Indoor Air Ventilation Issues in California Childcare Facilities

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ABSTRACT

Indoor Air Quality (IAQ) significantly affects public health, particularly for children who are highly susceptible to its adverse effects due to their vulnerable immune system, and considerable time spent indoors in childcare facilities. Acknowledging the pivotal role of IAQ in affecting children's health and educational outcomes, this research aims to highlight discrepancies between subjective assessments and actual air quality metrics within educational settings. This study focuses on the IAQ in childcare facilities across California, emphasizing those in the Bay Area due to its specific environmental challenges, including frequent wildfires and industrial pollution. The research identifies common ventilation situations in California classrooms and childcare facilities and policies around indoor air quality mitigation. This study employed a mixed-methods approach, including literature review on recent IAQ studies and policy review and qualitative surveys regarding ventilation practices. Additionally, the study considers the impact of current policies and the pivotal role of educators in recognizing and addressing IAQ issues. The findings reveal a critical need for comprehensive policy reform and enhanced resources to support effective IAQ management in educational settings, aiming to safeguard children's health and optimize their learning environments. Suggestions for future research include expanding the scope of study locations to enhance the applicability of findings, conducting longitudinal studies to evaluate the prolonged effects of indoor air quality (IAQ), and employing advanced monitoring technologies to better align interventions with the actual conditions of IAQ.

KEYWORDS

Indoor air quality (IAQ), children’s health, air quality improvement, policy reform, childcare facilities and classrooms

INTRODUCTION

In the broader realm of environmental quality and air pollution, the focus has predominantly been on outdoor pollutants, such as those emitted from vehicles, industries, and natural sources. While these external factors rightfully garner attention, the quality of indoor air, often overlooked, constitutes a significant yet underappreciated facet of environmental health. While the majority of environmental research and environmental activism focuses on the implication of outdoor pollutants, it's crucial to recognize that people, mostly in urban settings, nowadays spend a significant portion of their time indoors (Kim et al., 2004). Indoor Air quality has often been overshadowed by the most visible threat of outdoor pollution. Poor IAQ has been linked to a range of health issues, from respiratory distress, allergic reaction to heart and lung diseases, and cognitive impairments (Deng & Lau, 2019). Factors like temperature, humidity, ventilation rates, and the presence of pollutants such as volatile organic compounds (VOCs), particulate matter, and microbial contaminants play a pivotal role in determining IAQ (Kim et al., 2004). IAQ encompasses a range of physical, chemical, and biological attributes of indoor air and the intricate dynamics of indoor air pollutants, their sources, and their potential health impacts necessitate rigorous scientific inquiry and attention. Within this indoor environment, children, especially during their early childhood years, represent a demographic that is uniquely susceptible to the adverse effects of IAQ issues.

Children, especially during their early childhood years, represent a demographic that is uniquely susceptible to the adverse effects of IAQ issues (Lanphear et al., 2001). Their physiological trajectory, marked by a rapidly evolving respiratory and immune system, predispose them to detrimental impacts of indoor pollutants (Yoon et al., 2011). Even minor fluctuation in IAQ can lead to significant health repercussions in children because their higher breathing rates relative to their body size result in a greater intake of pollutants per unit of body weight. This physiological predisposition is further exacerbated in educational and childcare settings where they are exposed for prolonged duration during their active hours (Carroquino et al., 2012). Childcare facilities are densely populated spaces, often accommodating a large number of young children in confined areas for extended periods of time. Liu et al. (2023) emphasized that even minor deviations in IAQ standards in childcare facilities can lead to widespread health repercussions among attending children. Therefore, given the context that children spend up to 90% of their time

and most day time at childcare facilities, the imperative to ensure optimal IAQ in these settings is not just an environmental concern—it's a pressing public health emergency (Anake et al., 2023). Thus, rectifying issues in such a context and population can safeguard the health of numerous vulnerable individuals at once, making it a priority in the broader discourse on indoor air quality.

The Bay Area, characterized by its unique geographical, cultural, and environmental attributes, presents a compelling backdrop for IAQ research (Steiner et al., 2006). Recent years have seen this region grappling with numerous environmental adversities, wildfire, bay water quality and industrial urban smog and more. The convergence of all these environmental factors, coupled with the Bay Area's unique topography, often leads to trapping pollutants, resulting in episodes of poor air quality (Kim et al., 2004, Ulpiani, 2021). Nishimura et al. (2013) elucidated the complex relationship between early-life air pollution exposure and asthma risk and health complications in children throughout life, underscoring the necessity for region-centric studies. Moreover, while a plethora of studies have addressed outdoor pollutants in the Bay Area, a discernible research void exists concerning IAQ in childcare facilities. This gap is further accentuated by potential policy shortcomings that may not comprehensively address the intricacies of indoor air pollution, especially in the context of external challenges like wildfire smoke (Liang et al., 2021).

The central research question explores the impacts of teachers' perceptions and practices on indoor air quality (IAQ) in classrooms and examines the support or hindrances provided by existing resources and policies. The study delves into several sub-questions: Firstly, it investigates the correlation between a teacher's perception of indoor air quality and the actual ventilation practices observed in classrooms. Secondly, it evaluates the effectiveness of various IAQ technologies and practices in enhancing air quality within classrooms. Lastly, the research assesses the current resources and policies available to teachers and schools aimed at mitigating poor indoor air quality, and analyzes how these tools influence IAQ practices in educational settings.

EXTENDED INTRODUCTION

Ventilation in Classrooms

Proper ventilation is essential for ensuring optimal indoor air quality in educational environments (Sadrizadeh et al., 2022). The presence of sufficient ventilation systems is crucial in order to effectively mitigate and eliminate indoor pollutants, as well as to provide the indoor environment with unpolluted outdoor air. The efficacy of ventilation in educational settings is dependent on a multitude of aspects, encompassing the configuration and functioning of the school's Heating, Ventilation, and Air Conditioning (HVAC) systems, the quantity of individuals there, and their activities. Research has indicated positive correlation between greater breathing rates and improved respiratory health outcomes, as well as improved academic performance, among student populations (Mendell et al., 2005). The ventilation rates recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) are designed to maintain CO2 levels below a specified threshold in classroom environments, ensuring an adequate supply of fresh air indoors (Johnson et al., 2018). However, in many aging school buildings, achieving these recommended ventilation rates can be challenging due to outdated HVAC systems or structural limitations (Chan et al., 2020).

