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AN ASSESSMENT OF INDOOR AIR QUALITY FACTORS IN DESIGNING HEALTHY SCHOOLS

Environmental Science

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ABSTRACT

The aim of this study was to examine and assess research studies related to indoor air quality factors. This study also seeks to summarize and synthesize research findings to design a framework for healthy schools that can be utilized to improve the indoor air quality alongside associating respiratory signs and symptoms that emerge upon exposure to poor indoor air quality. Poor indoor air quality, even low levels of exposure, increases health risks among both students and teachers. Reducing air pollutants in schools and its health symptoms require knowledge of the consequences of poor indoor air quality if schools are to develop and implement effective interventions to design health schools. This integrative review targets research studies published from 2014 to 2017 that examined poor indoor air pollutants in a school setting and ways to optimize good indoor air quality. School buildings readily encounter high levels of varying indoor air pollutants. Air pollutants inclusive of CO_2, CO, formaldehyde, NO, O3, PM, RH, SO2, space and air volume, and VOCs contribute to the rise of adverse health outcomes in teachers and students. However, CO_2 is highly indicative of a need for interventions to minimize air pollutants and improve ventilation in schools. Ensuring good air quality in a school setting requires interventions to reduce the presence of air pollutants. Key recommendations focused on construction materials such as adhesives, carpeting, cleaning supplies used, composite wood-based products, and paints. Improved ventilation, quarterly HVAC maintenance, as well as heating and cooling systems with humidity control (50% RH) are also proposed.

KEYWORDS

School Buildings, Indoor air quality, Ventilation, Air pollutants, Children, Health

1. Introduction

According to standards established by the United States Environment Protection Agency (EPA) (2017) and the Centers for Disease Control and Prevention (2015), both primary and secondary air pollutants compromise health upon exposure. Several studies have been conducted to assess indoor air pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde, nitrogen oxide (NO2), ozone (O3), particulate matter (PM), sulfur dioxide (SO2), and volatile VOCs, only a few studies measured indoor air quality in preschools (Hou, Liu, & Li, 2015; Mainka & Zajusz-Zubek, 2015). Indoor air quality within schools is of increased significance due to the affects attributed to the health and performance of teachers and children (U.S. Department of Labor, 2017). Children are considered the most vulnerable population exposed to potential health hazards of air pollutants in school buildings where they spend most their day (Abdel-Salam, 2015). Even indoor air pollutants at low levels of exposure are correlated with the development of respiratory signs and symptoms (Madeira et al., 2015).

In a healthy school building, the indoor environment is comfortable and safe for all occupants with a focus on children since they have developing physiology and immature blood systems (Blaga, 2016). The World Health Organization (WHO) Regional Office for Europe (2015) posits that appropriate control strategies must be implemented to minimize the potential exposure to indoor air pollutants while optimizing good indoor air quality in schools.

The main objective is to examine and assess research related to indoor air quality factors as well as summarize and synthesize research findings to design a framework for healthy schools that can be utilized to improve the indoor air quality and corresponding respiratory signs and symptoms involved with poor indoor air quality.

2. Methodology

An integrative review was used to synthesize data collected from five research studies.

2.1. Search method

CINAHL Complete, Science & Technology Collection, and Science Direct databases were searched for articles published between 2014 and 2017. The following search terms were used: indoor air quality AND school* OR healthy school*. A primary search identified a total of 3,646 articles from databases and 11 articles from manual searches, of which 1,783 were duplicate articles. The abstracts were screened for relevancy and 1,542 articles were excluded. Articles were then screened for full-text versions, which further excluded an additional 327 articles. The remaining five articles were retained and included within this integrative review.

3. Data Abstraction and Synthesis

Studies involved in this integrative review were analyzed by the author of this review. Data extraction was measured in accordance to the impact that various factors have on indoor air quality in school buildings. Several tools were used to measure in real-time factors that influence indoor air quality. The characteristics of each research study and key findings are summarized. Data analysis varied and included adjusted risk ratios (RR) and 95% confidence intervals (CI), ANOVA, chi-square test, descriptive analysis, distributions, Fisher's exact test, Kolmogorov-Smirnov goodness-of-fit test, Kruskal-Wallis and Mann-Whitney U test, Mann-Whitney U test, multivariate analysis, regression models estimating relative risk (RR), SPSS, and t-test.

