REVIEW ARTICLE

Ventilation in school and students' health after outbreak of COVID-19: A systematic literature review

DOI: 10.29063/ajrh2024/v28i9.46

Anita Dewi Moelyaningrum[1], Soedjajadi Keman[2], Soenarnatalina Melaniani[2] and Corie Indria Prasasti[2]*

Doctoral Degree Program of Public Health, Faculty of Public Health, Universitas Airlangga, Surabaya 60115, Indonesia[1]; Faculty of Public Health, Universitas Airlangga, Surabaya, Indonesia[2]

***For Correspondence:** Email: *Soedja_keman@fkm.unair.ac.id*; Phone: +628121729908

Abstract

Ventilation is one of the factors that support the health of students needed to support the goals of education. The objective of this study is to analyze how ventilation at school impacts the health of students. Scopus and Web of Science were used to retrieve published articles on ventilation at school and students' health. The search method used the keywords "ventilation" OR "Indoor air pollution" OR "Indoor environment quality" AND "School" AND "Student" OR "Children" AND "Health", from 2019- May 2023. The ventilation in schools researched were ventilation methods, insufficient or lack of ventilation, and the frequency of opening windows. The air quality parameters studied in classrooms were Nitrogen Dioxide (NO_2); Particulate matter 10 (PM_{10}); Particulate matter 2,5 ($PM_{2.5}$); Particulate matter (PM_1); Ozone (O_3), benzene (C_6H_6), and carbon dioxide (CO_2). The results showed that the diseases identified in students as a result of poor ventilation were tiredness, bronchitis, symptoms of asthma, risk of infection, rhinitis, etc. We conclude that as ventilation reduces indoor air pollutants, thus related to student health, it should be prioritized to fulfil the requirements for the health of students. *(Afr J Reprod Health 2024; 28 [10s]: 449-459).*

Keywords: Ventilation, School health, Students, health, COVID-19 outbreak

Résumé

La ventilation est l'un des facteurs qui soutiennent la santé des élèves et sont nécessaires pour soutenir les objectifs de l'éducation. L'objectif de cette étude est d'analyser l'impact de la ventilation à l'école sur la santé des élèves. Scopus et Web of Science ont été utilisés pour récupérer des articles publiés sur la ventilation à l'école et la santé des élèves. La méthode de recherche a utilisé les mots-clés « ventilation » OU « Pollution de l'air intérieur » OU « Qualité de l'environnement intérieur » ET « École » ET « Étudiant » OU « Enfants » ET « Santé », de 2019 à mai 2023. La ventilation dans les écoles étudiées était les méthodes de ventilation, l'insuffisance ou le manque de ventilation et la fréquence d'ouverture des fenêtres. Les paramètres de qualité de l'air étudiés dans les salles de classe étaient le dioxyde d'azote (NO2) ; les particules 10 (PM10) ; Particules 2,5 (PM2,5); Particules (PM1); L'ozone (O3), le benzène (C6H6) et le dioxyde de carbone (CO2). Les résultats ont montré que les maladies identifiées chez les étudiants en raison d'une mauvaise ventilation étaient la fatigue, la bronchite, les symptômes d'asthme, le risque d'infection, la rhinite, etc. Nous concluons que dans la mesure où la ventilation réduit les polluants de l'air intérieur, donc liés à la santé des étudiants, elle devrait être une priorité pour répondre aux exigences en matière de santé des étudiants. *(Afr J Reprod Health 2024; 28 [10s]: 449-459).*

Mots-clés: Ventilation, Santé scolaire, Élèves, santé, Éclosion de COVID-19

Introduction

The COVID-19 pandemic has posed considerable threat to the general population[1] Available evidence indicate that children can get COVID-19 when exposed to risky areas[2] such as schools and public places. The value of ventilation was emphasized during the COVID-19 epidemic[3], which led to new ventilation protocols being introduced in school buildings across the globe. An educational building, like a school, is a place where teaching activities have enormous impact on students' health, well-being, and educational achievement. A vital component of a student's academic success and overall well-being is the learning environment which includes the use of sanitizers to promote skin and eye health and reduces throat irritation[4]. An educational building is also one of the places that have the potentials to attract contagious diseases. The pandemic of COVID-19 teaches us to be concerned

about air quality in schools because of the ease with which the virus can be transmitted in crowded schools among students, teachers, and staff[5–7]

School sanitation is an essential part of school health[8], including classroom ventilation. Students spend more time in unfavourable indoor environments, but require a higher indoor air quality than adults. As a result of a variety of reasons, including their continual growth and the fact that they breathe more air, consume more food, and drink more water relative to their weight, children are more susceptible to environmental dangers than adults[9]. Children are in developmental age, they are sensitive people, and should be protected from poor environmental quality. They spend an extensive amount of time in the classroom at school, and the air quality in the classroom should be of concern.

Indoor air pollution levels can differ from outdoor levels in terms of both quantity and concentration. Students should receive protection that ensures that environmental conditions in classrooms are good so that they do not acquire or transmit diseases, both acute and chronic diseases. Evidence indicates that environmental quality in classrooms in several countries is often inadequate[10–16]There are 8000 school buildings in the Mediterranean area that do not adhere to standard environmental quality criteria[17]. There are many ways to maintain quality in the classroom, one of which is the use of ventilation. Ventilation designs in schools should be carried out at the beginning of the construction of the school buildings because it is often made based on many considerations[18]. Many ventilations often due not function properly[19], and have problems such as errors in sizing, reduced performance due to lack of maintenance, and lack of operator knowledge[20]. The space with poor ventilation has an increased risk of contamination like bacteria [21]. Ventilation has vital functions. It can decrease pollutants in the room like CO_2[22].

Several investigations have been carried out on ventilation in schools and indoor air qualification [23–25] but analysis on the health effects of poor ventilation effect on the health of students rarely had been conducted. The objective of this study is to determine the extent to which ventilation in the classroom correlates with students' health. We believe the results of the study will be relevant to design approaches for improving ventilation and the quality of air circulating in schools within the context of infectious pandemics such as COVID-19.

Conceptual framework

The conceptual framework of this research can be detailed with several variables, such as independent variables (Ventilation in school), dependent variables (Student Health), moderator variables (Indoor Quality) and media variables (Temperature, Moisture, Lighting, Disinfection etc). The objective of this research is focus in analysis about the existing ventilation in school impact the student health, not in the moderator variable and media variables although it cant avoided. (Figure1).

