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Review

Indoor Environmental Quality, Pupils' Health, and Academic Performance—A Literature Review

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Abstract: Classrooms have more students per square meter than other buildings such as offices, making them more crowded. In addition, children respire more than adults and are in contact with one another more often. For appropriate student comfort, wellbeing, and health, including reducing the risk of transferring communicable diseases (for example, COVID-19) in the school setting, adequate ventilation and thermal comfort is recommended, along with regular cleaning, especially of high-contact surfaces. However, this may lead to increased energy usage, especially in mechanically ventilated schools. While natural ventilation conserves energy, its usage may be limited in temperate regions, especially during the cold seasons, as more energy will be required for heating in order to achieve thermal comfort. In the tropics, natural ventilation alone may be insufficient for students' thermal comfort due to the possibility of unconditioned warm or cold outdoor air entering the classroom environment. Additionally, natural ventilation is difficult to control, as there may be overventilation or underventilation due to the ventilation rate being dependent on the outdoor environmental condition such as windspeed. This current traditional literature review appraises previous indoor environmental quality (IEQ) literature on ventilation, thermal comfort, moisture and mold, and cleanliness in schools. Furthermore, a further review was performed on the effect of IEQ (indoor air quality and thermal comfort) on student health and academic outcomes in order to summarize existing knowledge that can help other researchers avoid research duplication and identify research gaps for future school IEQ studies.

Keywords: school; ventilation; thermal comfort; mold and moisture; cleanliness; indoor environmental quality

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1. Introduction

Primary school education is essential for children; this basic education is compulsory for all children in most countries of the world and requires them to spend several hours in schools. It is important to investigate the school environment, to know what might affect students' learning, health, and wellbeing. Pupil health encompasses the physical, mental, and emotional well-being of students, which is vital for optimal learning and personal development, while academic performance pertains to a student's attainment and accomplishments in educational pursuits, encompassing their grades, test results, engagement in class, and overall grasp of the curriculum [1].

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Indoor environmental quality (IEQ) relates to the conditions that exist within a building; these include indoor air quality (IAQ), thermal conditions, visual (e.g., lighting) and aural (e.g., noise) comfort, and their potential effects on building occupants [2–6]. These factors can act independently or synergistically on students to cause an effect. For example, it is possible for high indoor temperature alone to cause thermal discomfort [7], and a combination of high indoor temperature and inadequate ventilation can, together, cause thermal discomfort [8]. In addition, studies have shown the effect of temperature, humidity, and air velocity on volatile organic compound (VOC) emissions (e.g., [9,10]). In a study by Tippayawong et al. [11], outdoor pollutants were found to extensively affect the concentration of indoor pollutants, especially in naturally ventilated school buildings (where air cleaning by filters is limited or not possible), with indoor/outdoor pollutant ratios sometimes being close to unity. The study found that the interacting factors influencing classroom IEQ include ambient conditions, building structure and materials, ventilation, and indoor activities. According to Cartieaux et al. [12] and Kapoor et al. [13], a combination of factors (physical, chemical, and biological) may affect classroom IEQ. The site of a school is another principal factor affecting school IEQ. Godoi and colleagues [14], in their Brazilian study, reported a higher prevalence of particulate matter (PM) in urban schools due to vehicular emissions from nearby highways. Similarly, in line with these findings, Zhang et al. [15] revealed that Beijing's primary schools are contaminated with pollutants such as ozone (O_3), $PM_{2.5}$, and PM_{10}, primarily due to their close proximity to heavy traffic and coal combustion sources. Outdoor pollutants can infiltrate indoor spaces through doors, windows, cracks, and other openings in the building envelope. In some cases, the level of pollution inside school buildings has been found to be higher than the levels outside [16,17]. In addition to the outdoor environment, factors affecting classroom IEQ include furnishing used in the school building, heating ventilation and air conditioning (HVAC) systems, other equipment such as printers, and human activities [18–20].

This current work aims to review literature on school IEQ with a focus on ventilation, thermal comfort, cleanliness, moisture, and mold, with a further appraisal of the effect of IEQ (thermal comfort and IAQ) on students' health and academic outcomes. Another aim of this review is to empower researchers to effectively identify areas that require their attention in future school IEQ research. This will help prevent redundant research efforts and the waste of valuable time and limited resources.

2. Methods

Several literature sources were retrieved from online repositories on classroom IEQ parameters, such as ventilation, thermal comfort, moisture and mold, and cleanliness. The IEQ parameters were critically reviewed, and discussions were had regarding their influence on the school environment, including their effects on students' health and learning outcomes.

Since this paper is a traditional literature review, a systematic approach was not employed for article retrieval [21]. Therefore, the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines were not utilized for article selection. The PRISMA approach is commonly employed in systematic reviews and evidence-based practices when a thorough and organized methodology is required to evaluate existing literature pertaining to a specific research question. In contrast, a traditional literature review primarily focuses on providing a comprehensive overview and synthesis of the existing literature on a particular topic, without adhering to the rigid protocols and guidelines of a systematic review. In a traditional literature review, the emphasis lies in summarizing and discussing key findings, themes, and arguments present in the literature, rather than strictly adhering to a predetermined methodology [21]. While the absence of the PRISMA format for article selection could be considered a significant limitation of this paper, it is worth noting that a robust review was conducted, encompassing over 160 scientific papers. Additionally, there were no restrictions placed on the type or age of the articles reviewed.

3. Results and Discussion

3.1. Ventilation and IEQ in Schools

Ventilation involves the removal of noxious indoor air and the supply and distribution of fresh (outdoor) air into the indoor environment. Ventilation is important for ensuring a favorable IEQ as it dilutes and removes pollutants, odors, and excessive moisture, while providing occupants with fresh air to breathe [20,22–26]. Ventilation is achieved through the implementation of various types of ventilation systems, including natural ventilation, mechanical ventilation, or a combination of both, known as hybrid/mixed-mode ventilation.

Natural ventilation relies on outdoor wind conditions and thermal buoyancy to direct air into a building through specifically designed openings, such as trickle ventilators, doors, and windows [27–29]. This implies that minimal or no electrical energy is required during its operation [29,30]. This reduces the energy cost associated with the day-to-day operation of buildings, especially public facilities like schools, resulting in potential savings of up to 30% of total energy [28] and a remarkable 78% reduction in cooling energy [31]. This invariably promotes environmental sustainability, as the system emits a limited amount of carbon dioxide (CO_2) and requires only a small space for its operation [31]. The system, however, has its drawbacks, including a reliance on outdoor wind speed to ensure ventilation adequacy [32,33], sensitivity to climatic conditions affecting thermal comfort and ventilation rates [30,34,35], and its inability to condition outdoor air before introducing it indoors due to the lack of temperature and humidity control [28]. Additionally, they might introduce raw outdoor air with high (in tropical climates) or low (in temperate climates) levels of temperature, humidity, and particle loads, while offering less control over the airflow rates [36,37]. Mechanical ventilation comes in two forms: a mechanical exhaust-only ventilation system, where polluted or spent air is extracted mechanically while fresh air is introduced naturally into the indoor environment; or a mechanical supply and exhaust ventilation system that employs mechanical systems for both introducing fresh air and removing polluted air [38,39]. The use of mechanical systems helps increase ventilation rates, and they can be designed or adjusted to deliver a specific flow rate. Such systems can also include options for conditioning and purifying incoming air with cooling, dehumidification, and filtering equipment. However, it is important to note that mechanical ventilation is associated with energy consumption, which comes at a cost [25]. Another challenge with the use of mechanical ventilation in schools is the need for ongoing maintenance and adequate control by specialists to ensure that the required classroom ventilation rate is consistently met [40,41].

A hybrid or mixed-mode ventilation system combines both natural and mechanical ventilation, where mechanical ventilation is utilized only when natural ventilation falls short of meeting the required standards [42]. Ji et al. [43] suggested that employing hybrid ventilation in buildings is a practical approach to attaining a desirable IEQ while minimizing energy consumption. Additionally, some studies have associated mechanical ventilation with a higher incidence of sick building syndrome (SBS) [44,45]. SBS might not be as prevalent in naturally ventilated rooms, where a continuous exchange of outdoor and indoor air occurs. Mechanical ventilation systems that recirculate air can contribute to an increase in indoor microorganisms and other pollutants [45]. Additionally, they may also have dirty or contaminated units, such as those with as mold and bacteria growth in vent pipes. However, some other research has concluded the opposite. For example, Wallner et al. [46] found that mechanically ventilated rooms had an overall better IEQ when compared to naturally ventilated rooms. Additionally, Yang et al. [47] recommended the use of a mechanical ventilation system to improve ventilation rates in schools for better classroom IEQ. In another study, classrooms with natural ventilation exhibited poor air quality due to inadequate ventilation, resulting in a high concentration of CO_2 [48]. The study found that ventilation adequacy was linked to the type of ventilation system, with mechanical supply and exhaust ventilation systems exhibiting the highest ventilation rates.

In a Finnish school study by Toyinbo et al. [19], none of the classrooms with natural ventilation and mechanical exhaust-only ventilation systems met the Finnish building code ventilation rate of 6 L/s per student. Meanwhile, 52% of the schools with a mechanical supply and exhaust ventilation system type met the recommendation. In a Netherlands intervention study, classrooms that relied on natural ventilation had their IEQ improved with a CO_2-controlled mechanical ventilation system. After the intervention, the average classroom CO_2 concentration decreased from 1335 ppm (range: 763–2000 ppm) to 841 ppm (range: 743–925 ppm) [49]. Improving ventilation comes at a cost, but the resultant benefit of enhanced ventilation may outweigh the amount paid in terms of improved health outcomes, productivity, and reduced absenteeism.

Physical, biological, and chemical factors, as well as ventilation and the extent of human activities, all act to contribute to the levels of pollution in any given indoor environment [47]. A high concentration of CO_2 in classrooms reflects inadequate ventilation [50,51]. The number of occupants in a building has been associated with CO_2 concentration. For example, a school study by Scheff et al. [52] found a continuous relationship between classroom occupancy and CO_2 concentration; there was an increase in CO_2 concentration associated with high occupancy. Indoor CO_2 concentration is related to outdoor concentration and the metabolic CO_2 exhaled by occupants [53,54]. The concentration of CO_2 in exhaled air is 100 times that of inhaled air [55]. Occupant-generated CO_2 may sometimes result in indoor CO_2 concentrations exceeding the outdoor levels, especially in highly occupied buildings such as schools [50,56,57].