4. Results

4.1. Samples

Samples varied an included students, teachers, classrooms and schools. Sample sizes ranged from 111 participants (Rawi et al., 2015) to a large sample size of 1,019 research participants (Ferreira & Cardoso, 2014) within private and public school settings. One study examined 31 schools (Babayiğit' et al., 2014) while a larger study assessed a total of 428 schools (Kielb et al., 2015). Studies were conducted in Balakong and Bangi, both of which are in Selangor (Rawi et al., 2015), the Keciören district located in Ankara (Babayiğit' et al., 2014), the Municipality of Coimbra in Portugal (Ferreira & Cardoso, 2014), New York State (Kielb et al., 2015), and North Carolina (Angelon-Gaetz et al., 2015).

4.2. Measures

Factors that influence indoor air quality in school buildings was examined and assessed by five research studies that included real-time measurements and survey questionnaires. Surveys were completed by teachers and parents or legal guardians of students attending the schools in question. These survey questionnaires were used to measure respiratory signs and symptoms. Real-time measurements used a range of instruments to measure factors inclusive of CO, CO_2, formaldehyde, NO_2, $PM_{2.5}$, PM_{10}, and VOC, which influences indoor air quality in school buildings (as depicted in Table 1). A portable infrared ambient, Miran SapphIRe 205B, were used to measure concentrations of CO, CO_2, formaldehyde, NO_2, and SO_2 concentrations (Babayiğit' et al., 2014). Other portable devices such as Q-Trak Plus Model 8554 (Rawi et al., 2015) and VelociCalc 9555-P measured CO, Cos, RH, and temperature (Ferreira & Cardoso, 2014). DustTrak, more specifically the TSI 8520 DustTrak was used to asses and monitor $PM_{2.5}$ and PM10 (Rawi et al., 2015). Concentrations of VOC was measured by PbbRAE (Rawi et al., 2015) or Voyager (Ferreira & Cardoso, 2014). The handheld Series 500, QRAE,Formal Demeter htV, Microbial Air Sample (MAS) – 100 NT, were used to measure O_3, NO2 and SO_2, formaldehyde, and microbes present in classrooms, respectively

(Ferreira & Cardoso, 2014). Air velocity was assessed using a TSI   Velocicalc Plus Model 8386 (Rawi et al., 2015).

Table 1 Factors influencing indoor air quality in school buildings

Factors that Influence the Quality of Indoor Air

Author(s), Year	Carbon Dioxide (CO2)	Carbon Monoxide (CO)	Formaldehyde	Nitrogen Dioxide (NO2)	Ozone (O3)	Particular Matter (PM)	Relative Humidity (RH)	Sulfur Dioxide (SO2)	Space & Air Volume	Volatile Organic Compounds (VOCs)	Known Indoor Air Pollutants Cause Respiratory Symptoms
Angelon-Gaetz et al., 2015	X										
Babayiğiť et al., 2014	X X X	X	X	X		X				X	
Ferreira & Cardosa, 2014	X X X X	X	X	X		X				X	
Kielb et al., 2015					X					X	
Rawi et al., 2015	X X X X	X			X					X	

4.3. Key Findings
4.3.1. Carbon Dioxide CO_2
Indoor CO2 levels is suggestive of the correlation between ventilation and occupancy alongside metabolic activity. The mean score (M) and standard deviation (SD) of CO_2 in classrooms was M = 717.3, SD = + 646.3 (P <0.05) (Babayiğiť et al., 2014). Mean concentrations in both sampling periods, fall/winter and spring/summer, were both significantly higher than the maximum reference value of CO2 concentrations (984 ppm) at concentrations of M = 1578.16, SD = + 12.49 and M = 1152.80, SD =+ 595.41, respectively (Ferreira & Cardoso, 2014). According to parametric test results, CO2 distribution was not normal in studied classrooms and comparative classroom areas. The mean CO2 level was higher in the comparative area (784.0; IQR = 526) than in the studied area (579.0; IQR = 340.0) yet no significant difference was found relative to the distribution of CO2 in comparative and studied areas (P = 0.774) (Rawi et al., 2015).