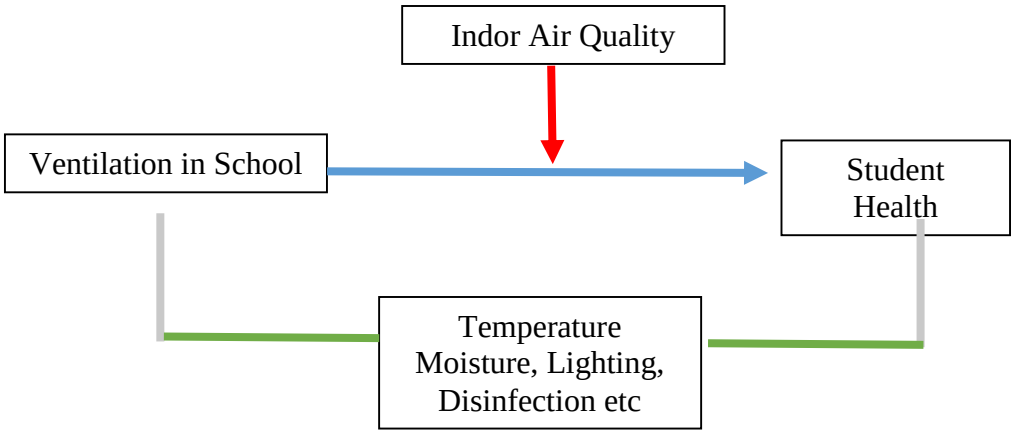

Figure 1: A conceptual framework for the ventilation, indoor air qualification, and health effects of students

Methods

The study was primarily based on a literature review. PRISMA guidelines were used to retrieve papers[26] (Figure 1). Data were found from search engines Scopus and the Web of Science. The Boolean technique was used to define the keywords. The database used for the search were: "Ventilation" OR "indoor air pollution" OR "Indoor environment quality" AND "School" AND "Students" OR "Children" AND "Health". The literature review was done for the period ranging from 2019 to May 2023. he article were in full text and English language, and the The article which not full text were exclude. search data was conducted in May 2023. Six articles met pre-defined criteria. Only studies reporting measurements in primary, middle, and secondary schools). (Figure 2).

Results

The objective of the research is to analyse how ventilation affected student health,but searching the articles from 2019 till May 2023 informed that some papers just analysed the school's ventilation and indoor air quality in school without continuing how it affects student health. The research only analysed the ventilation and indoor air quality in classrooms, not continuing to how it affects students' health[23,25-34]. The others analyse the ventilation and the health effects[35-39] and non-health effects[32,40-44], and also the research about indoor air quality and health students[45] (Figure 3).

Ventilation has many functions like keeping the air fresh in the rooms. According to the article published in 2019 till May 2023 showed that many types of ventilation are used in the classroom in schools. Some schools only use natural ventilation in classrooms or only use mechanical ventilation, but others use both (hybrid ventilation). The publication papers showed that the researcher analysed aperture ventilation, the frequency of opening windows, lack of ventilation, number of windows, etc., which is associated with indoor air quality in school or student health. Otherwise, the most parameter which was researched is Nitrogen Dioxide (NO_2), Particulate matter 10 (PM_{10}), Particulate matter 2,5 ($PM_{2,5}$), Particulate matter 1 (PM_1), Carbon Dioxide (CO_2), Benzen (C_6H_6), Ozone (O_3), etc.

The presence of pollution such as Nitrogen Dioxide (NO_2), Particulate matter (PM 1; PM 2,5; PM 10), and Carbon Dioxide (CO_2), Benzen can reduce the air quality in the classroom, which in turn can affect students' health and other conveniences[46-48]. Nitrogen Dioxide (NO_2) is the most important parameter that analysed indoor air quality attributed to ventilation at schools. NO_2 is a dangerous gas. It can be harmful to health. Nitrogen Dioxide (NO_2) was associated with adverse health effects influenza, asthma cases, paediatric asthma, lung cancer, mortality[49–55], and instability superoxide enzyme and malondialdehyde serum[56].

Particulate matter is one of the air pollutants in the classrooms in schools as found in several publications. It is dangerous for human health[57,58], and increases morbidity and mortality[59]. Particulate Matter can affect respiratory mortality[60], cardiovascular disease[51], adverse effects on renal health[61], Cardiovascular disease[61], incident diabetes[62]; respiratory, cancer, cardiovascular mortality[63], respiratory infection[61], lung injury[64], stroke[57]. Carbon dioxide (CO_2) has fatal effects. Carbon Dioxide reduces haemoglobin affinity for O_2[65], irritation, fatigue, anxiety, headaches, and poor cognitive performance [66], emotional responses of fear and panic[67], mortality[68], and headache[69]. Ozone (O_3) is a secondary pollutant with strong oxidizing properties[70]. Ozon (O_3) increased mortality[71], and short-term ozone exposure increased the risk of chronic obstructive pulmonary disease[72]. This increases the risk of mortality from respiratory disease, cardiovascular disease (CVD), ischemic heart disease (IHD), and stroke[73]. Long-term exposure to ozone (O_3) can increase cardiovascular mortality[74]. Sulphur dioxide (SO_2) is also the toxic air pollution. SO_2 can cause respiratory mortality[75], and ischemic heart disease (IHD)[76]. Exposure to benzene increases the risk of cancer[77]. Associated with abnormalities in hematologic, hepatic, respiratory, and pulmonary functions in children[78], hepatotoxicity[79]. These parameters are parameters that are often used as a measure of indoor air qualification which further often affect health. The results of research publications in 2019 - May 2023 show several health complaints experienced by students related to school ventilation and the state of indoor air quality in schools, including tiredness, bronchitis, asthma, tuberculosis, etc.