Most Commonly Measured Indoor Air Pollutants

Indoor air quality monitors are pivotal in assessing the environmental parameters within preschool classrooms, providing critical metrics on pollutants that can detrimentally impact children's health. These devices measure concentrations of particulate matter (PM2.5), carbon dioxide (CO2), temperature, humidity, and total volatile organic compounds (TVOCs). Understanding and controlling these measures is crucial, especially in the context of early childhood education facilities, where occupants are highly susceptible to the adverse effects of poor air quality.

CO2 levels are a key indicator of ventilation adequacy in indoor environments. The findings of Satish et al. (2012) underscore the cognitive declines associated with increased CO2 concentrations, implicating poor ventilation as a barrier to academic performance and overall health. Elevated CO2 levels can signify insufficient ventilation, leading to the accumulation of pollutants emitted by occupants and materials within the space. High CO2 concentrations have been linked to decreased cognitive performance and increased health symptoms, suggesting that poor ventilation may not only affect the health of students and teachers but also their ability to

concentrate and learn. Monitoring CO2 levels in real-time allows for adjustments in ventilation to ensure that indoor air remains healthy and conducive to learning. Integrating CO2 monitoring into classroom management practices can significantly enhance the learning environment by ensuring that ventilation systems are functioning effectively and that occupants are not exposed to deleterious air quality. Monitoring CO2 is therefore essential not only for comfort but also for safeguarding cognitive function and reducing absenteeism through enhanced ventilation.

Other Indoor Air Quality Measures

Beyond chemical pollutants, thermal comfort—defined by air temperature and humidity—is integral to maintaining a healthy and productive learning environment. As children's thermoregulatory systems are still developing, as pointed out by Sun et al. (2021), they are more vulnerable to variations in temperature and humidity. Monitors that can provide real-time data on these parameters enable schools to adjust heating, ventilation, and air conditioning (HVAC) systems to maintain optimal conditions, thus mitigating the risk of respiratory illnesses and enhancing overall student well-being.

Humidity levels are equally crucial; both low and high extremes can contribute to health problems. Mendell (2005) cautions that inadequate humidity can lead to mucosal irritation, increasing susceptibility to infections, while excessive humidity can foster the proliferation of molds and dust mites, potent allergens for children. Monitoring humidity allows for the maintenance of balanced levels, thus reducing the risk of asthma and allergic reactions.

Gap to Address in this Study

Given the crucial role that teachers play in recognizing and mitigating indoor air quality (IAQ) issues, our study seeks to comprehensively explore the dynamics between teachers' perceptions of IAQ, the effectiveness of IAQ technologies or practices, and the existing resources and policies that support IAQ improvements in educational settings (Sasan et al. 2022). Currently, there is limited research on how teachers' understanding of IAQ correlates with actual air quality outcomes in California classrooms. This gap includes a need for deeper insights into teachers' ability to recognize IAQ issues, their knowledge of IAQ standards, and their perceptions of health

risks associated with poor air quality. Understanding these perceptions is crucial for developing targeted educational and training programs. While various IAQ technologies and practices are available, there is a scarcity of comprehensive evaluations of their effectiveness in the unique context of classroom environments. This includes understanding the practical challenges of implementing these technologies, such as cost, maintenance, and operational feasibility, and how they fit into daily classroom activities and routines.

METHOD

To holistically address the research question, I reviewed recent literature on air ventilation situations in California classrooms, policy review, and coupled with qualitative survey into the ventilation and air quality related practices and observational field note of potential sources of pollutants in the facility environment. Also, I wanted to recognize the intricate relations between environmental issues in the ambient environment. Ultimately, my objective is to pinpoint the challenges faced by teachers and children with IAQ and what are the current practices and policies available.

Literature Search and Selection Criteria

To conduct a comprehensive analysis of indoor air quality (IAQ) in childcare facilities, this paper systematically reviewed existing literature with an emphasis on examining the effects of IAQ improvement technologies and understanding teacher perceptions of IAQ. This review specifically targeted studies focused on the Bay Area or similar urban settings, scrutinizing publications from 2012 to 2024 that report on IAQ in California's educational settings. The literature search was conducted across several academic databases, including PubMed, ScienceDirect, and Wiley, using keywords such as IAQ, schools, CO2, ventilation, and HVAC. To systematically review these papers, I adopted a structured approach by first screening titles and abstracts for relevance, followed by a thorough review of full-text articles to ensure they met our inclusion criteria based on predefined relevance to IAQ technologies and teacher perceptions. Data extraction from selected studies was standardized to capture key variables and findings related to IAQ levels, technological

interventions, and educational impacts, allowing for a detailed and comparative analysis of the collected data.

After excluding studies outside our specified 2012 to 2024 range to capture recent IAQ technologies and policies,These studies were chosen for their focus on urban environments and detailed pollutant reporting, crucial for assessing IAQ changes and teacher perceptions pre- and post-intervention. I extracted data on CO2, temperature, and humidity levels to identify significant IAQ improvements and explore the relationship between empirical data and teacher assessments. The broader literature review conducted for this study offers a detailed overview of the issues surrounding indoor air quality (IAQ) in California schools and the policies governing it. This review encompassed research on the physiological impacts of poor IAQ on children, the effectiveness of IAQ monitoring and improvement technologies, and the policy landscape affecting IAQ management in educational settings.

Secondary data analysis

In the conducted analysis, data were extracted from the three selected studies focused on indoor air quality IAQ within California's educational settings. The approach entailed a comprehensive analysis strategy designed to elucidate the modifications in IAQ preceding and succeeding the implementation of IAQ improvement technologies, as well as to examine the correlation between these modifications and teacher perceptions.

Following data extraction from this literature, I conducted a descriptive analysis using R. This analysis involved calculating average (mean and median) pollutant levels for both the pre- and post-intervention phases across the selected studies.The relationship between objective improvements in IAQ and subjective teacher perceptions was investigated through correlation analyses. I also used linear models to explore the relationship between changes in pollutant levels and shifts in teacher perceptions of IAQ. Potential moderators or mediators, such as the type of IAQ intervention or external environmental factors, were examined to understand their influence on the strength or direction of these correlations.

Teacher’s Perspectives Survey

To assess the current indoor air quality conditions in schools, a comprehensive survey was developed utilizing the Google Form platform. The survey targeted schools within the Bay Area, San Francisco, where 40 schools in various locations were initially identified. To identify these 40 schools, I used a selection criteria based on a combination of factors including school size, location (urban or suburban), and the socioeconomic demographics of the student population, which could influence the IAQ issues faced by each school. This method ensured a diverse representation of the various potential factors and all data were collected from Google search and school websites.
To recruit participants, I reached out to teachers who could provide insights across different grades and subjects, as they might experience varying IAQ conditions within their school environments. I reached out to potential participants through established educational social media groups and networks, and via direct email, using contacts obtained from school websites. I clearly communicated the survey's objectives, emphasizing the importance of their input to understand and improve IAQ within their schools. The recruitment strategy ensures a representative sample of educators, enhancing the reliability of the survey results.