A common 'rule of thumb' has been to keep the indoor CO_2 concentration below 1000 ppm (e.g., [58]). While CO_2 concentrations lower than 5000 ppm are not associated with direct health effects, ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) Standard 62.1 [59] associates CO_2 levels greater than 700 ppm above outdoor air levels (i.e., usually around 1000 ppm) with inadequate ventilation in terms of the removal of human bio-effluents (body odors). This can result in dissatisfaction among the people entering such rooms. Improving ventilation reduces indoor CO_2 levels [49,51], and the higher the CO_2 concentration indoors, the lower the ventilation rate per student. Some countries have recommended ventilation rates for classrooms. For example, the ventilation rate recommendation for classrooms in the U.S. (United States) is about 7.1 L/s per person [59], while that for Finnish schools is 6 L/s per person [60,61]. The ventilation recommendations for classrooms for some countries is based on classroom CO_2 concentration. The recommended limit for indoor CO_2 is 700 ppm above the outdoor level in Singapore [62]. Further information regarding ventilation, temperature, and other IAQ parameters for various countries can be found in the summaries provided by Toyinbo et al. [63] and Dimitroulopoulou et al. [64]. In addition, some countries only gave recommendation on how best to construct classrooms for better ventilation. For example, the National Building Code of Nigeria [65] suggests positioning windows directly opposite each other to facilitate cross-ventilation and ensure adequate airflow.

Ventilation has been found to be inadequate in many classrooms [18,51,66,67]. This may be due to overcrowding, ventilation system type, climatic condition, and school building type. A study of Hong Kong schools by Lee and Chang [68] found that CO_2 levels in some classrooms exceeded 1000 μL/L (ppm) for air-conditioned/ceiling fan classrooms and reached 5900 μL/L in classrooms with cooling tower ventilation system; these numbers are more than ASHRAE recommended levels. The study found overcrowding of classrooms and the inability to adhere to ASHRAE standard 62 [69], classroom occupancy of 50 person/100 m^2, as the probable cause of ventilation inadequacy. In a British primary school study, over 75% of classrooms had CO_2 concentrations that exceeded ASHRAE recommendations [70]. Another study by Ferreira and Cardoso [71] found classroom CO_2 concentration to exceed recommendations of the Portuguese legislation of 984 ppm, with some classrooms exceeding 5000 ppm.

A review of ventilation rates in elementary school classrooms conducted by Batterman [50] reveals that ventilation is often insufficient during school days, with measured values falling below the minimum recommendation of 7.1 L/s/person in U.S schools. Haverinen-Shaughnessy et al. [66] found that 87% of the studied classrooms had ventilation rates lower than the recommended levels. Gaihre et al. [70] proposed continuous CO_2 monitoring in classrooms to enable ventilation adjustments whenever classroom CO_2 concentrations exceed acceptable limits.

3.2. Thermal Comfort and IEQ in Schools

Thermal comfort relates to how people feel about the thermal conditions of their environment [72]. ASHRAE standard 55 [73] defines thermal comfort as a state of mind regarding a person's thermal environment. In a typical application of the standard, it recommended that at least 80% of building's occupants should feel thermally satisfied with their thermal environment, while 90% satisfaction is encouraged when a higher level of thermal satisfaction is desired in indoor spaces. According to Fanger [74] and Daghigh [75], six factors can influence people's responses to their thermal environment: air temperature, mean radiant heat, air velocity, relative humidity, clothing thermal resistance, and metabolic rate. Thermal comfort is also influenced by factors such as the seasons of the year and location, age, gender, and individual adaptive characteristics [76,77]. Given the amount of time students spend in schools and the impact of thermal conditions on health and performance, ensuring their thermal comfort is essential [78,79].

Thermal comfort is closely linked to ventilation adequacy, particularly in temperate regions where energy-efficient buildings with tight construction are common. Increased ventilation has been shown to result in lower indoor temperatures, thus contributing to the thermal comfort of building occupants [75,80]. Ventilation with air conditioning appears to influence thermal comfort in the tropics rather than just adequate ventilation. This is because warm unconditioned air can be introduced into the indoor space, making students uncomfortable. A Nigerian school study confirmed this. In the study, most of the investigated classrooms had adequate ventilation, judging by their CO_2 concentration level. However, the lack of proper thermal insulation against solar radiation and the introduction of warm, unconditioned outdoor air into the classrooms adversely affected the thermal comfort experienced by the students [37].

Mechanically ventilated and air-conditioned rooms offer improved thermal comfort for occupants compared to naturally ventilated rooms [35,75,81]. This is primarily because controlling and adjusting natural ventilation systems can be challenging due to their dependence on outdoor wind speed and weather conditions [36,75]. For instance, a study conducted by Yang and Zhang [82] demonstrated that naturally ventilated rooms often fail to provide sufficient comfort to occupants and do not meet the recommended standards set by ASHRAE Standard 55. Similarly, Indraganti's study [83] found that 60% of building occupants expressed thermal discomfort in naturally ventilated rooms. Even when Prajongsan and Sharples [84] improved natural ventilation in their study, thermal comfort only increased from 38% to 56%, which still fell short of the ASHRAE recommendation. Another study by Lu et al. [72] showed that 76% of respondents in naturally ventilated buildings preferred a cooler environment. Daghigh et al. [85] achieved thermal comfort, meeting ASHRAE Standard 55 in mechanically ventilated rooms, but the results changed when natural ventilation was substituted for mechanical ventilation in the same space. According to Brittle et al. [42], a hybrid ventilation system provides enhanced comfort and enables energy savings ranging from 21% to 39%.

Lu et al. [72] recommended that the upper limit of acceptable indoor temperature for naturally ventilated buildings should be 30.6 °C. Andersen and Gyntelberg [86], in their review, suggested indoor temperatures below 24 °C for 85% of building occupants to achieve thermal comfort. For classrooms, Andersen and Gyntelberg [86] recommended an indoor temperature not exceeding 23 °C in order for students to function well. A similar set point (classroom temperature of 20–22 °C) was also recommended by Salthammer et al. [87]. On the other hand, Schiavon et al. [88] suggested that indoor temperatures between 26 °C and 29 °C would lead to better performance. The lowest health-based recommendation for indoor temperature is usually 18 °C [89].

Unfavorable thermal conditions in the classroom can have adverse effects on students [90,91]. Studies have shown that temperatures above or below the comfort level may affect students' health and learning outcomes (e.g., [91,92]). Due to this, there is the need to constantly maintain and upgrade HVAC systems in school buildings. The impact of this can be immediately felt, as reported by Almeida and de Freitas [93]. In their study, students felt better after an extensive renovation of their school HVAC, which lowered their classroom CO_2 concentration as well as the indoor temperature. The result is similar to that from Toyinbo et al. [19], where an upgrade to the school HVAC was negatively significantly associated with classroom temperature.

3.3. Moisture and Mold in Schools

It is believed that the operation and maintenance of school facilities are often not funded as adequately as other types of buildings, such as offices. This lack of funding may lead to persistence of environmental problems [94,95]. Insufficient maintenance can result in the deterioration of building materials and systems, leading to failures in moisture control. Furthermore, school buildings may have areas that are prone to leaks, causing moisture damage that can contribute to the growth of microbial organisms [96–98]. A school study conducted by Cho et al. [99] found that classrooms with recent water leakage exhibited higher levels of dampness compared to those with only previous or no history of leakage. The study also found a linear association between dampness and the presence of culturable bacteria, with 63% of the examined classrooms exhibiting both dampness and mold. In a Danish study, moisture damage was reported in 49% of the sampled schools [100], while similar problems were identified in 20%, 41%, and 24% of schools in three other European countries (the Netherlands, Spain, and Finland, respectively) [97]. Additional investigations of schools in the Netherlands, Spain, and Finland revealed a high prevalence of microbial secondary metabolites in damp schools [101] and reported respiratory health symptoms among school children [102,103]. Table 1 shows a summary of some school study results conducted on moisture and mold in school buildings.

Table 1. Summary of results from school studies conducted on moisture and mold.

Reference	Summary of Result
[99]	Classrooms with recent water leakage are damp. There was a linear association between dampness and culturable bacteria, with 63% of the classrooms examined having dampness and mold.
[100]	Moisture damage was found in 49% of sampled Danish schools.
[98]	Moisture damage in schools is associated with microbial growth. Schools with timber-frame construction were majorly in need of moisture and mold damage repair.
[104]	Inadequate school maintenance can result in moisture damage of the school structure.
[105]	Effective ventilation and cleaning guard against moisture and mold growth risk.

The materials used in school buildings can also influence the occurrence of moisture and mold growth. For instance, in a study involving 32 Finnish schools—17 constructed with wood and 15 with concrete—it was observed that airborne fungal concentrations were higher in schools built with wood compared to those constructed with concrete [106]. While indoor fungi were detected in all schools with wooden frames (5 to 948 cfu/m^3), the concentrations of fungi were at times undetectable in certain concrete school buildings (<2–5 cfu/m^3 to 507 cfu/m^3). Concrete tends to exhibit better moisture resistance than wooden frames, which are susceptible to microbial degradation, including wood rot [107,108]. A study conducted by Annila et al. [98] highlighted that the highest number of public buildings in need of urgent repair due to moisture and mold damage were those featuring timber-frame ground floors, including schools.

Although relative humidity was higher in buildings with high fungal concentration, moisture damage in the school buildings commonly resulted from inadequate maintenance, as well as from mistakes made during construction [104,106]. After proper renovation of moisture-damaged parts in schools, the concentration of mold usually reduces [109]. Another school study reported a decrease in health symptoms among students following remediation of a moisture-damaged school building [110].

While effective moisture control during building construction and operation is crucial to preventing the deteriorative effects of moisture damage and mold growth on indoor air quality [111–113], another important mechanism that helps to reduce such risks include effective ventilation and cleaning strategies [105]. Effective ventilation plays a critical role in diluting and ultimately removing indoor microbes such as mold and bacteria [114,115].

Additionally, thorough cleaning of indoor mold after addressing the root cause of moisture issues, such as plumbing leaks, can help minimize its presence [105].

3.4. Cleanliness in Schools

Cleaning and hygiene involve the removal of unwanted substances from the school environment. These unwanted substances may include noticeable dirt on surfaces, such as students' desks, and disinfecting high-contact objects, such as toilet seats and doors, which may be contaminated with pathogenic microorganisms. It also includes hand washing practices and other forms of sanitation among students and school staff, such as proper waste disposal in schools, eating in the cafeteria, and the use of functioning toilets. Classrooms are usually more crowded than other occupied spaces (such as offices); hence, students meet one another more often. Therefore, it is important that their school environment is clean and that hygiene is enhanced to avoid the start and exacerbation of diseases or their spread. Table 2 shows a summary of some school study results on cleanliness in schools.

Table 2. Summary of results from school studies conducted on cleanliness.

Reference	Summary of Result
[116]	A total of 10% of schools studied in rural India had drinking water problems, while 40% and 50% had waste disposal problems and toilet problems, respectively.
[117]	In a study in Bangladesh, 18 to 95 students shared one toilet, 36% of the schools studied had proper sanitation, and 47% had handwashing points.
[118]	There was lack of water and proper cleaning. Inadequate toilet systems made students prefer open defecation.
[119,120]	Ineffective classroom cleaning was related to absenteeism.
[121]	Improper cleaning of high-contact surfaces in schools was related to students' weekly absences from school due to gastrointestinal illness.
[122,123]	Improved sanitation was associated with a reduction in disease transmission.