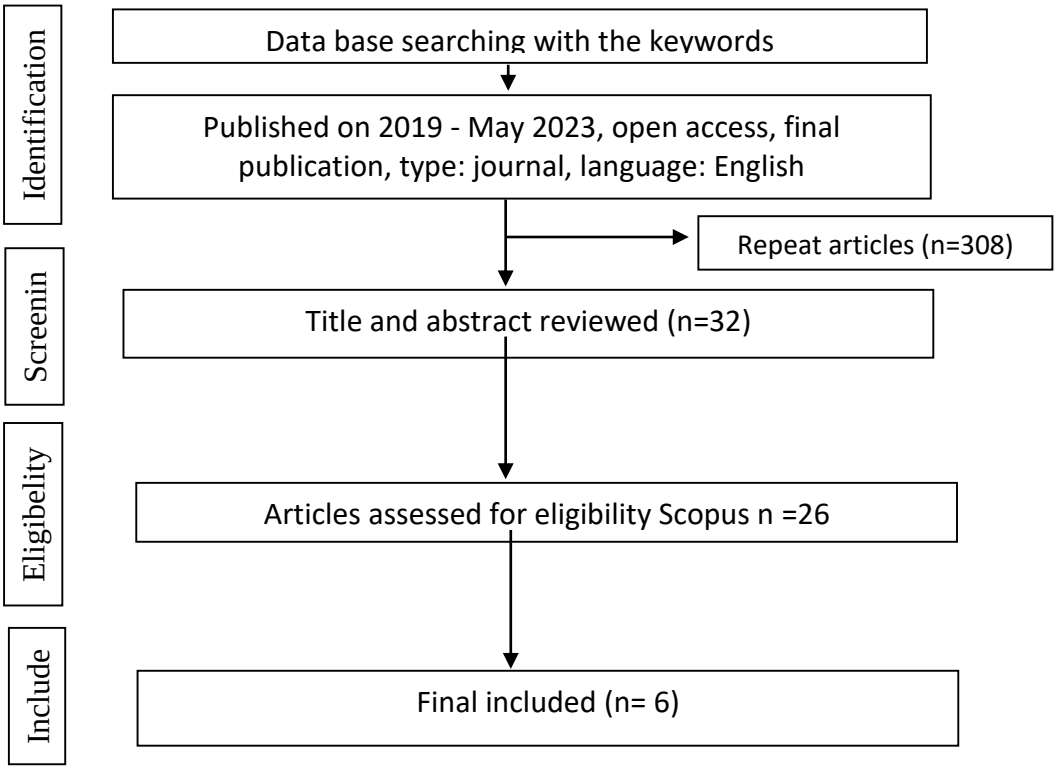

Figure 2: Process of selection papers based on PRISMA

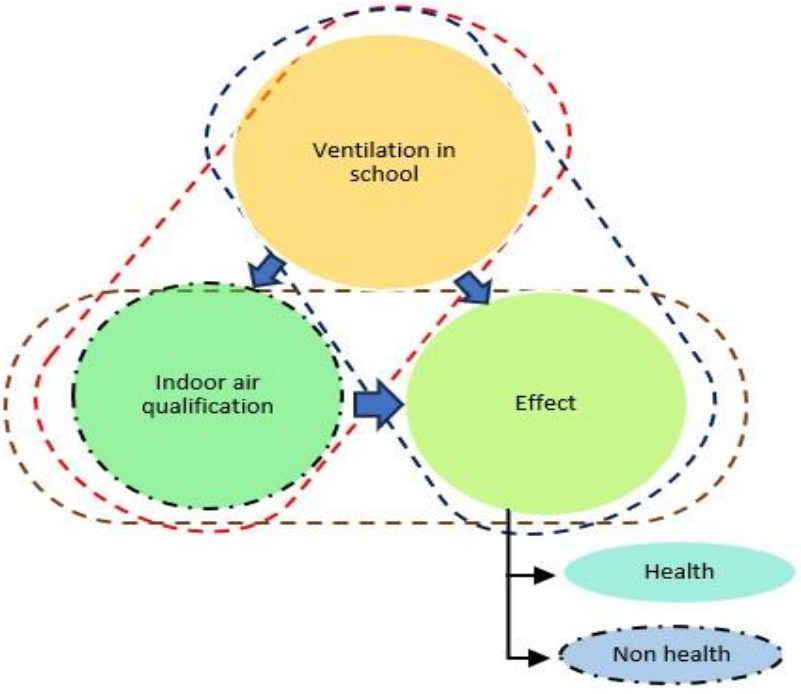

Figure 3: The publications that was founded and analyzed

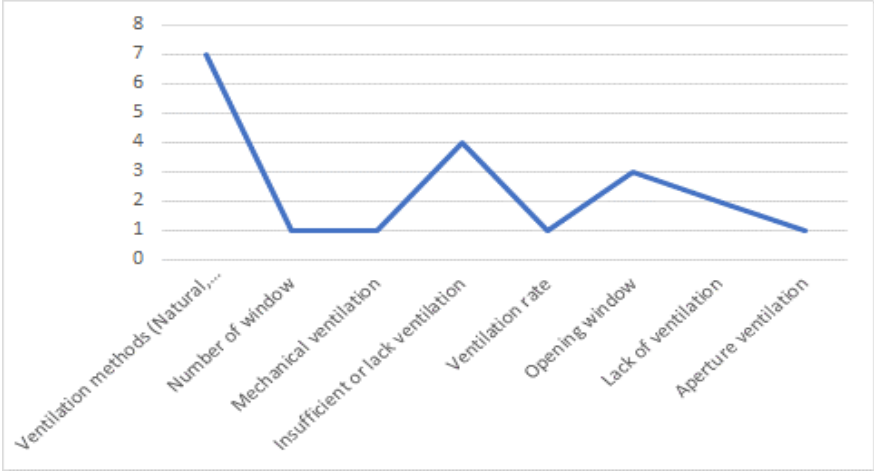

Figure 4: The variation of ventilation in classrooms variation

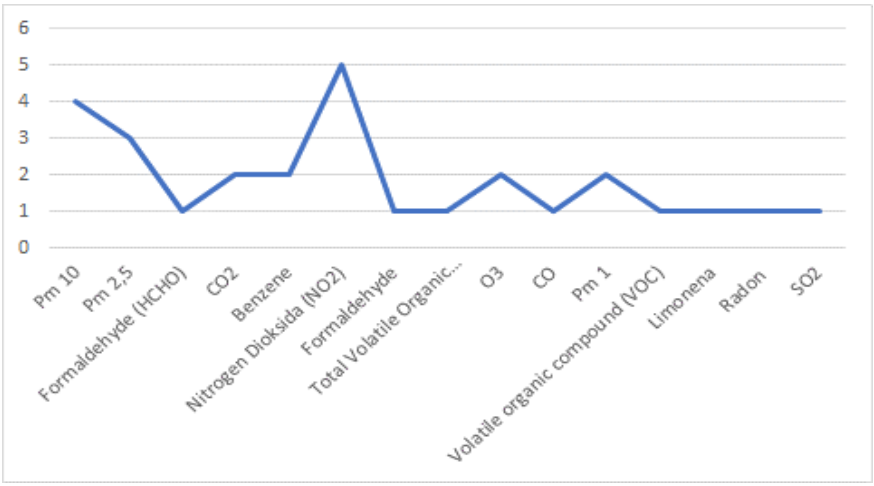

Figure 5: The parameters of classroom Air quality in school

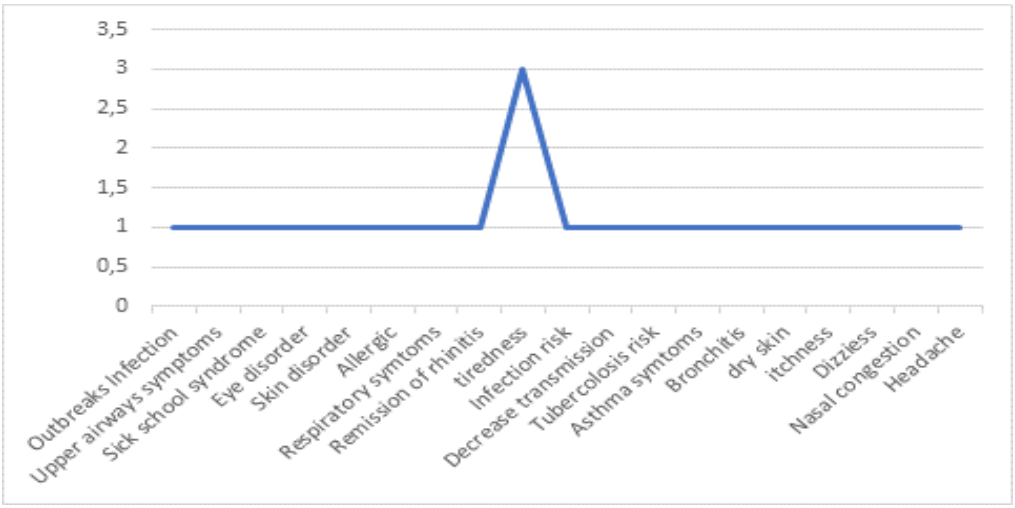

Figure 6: The health effects of ventilation on student health

Table 1: The effect of ventilation and students' health

No.	Author	Population	Location	Ventilation	Health effect
1.	Callies M. *et al*. 2023	Pupils and staff 43 primary and 38 secondary	Primary and secondary schools in Belgium	Ventilation	Increasing infection
2.	Gorgels, 2022	three primary school	Netherlands	Insufficient ventilation	School outbreak
3.	Cordery, 2022	Eight schools	London, UK in	Lack of ventilation	Increase transmission
4.	Sahin, 2022	Five schools	Sanliurfa, Turkey,	Natural Ventilation	Asthma symptoms, Bronchitis
5.	Baloch, 2020	115 schools, 5175 schoolchildren	54 European cities from 23 countries	Ventilation rate	Eye, skin disorder, upper airway symptoms, sick school syndrome
6.	Aguera, 2019	42 classrooms from 8 school buildings	Andalusia, Spanish	Opening window	Dizziness, dry skin, itchiness and nasal congestion dry skin, headache and tiredness

Discussion

This study focuses on the objective of analysing the relationship between ventilation in schools and student health. Finally, six articles analysed ventilation and health effects on students (Table 1). The poorer ventilation in schools was significant with a higher prevalence of SARS CoV-2 antibodies among pupils (RR: 0.96, 95% CI: 0.76 - 1.22)[35]. In the same way, an American study found that the danger of face-to-face instruction decreased when ventilation measures were implemented (Lessler, Grabowski, Grantz, & Badillo-Goicoechea, 2021). Insufficient ventilation causes the primary school outbreaks SAR CoV 2 Alpha variant at primary school which has no mechanical ventilation and increased ventilation by opening windows and doors[36]. Similar to other research, The frequency of COVID-19 in schools decreased by 37–48% as a result of improved classroom ventilation[81,82]. Ventilation in schools is very important in the cases of SARS Cov 2 because of the various ways that SARS-CoV-2 might spread, such as contact, droplet, aerosol, fomite, faecal-oral, bloodborne-, mother-to-child, and animal-to-human[83]. The airborne disease is very dependent on air quality conditions, when air quality is not good, the potential for transmission will be higher, this is where the role of ventilation becomes very important. Ventilation is the act or process of allowing fresh air to get into a room or building. Ventilation also correlates with SARSCOV 2 in bus[84]. When ventilation works well, the air quality will be better which will reduce the risk of transmission of airborne disease