The design of the survey emphasized brevity and relevance to ensure completion within a 10-minute timeframe, thereby maximizing response rates while capturing essential data on indoor air quality. The survey addressed key aspects such as the overall location and surrounding environment of the school, air smell and freshness, ventilation methods, hours of indoor activity, school guidelines or regulations on ventilation, and the average incidence of student sickness or respiratory discomfort.

I conducted a pilot test involving a subset of 10 schools or teachers to refine the survey before its broader implementation. This preparation was essential to ensure clarity and comprehensiveness, focusing on several key themes: evaluating current ventilation practices, assessing teachers' perceptions of indoor air quality (IAQ) and related health symptoms among students, examining awareness and training concerning IAQ management, and understanding the impact of external environmental factors such as traffic and industrial emissions on IAQ. The survey aimed to gather diverse data to evaluate the existing state of IAQ in schools, the effectiveness of current ventilation strategies, and identify potential areas for policy and intervention improvements. To boost participation, an incentive of $10 was offered to each participant.

Survey Response Analysis

For analyzing survey responses collected from teachers regarding their perspectives on indoor air quality within schools, I used both qualitative and quantitative data analysis techniques Quantitative data extracted from the survey, such as the average hours of indoor activity, hours of ventilation and other measurable responses and calculated for statistical summaries. Descriptive statistics, including means, medians, and standard deviations, were calculated to summarize the central tendencies and dispersion of responses.

In parallel to the quantitative analysis, qualitative data from open-ended survey questions, such as descriptions of the overall location and surrounding environment of the school or specific comments on ventilation methods, were analyzed using thematic analysis. This process involved coding the textual responses to identify recurring themes or patterns. Key themes related to IAQ perceptions, concerns, and suggested improvements were highlighted, providing insights into the subjective experiences and priorities of teachers regarding IAQ.

RESULT

Ventilation Inadequacies in Classrooms

Through literature review, I identified a notable gap in the literature regarding the alignment of policies and available resources with the actual needs for IAQ management in schools. This includes an examination of how current policies support or inhibit effective IAQ practices and the adequacy of resources (such as funding, training, and access to IAQ monitoring tools) provided to teachers and schools. There is a need to explore the existing communication channels and collaborative practices among these stakeholders to identify barriers and facilitators to effective IAQ management.

Across the studies, a common theme emerged regarding the perceived inadequacy of ventilation in classrooms. Sanguinetti et al. (2022) and Chan et al. (2019) both reported that a significant portion of teachers (approximately 65%) felt their classrooms lacked sufficient fresh air, attributing this to issues with HVAC systems such as poor installation, maintenance, and ineffective air mixing. These perceptions were often supported by objective measures, such as CO2 levels,

which provided a quantitative backbone to the teachers' concerns. However, there were interesting contradictions in perceptions, where classrooms perceived as well-ventilated based on teacher feedback often showed poorer ventilation measures, suggesting possible misinterpretations of air quality based on sensory cues or the effectiveness of supplemental strategies like opening doors and windows. These studies also highlighted issues related to thermal comfort, with teachers reporting dissatisfaction primarily due to uneven air distribution, which led to variable temperatures within classrooms. This situation often resulted in discomfort and distraction for students, impacting the overall learning environment. Interestingly, there was a strong negative correlation between satisfaction with air temperature and actual ventilation rates, indicating that increased ventilation could lead to reduced temperature satisfaction, likely due to overcooling or drafts.

Bradman et al.'s findings provided a more detailed look at specific pollutant levels within early childhood education (ECE) facilities. The study found that indoor carbon monoxide (CO) levels and other pollutants were well within safety standards, with overall comfortable and healthy indoor environmental conditions. Additionally, the air exchange rates (AER) in these facilities generally surpassed the minimum standards set by the California Building Code, demonstrating effective natural ventilation, particularly during favorable weather conditions. Studies also considered the role of external environmental factors like traffic and industrial emissions, which can significantly influence indoor air quality. The integration of external air quality measures into the analysis helped elucidate the broader challenges faced by schools in maintaining healthy indoor environments amid varying urban pollution levels.

Thermal Discomfort in Classrooms

In Sanguinetti et al.’s study, school classrooms reported thermal discomfort, attributing it to uneven distribution of air due to poor HVAC "mixing.” Counterintuitively, classrooms where teachers perceived sufficient fresh air from the HVAC system had worse ventilation measures, which could imply misperceptions about HVAC effectiveness or the impact of supplemental ventilation strategies like opening doors and windows. The research mentioned concerns related to thermal discomfort but did not provide specific temperature or humidity measurements. While teachers' satisfaction with air quality did not correlate directly with ventilation rates, there was a strong negative correlation with satisfaction regarding temperature, suggesting that better-ventilated

classrooms experienced less temperature satisfaction due to possibly cooler conditions. Some significant findings indicated that classrooms with frequent "stuffy or stale" or "too humid" complaints in the cooling season had lower peak CO2 levels, suggesting some correlation between perceived air quality issues and measured CO2 levels (Sanguinetti et al.,2022).

Teacher's Perception of IAQ Management and HVAC System

As the primary stewards of classroom environments, teachers' knowledge, attitudes, and practices significantly influence the IAQ and, by extension, the health, well-being, and academic performance of students. Recognizing the importance of this relationship necessitates a closer examination of how teacher training and awareness impact IAQ management practices and outcomes. The extent of teachers' knowledge and training in indoor air quality (IAQ) has a direct impact on their ability to uphold and enhance air quality inside educational environments. The important role that teachers have in recognizing and addressing IAQ issues is highlighted by recent research. Mendell et al. (2013) found a relationship between the frequency of respiratory and concentration problems among students and teachers' reports of IAQ-related symptoms. This suggests that teachers' perceptions of IAQ can act as an early warning system for underlying problems. Similarly, Smedje and Norbäck's (2000) study highlighted the dual effects of IAQ on teachers and students by finding a correlation between teachers' knowledge of IAQ issues and their own health concerns. IAQ-focused training programs can give educators the tools they need to implement actions that drastically lower their exposure to pollutants. According to Shendell et al. (2004), certified educators had a higher propensity to adopt practices that improve air quality, like keeping appropriate ventilation and avoiding the use of hazardous products.