Studies have found that defects in cleanliness and hygiene in schools are common worldwide. For example, about 90% of schools studied in rural India were overcrowded, only 10% had access to hand washing points, 10% had drinking water problems, and up to 40% and 50% had waste disposal problems and toilet problems, respectively [116]. In a study in Bangladesh, 18 to 95 students had to share one toilet, while only 36% and 47% of the studied schools had proper sanitation and handwashing points, respectively [117]. Xuan et al. [118] found a lack of proper school sanitation in their Vietnam school study. They observed a student preference for open defecation due to inadequate and ineffective toilet systems, as well as lack of water for proper cleaning. Improved school hygiene was also recommended in a Nigerian school study by Toyinbo and colleagues [37], where most of the schools studied had limited functioning plumbing and toilet systems. Joshi and Amadi [124] found, in their literature review, that 73% of school studies performed on sanitation focused on developing countries, with 53% being performed in rural communities. A more recent review by McMichael [125] supported this assertion, highlighting the continued prevalence of this focus. This trend is attributed to inadequate school sanitation funding in developing countries, as described by Alexander et al. [126].

Water, sanitation, and hygiene (WASH) are extremely important in schools. The lack of adequate sanitation may encourage the transfer of infectious diseases, including COVID-19, while improving sanitation was associated with a reduction in disease transmission [122,123]. According to a review by Annesi-Maesano et al. [119], dirty classrooms was related to absenteeism. Comparable results were seen in the work of Hammond et al. [127] and Wang et al. [120]. Annesi-Maesano et al. [119] reported the rate of infections leading to absenteeism was reduced by up to 55% in two years after a cleaning intervention. A recent longitudinal study by Shaughnessy et al. [121] found adenosine triphosphate (ATP) levels that indicate improper cleaning of high-contact surfaces in schools to be related to students' weekly absences from school because of gastrointestinal illness. Hammond et al. [127] reported reduced student absenteeism by 20% after sanitation intervention, while Wang et al. [120] reported reduced absenteeism related to gastrointestinal illnesses following a hand washing intervention. A systematic review of literature on school sanitation by Jasper and colleagues [128] reported an increased rate in female students' absenteeism during menstruation due to sanitation problems in school. It also found that adequate sanitation led to a reduction in parasitic infections causing gastrointestinal illness in students. An intervention study in which students were trained on the importance of cleanliness and health promotion made students engage in a cleaner, friendly approach in schools, including more hand washing practices and the use of toilets [129].

An intervention study [130] on WASH found an increased risk of Escherichia coli contamination among students (RR (relative risk) = 2.63, 95% CI (Confidence Interval) = 1.29–5.34 for girls and RR = 1.36, 95% CI = 0.74–2.49 for boys). Students in the intervention school group used toilets more than those in the control group during the study, but with insufficient hygiene behavior, which may be due to improper management. Chatterley et al. [117] suggested that adequate funding for sanitation through interventions should be combined with proper management of school facilities and regular supervision. When Lau et al. [131] repeatedly instructed students on effective hand washing in a hygiene intervention study, illness related absence and total absence from school was reduced when compared with students from schools not given repeated instructions. Another intervention study [132] which offered treatment to students before intervention, found that the prevalence of re-infection of students with soil-transmitted helminths was reduced after the intervention (OR (odd ratio) = 0.34, 95% CI 0.31–1.00). A meta-analysis on WASH and soil helminth infection [133] also found improved sanitation to be related to a corresponding decrease in soil-transmitted helminth infection (OR 0.66, 95% CI 0.57–0.76). Also, PM levels in classrooms reduced significantly due to intensified cleaning [134,135]. Additionally, cleaning activities in classrooms may also pose a source of pollution for students when not executed correctly. It is recommended that classroom cleaning activities take place after lessons, when students are not present, or a few hours prior to students being allowed to enter the classroom [136].

3.5. Effects of IEQ (Thermal Environment and Indoor Air Quality) on Students' Health Outcomes

IEQ in schools has been identified as a major influencing factor on students' health outcomes. Apart from their homes, students spend quality time in their classrooms, where they are exposed to their school environment, which studies have shown to be related to their health. This, in part, is due to their inability to fully understand their environment and what might affect it (such as students not knowing the importance of desk cleaning). They are not able to effectively influence decisions concerning their school environment, they have developing organ systems (digestive, respiratory, nervous, and reproductive), breathe more air per body size ratio in comparison to adults, and have a weak immunity that is sensitive to pathogens and other pollutants [137,138]. Therefore, it is important to pay attention to the factors that affect students' health. Table 3 shows a summary of some school studies conducted on IEQ and students' health.

Table 3. Summary of school studies conducted on IEQ and students' health outcomes.

Reference	Study Population	IEQ Parameters Studied	Health Outcomes/Effect
[139]	108 schools (401 classrooms) with 6590 pupils in France.	Formaldehyde, $PM_{2.5}$, Aldehyde acrolein, Nitrogen dioxide (NO_2).	Rhino-conjunctivitis was associated with high concentration of formaldehyde (OR 1.19; 95% CI 1.04 to 1.36). The prevalence of asthma was associated with high concentration of $PM_{2.5}$ (OR 1.21; 95% CI 1.05 to 1.39), aldehyde (OR 1.22; 95% CI 1.09 to 1.38), and NO_2 (OR 1.16; 95% CI 0.95 to 1.41).
[140]	8 schools (23 classrooms) with 1014 pupils in Sweden.	Microbial volatile organic compounds (MVOCs), plasticizers.	Wheezing, daytime breathlessness, nocturnal breathlessness, and asthma associated with MVOCs (e.g., Isobutanol) OR 2.74 (0.71–10.57), 2.05 (0.30–13.87), 7.23 (0.60–87.16) and 1.43 (0.35–5.87), respectively.

Table 3. *Cont.*

Reference	Study Population	IEQ Parameters Studied	Health Outcomes/Effect
[141]	10 schools (30 classrooms) with 1414 students in China.	Mold, temperature, CO_2, NO_2, O_3, CH_2O	Asthma attacks associated with mold (OR 2.40: $p < 0.05$). Daytime breathlessness associated with temperature (OR 1.26: $p < 0.001$). Current asthma associated with CO_2 (OR 1.18 for 100 ppm: $p < 0.01$) and NO_2 (OR 1.51 for 10 μg/m^3: $p < 0.01$)
[142]	28 schools (162 classrooms) with 45,000 students in U.S.	Ventilation rate	Students' illness absences increases with a reduced ventilation rate/student that is below California standard (7.1 L/s-person).
[67]	51 schools (81 classrooms) with 1019 students in Portugal.	IEQ (T, RH, CO, CO_2, O_3, etc.)	A total of 2.2% of students had chronic bronchitis ($p > 0.05$), 15.2% had wheezing ($p > 0.05$), 26.1% had sneezing attacks ($p > 0.05$), 18.9% had rhinitis ($p > 0.05$), 16.1% had coughs ($p > 0.05$), and 10.1% had breathing difficulties ($p > 0.05$).
[143]	8 schools (8 classrooms) with 252 students	Temperature	97%, 97%, and 94% of students were tired, lost concentration, and were sleepy due to thermal discomfort.
[121]	34 schools with 15,814 students	ATP as a measure of high contact surface contamination	ATP levels increased the probability of students being absent from school due to gastrointestinal illness (parameter estimate 0.91 (0.84–1.00) $p = 0.04$).

Students' health is affected by the many contaminants that can exist in their classrooms [144,145]. These contaminants may be physical, chemical, or biological in nature, such as particulate matter (PM), VOCs, and mold, respectively [119,146–148]. These can be generated indoors: for example, mold growth is associated with moisture damage [100,149] and VOCs with emissions from building materials [150–152]. They can also originate from outdoor sources when schools are built near pollution sources, such as incinerators and power plants. For example, Brazilian schools that were closed to potential sources of pollutants such as vehicular traffic and petrochemical plants had high concentrations of pollutants such as PM and VOCs [14]. Exposure to these agents may cause or exacerbate pre-existing health conditions, as presented in the following.

A multi-country school exposure study by Adams et al. [153] linked both bacteria and mold in classrooms to moisture-damaged schools that resulted in health effects for students. Students who were exposed to microbial contamination (bacterial and fungi) in their classrooms due to moisture damage experienced respiratory symptoms that affected their health outcomes. The study by Mi et al. [141] found an association between indoor mold in classrooms and asthmatic attacks (OR 2.40: $p < 0.05$). This further validates the effect microbial contamination can have on the health and wellbeing of students. In addition to biological contaminants, high concentrations of chemical pollutants in the classroom, often exceeding recommended levels, can also impact students' health outcomes. A study of French primary schools reported an increased prevalence of rhinitis and asthma in pupils due to a high concentration of VOCs (OR 1.19; 95% CI 1.04 to 1.36) and of $PM_{2.5}$ (OR 1.21; 95% CI 1.05 to 1.39), respectively, in classrooms [139]. An investigation by Kim et al. [140] found that a higher concentration of microbial volatile organic compounds (MVOCs) resulted in pupils experiencing nocturnal breathlessness, daytime breathlessness, wheezing, and doctor-diagnosed asthma.

Inadequate ventilation (indicated by high classroom CO_2) has been associated with children experiencing asthmatic attacks, cough, and rhinitis, as well as increased illness absenteeism [119,142], reduced students' cognitive performance [154], and reduced levels of concentration [67]. Mi et al. [141] found classroom indoor CO_2 to be related to current asthma (OR 1.26: $p < 0.001$). Daisey et al. [146] also reported that inadequate ventilation in classrooms led to adverse health symptoms in their study. A study by Cartieaux et al. [12] found that IEQ adversely affected students' health, resulting in respiratory symptoms and other respiratory diseases. This was supported by the study of Sundell et al. [155], which showed that inadequate ventilation reduced respiratory functions and resulted in asthmatic symptoms. While CO_2 itself is not considered a pollutant, it is used as a proxy for ventilation adequacy. A high concentration of indoor CO_2 serves as an indicator of low oxygen (O_2) levels in the indoor space, which is related to ineffective air exchange.

A review by Brockmeyer and D'Angiulli [138] explained the detrimental effect that polluted indoor environments may have on children's brain development, causing neurological problems which may reduce their intellectual capability. These neurological problems can exacerbate later development of Alzheimer's and Parkinson's diseases [156]. In addition to the above, several childhood diseases, such as asthma, may be triggered by students' exposure to classroom microbial contaminants, such as allergens in dust, fungi and bacteria related to moisture damage, VOCs, and MVOCs [146]. A school study by Mi et al. [141] also found that indoor nitrogen dioxide (NO_2) was associated with current asthma (OR 1.51 for 10 $\mu g/m^3$: $p < 0.01$) among pupils.