4.3.2. Carbon Monoxide (CO)
An accumulation of CO indoors is influenced by poorly ventilated heating and water systems and commonly occurs during times involving high volumes of traffic as CO is released from cars travels in the air and enters school buildings upon entry and exit. The mean score of CO in 172 classrooms was M = 1.8, SD = + 1.8 (P >0.05) (Babayiğiť et al., 2014). School building less than 10 years old had a mean CO level of -8.076 (P < 0.001) (Rawi et al., 2015). A statistically significant difference was found between the CO levels in studied areas compared to comparative areas Z = 7.866 (P < 0.001) (Rawi et al., 2015). Ferreira and Cardoso (2014) reported higher statistically significant mean CO concentrations in the fall/winter (0.42 + 0.53) compared to the spring/summer (0.14 + 0.13). Schools built near heavily trafficked areas demonstrated a statistically significant mean CO score of 1.7 (Babayiğiť et al., 2014). Indoor CO levels are of importance in schools since a significant relationship (P = 0.003) was found between CO concentrations and a lung function parameter, forced vital capacity (FVC%) abnormality (Rawi et al., 2015).

4.3.3. Formaldehyde
The presence of formaldehyde in school building materials and classroom products manufactured using certain paints, hardwood plywood, medium-density fiberboard, and particle board is correlated with poor indoor air quality. Babayiğiť et al. (2014) revealed a mean concentration of formaldehyde of M = 0.6, SD = + 0.5 (P > 0.05) in classrooms. Mean concentrations of formaldehyde was slightly higher in the spring/summer (0.02 + 0.02) compared to fall/winter (0.01 + 0.01), both sampling periods of which were below the maximum reference value (0.08) in accordance to Portuguese Law (Ferreira & Cardoso, 2014).

4.3.4. Nitrogen Dioxide (NO2) and Ozone (O3)
Indoor NO2 concentrations is influenced by the prevalence of indoor and outdoor sources. Heavy local traffic reportedly increased NO2 concentrations from automobiles and varying sources of combustion. Since the schools were in a heavily trafficked area, Babayiğiť et al. (2014) reported a mean NO2 concentration of M = 2.0, SD = + 1.3 (P < 0.05) in classroom settings. O3 was relatively higher in the fall/winter compared to the spring/summer as indicated by M = 0.002 (SD = + 0.060) and M = 0.0009 (SD = + 65.66), respectively (Ferreira & Cardoso, 2014).

4.3.5. Particulate Matter (PM)
PM concentrations (PM2.5 and PM10) are correlated with indoor air quality in school buildings. The mean concentration of PM2.5 was highest in the spring/summer (0.11 + 0.03) compared to the fall/winter (0.08 + 0.04); however, PM10 was higher in the fall/winter (0.12 + 0.05) than in the spring/summer (0.11 + 0.03) (Ferreira & Cardoso, 2014). Newly constructed buildings less than 10 years old had a mean P2.5 concentration of Z = -5.494 (P <0.001) (Rawi et al., 2015). Statistical analysis revealed a significant difference in PM10 concentrations between comparative and studied areas of Z = -6.445 (P < 0.001). Another significant relationship was identified between indoor PM2.5 concentrations and FVC% abnormality (P = 0.014) (Rawi et al., 2015).

4.3.6. Relative Humidity (RH)
Increased indoor RH is associated with increased outdoor humidity, of which a stronger relationship was observed when the classroom was occupied. Mean indoor RH was 42.7 (SD = 12.3) (Angelon-Gaetz et al., 2015). Occupied and unoccupied times were categorized as OR $_{10\%~increase~in~outdoor~RH}$= 1.70 (1.57, 1.83) and OR $^{10\%~increase~in~outdoor~RH}$= 1.49 (1.43, 1.55), respectively (Angelon-Gaetz et al., 2015). An increased likelihood of increased indoor RH is attributed to less frequent scheduled HVAC maintenance and a RH cut off at >50% and >60% (Angelon-Gaetz et al., 2015). One school reported that a total of 12 classrooms throughout their school had RH levels outside the conservative RH range (30-50%) for approximately 89% of classroom-days. During inspection, water damage failed to generate high RH (Angelon-Gaetz et al., 2015).