Sanguinetti et al.'s (2022) study explored the correlation between teachers' perceptions of indoor environmental quality (IEQ) and actual ventilation rates. Interestingly, satisfaction with air quality was not directly correlated with measured ventilation rates. However, a strong negative correlation existed between satisfaction with temperature and ventilation rates, indicating that increased ventilation may lead to decreased temperature satisfaction, possibly due to overcooling or drafts. Counterintuitively, classrooms perceived to have adequate fresh air from HVAC systems demonstrated worse ventilation measures. This suggests potential misperceptions about the effectiveness of HVAC systems or the positive impact of supplemental ventilation strategies.

Teachers frequently resorted to opening exterior doors to improve ventilation, despite concerns about safety, energy efficiency, and policy restrictions. This indicates a reliance on manual strategies to compensate for perceived or actual deficiencies in mechanical ventilation. The practice of opening doors was significantly more common among teachers who believed their HVAC systems did not provide sufficient fresh air, suggesting an attempt to manually increase air circulation and fresh air intake (Sanguinetti et al., 2022). Most classrooms allowed some degree of temperature control via thermostats, with teachers expressing a preference for having control over temperature settings. However, frustrations were noted regarding limitations on thermostatic control, especially in terms of adjusting to optimal comfort levels or achieving efficient conditioning. The study mentions that only a small number of teachers had direct control over their HVAC fans, with many systems set to "Auto," meaning the fan operates only when heating or cooling is active. This arrangement often led to issues with achieving continuous ventilation or fresh air intake without altering the room's temperature.

The multifaceted role of air quality monitors is indispensable in the continuous surveillance and management of indoor air quality in preschool settings. These monitors not only serve as an early warning system for the presence of harmful pollutants but also guide the necessary interventions to sustain a safe, comfortable, and health-promoting environment for young learners. In California, IAQ in educational settings, like childcare facilities, are under the advisory purview of the California Department of Education. The guide for educators for IAQ is not binding but only serves to raise awareness about the health risk associated with pollutant exposure in the classroom and recommends procedures.

Practical Challenges in Policies around IAQ Practices

However, on the policy side, most classrooms don’t have access to indoor air quality monitors that inform the inhabitants about the air they are exposed to. Currently, California schools have no clear mandate other than the guide on IAQ for the use of monitoring equipment in educational settings. Without continuous monitoring of indoor air quality in classrooms and standardized policies enforcing monitoring and identifying issues in indoor air quality in specific contexts, it is difficult to ensure that air quality remains within safe limits and provide a systematic approach to improve problematic air quality. The gap in policy around monitoring and

standardizing IAQ in the classroom is notable, considering the susceptibility of children to poor air quality and that IAQ can fluctuate due to a variety of factors in the surrounding that occupants and parents may not be made aware of.

Identifying the sources of indoor air pollution is critical for formulating effective strategies to enhance indoor air quality (IAQ) within educational environments. In a comprehensive study, Fisk et al. (2021) delineated several primary pollution sources in early childhood education settings. These encompass off-gassing from building materials and furnishings, which can release formaldehyde and various volatile organic compounds (VOCs), as well as cleaning agents and air fresheners, which contribute to the heightened levels of VOCs. Additionally, everyday classroom activities, such as arts and crafts, can emit particulate matter and chemical pollutants into the atmosphere. High levels of PM2.5, surpassing recommended concentrations, are frequently observed in naturally ventilated buildings, which depend on windows and vents to circulate fresh air. However, the efficiency of natural ventilation can be heavily influenced by external conditions such as weather patterns and outdoor pollution, particularly in urban localities.

Conversely, mechanical ventilation systems, including air conditioning (AC), while offering more control over indoor environments, are not without their own set of challenges. These systems, if not properly maintained, can become sources of indoor air pollution themselves by distributing airborne pathogens, allergens, and particulates throughout the indoor space (Sundell, 2004). Additionally, the recirculation of air can contribute to the accumulation of VOCs if fresh air intake is inadequate. It's also noteworthy that rural preschools may face distinct IAQ challenges compared to urban centers, with a propensity for higher pollutant concentrations owing to the use of lower quality fuels such as coal and biomass for heating purposes (Mainka et al., 2016; Zhao et al., 2020). Both natural and mechanical ventilation systems possess inherent drawbacks that can impact IAQ.

Survey Responses on Teachers' Perception of IAQ

A total of 17 schools had submitted valid responses to the survey. The teachers' response indicated that their schools were distributed across different cities, including San Francisco, Oakland, Berkeley, Richmond, and El Cerrito (Figure 1). The types of schools varied, highlighting a diverse representation in the study population. The data indicated a balanced mix of school locations, with both urban and suburban environments represented, suggesting a wide range of IAQ challenges and considerations across different settings.

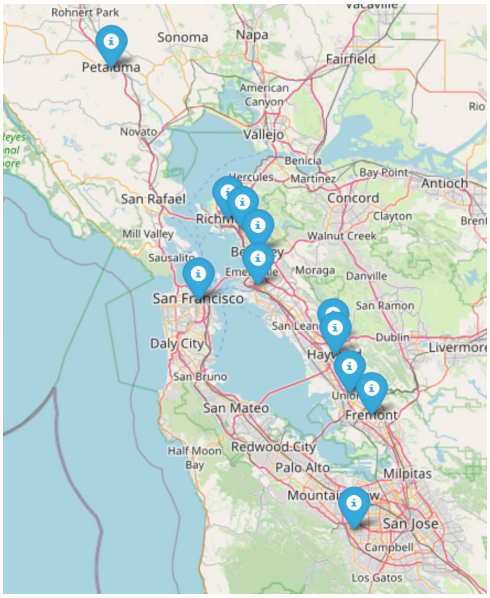

Figure 1. San Francisco Bay Area Map with Survey Collection Locations (Map 13: S.F. Bay Area Interactive, n.d.)

The average amount of time children spent indoors was 4.44 hours, with a median of 4.5 hours. The distribution of responses showed a 1st quartile at 4 hours and a 3rd quartile at 5 hours, indicating that most children spend a significant portion of their school day indoors. The standard deviation of 0.81 hours reflects a moderate variability in indoor time across different schools. The average number of children per classroom was approximately 19, with a median of 20 children. A total of 10 respondents indicated the presence of major traffic around their schools, while 7 respondents did not, pointing to external environmental factors that could influence IAQ. schools located near major traffic sources reported a higher frequency of odor or discomfort, which is a proxy for poor air quality. This suggests that traffic could be a significant factor affecting the air quality within these preschool environments. Schools that reported 'Sometimes' experiencing odor or discomfort also indicated the highest indoor times, averaging around 5 hours per day, which could increase children's exposure to harmful indoor pollutants. (Figure 2)