Thermal discomfort in classrooms causes inconvenience, significantly affecting students' ability to perform mental tasks and their overall academic achievements [157]. It is also associated with various health complaints among students, such as drowsiness, headaches, respiratory issues, and eye problems [86]. Additionally, thermal discomfort is linked to respiratory illnesses and an increase in absenteeism by up to 1.3-fold [119]. In another study on thermal comfort in classrooms, 97% of students reported feeling tired and experiencing difficulty concentrating, while 94% mentioned sleeping problems due to heat stress [143]. Moreover, daytime breathlessness may also be attributed to thermal discomfort in schools, with an odds ratio (OR) of up to 1.26: $p < 0.001$ [141].

Classroom thermal comfort is expected to improve with increased ventilation. Moreover, absenteeism due to illness was found to be reduced by up to 1.5% per L/s-person increase in the classroom ventilation rate [142].

3.6. Effect of IEQ (Thermal Environment and Indoor Air Quality) on Learning Outcomes

Studies have shown the negative impact of being absent from classes on student learning achievement. An absent student misses out on the complete lesson experience, unlike their peers. This absence could potentially impact their understanding of the subject. In a study by Gottfried [158], absent school days by pupils were found to affect their learning achievement, lowering their mathematical and reading achievement results. Missed school days affected the grades of student negatively in a study by Hidayat et al. [159]. Moonie et al. [160] recorded a similar result, finding a negative relationship between absenteeism and student performance. A meta-analysis performed by Credé et al. [161] found class attendance to have a serious impact on student grades. The impact of IEQ on students' absenteeism or on their health, which leads to missed school days, can be said to have an indirect impact on their learning outcomes. For example, an increase in classroom CO_2 concentration levels was related to reduced ventilation and associated with up to one half-day increase in student absence from school [70]. While missed school days were negatively associated with students' academic outcomes in a study by Young et al. [162], the association between a lower student grade and IEQ parameters analyzed in the study was not moderated by students' missed school days.

Exposure to PM was associated with about a 2% increase in absence rates per academic year [163]. As explained by Gaihre et al. [70] and Mendell et al. [142], IEQ may not only affect students' academic performance but can also result in parents missing work to stay with their kids at home, ultimately having economic consequences. A summary showing the association between IEQ and learning outcomes is shown in Table 4.

Table 4. Summary of school studies conducted on IEQ and students' learning outcomes.

Reference	Study Population	IEQ Parameters Studied	Academic Outcomes/Effect
[164]	22 schools (436 classrooms), all students included. Study conducted in the U.S.	dCO_2 (indoor CO_2 minus outdoor CO_2)	A 1000 ppm increase in dCO_2 associated with 10–20% student absence rate ($p < 0.05$).
[70]	30 schools (60 classrooms), all students included. Study conducted in Scotland.	CO_2	A 100 ppm increase in CO_2 was linked to 0.2% (0.4 days/session) increased student absenteeism.

Table 4. *Cont.*

Reference	Study Population	IEQ Parameters Studied	Academic Outcomes/Effect
[163]	1772 schools with about 1 million students in the U.S.	P.M$_{2.5}$, greenness (Normalized Difference Vegetation Index (NDVI))	A 1 μg/m^3 increase in PM$_{2.5}$ per session was associated with a 1.58% ($p < 0.0001$) increase in students' chronic absenteeism. A 0.15 increase in NDVI during the school year was related to a 2.6% ($p < 0.0001$) decrease in chronic absence rate.
[165]	2751 Schools with >1.6 million students in the U.S.	Ventilation rate, mold, humidity, adverse school conditions	Students' absenteeism was linked to ventilation inadequacy (OR = 3.10; 95% CI = 1.79–5.37), mold presence (OR = 2.33; 95% CI = 1.34–3.68), humidity (OR = 3.07; 95% CI = 1.37–6.89), and adverse school conditions (OR = 2.97; 95% CI = 1.84–4.79).
[66]	104 schools (104 classrooms) with between 12 and 45 students per class in the U.S.	Temperature, relative humidity, ventilation rate (CO_2)	Math and reading achievement were increased by 2.9% (95%CI 0.9–4.8%) and 2.7% (95% CI 0.5–4.9%), respectively, per each 1 L/s per person increase in ventilation rate.
[154]	9 schools (18 classrooms) with 596 children (436 performed a cognitive test) in Austria.	TCEP, CO_2	Cognitive performance was correlated with TCEP ($r = -0.149$, $p = 0.002$) and CO_2 ($r = -0.102$, $p = 0.034$) in classroom.
[166]	8 schools (16 classrooms) with 332 students in England.	Ventilation rates	Higher ventilation increases students' responses and accuracy by 15% for word recognition, 8% for picture memory, 2.7% for color word vigilance, and 2.2% for choice reaction.
[8]	70 schools (140 classrooms) in the U.S.	Ventilation rate, temperature	Mathematics test scores increased by 0.5% for 1 L/s-person increase in ventilation. A similar result was achieved for 1 °C reduction of classroom temperature.
[48]	399 schools (820 classrooms) in Denmark.	Ventilation rate	Students in mechanically ventilated classrooms had higher academic achievement than those in naturally ventilated classrooms, with a relative difference of 1.45% points $p < 0.05$.
[167]	39 schools (220 classrooms) with about 5000 students in the U.S.	Ventilation rate	Higher ventilation was positively associated with both mathematics and reading achievement of students ($p < 0.01$).

Students' complaints about unsatisfactory IEQ have been negatively associated with their educational achievements. Mendell and Heath, in their review [168], suggested that IEQ affected students' learning outcomes, as well as the productivity of the staff and teachers; the study reported the adverse effect of poor IEQ on student performance and absenteeism due to health problems caused or exacerbated by indoor pollutants. A 2010 study by Simons et al. [165] found student absenteeism to be related to ventilation inadequacy (OR = 3.10; 95% CI = 1.79–5.37), mold presence (OR = 2.33; 95% CI = 1.34–3.68), humidity (OR = 3.07; 95% CI = 1.37–6.89), and adverse school conditions (OR = 2.97; 95% CI = 1.84–4.79). Gaihre et al. [70] found inadequate classroom ventilation to be associated with absenteeism, with a 100 ppm increase in classroom CO_2 being related to missing a half day of school per year.

A linear association was found between classroom ventilation rates and pupils' learning outcomes, where students' achievement increased with increased ventilation [66]. A strong relationship was found between low ventilation rates in elementary classrooms and students' concentration, memory, vigilance, and attention [166]. Haverinen-Shaughnessy and Shaughnessy [8] reported a 0.5% increase in students' mathematics test scores per 1 L/s-person increase in classroom ventilation, and about the same margin for each 1 °C reduction in classroom temperature. According to the findings of Wargocki et al. [169], reducing classroom CO_2 concentration from 2100 ppm to 900 ppm was predicted to significantly enhance students' academic performance. The improvement was estimated to be around 12% in terms of task speed and 2% in terms of error reduction. Additionally, lowering the CO_2 concentration from 2300 ppm to 900 ppm resulted in a 5% increase in performance on learning assessment tests. Similarly, reducing the concentration from 4100 ppm to 1000 ppm led to a 2.5% rise in daily attendance. The study also concluded that increasing the ventilation rate in classrooms up to 10 L/s-person could yield noteworthy benefits in terms of learning performance and student attendance. In a study by Hutter et al. [154], the presence of semi-volatile compounds, such as phthalates and phosphororganic compounds (POC), and a high level of CO_2 in schools was found to negatively affect pupils' cognitive performance. Eide et al. [170] found that students' health problems had a negative impact on learning outcomes in mathematical and reading achievements.

Missed school days can detrimentally impact academic performance. Absences lead to incomplete learning, hinder interaction with teachers and peers, and disrupt the learning rhythm. This can result in gaps in understanding and lowered grades.

4. Conclusions

This literature review appraises the importance of IEQ in schools, as poor IEQ has been shown to have an effect on learning and concentration, as well as impact the long-term health of students. A continuous classroom IEQ research review and appraisal are needed to summarize existing knowledge, which can help other researchers avoid research duplication and identify research gaps for future studies. It can be seen from this review that maintaining good IEQ in schools is crucial for providing a conducive learning environment and ensuring healthy and happy students while creating a positive impact on their long-term health and wellbeing. For example, an improvement in classroom IAQ and general student comfort is related to better academic outcomes and health improvements.

From the reviewed papers, there is a significant lack of scientific research pertaining to IEQ in classroom settings within developing countries, particularly in Africa and Asia. This scarcity is likely related to the insufficient funding available for research and development in these regions. Existing studies from these areas mainly focus on hygiene and cleanliness to mitigate the spread of communicable diseases, which are prevalent in these regions. However, considering the escalating temperatures caused by climate change, especially in tropical developing countries, there is an urgent need for additional research to assess the implications of these changes on students' classroom experiences, as well as their health, well-being, and academic achievements. It is essential to recognize that the interrelationship between different IEQ parameters varies in different locations with diverse climatic conditions. For instance, while there is a correlation between classroom ventilation and temperature in temperate school classrooms, they appear to be independent in tropical climate schools.

To address this knowledge gap and arrive at more conclusive findings regarding the impact of classroom IEQ on students' well-being, health, and academic outcomes, a systematic review and meta-analysis of data from research conducted in various locations can be conducted. Moreover, it is crucial to explore and identify cost-effective strategies that can effectively address potential IEQ issues in classrooms, ensuring their feasibility for large-scale implementation. Research without subsequent implementation may not yield tangible improvements in the learning environment.

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References

1. Çelik, A.; Özkan, F. Premorbid Adjustment Effect on Academic Performance: A Review. *Sage Sci. Rev. Educ. Technol.* **2003**, *6*, 1–11.
2. Jung, C.C.; Liang, H.H.; Lee, H.L.; Hsu, N.Y.; Su, H.J.A. llostatic Load Model Associated with Indoor Environmental Quality and Sick Building Syndrome among Office Workers. *PLoS ONE* **2014**, *9*, e95791. [CrossRef]
3. Ramos, T.; Dedesko, S.; Siegel, J.A.; Gilbert, J.A.; Stephens, B. Spatial and Temporal Variations in Indoor Environmental Conditions, Human Occupancy, and Operational Characteristics in a New Hospital Building. *PLoS ONE* **2015**, *10*, e0118207. [CrossRef]
4. Sakellaris, I.A.; Saraga, D.E.; Mandin, C.; Roda, C.; Fossati, S.; de Kluizenaar, Y.; Carrer, P.; Dimitroulopoulou, S.; Mihucz, V.G.; Szigeti, T.; et al. Perceived Indoor Environment and Occupants' Comfort in European "Modern" Office Buildings: The OFFICAIR Study. *Int. J. Environ. Res. Public Health* **2016**, *13*, 444. [CrossRef] [PubMed]
5. Al-Awadi, L. Assessment of indoor levels of volatile organic compounds and carbon dioxide in schools in Kuwait. *J. Air Waste Manag. Assoc.* **2017**, *68*, 54–72. [CrossRef] [PubMed]
6. Toyinbo, O. Indoor environmental quality. In *Sustainable Construction Technologies*; Butterworth-Heinemann: Oxford, UK, 2019; pp. 107–122.

