized and poorly distributed air footprint hence, there is a greater risk of clogging into a mechanically ventilated room</td>
</tr>
</tbody>
</table>

SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2

Discussion

The role of indoor air control techniques against the risk of COVID-19 transmission through aerosols

Based on the results, COVID-19 transmission through aerosols has a high risk of transmission in indoor air because humans naturally produce droplets with micro-sized droplets (0.25–10 μm) [25], [33]. Nissen et al. [20] found ten out of 17 positive samples of SARS-CoV-2 virus protein in hospital ventilation with a height of 49–60 m above the floor surface; hence, it is believed that the virus might be transmitted through microsized droplets. The small size of the SARS-CoV-2 virus and its ability to survive in the air was found to enhance COVID-19 transmission in a restaurant in South Korea with 6.5 m and direct airflow conditions [17]. However, Nissen et al. [20] showed that the SARS-CoV-2 virus found in indoor air was not contagious. These findings indicate the need for further studies on the infectivity of the SARS-CoV-2 virus through aerosols.

Airborn is the medium is where the disease is transmitted; therefore, an action is required to disrupt the airflow to reduce the disease transmission risk. The airflow direction and distribution influence the risk of transmission through aerosols and the distribution of particles in the air [17], [18], [20], [21], [22], [23], [24]. To reduce the transmission risk through aerosols, the direction and distribution of airflow need to be regulated [21] from clean to dirty air [24], avoid dirty air areas [17], [24], and air recirculation [19], [22]. Meanwhile, factors affecting the airflow direction and distribution include ventilation rate [18], [20], [21], [24] and type [18], [24], as well as temperature [18], [19], [23].

Ventilation rate is the degree and the quality or air exchange between indoor and outdoor [45], [46]. Based on the results, an increase in the ventilation...
rates reduces aerosol concentrations of SARS-CoV-2 in indoor air [18], [19], [25], [33]. However, Deng et al. [23] stated that an increase in the ventilation rate has a maximum impact on indoor air that ranging from neutral to unstable. Furthermore, Pease et al. [21] reported that the increase in ventilation rates should be associated with certain building design to avoid aerosols of SARS-CoV-2 spreading to other rooms in a building. Li et al. [18], Liu et al. [19], and Deng et al. [23] explained that the temperature of environmental components in a room affects the dynamics of the particulate's movement in the air, including aerosols of SARS-CoV-2. Furthermore, Li et al. [18] showed that in natural ventilation, the airflow movement is mainly affected by thermal effects. Aside from its effect on the air particles movement, temperature also affects the comfort of the room occupants; hence, temperature regulation is generally incorporated in the mechanical ventilation system. However, based on research, there are no studies that explain the ideal temperature to reduce the risk of transmitting COVID-19 through aerosols. Furthermore, relative humidity affects the ability of aerosolized SARS-CoV-2 to survive in the air [20], [26]. The recommended relative humidity, based on Arias and Heras [26], corresponds with the appropriate comfort level for the room occupants is 30–70%. The higher the relative humidity, the lower the risk of COVID-19 transmission through aerosols.

The ventilation type also influences the direction and distribution of airflow and ventilation rate. Based on the results, the air particles movement is mainly affected by thermal buoyancy. Meanwhile, mechanical ventilation is influenced by the fan used [18], [24], [32], [33], [34], while the use of air purifiers is highly recommended to reduce the risk of COVID-19 transmission through aerosols [19], [21], [33], [34]. However, Blocken et al. [33] stressed that the use of air purifiers is not meant to replace the ventilation role. This shows that air purifiers need to be supported by good ventilation to obtain optimal results in preventing transmission through aerosols.

**Indoor activity policy during the COVID-19 pandemic**

SARS-CoV-2 is initially thought to be mainly transmitted through droplets [47]. Hence, the designed protocols prioritized preventing the spread of droplets, including using masks and/or face shields, maintaining distance, handwashing with soap or using hand sanitizer, and surface disinfectants [48]. As the study progresses and mutations are found in the SARS-CoV-2 virus, it is clear that it survives in the air for several hours and spreads over a certain distance. Meanwhile, the SARS-CoV-2 virus in aerosol form is also thought to have caused various mass transmission events in various places, especially indoors [18], [22], [34]. A study conducted in student dormitories showed that rooms with pure outdoor air and mechanical ventilation system had fewer cases of respiratory tract infection compared to rooms with only air filtration [49].