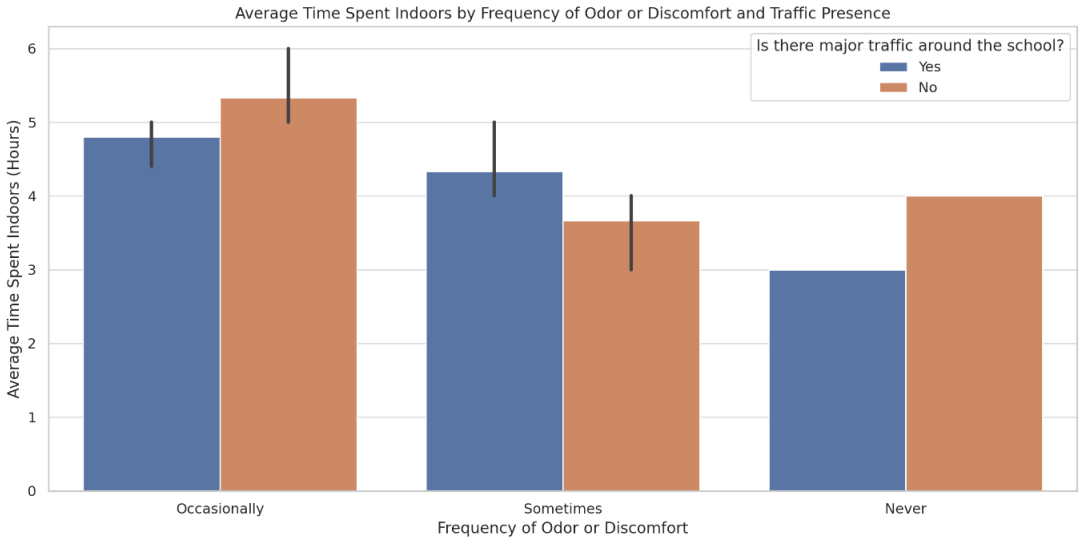

Figure 2. Average Time Spent Indoors by Frequency of Odor or Discomfort and Major Traffic

An equal distribution was observed in responses regarding the existence of IAQ regulations or monitoring procedures within schools, with 10 affirming and 7 denying such measures. This split highlights the inconsistency in policy implementation across different educational institutions. There was a noticeable correlation between the frequency of reported odor or discomfort and the presence of air quality regulations at schools. Schools that had established monitoring or regulatory procedures were less likely to report frequent discomfort, indicating that proactive measures might help in managing or mitigating poor air quality. This was evident as schools with no regulations reported discomfort more frequently, which underscores the importance of formal air quality management practice. (Figure 3)

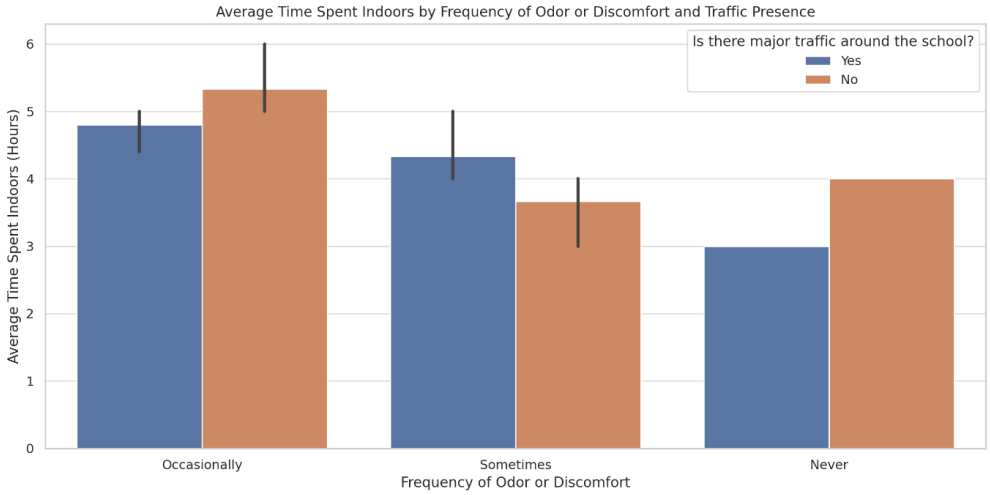

Figure 3. Average Time Spent Indoors by Frequency of Odor or Discomfort and Traffic

Overwhelmingly, 16 out of 17 respondents agreed that schools need more support and resources to improve IAQ in classrooms, with only 1 dissenting. This strong consensus underscores the recognized need for enhanced efforts and interventions to address IAQ challenges effectively. Educators' responses suggest that while some schools have implemented measures to regulate and monitor indoor air quality, including ventilation improvements, there exists a significant portion of institutions where such interventions are either lacking or insufficiently communicated. The presence of major traffic near many schools further exacerbates the need for effective ventilation systems to mitigate external pollutants' infiltration into classrooms.

When asked for comments and suggestions on IAQ issues in classrooms, the answers provided a comprehensive view into the level of concerns, awareness, and perception of IAQ. Many teacher highlighted the necessity of air quality for health and cognitive function, stating, “Ensuring clean air in our classrooms is crucial for keeping our children healthy and attentive.” Teachers also raise questions about resource availability and financial constraints in implementing IAQ improvement practices, “it’s challenging to invest in expensive air filtration systems”. Seasonal variation could also contribute to worser ventilation and IAQ, “ Sometimes, the air does seem a bit stale, especially during winter when windows are mostly closed.”. Teachers in schools that invested in air quality improvements reported positive outcomes, demonstrating the value of practice air quality management, “Our school is pretty up-to-date with air quality measures, and it significantly

improves both staff and children's daily experiences." Overall, the teachers' comments paint a picture of varied levels of concern and awareness about indoor air quality across different school settings. While there is a general recognition of the importance of good air quality, the ability to address it effectively is often hindered by financial and operational constraints.

DISCUSSION

This study delves into the crucial insights from the investigation into indoor air quality and ventilation in California childcare facilities. Our analysis provides an overview of the ventilation systems' efficacy, CO2 levels, and temperature and humidity levels within these educational settings. In addition, I compare important patterns that arise from teachers' survey replies with the results of prior studies to provide a thorough understanding of the consequences and teachers' perceptions of indoor air quality (IAQ), supported by current regulations and practices.

Predominant Pollutants in Childcare Facilities

This study identified specific contaminants that define indoor air quality (IAQ) in childcare facilities, emphasizing the dangers of exposure to children. The key problems highlighted were CO2 levels, ventilation methods, and temperature and humidity. With studies by Bradman (2012), I have set a standard for pollutant levels, emphasizing the crucial importance of focused pollutant monitoring as a fundamental aspect of efficient indoor air quality (IAQ) management. This methodology not only facilitates the identification of urgent concerns but also enables the design of solutions to alleviate them.