7. Wargocki, P.; Porras-Salazar, J.A.; Contreras-Espinoza, S. The relationship between classroom temperature and children's performance in school. *Build. Environ.* **2019**, *157*, 197–204. [CrossRef]
8. Haverinen-Shaughnessy, U.; Shaughnessy, R.J. Effects of classroom ventilation rate and temperature on students' test scores. *PLoS ONE* **2015**, *10*, e0136165.
9. Zhang, Y.; Luo, X.; Wang, X.; Qian, K.; Zhao, R. Influence of temperature on formaldehyde emission parameters of dry building materials. *Atmos. Environ.* **2007**, *41*, 3203–3216.
10. Huang, S.; Xiong, J.; Cai, C.; Xu, W.; Zhang, Y. Influence of humidity on the initial emittable concentration of formaldehyde and hexaldehyde in building materials: Experimental observation and correlation. *Sci. Rep.* **2016**, *6*, 23388. [CrossRef]
11. Tippayawong, N.; Khuntong, P.; Nitatwichit, C.; Khunatorn, Y.; Tantakitti, C. Indoor/outdoor relationships of size-resolved particle concentrations in naturally ventilated school environments. *Build. Environ.* **2009**, *44*, 188–197.
12. Cartieaux, E.; Rzepka, M.A.; Cuny, D. Indoor air quality in schools. *Arch. Pediatr.* **2011**, *18*, 789–796. [CrossRef] [PubMed]
13. Kapoor, N.R.; Kumar, A.; Alam, T.; Kumar, A.; Kulkarni, K.S.; Blecich, P. A review on indoor environment quality of Indian school classrooms. *Sustainability* **2021**, *13*, 11855. [CrossRef]
14. Godoi, R.H.; Godoi, A.F.; Gonçalves Junior, S.J.; Paralovo, S.L.; Borillo, G.C.; Barbosa, C.G.G.; Arantes, M.G.; Charello, R.C.; Filho, N.A.R.; Grassi, M.T.; et al. Healthy environment--indoor air quality of Brazilian elementary schools nearby petrochemical industry. *Sci. Total Environ.* **2013**, *463–464*, 639–646. [CrossRef] [PubMed]
15. Zhang, L.; Morisaki, H.; Wei, Y.; Li, Z.; Yang, L.; Zhou, Q.; Zhang, X.; Xing, W.; Hu, M.; Shima, M.; et al. Characteristics of air pollutants inside and outside a primary school classroom in Beijing and respiratory health impact on children. *Environ. Pollut.* **2019**, *255*, 113147. [CrossRef] [PubMed]
16. Pegas, P.N.; Evtyugina, M.G.; Alves, C.A.; Nunes, T.; Cerqueira, M.; Pio, M.F.C. Outdoor/indoor air quality in primary schools in Lisbon: A preliminary study. *Quim. Nova* **2010**, *33*, 1145–1149. [CrossRef]
17. Leung, D.Y.C. Outdoor-indoor air pollution in urban environment: Challenges and opportunity. *Front. Environ. Sci.* **2015**, *2*, 69. [CrossRef]
18. Madureira, J.; Paciência, I.; Pereira, C.; Teixeira, J.P.; Fernandes, E.O. Indoor air quality in Portuguese schools: Levels and sources of pollutants. *Indoor Air* **2016**, *26*, 526–537. [CrossRef]
19. Toyinbo, O.; Shaughnessy, R.; Turunen, M.; Putus, T.; Metsämuuronen, J.; Kurnitski, J.; Haverinen-Shaughnessy, U. Building characteristics, indoor environmental quality, and mathematics achievement in Finnish elementary schools. *Build. Environ.* **2016**, *104*, 114–121. [CrossRef]
20. Zhang, R.; Tan, Y.; Wang, Y.; Wang, H.; Zhang, M.; Liu, J.; Xiong, J. Predicting the concentrations of VOCs in a controlled chamber and an occupied classroom via a deep learning approach. *Build. Environ.* **2022**, *207*, 108525. [CrossRef]
21. Stratton, S.J. Literature reviews: Methods and applications. *Prehospital Disaster Med.* **2019**, *34*, 347–349. [CrossRef]
22. Wargocki, P.; Wyon, D.P.; Sundell, J.; Clausen, G.; Fanger, P.O. The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. *Indoor Air* **2000**, *10*, 222–236. [CrossRef] [PubMed]
23. MacNaughton, P.; Pegues, J.; Satish, U.; Santanam, S.; Spengler, J.; Allen, J. Economic, Environmental and Health Implications of Enhanced Ventilation in Office Buildings. *Int. J. Environ. Res. Public Health* **2015**, *12*, 14709–14722. [CrossRef] [PubMed]
24. Sharpe, T.; Farren, P.; Howieson, S.; Tuohy, P.; McQuillan, J. Occupant Interactions and Effectiveness of Natural Ventilation Strategies in Contemporary New Housing in Scotland, UK. *Int. J. Environ. Res. Public Health* **2015**, *12*, 8480–8497. [CrossRef] [PubMed]
25. Rim, D.; Schiavon, S.; Nazaroff, W.W. Energy and Cost Associated with Ventilating Office Buildings in a Tropical Climate. *PLoS ONE* **2015**, *10*, e0122310. [CrossRef]
26. Patton, A.P.; Calderon, L.; Xiong, Y.; Wang, Z.; Senick, J.; Allacci, M.S.; Plotnik, D.; Wener, R.; Andrews, C.J.; Krogmann, U.; et al. Airborne Particulate Matter in Two Multi-Family Green Buildings: Concentrations and Effect of Ventilation and Occupant Behavior. *Int. J. Environ. Res. Public Health* **2016**, *13*, 144. [CrossRef]
27. Aflaki, A.; Mahyuddin, N.; Mahmoud, Z.A.; Baharum, M.R. A review of natural ventilation applications through building façade components and ventilation openings in tropical climates. *Energy Build.* **2015**, *101*, 153–162. [CrossRef]
28. Walker, A. *Natural Ventilation, Whole Building Design Guide (WBDG), a Program of the National Institute of Building Sciences*; National Renewable Energy Laboratory: Golden, CO, USA, 2016.
29. Bamdad, K.; Matour, S.; Izadyar, N.; Omrani, S. Impact of climate change on energy saving potentials of natural ventilation and ceiling fans in mixed-mode buildings. *Build. Environ.* **2022**, *209*, 108662. [CrossRef]
30. Tong, Z.; Chen, Y.; Malkawi, A. Estimating natural ventilation potential for high-rise buildings considering boundary layer meteorology. *Appl. Energy* **2017**, *193*, 276–286. [CrossRef]
31. Tong, Z.; Chen, Y.; Malkawi, A.; Liu, Z.; Freeman, R.B. Energy saving potential of natural ventilation in China: The impact of ambient air pollution. *Appl. Energy* **2016**, *179*, 660–668. [CrossRef]
32. Zhai, Z.J.; El Mankibi, M.; Zoubir, A. Review of natural ventilation models. *Energy Procedia* **2015**, *78*, 2700–2705. [CrossRef]
33. Chu, C.R.; Chiu, Y.H.; Tsai, Y.T.; Wu, S.L. Wind-driven natural ventilation for buildings with two openings on the same external wall. *Energy Build.* **2015**, *108*, 365–372. [CrossRef]
34. Haase, M.; Amato, A. An investigation of the potential for natural ventilation and building orientation to achieve thermal comfort in warm and humid climates. *Sol. Energy* **2009**, *83*, 389–399. [CrossRef]