The other research which was implemented at eight schools in the UK London showed that lack of ventilation increased transmission of disease, whereas low levels of environmental contamination in schools were consistent ventilation in schools during the period of a study conducted[37]. The research which analysed 25 classrooms in five schools using only natural ventilation like opening windows and doors, showed that ventilation contributed to indoor air quality ($PM_{2,5}$ and PM_{10}) thus health students with asthma symptoms and bronchitis[38]. Acute bronchitis is a clinical diagnosis characterized by cough[85]. Asthma is a chronic non-communicable disease, nonetheless, asthmatic patients should avoid respiratory viral infections (such as colds and influenza) as these can induce problems. In contrast to bronchitis, an infection is typically spread by microscopic, airborne droplets that are released by speaking, sneezing, or coughing and contain a germ. Additionally, it can spread through handshakes and other physical interactions with an infected individual. Asthma and bronchitis correlate with indoor air quality[86].

The ventilation in schools can cause school syndromes like eye, and skin disorders, upper airway symptoms, and sickness[39]. Their research involved 7089 children, aged 7–14 years from 115 schools in 54 cities of 23 European countries. Their research analysed natural dan mechanical ventilation and Volatile Organic Compounds (VOCs), $PM_{2.5}$, CO

(ppm), ozone, and radon, further identifying the health. The ventilation rate had an apparent protective effect over eye and skin-related disorders and airway symptoms.

About 917 students (11–17 years of age) were surveyed on symptoms and effects on their health like dizziness, dry skin, headache, and tiredness because of the lack of ventilation facilities in Andalusia[33]. The lack of ventilation facilities correlates with CO_2 in the 42 classrooms in 8 school buildings. Nearly 1878 parts per million is the average CO_2 concentration, and 42% of the case studies show values exceeding 2000 parts per million when the windows are closed. The symptoms that occurred when windows were closed were itchiness and nasal congestion in over 30%. When the windows are open the respondents report dry skin and headache.

The low ventilation rate causes the prevalence of rhinitis in schools[87]. The poor indoor air quality in school potentially leads to allergic diseases or asthma[88]. Analysis of 1325 students in eight junior schools, showed that PM_{10}, CO_2, and NO_2 at school can increase the onset of rhinitis[45]. In classrooms, efficient mechanical and natural ventilation systems lower infection risks by over 80%.The information about the ventilation in classroom affected the student health, may help policy makers to make stricter regulations regarding the type, amount, and condition of ventilation in the classroom to control the disease transmission, however they are still few studies about it. (Table 1)

Conclusion

The ventilation in schools affected the student's health. Previous studies analysis the natural ventilation, aperture ventilation, mechanical and hybrid ventilation, lack of ventilation, number of windows, etc, and the parameters of air quality in the classroom are NO_2, particulate matter, benzene, CO_2, etc. The ventilation should be designed at the beginning of school construction to maximize its function in ensuring students' health.

Author contribution

Anita D. Moelyaningrum: conceptualized and searching data, writing manuscript draft
Soedjajadi Keman: review empirical study and analysed data
Soenarnatalina Melaniani: designed the methodology and edited the paper.
Corie I. Prasasti: searching data and edited paper.

Data availability

Data was openly available in a public repository

Conflict of interest

The authors declare no competing interest.

Acknowledgement

Thanks to PUSLABDIK Beasiswa Pendidikan Indonesia, BPPT, and LPDP.