Low classroom RH was identified as <30%; however, some findings from Ferreira and Cardoso's (2014) study found RH values that were not between the lower limits (30%) and upper limits (70%). RH levels were above the upper limits in both sampling periods in the fall/winter. RH in the studied area was 78.1 (IQR = 13.5), which is beyond the upper RH limits but was within RH limits in the comparative area (54.7; IQR = 31.7) (Rawi et al., 2015). School buildings less than 10 years old had a mean RH equivalent to -2.821 (P = 0.005) (Rawi et al., 2015). A high level of humidity is problematic since it exacerbates the growth and reproduction of allergens, bacteria, fungi, and mold indoors, especially among buildings damaged by water (Babayiğiť et al., 2014).

4.3.7. Sulfur Dioxide (So²)

So₂, an air pollutant with a distinct smell, is associated with emissions from motor vehicles, fuel combustion, and other industrial activities or processes. Schools built near heavily trafficked areas demonstrated a statistically significant mean concentration of SO2 in classrooms was $M = 4.1$, $SD = + 3.6$ ($P > 0.05$) in classrooms (Babayiğit' et al., 2014). Mean concentrations from fall/winter throughout spring/summer was 0.001 ppm for SO2, which was relatively similar as fall/winter and spring/summer SO2 concentrations were equivalent to $M = 0.005$, SD = +0.020 and $M = 0.004$, $SD = + 0.030$, respectively (Ferreira & Cardoso, 2014).

4.3.8. Space and Air Volume

In accordance with standards, the size of a classroom should be comprised of 35 students with a sufficient air volume of 6.0 m^3 per student and sufficient space of 1.2 m^2 per student (Babayiğit' et al., 2014). Findings demonstrate that approximately 61.0% of classrooms reported sufficient space (> 1.2 m^2) per student; however, merely 8.1% of classrooms demonstrated sufficient air volume (> 6.0 m^3) per student (Babayiğit' et al., 2014). Classrooms that reported less than 6 m3 of air volume demonstrated increased mean scores of CO (1.8 + 1.9; P >0.05), CO₂(729.0 + 643.9; P >0.05), formaldehyde (0.6 + 0.5; P>0.05), NO₂(2.0 + 1.3; P >0.05), and SO²(4.1 + 3.5; P >0.05) (Babayiğit' et al., 2014). Additional findings revealed that classrooms with more than 35 students had statistically significant mean scores of CO²(827.3 + 708.5; P <0.05), formaldehyde (0.7 + 0.5; P <0.05), No² (2.1 + 1.3; P <0.05), and SO² (3.6 + 3.6; P <0.05) compared to classrooms with less than 35 students (Babayiğit' et al., 2014). The median number of viable microorganisms 35.5 (P <0.0083) were more likely to thrive and reproduce in classrooms with 35 or more students (Babayiğit' et al., 2014). Gram-negative bacilli, Gram-positive cocci, mold/fungi, and micrococcus were present in a classroom size > 35 students at a median of 14.5 (P <0.0083), 53.0 (P <0.0083), 2.0 (P <0.05), and 0.00 (P <0.05), respectively (Babayiğit' et al., 2014).

4.3.9. Volatile organic compounds (VOCs)

A number of carbon containing chemicals are considered VOCs. Art supplies, air fresheners, cleaning chemicals, paint, pesticides, markers, and whiteboard markers regulate the presence and concentrations of VOC, which tend to accumulate in a school environment (Kielb et al., 2015). Findings from Kielb's et al. (2015) study revealed that paint and pesticides were the most prevalent odor or fume reported by teachers at a rate of 76.3% and 75.0% respectively. Other additional odors and fumes included art supplies and whiteboard markers (54.4%), air fresheners and perfumes (58.2%), and cleaning chemicals (59.5%) (Kielb et al., 2014). The mean level of VOCs in preschool classrooms were higher in the comparative area as opposed to the studied area (Rawi et al., 2015). School buildings less than 10 years old had a mean VOC of $Z = 2.214$ ($P = 0.027$) between the studied and comparative area (Rawi et al., 2015). Ferreira and Cardoso (2014) showed a mean VOC concentration of $M = 7.32$ during the fall/winter and spring/summer. Additional findings showed that VOC was higher in the fall/winter (97.82 + 73.72) than in the spring/summer (90.51 + 65.66) (Ferreira & Cardoso, 2014).