35. Jamaludin, N.; Mohammed, N.I.; Khamidi, M.F.; Wahab, S.N.A. Thermal comfort of residential building in Malaysia at different micro-climates. *Procedia Soc. Behav. Sci.* **2015**, *170*, 613–623. [CrossRef]
36. Fuoco, F.C.; Stabile, L.; Buonanno, G.; Trassiera, C.; Massimo, A.; Russi, A.; Mazaheri, M.; Morawska, L.; Andrade, A. Indoor Air Quality in Naturally Ventilated Italian Classrooms. *Atmosphere* **2015**, *6*, 1652–1675. [CrossRef]
37. Toyinbo, O.; Phipatanakul, W.; Shaughnessy, R.; Haverinen-Shaughnessy, U. Building and indoor environmental quality assessment of Nigerian primary schools: A pilot study. *Indoor Air* **2019**, *29*, 510–520. [CrossRef]
38. Awbi, H.B. *Ventilation Systems: Design and Performance*; Routledge: Oxfordshire, UK, 2007.
39. Reshetniak, E. Mechanical Supply and Exhaust Ventilation in Residential Building. Bachelor's Thesis, Mikkeli University of Applied Sciences, Mikkeli, Finland, 2014.
40. Ianniello, E. Ventilation Systems and IAQ in School Buildings. *Rehva J.* **2011**, 26–29. Available online: https://www.rehva.eu/fileadmin/hvac-dictio/02-2011/Ventilation_systems_and_IAQ_in_school_buildings.pdf (accessed on 1 August 2023).
41. van der Zee, S.C.; Strak, M.; Dijkema, M.B.; Brunekreef, B.; Janssen, N.A. The impact of particle filtration on indoor air quality in a classroom near a highway. *Indoor Air* **2017**, *27*, 291–302.
42. Brittle, J.P.; Eftekhari, M.; Firth, S.K. Mechanical ventilation & cooling energy versus thermal comfort: A study of mixed mode office building performance in Abu Dhabi. In Proceedings of the 9th Windsor Conference: Making Comfort Relevant, Windsor, UK, 7–10 April 2016.
43. Ji, Y.; Lomas, K.J.; Cook, M.J. Hybrid ventilation for low energy building design in south China. *Build. Environ.* **2009**, *44*, 2245–2255. [CrossRef]
44. Seppänen, O. Ventilation, energy and indoor air quality. In Proceedings of the 2016, 9th International Conference on Indoor Air Quality and Climate, Monterey, CA, USA, 1–5 July 2002.
45. Joshi, S.M. The sick building syndrome. *Indian J. Occup. Environ. Med.* **2008**, *12*, 61–64. [CrossRef]
46. Wallner, P.; Munoz, U.; Tappler, P.; Wanka, A.; Kundi, M.; Shelton, J.F.; Hutter, H.P. Indoor Environmental Quality in Mechanically Ventilated, Energy-Efficient Buildings vs. Conventional Buildings. *Int. J. Environ. Res. Public Health* **2015**, *12*, 14132–14147. [CrossRef]
47. Yang, W.H.; Sohn, J.; Kim, J.W.; Son, B.; Park, J. Indoor air quality investigation according to age of the school buildings in Korea. *J. Environ. Manag.* **2009**, *90*, 348–354. [CrossRef] [PubMed]
48. Toftum, J.; Kjeldsen, B.U.; Wargocki, P.; Menå, H.R.; Hansen, E.M.N.; Clausen, G. Association between classroom ventilation mode and learning outcome in Danish schools. *Build. Environ.* **2015**, *92*, 494–503. [CrossRef]
49. Rosbach, J.T.M.; Vonk, M.; Duijm, F.; van Ginkel, J.T.; Gehring, U.; Brunekreef, B. A ventilation intervention study in classrooms to improve indoor air quality: The FRESH study. *Environ. Health* **2013**, *12*, 110. [CrossRef]
50. Batterman, S. Review and Extension of CO_2-Based Methods to Determine Ventilation Rates with Application to School Classrooms. *Int. J. Environ. Res. Public Health* **2017**, *14*, 145. [CrossRef]
51. Zapata-Lancaster, M.G.; Ionas, M.; Toyinbo, O.; Smith, T.A. Carbon dioxide concentration levels and thermal comfort in primary school classrooms: What pupils and teachers do. *Sustainability* **2023**, *15*, 4803. [CrossRef]
52. Scheff, P.A.; Paulius, V.K.; Huang, S.W.; Conroy, L.M. Indoor air quality in a middle school, Part I: Use of CO_2 as a tracer for effective ventilation. *Appl. Occup. Environ. Hyg.* **2000**, *15*, 824–834. [CrossRef]
53. Smith, P.N. Determination of ventilation rates in occupied buildings from metabolic CO_2 concentrations and production rates. *Build. Environ.* **1988**, *23*, 95–102. [CrossRef]
54. Shen, G.; Ainiwaer, S.; Zhu, Y.; Zheng, S.; Hou, W.; Shen, H.; Chen, Y.; Wang, X.; Cheng, H.; Tao, S. Quantifying source contributions for indoor CO2 and gas pollutants based on the highly resolved sensor data. *Environ. Pollut.* **2020**, *267*, 115493. [CrossRef]
55. Zhang, T.T.; Yin, S.; Wang, S. Quantify impacted scope of human expired air under different head postures and varying exhalation rates. *Build. Environ.* **2011**, *46*, 1928–1936. [CrossRef]
56. World Health Organization. *Methods for Monitoring Indoor Air Quality in Schools: Report of a Meeting, Bonn, Germany, 4–5 April 2011*; World Health Organization: Geneva, Switzerland, 2011.
57. Hänninen, O. Combining CO_2 Data from Ventilation Phases Improves Estimation of Air Exchange Rates. In Proceedings of the 10th International Conference on Healthy Buildings, Brisbane, Australia, 8–12 July 2012.
58. *ASHRAE Standard 62-1992*; Ventilation for Acceptable Indoor Air Quality. American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 1992.
59. *ANSI/ASHRAE Standard 62.1-2016*; Ventilation for Acceptable Indoor Air Quality. Approved American National Standard (ANSI)/American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2016.
60. National Building Code of Finland (G1) Ministry of Environment. *Housing Design Regulations and Guidelines 2005: Adopted in Helsinki on the 1st of October 2004*; Ministry of Environment: Helsinki, Finland, 2004.
61. Ministry of Social Affairs and Health. *Decree of the Ministry of Social Affairs and Health on Health-related Conditions of Housing and Other Residential Buildings and Qualification Requirements for Third-party Experts; 2015, 545/2015*; Ministry of Social Affairs and Health: Helsinki, Finland, 2015.
62. National Environment Agency. Indoor Air Quality Parameters and Measurement. 2016. Available online: http://www.enviresearch.co.th/wp-content/uploads/2020/01/Indoor-Air-2016.pdf (accessed on 11 July 2023).
63. Toyinbo, O.; Hägerhed, L.; Dimitroulopoulou, S.; Dudzinska, M.; Emmerich, S.; Hemming, D.; Park, J.H.; Haverinen-Shaughnessy, U.; Committee, S.T. Open database for international and national indoor environmental quality guidelines. *Indoor Air* **2022**, *32*, e13028. [CrossRef]

64. Dimitroulopoulou, S.; Dudzińska, M.R.; Gunnarsen, L.; Hägerhed, L.; Maula, H.; Singh, R.; Toyinbo, O.; Haverinen-Shaughnessy, U. Indoor Air Quality Guidelines from Across the World: An Appraisal Considering Energy Saving, Health, Productivity, and Comfort. *Environ. Int.* **2023**, *178*, 108127. [CrossRef]
65. National Building Code of Nigeria. 2006. Available online: https://docplayer.net/31726834-National-building-code.html (accessed on 22 May 2023).
66. Haverinen-Shaughnessy, U.; Moschandreas, D.J.; Shaughnessy, R.J. Association between substandard classroom ventilation rates and students' academic achievement. *Indoor Air* **2011**, *21*, 121–131. [CrossRef]
67. Ferreira, A.M.; Cardoso, M. Indoor air quality and health in schools. *J. Bras. Pneumol.* **2014**, *40*, 259–268. [CrossRef] [PubMed]
68. Lee, S.C.; Chang, M. Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere* **2000**, *41*, 109–113. [PubMed]
69. *ASHRAE Standard 62-1989*; Ventilation for Acceptable Indoor Air Quality. American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 1989.
70. Gaihre, S.; Semple, S.; Miller, J.; Fielding, S.; Turner, S. Classroom carbon dioxide concentration, school attendance, and educational attainment. *J. Sch. Health* **2014**, *84*, 569–574. [CrossRef] [PubMed]
71. Ferreira, A.M.C.; Cardoso, S.M. Exploratory study of air quality in elementary schools, Coimbra, Portugal. *Rev. Saúde Pública* **2013**, *47*, 1059–1068. [CrossRef]
72. Lu, S.; Fang, K.; Qi, Y.; Wei, S. Influence of Natural Ventilation on Thermal Comfort in Semi-open Building under Early Summer Climate in the Area of Tropical Island. *Procedia Eng.* **2015**, *121*, 944–951. [CrossRef]
73. *ASHRAE Standard 55-2010*; Thermal Environmental Conditions for Human Occupancy. American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2016. Available online: https://www.ashrae.org/File%20Library/Technical%20Resources/Standards%20and%20Guidelines/Standards%20Addenda/55_2010_a.pdf (accessed on 5 May 2023).
74. Fanger, P.O. *Thermal Comfort. Analysis and Applications in Environmental Engineering*; Danish Technical Press: Copenhagen, Denmark, 1970.
75. Daghigh, R. Assessing the thermal comfort and ventilation in Malaysia and the surrounding regions. *Renew Sustain. Energy Rev.* **2015**, *48*, 681–691. [CrossRef]
76. Quang, T.N.; He, C.; Knibbs, L.D.; de Dear, R.; Morawska, L. Co-optimisation of indoor environmental quality and energy consumption within urban office buildings. *Energy Build.* **2014**, *85*, 225–234. [CrossRef]
77. Al horr, Y.; Arif, M.; Katalygiotou, M.; Mazroei, A.; Kaushi, A.; Elsarrag, E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *Int. J. Sust. Built. Environ.* **2016**, *5*, 1–11. [CrossRef]
78. Teli, D.; James, P.A.B.; Jentsch, M.F. Thermal comfort in naturally ventilated primary school classrooms. *Build. Res. Inf.* **2013**, *41*, 301–316. [CrossRef]
79. Zomorodian, Z.S.; Tahsildoost, M.; Hafezi, M. Thermal comfort in educational buildings: A review article. *Renew. Sustain. Energy Rev.* **2016**, *59*, 895–906. [CrossRef]
80. Sekhar, S.C. Thermal comfort in air-conditioned buildings in hot and humid climates—Why are we not getting it right? *Indoor Air* **2016**, *26*, 138–152. [CrossRef]
81. Damiati, S.A.; Zaki, S.A.; Rijal, H.B.; Wonorahardjo, S. Field study on adaptive thermal comfort in office buildings in Malaysia, Indonesia, Singapore, and Japan during hot and humid season. *Build. Environ.* **2016**, *109*, 208–223. [CrossRef]
82. Yang, W.; Zhang, G. Thermal comfort in naturally ventilated and air-conditioned buildings in humid subtropical climate zone in China. *Int. J. Biometeorol.* **2007**, *52*, 385–398. [CrossRef] [PubMed]
83. Indraganti, M. Adaptive use of natural ventilation for thermal comfort in Indian apartments. *Build. Environ.* **2010**, *45*, 1490–1507. [CrossRef]
84. Prajongsan, P.; Sharples, S. Enhancing natural ventilation, thermal comfort and energy savings in high-rise residential buildings in Bangkok through the use of ventilation shafts. *Build. Environ.* **2012**, *50*, 104–113. [CrossRef]
85. Daghigh, R.; Adam, N.M.; Sahari, B.B. Ventilation Parameters and Thermal Comfort of Naturally and Mechanically Ventilated Offices. *Indoor Built Environ.* **2009**, *18*, 113–122. [CrossRef]
86. Andersen, I.; Gyntelberg, F. Modern indoor climate research in Denmark from 1962 to the early 1990s: An eye witness report. *Indoor Air* **2011**, *21*, 182–190. [CrossRef]
87. Salthammer, T.; Uhde, E.; Schripp, T.; Schieweck, A.; Morawska, L.; Mazaheri, M.; Clifford, S.; He, C.; Buonanno, G.; Querol, X.; et al. Children's well-being at schools: Impact of climatic conditions and air pollution. *Environ. Int.* **2016**, *94*, 196–210. [CrossRef]
88. Schiavon, S.; Yang, B.; Donner, Y.; Chang, V.C.; Nazaroff, W.W. Thermal comfort, perceived air quality, and cognitive performance when personally controlled air movement is used by tropically acclimatized persons. *Indoor Air* **2017**, *27*, 690–702. [CrossRef] [PubMed]
89. WHO (World Health Organization). *Housing, Energy and Thermal Comfort: A Review of 10 Countries within the WHO European Region*; WHO Regional Office for Europe: Copenhagen, Denmark, 2007.
90. Singh, M.K.; Ooka, R.; Rijal, H.B.; Kumar, S.; Kumar, A.; Mahapatra, S. Progress in thermal comfort studies in classrooms over last 50 years and way forward. *Energy Build.* **2019**, *188*, 149–174. [CrossRef]
91. Lamberti, G.; Salvadori, G.; Leccese, F.; Fantozzi, F.; Bluyssen, P.M. Advancement on thermal comfort in educational buildings: Current issues and way forward. *Sustainability* **2021**, *13*, 10315. [CrossRef]