References

1. Adetuyi BO, Olajide PA, Awoyelu EH, Adetuyi OA, Adebisi OA and Oloke JK. Epidemiology and treatment options for COVID-19: A review. *Afr J Reprod Health*. 2020;24 (2 Special Edition COVID-19):142-153. doi:10.29063/ajrh2020/v24i2s.18
2. Balogun JA. The epidemiology of COVID-19: A review. *Afr J Reprod Health*. 2020;24(2SpecialEditionCOVID-19):117-124. doi:10.29063/ajrh2020/v24i2s.16
3. CDC. *Ventilation in Schools and Child Care Programs.*; 2021:2021. https://www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/ventilation.html.
4. Hashemi F, Hoepner L, Hamidinejad FS Hashemi F, Hoepner L, Hamidinejad FS, Haluza D, Afrashteh S, Abbasi A, Omeragić E, Imamović B, Rasheed NA, Taher TMJ, Kurniasari F, Wazqar DY, Apalı ÖC, Yildirim AD, Zhao B, Kalikyan Z, Guo C, Valbuena AC, Mititelu M, Pando CM, Saridi M, Toska A, Cuba ML, Kwadzokpui PK, Tadele N, Nasibova T, Harsch S, Munkh-Erdene L, Menawi W, Evangelou E, Dimova A, Marinov D, Dimitrova T, Shalimova A, Fouly H, Suraya A, da Silva Faquim JP, Oumayma B, Annunziato MA, Lalo R, Papastavrou E, Ade AD, Caminada S, Stojkov S, Narvaez CG, Mudau LS, Rassas I, Michel D, Kaynar NS, Iqbal S, Elshwekh H, Hossain I, Al-Fayyadh S, Sydorchuk A, Alnusairat DMH, Abdullahi AM, Iqbal N, Pandey A, Gómez-Gómez B, Akyildiz AG, Morosan E, Dwarica D, Dorj G, Hasan SY, Al-Shdayfat NM, Knezevic B, Valladares W, Severi C, Fuentes SC, Augusto S, Sidorova E, Moelyaningrum AD, Alawad T, Khalid A, Elehamer NMK, Mihaylova A, Tsigengagel O, Menouni A, Wojtecka A, Hod R, Idayat YB, Othman K, Harfouch RM, Paunov T, Omar M, Benderli NC, Nurika G, Amjad S, Elnoamany S, Elesrigy F, Shaban MM, Acevedo-López D, Kartashova M, Khalaf A, Jaafar SA, Kadhim TA, Hweissa NA, Teng Y, Mohammed FE, Sasikumar T, Hikaambo CN, Kharat

A and Lyamts. A comprehensive health effects assessment of the use of sanitizers and disinfectants during COVID-19 pandemic: a global survey. *Environ Sci Pollut Res*. 2023;30(28):72368-72388. doi:10.1007/s11356-023-27197-6

5. Chawla D, Trent M, Moa A, Stone H and Macintyre CR. An analysis of COVID-19 outbreaks in schools in South and Southwestern United States using open-source data. *Glob Biosecurity*. 2021;3(1). doi:10.31646/gbio.132
6. Yan L, Talic S, Wild H, Gasevic D, Gasević D, Ilic D, Deppeler J, Corrigan D, Martinez-Maldonado R and Trauer J. Transmission of SARS-CoV-2 in a primary school setting with and without public health measures using real-world contact data: A modelling study. *J Glob Health*. 2022;12. doi:10.7189/jogh.12.05034
7. Heinsohn T, Lange B, Vanella P, Rodiah I, Glöckner S, Joachim A, Becker D, Brändle T, Dhein S, Ehehalt S, Fries M, Galante-Gottschalk A, Jehnichen S, Kolkmann S, Kossow A, Hellmich M, Dötsch J and Krause G. Infection and transmission risks of COVID-19 in schools and their contribution to population infections in Germany: A retrospective observational study using nationwide and regional health and education agency notification data. *PLoS Med*. 2022;19(12):1-25. doi:10.1371/journal.pmed.1003913
8. Moelyaningrum AD, Keman S, Notobroto HB, Melaniani S, Sulistyorini L and Efendi F. School sanitation and student health status: a literature review. *J Public Health in Africa*. 2023;14(S2). doi:10.4081/jphia.2023.2540
9. WHO. *Children's Environmental Health Center*.; 2020. https://www.who.int/health-topics/children-environmental-health#tab=tab_1.
10. Galičič A, Rožanec J, Kukec A, Carli T, Medved S and Eržen I. Identification of Indoor Air Quality Factors in Slovenian Schools: National Cross-Sectional Study. *Processes*. 2023;11(3). doi:10.3390/pr11030841
11. Lee YK and Kim Y Il. Analysis of indoor air pollutants and guidelines for space and physical activities in multi-purpose activity space of elementary schools. *Energies*. 2022;15(1):1-21. doi:10.3390/en15010220
12. Zaki NKMN and Bari NAA. A Study on the indoor air quality (IAQ) at primary school in Industrial Area: A case study to Sekolah Kebangsaan Pasir Gudang 3(SKPG3). *IOP Conf Ser Earth Environ Sci*. 2022;1067(1):1-10. doi:10.1088/1755-1315/1067/1/012010
13. Pegas PN, Alves CA, Nunes T, Bate-Epey EF, Evtyugina M and Pio CA. Could houseplants improve indoor air quality in schools? *J Toxicol Environ Heal - Part A Curr Issues*. 2012;75(22-23):1371-1380. doi:10.1080/15287394.2012.721169
14. Raysoni AU, Armijos RX, Weigel MM, Echanique P, Racines M, Pingitore NE and Li WW. Evaluation of sources and patterns of elemental composition of PM2.5at three low-income neighborhood schools and residences in Quito, Ecuador. *Int J Environ Res Public Health*. 2017;14(7):1-26. doi:10.3390/ijerph14070674
15. Ferreira AM da C and Cardoso M. Indoor air quality and health in schools. *J Bras Pneumol*. 2014;40(3):259-268. doi:10.1590/s1806-37132014000300009
16. Fisk WJ. The ventilation problem in schools: literature review. *Indoor Air*. 2017;27(6):1039-1051. doi:10.1111/ina.12403
17. ZEMeds. ZEMeds- Promoting renovation of schools in a Mediterranean climate up to nearly Zero-Energy Buildings. *WwwZemedsEu*. 2016:8-11. http://www.zemeds.eu/.
18. Liu X, Yang L and Niu S. Research on the effect of different position on classroom ventilation in a "L" type teaching building. *J Build Eng*. 2021;33(May 2020):101852. doi:10.1016/j.jobe.2020.101852
19. Vornanen-Winqvist C, Salonen H, Järvi K, Andersson MA, Mikkola R, Marik T, Kredics L and Kurnitski J. Effects of ventilation improvement on measured and perceived indoor air quality in a school building with a hybrid ventilation system. *Int J Environ Res Public Health*. 2018;15(7):1-18. doi:10.3390/ijerph15071414
20. Lipinski T, Ahmad D, Serey N and Jouhara H. Review of ventilation strategies to reduce the risk of disease transmission in high occupancy buildings. *Int J Thermofluids*. 2020;7-8:100045. doi:10.1016/j.ijft.2020.100045
21. Lee MCJ and Tham KW. Public toilets with insufficient ventilation present high cross infection risk. *Sci Rep*. 2021;11(1):1-8. doi:10.1038/s41598-021-00166-0
22. Rosbach JT, Vonk M, Duijm F, Van Ginkel JT, Gehring U and Brunekreef B. A ventilation intervention study in classrooms to improve indoor air quality: The FRESH study. *Environ Heal A Glob Access Sci Source*. 2013;12(1):1-10. doi:10.1186/1476-069X-12-110
23. Matthaios VN, Kang CM, Wolfson JM, Greco KF, Gaffin JM, Hauptman M, Cunningham A, Petty CR, Lawrence J, Phipatanakul W, Gold DR and Koutrakis P.Factors Influencing Classroom Exposures to Fine Particles, Black Carbon, and Nitrogen Dioxide in Inner-City Schools and Their Implications for Indoor Air Quality. *Environ Health Perspect*. 2022;130(4):1-11. doi:10.1289/EHP10007
24. Hu D, Tobon Y, Agostini A, Grosselin B, Chen Y, Robin C, Yahyaoui A, Colin P, Mellouki A and Daële V. Diurnal variation and potential sources of indoor formaldehyde at elementary school, high school and university in the Centre Val de Loire region of France. *Sci Total Environ*. 2022;811:76-78. doi:10.1016/j.scitotenv.2021.152271
25. Ukëhaxhaj A, Ramadani N, Moshammer H and Zogaj D. Sources of Indoor Air Pollution in Schools in Kosovo. *Buildings*. 2023;13(3). doi:10.3390/buildings13030668
26. Higgins JPT GS. *Cochrane Handbook for Systematic Reviews of Intervention*. Willey; 2011. https://handbook-5-1.cochrane.org/.
27. Leite ADS, Rousse S, Léon JF, Trindade RIF, Haoues-Jouve S, Carvallo C, Dias-Alves M, Proietti A, Nardin E and Macouin M. Barking up the Right Tree: Using Tree Bark to Track Airborne Particles in School Environment and Link Science to Society. *GeoHealth*.