The comprehensive analysis of the sources of pollutants provided a dual perspective. One establishes a connection between everyday activities and air quality, and another examines the impact of ventilation and cleaning procedures on the preservation or degradation of indoor air quality. Through the integration of research conducted by Chan et al. (2019) and Bradman (2012), a comprehensive understanding of the complex correlation between routine educational activities and the subsequent air quality can be attained. This underscores the significance of employing comprehensive management approaches that encompass routine cleaning and sufficient ventilation.

Efficacy of Remediation Strategies

The investigation into remediation strategies illustrated the comparative efficacy of different approaches. Significantly impactful interventions were observed in the form of improvements in HVAC systems and the improvement of natural ventilation. The significance of these treatments was further substantiated by the feedback provided by Sanguinetti et al. (2022) about their perceived effectiveness. These observations emphasize the importance of educational institutions giving priority to HVAC maintenance and instruction on proper natural ventilation to provide the best indoor air quality (Mendell et al., 2005).

Continuous Monitoring and Improvement

The results of our study emphasize the importance of ongoing monitoring and the adoption of customized therapies. These metrics are crucial not only for the early detection of indoor air quality (IAQ) issues but also for maximizing the effectiveness of remedial activities. The significant contribution of educators in this process is of utmost importance; their views and subsequent actions, influenced by these perceptions, are crucial in the continuous endeavor to uphold and enhance indoor air quality (IAQ) in childcare facilities.

The Role of Educators

The role of educators in the management and improvement of IAQ in classrooms is vital because of their direct engagement with the conditions that impact students' and teachers' health and performances. As frontline observers and managers of classroom environments, educators have the potential to improve the efficacy of IAQ interventions. Their perceptions of air quality, understanding of its importance, and active involvement and advocation in IAQ improvement practices are crucial for the successful implementation and sustainability of IAQ management strategies. Educators' awareness of indoor air quality (IAQ) concerns and their dedication to resolving them can convert them into proficient proponents for promoting healthier school environments. Advocacy has a crucial role in promoting action inside institutions of higher administration and policy-making. Their perspectives can also inform the creation of more focused

and efficient IAQ enhancement strategies, guaranteeing that interventions are adaptable to the particular requirements and difficulties of their classes.

Teachers' responses from the survey collected underscore a keen awareness of IAQ's significant impact on students' health and learning outcomes. This aligns with the findings of Mendell et al. (2011), who demonstrated that poor IAQ could lead to increased respiratory symptoms, absenteeism, and reduced academic performance among students. The concerns raised by teachers about ventilation adequacy in their classrooms reflect a critical need for improved environmental conditions, emphasizing the role of clean air in fostering a conducive learning environment.

Policy Gap in IAQ Management

The survey response from teachers revealed a notable discrepancy in the existence and implementation of regulations or monitoring procedures for IAQ across schools. Despite the critical importance of IAQ for student health and academic performance, many schools, particularly in California, face systemic barriers that limit the provision of necessary information, resources, and support for teachers and staff to address IAQ issues effectively. This variation in policy application suggests a broader systemic issue, where a lack of standardized IAQ guidelines leads to inconsistent quality of air in educational settings. Fisk et al. (2011) have highlighted the effectiveness of well-implemented IAQ management programs in significantly improving classroom air quality. Therefore, the development and enforcement of comprehensive IAQ policies are imperative for ensuring health protection for all students.

One of the primary policy gaps identified in this study was the lack of consistent, enforceable regulations across the board on IAQ standards. While the California Department of Education provided guidelines for IAQ and safe pollutant measures, these recommendations lack the force of law that is required to ensure compliance. Without enforceable IAQ standards and timely implementation and monitoring of IAQ in classrooms, schools and teachers may struggle to prioritize and implement effective IAQ management practices.

In the survey response, an overwhelming consensus among educators points to a dire need for more support and resources aimed at enhancing IAQ in schools. This gap indicates a broader issue within the educational system where IAQ management is often overlooked in professional

development programs and school budgets. The lack of tragedy training and resources leave the educators inadequate to identify IAQ problems and much less address them. When schools are not enforcing and proactively following up with implementations, teachers are overwhelmed by the already burdened workload and the poor work environment. This finding is crucial, considering the documented effectiveness of interventions such as HVAC improvements and the introduction of natural ventilation strategies in mitigating indoor air pollution (Shendell et al., 2004). The call for increased resources and support reflects a broader issue addressed in the literature, where financial and informational constraints limit the ability of schools to implement necessary IAQ improvements (Chatzidiakou et al., 2015).The provision of financial, technical, and informational resources is essential for enabling schools to implement effective IAQ improvements (Paulson & Barnett, 2016).

From our study surveys, I found that teachers expressed a strong desire to participate and help advocate for IAQ improvement. Many hoped to have access to IAQ monitoring tools that help them track the level of pollutants and help them make judgments on practices to improve IAQ. Tools like portable air quality sensors or integrated systems that provide continuous feedback on IAQ parameters could be invaluable in supporting teachers' efforts to maintain healthy classroom environments. Teachers also seek to have clearer guidelines and policies that specify their roles and responsibilities regarding IAQ management. These guidelines could offer step-by-step actions for common IAQ issues, outline best practices for classroom ventilation, and provide a framework for reporting and addressing IAQ concerns. Moreover, policies that establish minimum IAQ standards for classrooms would help ensure a consistent approach to air quality across all educational facilities.

Though the study provided insights into the perception of educators regarding IAQ in classrooms and their implications for policy and practice improvement, there are many limitations to the research that need future investigation. By fostering an environment that supports the active involvement of educators and ensures the implementation of effective IAQ management practices, I can make significant moves toward safeguarding health and enhancing the learning experiences of students. This cooperation not only underscores the importance of clean air within educational environments but also reaffirms our commitment to creating healthier, more sustainable communities for future generations.

LIMITATIONS AND FUTURE RESEARCH

This study acknowledges some limitations that require additional examination, despite its useful insights into indoor air quality (IAQ) issues in childcare facilities. Firstly, the small sample size may hinder the capacity to extrapolate findings to larger populations or regions. Moreover, the possibility of response bias in survey data presents a possible danger of distorting the perceptions compared to the actual indoor air quality conditions. This highlights the necessity for employing more objective measuring methods.

This research emphasizes the difference between subjective perceptions and objective measurements of indoor air quality (IAQ). This discrepancy requires thorough empirical study in order to provide more accurate information for IAQ management techniques. In order to tackle these problems, future research should prioritize broadening the geographical range of studies to include a diverse range of environmental situations and building types. This would improve the overall applicability of the results.