There are differences in the regulation and monitoring of indoor air between the health protocol for indoor activities issued by the Indonesian government and the one issued by the WHO. In the protocol established in Indonesia, indoor air regulation only requires maintaining air quality by optimizing air circulation and sunlight, as well as cleaning AC filters. In addition, essential workers who continue to work in the office are encouraged to optimize air circulation and sunlight at home, let outdoor air and sunlight enter the house, and clean the workspace used by people under surveillance Orang Dalam Pemantauan, patient under supervision Pasien Dalam Pengawasan positive confirmation of COVID-19 [27], [28]. This approach is not mentioned in the protocol for boarding school. Meanwhile, in the protocol made by the WHO, regulation and monitoring related to air are explained in several points, namely, (1) maximizing natural ventilation, (2) monitoring, inspection, and cleaning the heating, ventilation, and air-conditioning (HVAC) system, (3) increasing the total airflow supply of outdoor air, and regulating the relative temperature and humidity of the available HVAC system, (4) cleaning airflow to dirty air by evaluating the position of the air supply and air outlet as well as ensuring the room occupants are in the clean area, (5) performing a non-active mode on the demand-controlled ventilation setting, (6) ensuring the exhaust fan runs optimally when there are activities in the building, and (7) avoiding air recirculation caused by the ventilation system. When this is not possible, the exchange of indoor with outdoor air is increased using natural ventilation such as doors and windows and minimizes the possibility of air moving directly from one person to another to avoid the spread of droplets and aerosols [30], [31], [32].

CDC also recommends a layered approach to controlling COVID-19 in buildings and households. The approach is carried out with several strategies, including increasing the use of building ventilation to reduce the spread of disease and reduce the level of exposure risk [35]. Ventilation for households is recommended to use fresh air from outside the house as much as possible, use air filters, turn on exhaust fans in bathrooms and kitchens, use fans to increase air flow and limit guests, and the time guests spend in the house [36].

The COVID-19 control guidelines in the UK explain that there are several ways that can be done to ventilate the room and minimize transmission risk by maximizing the open ventilation. The more ventilation, the fresher air comes in for breathing and the lower the chance of inhaling air that contains infectious particles [37].

Singapore’s National Environment Office has also developed guidelines on improving ventilation and air quality in buildings during the COVID-19 pandemic.
This guide presents how to measure air quality in air conditioning and regular ventilation rooms [39]. In addition, the Singapore Government has amended air conditioning and mechanical ventilation regulations concerning the COVID-19 pandemic [40]. The North California State Government also regulates the use of natural and mechanical ventilation as an effort to control COVID-19 in indoor fitness facilities [41].

DKI Jakarta Government has also issued several Governor Regulations and Governor Decrees in controlling COVID-19. Some of them also mention about indoor air such as the minimum standard and room criteria for patient isolation in private and public facilities [44], regulate air circulation in places contaminated with sick workers and confirmed positive COVID-19 [41], [42], as well as optimize the design and function of a workspace with good air circulation and get enough sunlight [43].

Based on the policy analysis, the health protocols for indoor activities during the pandemic developed by the Indonesian Government are still inadequate in regulating and monitoring of indoor air as a medium with a high risk of transmitting COVID-19 through aerosol. Meanwhile, the essential and non-essential sectors are still allowed to carry out activities indoors. Therefore, the Indonesian government needs to develop health protocols, by considering the risk of aerosolized SARS-CoV-2 which survives in the air for a certain distance and time.

**Conclusion**

Based on the systematic review, SARS-CoV-2 is found in the aerosols. Therefore, there is a high risk of indoor transmission. Furthermore, indoor air control technique affects the risk of transmission through aerosol. Proposed efforts to reduce the risk of transmission through aerosols during indoor activities include (1) increasing the rate of indoor air exchange with outdoor, (2) using air purifiers, and (3) paying attention to the layout of ventilation devices, airflow direction and distribution, as well as the flow of clean and dirty air in a room. However, based on the indoor activity policy in Indonesia, transmission through aerosols has not become a major concern because the regulation and monitoring of indoor air are still minimal; therefore, health protocols in Indonesia are still needed.

**Recommendation**

Even though currently there is no more restriction related to COVID-19; however, the likelihood of infectious diseases reemergence in the future, it may still happen, so it is necessary to develop any health’s preventive and promotion actions and guidelines in indoor air such as on ventilation and air circulation in rooms such as homes, gyms, meeting rooms, and residential/office buildings so that people have healthy ventilation during the COVID-19 pandemic.

**Ethics Approval and Consent to Participate**

This study was approved by the Research and Community’s engagement Ethical Committee, Faculty of Public Health, Universitas Indonesia, No. 366/UN2. F10.D11/PPM.00.02/2021.

**Authors’ Contributions**

MM contributed substantially to the concept, work design, data analysis, data interpretation, and manuscript drafting. BW made critical input to the concept and supervising the process of data interpretation. DS made critical revisions of important intellectual content and finalized approval of the version to be published. AS add revision and critical substance in the manuscript.

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