2022;6(9):1-18. doi:10.1029/2022GH000633
28. Zauli-Sajani S, Marchesi S, Boselli G, Broglia E, Angella A, Maestri E, Marmiroli N and Colacci A. Effectiveness of a Protocol to Reduce Children's Exposure to Particulate Matter and NO2 in Schools during Alert Days. *Int J Environ Res Public Health*. 2022;19(17). doi:10.3390/ijerph191711019
29. Davis EA, Ou JY, Chausow C, Verdeja MA, Divver E, Johnston JD and Beard JD Associations between school characteristics and classroom radon concentrations in utah's public schools: A project completed by university environmental health students. *Int J Environ Res Public Health*. 2020;17(16):1-17. doi:10.3390/ijerph17165839
30. Bartyzel J, Zieba D, Necki J and Zimnoch M. Assessment of ventilation efficiency in school classrooms based on indoor-outdoor particulate matter and carbon dioxide measurements. *Sustain*. 2020;12(14):1-9. doi:10.3390/su12145600
31. Pacitto A, Amato F, Moreno T, Pandolfi M, Fonseca A, Mazaheri M, Stabile L, Buonanno G and Querol X. Effect of ventilation strategies and air purifiers on the children's exposure to airborne particles and gaseous pollutants in school gyms. *Sci Total Environ*. 2020;712(135673):135673. doi:10.1016/j.scitotenv.2019.135673
32. Campano-Laborda MÁ, Domínguez-Amarillo S, Fernández-Agüera J and Acosta I. Indoor comfort and symptomatology in non-university educational buildings: Occupants' perception. *Atmosphere (Basel)*. 2020;11(4). doi:10.3390/atmos11040357
33. Fernandez-Aguera J, Campano MÁ, Dom S and Acosta I, Jos J. CO2 Concentration and Occupymptoms in Mediterranean Climate. *Buildings*. 2019.
34. McLeod RS, Hopfe CJ, Bodenschatz E, Moriske HJ, Pöschl U, Salthammer T, Curtius J, Helleis F, Niessner J, Herr C, Klimach T, Seipp M, Steffens T, Witt C and Willich SN. A multi-layered strategy for COVID-19 infection prophylaxis in schools: A review of the evidence for masks, distancing, and ventilation. *Indoor Air*. 2022;32(10):1-11. doi:10.1111/ina.13142
35. Callies M, Kabouche I, Desombere I, Merckx J, Roelants M, Vermeulen M and Duysburgh E. SARS-CoV-2 infection prevention and control measures in Belgian schools between December 2020 and June 2021 and their association with seroprevalence: a cross-sectional analysis of a prospective cohort study. *BMC Public Health*. 2023;23(1):1-11. doi:10.1186/s12889-023-15806-5
36. Gorgels KMF, van Alphen LB, van der Veer BMJW, Hackert VH, Hensels AYJ, Heijer CDJD, Dingemans J, Savelkoul PHM and Hoebe CJPA. Increased transmissibility of SARS-CoV-2 alpha variant (B.1.1.7) in children: three large primary school outbreaks revealed by whole genome sequencing in the Netherlands. *BMC Infect Dis*. 2022;22(1):1-10. doi:10.1186/s12879-022-07623-9
37. Cordery R, Reeves L, Zhou J, Rowan A, Watber P, Rosadas C, Crone M, Storch M, Freemont P, Mosscrop L, Cowley A, Zelent G, Bisset K, Le Blond H, Regmi S, Buckingham C, Junaideen R, Abdulla N, Eliahoo J, Mindlin M, Lamagni T, Barclay W, Taylor GP and Sriskandan S. Transmission of SARS-CoV-2 by children to contacts in schools and households: a prospective cohort and environmental sampling study in London. *The Lancet Microbe*. 2022;3(11):e814-e823. doi:10.1016/S2666-5247(22)00124-0
38. Sahin C, Rastgeldi Dogan T, Yildiz M and Sofuoglu SC. Indoor environmental quality in naturally ventilated schools of a dusty region: Excess health risks and effect of heating and desert dust transport. *Indoor Air*. 2022;32(7):1-12. doi:10.1111/ina.13068
39. Baloch RM, Maesano CN, Christoffersen J, Banerjee S, Gabriel M, Csobod É, de Oliveira Fernandes E and Annesi-Maesano I.. Indoor air pollution, physical and comfort parameters related to schoolchildren's health: Data from the European SINPHONIE study. *Sci Total Environ*. 2020;739. doi:10.1016/j.scitotenv.2020.139870
40. Brink HW, Loomans MGLC, Mobach MP and Kort HSM. Classrooms' indoor environmental conditions affecting the academic achievement of students and teachers in higher education: A systematic literature review. *Indoor Air*. 2021;31(2):405-425. doi:10.1111/ina.12745
41. Ding E, Zhang D, Hamida A, García-Sánchez C, Jonker L, de Boer AR, Bruijning PCJL, Linde KJ, Wouters IM and Bluyssen PM. Ventilation and thermal conditions in secondary schools in the Netherlands: Effects of COVID-19 pandemic control and prevention measures. *Build Environ*. 2023;229(December 2022). doi:10.1016/j.buildenv.2022.109922
42. Alzahrani H, Arif M, Kaushik AK, Rana MQ and Aburas HM. Evaluatiannng the effects of indoor air quality on teacher performance using artificial neural network. *J Eng Des Technol*. 2023;21(2):604-618. doi:10.1108/JEDT-07-2021-0372
43. Wargocki P, Porras-Salazar JA, Contreras-Espinoza S and Bahnfleth W. The relationships between classroom air quality and children's performance in school. *Build Environ*. 2020;173(February):106749. doi:10.1016/j.buildenv.2020.106749
44. Kabirikopaei A, Lau J, Nord J and Bovaird J. Identifying the K-12 classrooms' indoor air quality factors that affect student academic performance. *Sci Total Environ*. 2021;786. doi:10.1016/j.scitotenv.2021.147498
45. Norback D, Li T, Bai X, Li C, Zhao Z and Zhang X. Onset and remission of rhinitis among students in relation to the home and school environment—A cohort study from Northern China. *Indoor Air*. 2019;29(4):527-538. doi:10.1111/ina.12559
46. Pannullo F, Lee D, Neal L, Dalvi M, Agnew P, O'Connor FM, Mukhopadhyay S, Sahu S and Sarran C.. Quantifying the impact of current and future concentrations of air pollutants on respiratory disease risk in England. *Environ Heal*. 2017;16(1):29. doi:10.1186/s12940-017-0237-1
47. Morakinyo OM, Adebowale AS, Mokgobu MI and Mukhola MS. Health risk of inhalation exposure to sub-10 μm particulate matter and gaseous pollutants in an urban-industrial area in South Africa: An ecological study. *BMJ Open*. 2017;7(3):1-9. doi:10.1136/bmjopen-2016-013941