Furthermore, there is an urgent need for longitudinal research to monitor the long-term effects of indoor air quality (IAQ) on health and educational achievements. Carrying out such studies would offer a more thorough comprehension of the time-related changes in indoor air quality (IAQ) and its impact on the health and welfare of children and educators.

The results of this study have important consequences for public health policy and the management of educational facilities. Establishing a definitive correlation, or determining the absence of one, between instructors' perceptions and real indoor air quality (IAQ) measures can significantly improve the efficacy of IAQ programs. To ensure the effectiveness and responsiveness of interventions in educational settings, policymakers and school administrators should match IAQ methods with the specific needs and concerns of the school community.

This research provides evidence to promote the creation of IAQ policies and practices that are more informed and more sensitive to perception. Therefore, it is imperative to advocate for more stringent indoor air quality (IAQ) regulations in childcare facilities. This is not only necessary to protect the health of children but also to enhance their scholastic achievements. The potential for policy reforms to be implemented at both the state and national levels presents an opportunity to establish standardized procedures for best practices and ensure their consistent application across all educational environments.

To further explore the research around IAQ in schools, here are some future directions: Conducting empirical monitoring of indoor air quality (IAQ) in the schools that participated in the survey will enable direct measurement of pollutants and correlation with the perceptions reported by teachers. This method would facilitate the verification of the subjective data and result in a more precise evaluation of IAQ.

Implementing advanced air quality monitoring systems in educational facilities to detect humidity, temperature, PM2.5, CO2, and VOC levels continuously. The acquisition of real-time data from these instruments would provide invaluable insights into the dynamic and immediate indoor air quality conditions.

Employing a longitudinal study design to examine the effects of seasonal fluctuations in indoor air quality (IAQ) on the perception of air quality by both students and educators. This is critical in order to understand the ways in which variations in the internal and external environments impact IAQ throughout the year.

Incorporating health outcome data into the research framework, such as absenteeism rates attributed to respiratory issues. By incorporating this aspect, the correlation between perceived and measured IAQ would be even more firmly established, providing a tangible foundation for assessing the efficacy of IAQ interventions.

BROADER IMPLICATIONS

This research has more implications for environmental health, public health, and educational policy, among other critical fields. Child health and educational outcomes could be significantly improved through the promotion of improved indoor air quality (IAQ) standards and the prioritization of implementing efficacious IAQ interventions. The importance of interdisciplinary approaches to IAQ improvement cannot be overstated, as their success requires the cooperation of researchers, healthcare professionals, educators, and policymakers. Through these efforts, substantial progress can be achieved in the establishment of secure and health-conscious educational settings for subsequent generations.

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REFERENCES

Anake, W. U., & Nnamani, E. A. (2023). Indoor air quality in day-care centers: a global review. Air Quality, Atmosphere and Health, 16(5), 997–1022. https://doi.org/10.1007/s11869-023-01320-5

California Department of Education. Indoor Air Quality, A Guide for Educators - School Facility Design. [Internet]. [cited 2023 Nov 7]. Available from: https://www.cde.ca.gov/ls/fa/sf/indoorairquality.asp

California Department of Education. Laws, Regulations, & Requirements - Early Education. [Internet]. [cited 2023 Nov 7]. Available from: https://www.cde.ca.gov/sp/cd/lr/

Carroquino, M. J., Posada, M., & Landrigan, P. J. 2012. Environmental Toxicology Environmental impact assessment (EIA)toxicology: Children at Risk Environmental impact assessment (EIA)toxicology children at risk. In Encyclopedia of Sustainability Science and Technology (pp. 3620–3655). Springer New York. https://doi.org/10.1007/978-1-4419-0851-3_35

Chan, W. R., Li, X., Singer, B. C., Pistochini, T., Vernon, D., Outcault, S., Sanguinetti, A., & Modera, M. 2020. Ventilation rates in California classrooms: Why many recent HVAC retrofits are not delivering sufficient ventilation.

Chatzidiakou, L., Mumovic, D., & Summerfield, A. 2015. Is CO2 a good proxy for indoor air quality in classrooms? Part 1: The interrelationships between thermal conditions, CO2

levels, ventilation rates and selected indoor pollutants. Building Services Engineering Research & Technology, 36(2), 129–161. https://doi.org/10.1177/0143624414566244

Cionita, J., Jalaludin, N.M., Adam, N.M., & Siregar, J.P. 2014. Assessment of Children's Health and Indoor Air Contaminants of Day Care Centre in Industrial Area. Iranian Journal of Public Health 43(3):81–.

Deng, Q. & Lau, S.S.Y. 2019. Seasonal variations of indoor air quality and thermal conditions and their correlations in 220 classrooms in the Midwestern United States. Building and Environment 157:79–88. DOI: 10.1016/j.buildenv.2019.04.038.

Fisk, W.J., Chan, W.R., & Mendell, M.J. 2021. Health benefits of particle filtration. Indoor Air, 31(5). DOI:10.1111/ina.12782.

Hoang, T., Castorina, R., Gaspar, F., Maddalena, R., Jenkins, P.L., Zhang, Q., McKone, T.E., Benfenati, E., Shi, A.Y., & Bradman, A. 2017. VOC exposures in California early childhood education environments. Indoor Air 27(3): 609–621. DOI:10.1111/ina.12340.

Johnson, D. L., Lynch, R. A., Floyd, E. L., Wang, J., & Bartels, J. N. 2018. Indoor air quality in classrooms: Environmental measures and effective ventilation rate modeling in urban elementary schools. Building and Environment, 136, 185–197. https://doi.org/10.1016/j.buildenv.2018.03.040

Kapoor, N.R., Kumar, A., Meena, C.S., Kumar, A., Alam, T., Balam, N.B., & Ghosh, A. 2021. A Systematic Review on Indoor Environmental Quality in Naturally Ventilated School Classrooms: A Way Forward. Advances in Civil Engineering 2021: Article ID 8851685. DOI: 10.1155/2021/8851685.

Kim, J.J., Smorodinsky, S., Lipsett, M., Singer, B.C., Hodgson, A.T., & Ostro, B. 2004. Traffic-related Air Pollution near Busy Roads: The East Bay Children's Respiratory Health Study. DOI: 10.1164/rccm.200403-281OC.

Lanphear, B. P., Kahn, R. S., Berger, O., Auinger, P., Bortnick, S. M., & Nahhas, R. W. 2001). Contribution of residential exposures to asthma in us children and adolescents. Pediatrics, 107(6), E98. https://doi.org/10.1542/peds.107.6.e98

Liang, Y., Sengupta, D., Campmier, M. J., Lunderberg, D. M., Apte, J. S., & Goldstein, A. H. (2021). Wildfire smoke impacts on indoor air quality assessed using crowdsourced data in California. Proceedings of the National Academy of Sciences of the United States of America, 118(36).