92. Amasuomo, T.T.; Amasuomo, J.O. Perceived Thermal Discomfort and Stress Behaviours Affecting Students' Learning in Lecture Theatres in the Humid Tropics. *Buildings* **2016**, *6*, 18. [CrossRef]
93. Almeida, R.M.S.F.; de Freitas, V.P. IEQ assessment of classrooms with an optimized demand controlled ventilation system. *Energy Procedia* **2015**, *78*, 3132–3137. [CrossRef]
94. Leachman, M.; Albares, N.; Masterson, K.; Wallace, M. Most states have cut school funding, and some continue cutting. *Cent. Budg. Policy Priorities* **2016**, *4*, 1–16.
95. Leachman, M.; Masterson, K.; Figueroa, E. A punishing decade for school funding. *Cent. Budg. Policy Priorities* **2017**, *29*, 1–17.
96. Lappalainen, S.; Kähkönen, E.; Loikkanen, P.; Palomäki, E.; Lindroos, O.; Reijula, K. Evaluation of priorities for repairing in moisture-damaged school buildings in Finland. *Build. Environ.* **2001**, *36*, 981–986. [CrossRef]
97. Haverinen-Shaughnessy, U.; Borras-Santos, A.; Turunen, M.; Zock, J.P.; Jacobs, J.; Krop, E.J.; Casas, L.; Shaughnessy, R.; Täubel, M.; Heederik, D.; et al. Occurrence of moisture problems in schools in three countries from different climatic regions of Europe based on questionnaires and building inspections—The HITEA study. *Indoor Air* **2012**, *22*, 457–466. [CrossRef]
98. Annila, P.J.; Lahdensivu, J.; Suonketo, J.; Pentti, M.; Vinha, J. Need to repair moisture-and mould damage in different structures in finnish public buildings. *J. Build. Eng.* **2018**, *16*, 72–78. [CrossRef]
99. Cho, S.J.; Cox-Ganser, J.M.; Park, J.-H. Observational scores of dampness and mold associated with measurements of microbial agents and moisture in three public schools. *Indoor Air* **2016**, *26*, 168–178. [CrossRef]
100. Clausen, G.; Host, A.; Toftum, J.; Bekö, G.; Weschler, C.; Callesen, M.; Buhl, S.; Ladegaard, M.B.; Langer, S.; Andersen, B.; et al. Children's health and its association with indoor environments in Danish homes and daycare centres—methods. *Indoor Air* **2012**, *22*, 467–475. [CrossRef] [PubMed]
101. Peitzsch, M.; Sulyok, M.; Täubel, M.; Vishwanath, V.; Krop, E.; Borràs-Santos, A.; Hyvärinen, A.; Nevalainen, A.; Krska, R.; Larsson, L. Microbial secondary metabolites in school buildings inspected for moisture damage in Finland, The Netherlands and Spain. *J. Environ. Monit.* **2012**, *14*, 2044–2053. [CrossRef]
102. Borràs-Santos, A.; Jacobs, J.H.; Täubel, M.; Haverinen-Shaughnessy, U.; Krop, E.J.; Huttunen, K.; Hirvonen, M.R.; Pekkanen, J.; Heederik, D.J.; Zock, J.P.; et al. Dampness and mould in schools and respiratory symptoms in children: The HITEA study. *Occup. Environ. Med.* **2013**, *70*, 681–687. [CrossRef] [PubMed]
103. Jacobs, J.; Borràs-Santos, A.; Krop, E.; Täubel, M.; Leppänen, H.; Haverinen-Shaughnessy, U.; Pekkanen, J.; Hyvärinen, A.; Doekes, G.; Zock, J.-P.; et al. Dampness, bacterial and fungal components in dust in primary schools and respiratory health in schoolchildren across Europe. *Occup. Environ. Med.* **2014**, *71*, 704–712. [CrossRef] [PubMed]
104. Annila, P.J.; Hellemaa, M.; Pakkala, T.A.; Lahdensivu, J.; Suonketo, J.; Pentti, M. Extent of moisture and mould damage in structures of public buildings. *Case Stud. Constr. Mater.* **2017**, *6*, 103–108. [CrossRef]
105. Uotila, U.; Saari, A. Determining ventilation strategies to relieve health symptoms among school occupants. *Facilities* **2023**, *41*, 1–20. [CrossRef]
106. Meklin, T.; Hyvärinen, A.; Toivola, M.; Reponen, T.; Koponen, V.; Husman, T.; Taskinen, T.; Korppi, M.; Nevalainen, A. Effect of building frame and moisture damage on microbiological indoor air quality in school buildings. *AIHA J.* **2003**, *64*, 108–116. [CrossRef]
107. Viitanen, H.; Bjurman, J. Mould growth on wood under fluctuating humidity conditions. *Mater. Und Org.* **1995**, *29*, 27–46.
108. Crawford, J.A.; Rosenbaum, P.F.; Anagnost, S.E.; Hunt, A.; Abraham, J.L. Indicators of airborne fungal concentrations in urban homes: Understanding the conditions that affect indoor fungal exposures. *Sci. Total Environ.* **2015**, *517*, 113–124. [CrossRef]
109. Meklin, T.; Potus, T.; Pekkanen, J.; Hyvärinen, A.; Hirvonen, M.R.; Nevalainen, A. Effects of moisture-damage repairs on microbial exposure and symptoms in schoolchildren. *Indoor Air* **2005**, *15*, 40–47. [CrossRef]
110. Haverinen-Shaughnessy, U.; Pekkanen, J.; Nevalainen, A.; Moschandreas, D.; Husman, T. Estimating effects of moisture damage repairs on students' health—A long-term intervention study. *J. Expo. Anal. Environ. Epidemiol.* **2004**, *14*, S58–S64. [CrossRef]
111. Othman, N.L.; Jaafar, M.; Harun, W.M.W.; Ibrahim, F. A case study of moisture problems and building defects. *Procedia Soc. Behav. Sci.* **2015**, *170*, 27–36. [CrossRef]
112. Kettleson, E.M.; Adhikari, A.; Vesper, S.; Coombs, K.; Indugula, R.; Reponen, T. Key determinants of the fungal and bacterial microbiomes in homes. *Environ. Res.* **2015**, *138*, 130–135. [CrossRef]
113. Dannemiller, K.C.; Gent, J.F.; Leaderer, B.P.; Peccia, J. Influence of housing characteristics on bacterial and fungal communities in homes of asthmatic children. *Indoor Air* **2016**, *26*, 179–192. [CrossRef] [PubMed]
114. Ginestet, S.; Aschan-Leygonie, C.; Bayeux, T.; Keirsbulck, M. Mould in indoor environments: The role of heating, ventilation and fuel poverty, A French perspective. *Build. Environ.* **2020**, *169*, 106577. [CrossRef]
115. Menneer, T.; Mueller, M.; Sharpe, R.A.; Townley, S. Modelling mould growth in domestic environments using relative humidity and temperature. *Build. Environ.* **2022**, *208*, 108583. [CrossRef]
116. Majra, J.P.; Gur, A. School Environment and Sanitation in Rural India. *J. Glob. Infect. Dis.* **2010**, *2*, 109–111. [CrossRef] [PubMed]
117. Chatterley, C.; Javernick-Will, A.; Linden, K.G.; Alam, K.; Bottinelli, L.; Venkatesh, M. A qualitative comparative analysis of well-managed school sanitation in Bangladesh. *BMC Public Health* **2014**, *14*, 6. [CrossRef]
118. Xuan, L.T.; Hoat, L.N.; Rheinländer, T.; Dalsgaard, A.; Konradsen, F. Sanitation behavior among schoolchildren in a multi-ethnic area of Northern rural Vietnam. *BMC Public Health* **2012**, *12*, 1–11. [CrossRef]
119. Annesi-Maesano, I.; Baiz, N.; Banerjee, S.; Rudnai, P.; Rive, S.; SINPHONIE Group. Indoor air quality and sources in schools and related health effects. *J. Toxicol. Environ. Health B Crit. Rev.* **2013**, *16*, 491–550. [CrossRef] [PubMed]