48. Huangfu P and Atkinson R. Long-term exposure to NO2 and O3 and all-cause and respiratory mortality: A systematic review and meta-analysis. *Environ Int*. 2020;144(October):105998. doi:10.1016/j.envint.2020.105998
49. Zeng W, Zhao H, Liu R, Yan W, Qiu Y, Yang F, Shu C and Zhan Y Association between NO2 cumulative exposure and influenza prevalence in mountainous regions: A case study from southwest China. *Environ Res*. 2020;189(January):109926. doi:10.1016/j.envres.2020.109926
50. Anenberg SC, Henze DK, Tinney V, Kinney PL, Raich W, Fann N, Malley CS, Roman H, Lamsal L, Duncan B, Martin RV, van Donkelaar A, Brauer M, Doherty R, Jonson JE, Davila Y, Sudo K and Kuylenstierna JCI. Estimates of the Global Burden of Ambient PM2.5, Ozone, and NO2 on Asthma Incidence and Emergency Room Visits. *Environ Health Perspect*. 2018;126(10):1-14. doi:10.1289/EHP3766
51. Anenberg SC, Mohegh A, Goldberg DL, Kerr GH, Brauer M, Burkart K, Hystad P, Larkin A, Wozniak S and Lamsal L. Long-term trends in urban NO2 concentrations and associated paediatric asthma incidence: estimates from global datasets. *Lancet Planet Heal*. 2022;6(1):e49-e58. doi:10.1016/S2542-5196(21)00255-2
52. Achakulwisut P, Brauer M, Hystad P and Anenberg SC. Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO 2 pollution: estimates from global datasets. *Lancet Planet Heal*. 2019;3(4):e166-e178. doi:10.1016/S2542-5196(19)30046-4
53. Hamra GB, Laden F, Cohen AJ, Raaschou-Nielsen O, Brauer M and Loomis D. Lung cancer and exposure to nitrogen dioxide and traffic: A systematic review and meta-analysis. *Environ Health Perspect*. 2015;123(11):1107-1112. doi:10.1289/ehp.1408882
54. Crouse DL, Peters PA, Villeneuve PJ, Proux MO, Shin HH, Goldberg MS, Johnson M, Wheeler AJ, Allen RW, Atari DO, Jerrett M, Brauer M, Brook JR, Cakmak S and Burnett RT. Within- and between-city contrasts in nitrogen dioxide and mortality in 10 Canadian cities; A subset of the Canadian Census Health and Environment Cohort (CanCHEC). *J Expo Sci Environ Epidemiol*. 2015;25(5):482-489. doi:10.1038/jes.2014.89
55. Ogen Y. Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. *Sci Total Environ*. 2020;726 (March):138605. doi:10.1016/j.scitotenv.2020.138605
56. Kahar K, Sulistyorini L and Keman S. Nitrogen Dioxide Concentrations in the Air in Increasing Superoxide Dismutase Enzyme and Malondialdehyde Serum Levels in Bus Terminal Officers. *J Kesehat Lingkung*. 2021;13(3):166-173. doi:10.20473/jkl.v13i3.2021.166-173
57. Wu H, Zhang B, Wei J, Lu Z, Zhao M, Liu W, Bovet P, Guo X and Xi B. Short-term effects of exposure to ambient PM_1, $PM_{2.5}$, and PM_{10} on ischemic and hemorrhagic stroke incidence in Shandong Province, China. *Environ Res*. 2022;212(December 2021). doi:10.1016/j.envres.2022.113350
58. Li T, Yu Y, Sun Z and Duan J. A comprehensive understanding of ambient particulate matter and its components on the adverse health effects based from epidemiological and laboratory evidence. *Part Fibre Toxicol*. 2022;19(1):1-25. doi:10.1186/s12989-022-00507-5
59. Dominski FH, Lorenzetti Branco JH, Buonanno G, Stabile L, Gameiro da Silva M and Andrade A. Effects of air pollution on health: A mapping review of systematic reviews and meta-analyses. *Environ Res*. 2021;201(April). doi:10.1016/j.envres.2021.111487
60. Ngamsang P, Amnuaylojaroen T, Parasin N and Pimonsree S. Health Impact Assessment of Short-Term Exposure to Particulate Matter (PM10) in Northern Thailand. Buccolieri R, ed. *J Environ Public Health*. 2023;2023:1-9. doi:10.1155/2023/1237768
61. Jia H, Liu Y, Guo D, He W, Zhao L and Xia S. PM2.5-induced pulmonary inflammation via activating of the NLRP3/caspase-1 signaling pathway. *Environ Toxicol*. 2021;36(3):298-307. doi:10.1002/tox.23035
62. Laor P, Suma Y, Keawdounglek V, Hongtong A, Apidechkul T and Pasukphun N. Knowledge, attitude and practice of municipal solid waste management among highland residents in Northern Thailand. *J Heal Res*. 2018;32(2):123-131. doi:10.1108/JHR-01-2018-013
63. Kim IS, Yang PS, Lee J, Yu HT, Kim TH, Uhm JS, Kim JY, Pak HN, Lee MH and Joung B. Long-term fine particulate matter exposure and cardiovascular mortality in the general population: a nationwide cohort study. *J Cardiol*. 2020;75(5):549-558. doi:10.1016/j.jjcc.2019.11.004
64. Huang D, Shen Z, Zhao S, Pei C, Jia N, Wang Y, Wu Y, Wang X, Shi S, He Y, Wang Z and Wang F. Sipeimine attenuates PM2.5-induced lung toxicity via suppression of NLRP3 inflammasome-mediated pyroptosis through activation of the PI3K/AKT pathway. *Chem Biol Interact*. 2023;376(January):110448. doi:10.1016/j.cbi.2023.110448
65. Woyke S, Brugger H, Ströhle M, Haller T, Gatterer H, Dal Cappello T and Strapazzon G. Effects of Carbon Dioxide and Temperature on the Oxygen-Hemoglobin Dissociation Curve of Human Blood: Implications for Avalanche Victims. *Front Med*. 2022;8(February):1-10. doi:10.3389/fmed.2021.808025
66. Du B, Tandoc MC, Mack ML and Siegel JA. *Indoor CO2 Concentrations and Cognitive Function: A Critical Review*. Vol 30.; 2020. doi:10.1111/ina.12706
67. Améndola L, and Weary DM. Understanding rat emotional responses to CO2. *Transl Psychiatry*. 2020;10(1). doi:10.1038/s41398-020-00936-w
68. Boivin GP, Hickman DL and Creamer-hente MA, Pritchett-corning KR, Bratcher NA. Revisión del CO 2 como agente de eutanasia para ratas y ratones de laboratorio. *J Am Assoc Lab Anim Sci*. 2017;56(5):491-499. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5605172/pdf/jaalas2017000491.pdf.
69. Azuma K, Uchiyama I, Uchiyama S and Kunugita N. Assessment of inhalation exposure to indoor air pollutants: Screening for health risks of multiple