Liu, H.K., Tang, C.S., & Lin, Y.W. 2023. Preschool teachers' working environmental conditions – a preliminary survey of indoor air quality in North Taiwan. Occupational and Environmental Medicine.

Liu, C., Huang, Y., Hu, Y., Zou, Z., Zhao, Z., & Sundell, J. 2014. Association of building characteristics, residential heating, and ventilation with asthmatic symptoms of preschool children in Shanghai: A cross-sectional study. Indoor + Built Environment 23(2):270–283. DOI: 10.1177/1420326X13516970.

Lovec, T., Premrov, M., & Leskovar, V.Z. 2021. Practical Impact of the COVID-19 Pandemic on Indoor Air Quality and Thermal Comfort in Kindergartens. A Case Study of Slovenia. International Journal of Environmental Research and Public Health, 18(18), 9712–. DOI: 10.3390/ijerph18189712.

Mainka, A., Fantke, P. 2022. Preschool children's health impacts from indoor exposure to PM2.5 and metals. Environment International 160:107062. DOI:10.1016/j.envint.2021.107062.

Mainka, A., Zajusz-Zubek, E., & Kozielska, B. 2016. Concentration of particulate matter from indoor air in preschools - Ventilation system impact. Building and Environment, 98, 55-69. DOI:10.1016/j.buildenv.2015.12.011.

Map 13: S.F. Bay Area Interactive. (n.d.). https://dspace.mit.edu/handle/1721.1/7556

Mendell, M.J., Eliseeva, E.A., Davies, M.M., Spears, M., Lobscheid, A., Fisk, W.J., & Apte, M.G. 2013. Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools. Indoor Air 23(6):515–528. DOI: 10.1111/ina.12042.

Mendell, M. J., & Heath, G. A. 2005. Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. Indoor Air, 15(1), 27–52. https://doi.org/10.1111/j.1600-0668.2004.00320.x

Nishimura, K. K., Galanter, J. M., Brigino-Buenaventura, E., Davis, A., Lenoir, M. A., Meade, K., Rodriguez-Cintron, W., Avila, P. C., Borrell, L. N., Bibbins-Domingo, K., Rodriguez-Santana, J. R., Sen, S., Roth, L. A., Lurmann, F., Balmes, J. R., Burchard, E. G., Oh, S. S., Thakur, N., Nguyen, E. A., ... Kumar, R. 2013. Early-Life Air Pollution and Asthma Risk in Minority Children. The GALA II and SAGE II Studies. American Journal of Respiratory and Critical Care Medicine, 188(3), 309–318. https://doi.org/10.1164/rccm.201302-0264oc

Paulson, J. A., & Barnett, C. L. 2016. Public Health Stops at the SchoolHouse Door. Environmental Health Perspectives, 124(10), A171–A171. https://doi.org/10.1289/EHP530

Sadrizadeh, S., Yao, R., Yuan, F., Awbi, H., Bahnfleth, W., Bi, Y., Cao, G., Croitoru, C., de Dear, R., Haghighat, F., Kumar, P., Malayeri, M., Nasiri, F., Ruud, M., Sadeghian, P., Wargocki, P., Xiong, J., Yu, W., & Li, B. 2022. Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. Journal of Building Engineering, 57, 104908-. https://doi.org/10.1016/j.jobe.2022.104908

Sanguinetti, A., Outcault, S., Pistochini, T., & Hoffacker, M. 2022. Understanding teachers' experiences of ventilation in California K-12 classrooms and implications for supporting safe operation of schools in the wake of the COVID-19 pandemic. Indoor Air, 32(2), e12998--n/a. https://doi.org/10.1111/ina.12998

Sadrizadeh, S., Yao, R., Yuan, F., Awbi, H., Bahnfleth, W., Bi, Y., Cao, G., Croitoru, C., de Dear, R., Haghighat, F., Kumar, P., Malayeri, M., Nasiri, F., Ruud, M., Sadeghian, P., Wargocki, P., Xiong, J., Yu, W., & Li, B. (2022). Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. *Journal of Building Engineering*, *57*, 104908-. https://doi.org/10.1016/j.jobe.2022.104908

Satish, U., Mendell, M. J., Shekhar, K., Hotchi, T., Sullivan, D., Streufert, S., & Fisk, W. J. 2012. Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance. Environmental Health Perspectives, 120(12), 1671–1677. https://doi.org/10.1289/ehp.1104789

Shendell, D. G., Prill, R., Fisk, W. J., Apte, M. G., Blake, D., & Faulkner, D. 2004. Associations between classroom CO2 concentrations and student attendance in Washington and Idaho. Indoor Air, 14(5), 333–341. https://doi.org/10.1111/j.1600-0668.2004.00251.x

Smedje, G., & Norback, D. 2000. New ventilation systems at select schools in Sweden - effects on asthma and exposure. Arch. Environ. Health, 55, 18-.

Steiner, A. L., Tonse, S., Cohen, R. C., Goldstein, A. H., & Harley, R. A. 2006. Influence of future climate and emissions on regional air quality in California. Journal of Geophysical Research - Atmospheres, 111(D18), D18303-n/a. https://doi.org/10.1029/2005JD006935

Sun, C., Cai, G., Liu, W., Zou, Z., & Huang, C. 2021. Thermal comfort in residences related to respiratory diseases among preschool children in Shanghai. Energy and Buildings 236:110729. DOI:10.1016/j.enbuild.2021.110729.

Sundell, J. 2004. On the history of indoor air quality and health. Indoor Air, 14(Suppl 7), 51–58. DOI:10.1111/j.1600-0668.2004.00273.x.

Ulpiani, G. (2021). On the linkage between urban heat island and urban pollution island: Three-decade literature review towards a conceptual framework. The Science of the Total Environment, 751, 141727–141727. https://doi.org/10.1016/j.scitotenv.2020.141727

Wargocki, P. & Wyon, D.P. 2013. Providing better thermal and air quality conditions in school classrooms would be cost-effective. Building and Environment 59:581–589. DOI: 10.1016/j.buildenv.2012.10.007.

Yoon, C., Lee, K., & Park, D. 2011. Indoor air quality differences between urban and rural preschools in Korea. Environmental Science & Pollution Research International 18(3):333-45.

Zhao, B., Li, X., & Yan, Q. 2020. Comparative analysis of indoor air quality in rural and urban preschools in upper Silesia, Poland. Environmental Research, 183, 109173. DOI:10.1016/j.envres.2020.109173.