120. Wang, Z.; Lapinski, M.; Quilliam, E.; Jaykus, L.A.; Fraser, A. The effect of hand-hygiene interventions on infectious disease-associated absenteeism in elementary schools: A systematic literature review. *Am. J. Infect. Control* **2017**, *45*, 682–689. [CrossRef]
121. Shaughnessy, R.; Hernandez, M.; Haverinen-Shaughnessy, U. Effects of classroom cleaning on student health: A longitudinal study. *J. Expo. Sci. Environ. Epidemiol.* **2022**, *32*, 767–773.
122. World Health Organization. *Progress on Drinking Water, Sanitation and Hygiene in Schools: Special Focus on COVID-19*; Unicef: New York, NY, USA, 2020.
123. Purnama, S.G.; Susanna, D. Hygiene and sanitation challenge for COVID-19 prevention in Indonesia. *Kesmas J. Kesehat. Masy. Nas. Natl. Public Health J.* **2020**, *15*, 6–13. [CrossRef]
124. Joshi, A.; Amadi, C. Impact of Water, Sanitation, and Hygiene Interventions on Improving Health Outcomes among School Children. *J. Environ. Public Health* **2013**, *2013*, 984626. [CrossRef] [PubMed]
125. McMichael, C. Water, sanitation and hygiene (WASH) in schools in low-income countries: A review of evidence of impact. *Int. J. Environ. Res. Public Health* **2019**, *16*, 359.
126. Alexander, K.T.; Mwaki, A.; Adhiambo, D.; Cheney-Coker, M.; Muga, R.; Freeman, M.C. The Life-Cycle Costs of School Water, Sanitation and Hygiene Access in Kenyan Primary Schools. *Int. J. Environ. Res. Public Health* **2016**, *13*, 637. [CrossRef]
127. Hammond, B.; Ali, Y.; Fendler, E.; Dolan, M.; Donovan, S. Effect of hand sanitizer use on elementary school absenteeism. *Am. J. Infect. Control.* **2000**, *28*, 340–346. [PubMed]
128. Jasper, C.; Le, T.T.; Bartram, J. Water and Sanitation in Schools: A Systematic Review of the Health and Educational Outcomes. *Int. J. Environ. Res. Public Health* **2012**, *9*, 2772–2787. [CrossRef]
129. Hetherington, E.; Eggers, M.; Wamoyi, J.; Hatfield, J.; Manyama, M.; Kutz, S.; Bastien, S. Participatory science and innovation for improved sanitation and hygiene: Process and outcome evaluation of project SHINE, a school-based intervention in Rural Tanzania. *BMC Public Health* **2017**, *17*, 172. [CrossRef]
130. Greene, L.E.; Freeman, M.C.; Akoko, D.; Saboori, S.; Moe, C.; Rheingans, R. Impact of a School-Based Hygiene Promotion and Sanitation Intervention on Pupil Hand Contamination in Western Kenya: A Cluster Randomized Trial. *Am. J. Trop. Med. Hyg.* **2012**, *87*, 385–393. [CrossRef]
131. Lau, C.H.; Springston, E.E.; Sohn, M.W.; Mason, I.; Gadola, E.; Damitz, M.; Gupta, R.S. Hand hygiene instruction decreases illness-related absenteeism in elementary schools: A prospective cohort study. *BMC Pediatrics* **2012**, *12*, 52. [CrossRef]
132. Freeman, M.C.; Clasen, T.; Brooker, S.J.; Akoko, D.O.; Rheingans, R. The Impact of a School-Based Hygiene, Water Quality and Sanitation Intervention on Soil-Transmitted Helminth Reinfection: A Cluster-Randomized Trial. *Am. J. Trop. Med. Hyg.* **2013**, *89*, 875–883. [CrossRef]
133. Strunz, E.C.; Addiss, D.G.; Stocks, M.E.; Ogden, S.; Utzinger, J.; Freeman, M.C. Water, Sanitation, Hygiene, and Soil-Transmitted Helminth Infection: A Systematic Review and Meta-Analysis. *PLoS Med.* **2014**, *11*, e1001620. [CrossRef]
134. Heudorf, U.; Neitzert, V.; Spark, J. Particulate matter and carbon dioxide in classrooms—The impact of cleaning and ventilation. *Int. J. Hyg. Environ. Health* **2009**, *212*, 45–55.
135. Park, J.H.; Lee, T.J.; Park, M.J.; Oh, H.; Jo, Y.M. Effects of air cleaners and school characteristics on classroom concentrations of particulate matter in 34 elementary schools in Korea. *Build. Environ.* **2020**, *167*, 106437. [PubMed]
136. Settimo, G.; Indinnimeo, L.; Inglessis, M.; De Felice, M.; Morlino, R.; di Coste, A.; Fratianni, A.; Avino, P. Indoor Air quality levels in schools: Role of student activities and no activities. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6695.
137. Buka, I.; Koranteng, S.; Osornio-Vargas, A.R. The effects of air pollution on the health of children. *Paediatr. Child. Health* **2006**, *11*, 513–516. [PubMed]
138. Brockmeyer, S.; D'Angiulli, A. How air pollution alters brain development: The role of neuroinflammation. *Transl. Neurosci.* **2016**, *7*, 24–30. [CrossRef]
139. Annesi-Maesano, I.; Hulin, M.; Lavaud, F.; Raherison, C.; Kopferschmitt, C.; de Blay, F.; Charpin, D.A.; Denis, C. Poor air quality in classrooms related to asthma and rhinitis in primary schoolchildren of the French 6 Cities Study. *Thorax* **2012**, *67*, 682–688. [CrossRef]
140. Kim, J.L.; Elfman, L.; Mi, Y.; Wieslander, G.; Smedje, G.; Norbäck, D. Indoor molds, bacteria, microbial volatile organic compounds and plasticizers in schools—associations with asthma and respiratory symptoms in pupils. *Indoor Air* **2007**, *17*, 153–163.
141. Mi, Y.H.; Norback, D.; Tao, J.; Mi, Y.L.; Ferm, M. Current asthma and respiratory symptoms among pupils in Shanghai, China: Influence of building ventilation, nitrogen dioxide, ozone, and formaldehyde in classrooms. *Indoor Air* **2006**, *16*, 454–464.
142. Mendell, M.J.; Eliseeva, E.A.; Davies, M.M.; Spears, M.; Lobscheid, A.; Fisk, W.J.; Apte, M.G. Association of classroom ventilation with reduced illness absence: A prospective study in C alifornia elementary schools. *Indoor Air* **2013**, *23*, 515–528.
143. Bidassey-Manilal, S.; Wright, C.Y.; Engelbrecht, J.C.; Albers, P.N.; Garland, R.M.; Matooane, M. Students' Perceived Heat-Health Symptoms Increased with Warmer Classroom Temperatures. *Int. J. Environ. Res. Public Health* **2016**, *13*, 566. [CrossRef] [PubMed]
144. Madureira, J.; Paciência, I.; Ramos, E.; Barros, H.; Pereira, C.; Teixeira, J.P.; Fernandes, E.O. Children's Health and Indoor Air Quality in Primary Schools and Homes in Portugal-Study Design. *J. Toxicol. Environ. Health A* **2015**, *78*, 915–930. [CrossRef] [PubMed]
145. Sadrizadeh, S.; Yao, R.; Yuan, F.; Awbi, H.; Bahnfleth, W.; Bi, Y.; Cao, G.; Croitoru, C.; de Dear, R.; Haghighat, F. Indoor Air quality and health in schools: A critical review for developing the roadmap for the future school environment. *J. Build. Eng.* **2022**, *57*, 104908.
146. Daisey, J.M.; Angell, W.J.; Apte, M.G. Indoor air quality, ventilation and health symptoms in schools: An analysis of existing information. *Indoor Air* **2003**, *13*, 53–64.

147. Yousaf, A.R.; Khan, N. The Study of Particulate Matter Concentration in Schools of Lahore. *Nat. Environ. Poll. Tech.* **2013**, *12*, 289–296.
148. Zhong, L.; Su, F.C.; Batterman, S. Volatile Organic Compounds (VOCs) in Conventional and High Performance School Buildings in the U.S. *Int. J. Environ. Res. Public Health* **2017**, *14*, 100. [CrossRef]
149. Vilén, L.; Päivinen, M.; Atosuo, J.; Putus, T. Transferring from moisture damaged school building to clean facilities–The avoidance of mold exposure induces a decline in symptoms and improvement in lung function among personnel. *Environ. Res.* **2022**, *212*, 113598.
150. Zhang, Y.P.; Xu, Y. Characteristics and correlations of VOC emissions from building materials. *Int. J. Heat Mass Transf.* **2003**, *46*, 4877–4883. [CrossRef]
151. Kim, S.S.; Kang, D.H.; Choi, D.H.; Yeo, M.S.; Kim, K.W. VOC Emission from Building Materials in Residential Buildings with Radiant Floor Heating Systems. *Aerosol Air Qual. Res.* **2012**, *12*, 1398–1408. [CrossRef]
152. Huang, S.; Xiong, J.; Zhang, Y. A rapid and accurate method, ventilated chamber C-history method, of measuring the emission characteristic parameters of formaldehyde/VOCs in building materials. *J. Hazard Mater.* **2013**, *261*, 542–549. [CrossRef]
153. Adams, R.I.; Leppänen, H.; Karvonen, A.M.; Jacobs, J.; Borràs-Santos, A.; Valkonen, M.; Krop, E.; Haverinen-Shaughnessy, U.; Huttunen, K.; Zock, J.P.; et al. Microbial exposures in moisture-damaged schools and associations with respiratory symptoms in students: A multi-country environmental exposure study. *Indoor Air* **2021**, *31*, 1952–1966. [CrossRef]
154. Hutter, H.P.; Haluza, D.; Piegler, K.; Hohenblum, P.; Fröhlich, M.; Scharf, S.; Uhl, M.; Damberger, B.; Tappler, P.; Kundi, M.; et al. Semivolatile compounds in schools and their influence on cognitive performance of children. *Int. J. Occup. Med. Environ. Health* **2013**, *26*, 628–635. [CrossRef]
155. Sundell, J.; Levin, H.; Nazaroff, W.W.; Cain, W.S.; Fisk, W.J.; Grimsrud, D.T.; Gyntelberg, F.; Li, Y.; Persily, A.K.; Pickering, A.C.; et al. Ventilation rates and health: Multidisciplinary review of the scientific literature (Commemorating 20 Years of Indoor Air). *Indoor Air* **2011**, *21*, 191–204. [CrossRef] [PubMed]
156. Calderón-Garcidueñas, L.; Vojdani, A.; Blaurock-Busch, E.; Busch, Y.; Friedle, A.; Franco-Lira, M.; Sarathi-Mukherjee, P.; Martínez-Aguirre, X.; Park, S.B.; Torres-Jardón, R.; et al. Air pollution and children: Neural and tight junction antibodies and combustion metals, the role of barrier breakdown and brain immunity in neurodegeneration. *J. Alzheimer's Dis.* **2015**, *43*, 1039–1058. [CrossRef]
157. De Dear, R.J.; Akimoto, T.; Arens, E.A.; Brager, G.; Candido, C.; Cheong, K.W.; Li, B.; Nishihara, N.; Sekhar, S.C.; Tanabe, S.; et al. Progress in thermal comfort research over the last twenty years. *Indoor Air* **2013**, *23*, 442–461. [CrossRef]
158. Gottfried, M.A. Chronic Absenteeism and Its Effects on Students' Academic and Socioemotional Outcomes. *JESPAR* **2014**, *19*, 53–75. [CrossRef]
159. Hidayat, L.; Vansal, S.; Kim, E.; Sullivan, M.; Salbu, R. Pharmacy Student Absenteeism and Academic Performance. *Am. J. Pharm. Educ.* **2012**, *76*, 8. [CrossRef]
160. Moonie, S.; Sterling, D.A.; Figgs, L.W.; Castro, M. The relationship between school absence, academic performance, and asthma status. *J. Sch. Health* **2008**, *78*, 140–148. [CrossRef] [PubMed]
161. Crede, M.; Roch, S.G.; Kieszczynka, U.M. Class attendance in college: A meta-analytic review of the relationship of class attendance with grades and student characteristics. *Rev. Educ. Res.* **2010**, *80*, 272–295. [CrossRef]
162. Young, B.N.; Benka-Coker, W.O.; Weller, Z.D.; Oliver, S.; Schaeffer, J.W.; Magzamen, S. How does absenteeism impact the link between school's indoor environmental quality and student performance? *Build. Environ.* **2021**, *203*, 108053. [CrossRef]
163. MacNaughton, P.; Eitland, E.; Kloog, I.; Schwartz, J.; Allen, J. Impact of particulate matter exposure and surrounding "greenness" on chronic absenteeism in Massachusetts public schools. *Int. J. Environ. Res. Public Health* **2017**, *14*, 207. [CrossRef]
164. Shendell, D.G.; Prill, R.; Fisk, W.J.; Apte, M.G.; Blake, D.; Faulkner, D. *Associations between Classroom CO_2 Concentrations and Student Attendance in Washington and Idaho*; Lawrence Berkeley National Lab. (LBNL): Berkeley, CA, USA, 2004.
165. Simons, E.; Hwang, S.A.; Fitzgerald, E.F.; Kielb, C.; Lin, S. The impact of school building conditions on student absenteeism in upstate New York. *Am. J. Public Health* **2010**, *100*, 1679–1686. [CrossRef]
166. Bakó-Biró, Z.; Clements-Croome, D.J.; Kochhar, N.; Awbi, H.B.; Williams, M.J. Ventilation rates in schools and pupils' performance. *Build. Environ.* **2012**, *48*, 215–223. [CrossRef]
167. Kabirikopaei, A.; Lau, J.; Nord, J.; Bovaird, J. Identifying the K-12 classrooms' indoor air quality factors that affect student academic performance. *Sci. Total Environ.* **2021**, *786*, 147498. [CrossRef]
168. Mendell, M.J.; Heath, G.A. Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air* **2005**, *15*, 27–52. [CrossRef]
169. Wargocki, P.; Porras-Salazar, J.A.; Contreras-Espinoza, S.; Bahnfleth, W. The relationships between classroom air quality and children's performance in school. *Build. Environ.* **2020**, *173*, 106749. [CrossRef]
170. Eide, E.R.; Showalter, M.H.; Goldhaber, D.D. The relation between children's health and academic achievement. *Child. Youth Serv. Rev.* **2010**, *32*, 231–238. [CrossRef]

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