pollutants in Japanese dwellings. *Environ Res*. 2016;145:39-49. doi:10.1016/j.envres.2015.11.015

70. Cakmak S, Hebbern C, Vanos J, Crouse DL and Burnett R. Ozone exposure and cardiovascular-related mortality in the Canadian Census Health and Environment Cohort (CANCHEC) by spatial synoptic classification zone. *Environ Pollut*. 2016;214(2):589-599. doi:10.1016/j.envpol.2016.04.067
71. Huang WH, Chen BY, Kim H, Honda Y and Guo YL. Significant effects of exposure to relatively low level ozone on daily mortality in 17 cities from three Eastern Asian Countries. *Environ Res*. 2019;168(September 2018):80-84. doi:10.1016/j.envres.2018.09.017
72. Gao H, Wang K, Au WW, Zhao W and Xia ZL. A systematic review and meta-analysis of short-term ambient ozone exposure and copd hospitalizations. *Int J Environ Res Public Health*. 2020;17(6):1-14. doi:10.3390/ijerph17062130
73. US EPA. *Integrated Science Assessment for Ozone and Related Photochemical Oxidants*. Vol 78.; 2020:11172-11173. WWW.EPA.GOV/ISA.
74. Liu S, Zhang Y, Ma R, Liu X, Liang J, Lin H, Shen P, Zhang J, Lu P, Tang X, Li T and Gao P. Long-term exposure to ozone and cardiovascular mortality in a large Chinese cohort. *Environ Int*. 2022;165(February):107280. doi:10.1016/j.envint.2022.107280
75. Orellano P, Reynoso J and Quaranta N. Short-term exposure to sulphur dioxide (SO2) and all-cause and respiratory mortality: A systematic review and meta-analysis. *Environ Int*. 2021;150:106434. doi:10.1016/j.envint.2021.106434
76. Xu Z, Xiong L, Jin D and Tan J. Association between short-term exposure to sulfur dioxide and carbon monoxide and ischemic heart disease and non-accidental death in Changsha city, China. *PLoS One*. 2021;16(5 May):1-14. doi:10.1371/journal.pone.0251108
77. Jafari AJ, Faridi S and Momeniha F. Temporal variations of atmospheric benzene and its health effects in Tehran megacity (2010-2013). *Environ Sci Pollut Res*. 2019;26(17):17214-17223. doi:10.1007/s11356-019-05086-1
78. D'Andrea MA and Reddy GK. Health Risks Associated With Benzene Exposure in Children: A Systematic Review. *Glob Pediatr Heal*. 2018;5. doi:10.1177/2333794X18789275
79. Wang B, Xu S, Sun Q, Li X, Wang T, Xu K, Yin L, Sun R, Pu Y and Zhang J. Let-7e-5p, a promising novel biomarker for benzene toxicity, is involved in benzene-induced hematopoietic toxicity through targeting caspase-3 and p21. *Ecotoxicol Environ Saf*. 2022;246(June):114142. doi:10.1016/j.ecoenv.2022.114142
80. Lessler J, Grabowski MK, Grantz KH, Badillo-Goicoechea E, Metcalf CJE, Lupton-Smith C, Azman AS and Stuart EA. Household COVID-19 risk and in-person schooling. *Science (80-)*. 2021;372(6546):1092-1097. doi:10.1126/science.abh2939
81. Gettings J, Czarnik M, Morris E, Haller E, Thompson-Paul AM, Rasberry C, Lanzieri TM, Smith-Grant J, Aholou TM, Thomas E, Drenzek C and MacKellar D. Mask Use and Ventilation Improvements to Reduce COVID-19 Incidence in Elementary Schools — Georgia, November 16–December 11, 2020. *MMWR Morb Mortal Wkly Rep*. 2021;70(21):779-784. doi:10.15585/mmwr.mm7021e1
82. Villers J, Henriques A, Calarco S, Rognlien M, Mounet N, Devine J, Azzopardi G, Elson P, Andreini M, Tarocco N, Vassella C and Keiser O. SARS-CoV-2 aerosol transmission in schools: The effectiveness of different interventions. *Swiss Med Wkly*. 2022;152(21-22). doi:10.4414/smw.2022.w30178
83. WHO. Operational Planning Guidelines To Support Country Preparedness and Response. *WHO*. 2020;13(May):17.
84. Ou C, Hu S, Luo K, Yang H, Hang J, Cheng P, Hai Z, Xiao S, Qian H, Xiao S, Jing X, Xie Z, Ling H, Liu L, Gao L, Deng Q, Cowling BJ and Li Y Insufficient ventilation led to a probable long-range airborne transmission of SARS-CoV-2 on two buses. *Build Environ*. 2022;207(January):108414. doi:10.1016/j.buildenv.2021.108414
85. Kinkade S and Long NA. Acute bronchitis. *Am Fam Physician*. 2016;94(7):560-565. doi:10.5005/jp/books/10950_9
86. Olaniyan T, Dalvie MA, Röösli M, Naidoo R, Künzli N, de Hoogh K, Parker B, Leaner J and Jeebhay M Asthma-related outcomes associated with indoor air pollutants among schoolchildren from four informal settlements in two municipalities in the Western Cape Province of South Africa. *Indoor Air*. 2019;29(1):89-100. doi:10.1111/ina.12511
87. Simoni M, Annesi-Maesano I, Sigsgaard T, Norback D, Wieslander G, Nystad W, Canciani M, Sestini P and Viegi G.. School air quality related to dry cough, rhinitis and nasal patency in children. *Eur Respir J*. 2010;35(4):742-749. doi:10.1183/09031936.00016309
88. Chithra VS and Shiva NSM. A review of scientific evidence on indoor air of school building: Pollutants, sources, health effects and management. *Asian J Atmos Environ*. 2018;12(2):87-108. doi:10.5572/ajae.2018.12.2.87.