4.3.10. Known Indoor Air Pollutants and its Impact on Respiratory Symptoms

A correlation between classroom air quality characteristics exists between signs and symptoms of respiratory-related illnesses and medical conditions. Findings related to asthma demonstrate an association with dust, moldy odors, moisture damage, other odors from air fresheners and perfumes, and visible mold of $RR = 2.14$ (95% CI: 1.08 - 4.23), $RR = 2.34$ (95% CI: 1.09 - 5.02), $RR = 1.92$ (95% CI: 1.13 - 3.24), $RR = 1.98$ (95% CI: 1/12 - 3.50), and $RR = 2.10$ (95% CI: 1.10 – 4.03), respectively (Kielb et al., 2015). An increased number of classroom-based characteristics were significantly correlated with a heightened risk of acquiring health symptoms related to the school building. The most statistically significant relationships were found for dust reservoirs ($RR = 2.13$; 95% CI: 1.72 – 2.65), dust ($RR = 2.13$; 95% CI: 2.62 – 5.13), moldy odors ($RR = 1.65$; 95% CI: 1.30 – 2.10), dust reservoirs ($RR = 2.13$; 95% CI: 1.72 – 2.65), paint odors ($RR = 1.73$; 95% CI: 1.40-2.13), visible mold ($RR = 1.71$; 95% CI: 1.39 – 2.11), and paint odors ($RR = 1.73$; 95% CI: 1.40-2.13) (Kielb et al., 2015).

Cough and wheezing were the most common symptoms found in preschool-aged children in a school setting (Rawi et al., 2015). A significant correlation was found between wheezing and indoor concentrations of PM2.5 ($OR = 2.69$, 95% CI = $1.07 – 6.79$) and indoor concentrations of PM10 ($OR = 5.31$; 95% CI = $1.70 - 16.68$) yet no significant correlations were identified for other respiratory signs and symptoms (Rawi et al., 2015). Additional findings revealed the prevalence of several self-reported building-related symptoms. The highest self-reported building-related symptoms include sinus problems (16.8%), headache (15.0%), allergies/congestion (14.8%), throat irritation (14.6%), fatigue or drowsiness (12.0%), sneezing (11.2%), and eye irritation (10.6%); however, the percentage of teachers who building-related symptoms affect their absenteeism or ability to teach is highest amongst frequent colds (68.0%), asthma attacks (50.0%), inability to focus (47.1%), sinus problems (46.4%), throat irritation (38.4%), nausea (37.5%), headache (37.3%), and allergies/congestion (33.8%) (Kielb et al., 2015).

Table 2 : Summary of characteristics from quantitative studies

Author(s)	Year	Study Aim	Research Design	Sample	Key Findings
Angelon-Gaetz et al.	2015	To identify factors correlated with humidity that is poorly controlled in a school setting.	Longitudinal cohort study	Principals from 10 schools in North Carolina (134 classrooms)	Mean indoor RH was 43.0 in both school districts (Coastal and Piedmont). One school with 12 classrooms had RH outside the range (30-50%) for 89% classroom-days.
Babayiğit' et al.	2014	To determine the status of indoor air quality in primary schools to increase awareness of risk factors.	Cross-sectional study	172 classrooms throughout 31 primary schools in Ankara	Classrooms with > 35 students had increased mean scores in CO2, formaldehyde, NO2, and SO2 than classrooms with < 35 students. Schools located in heavy trafficked areas demonstrated a significant mean of CO and SO2 (P < 0.05).
Ferreira & Cardosa	2014	To assess whether indoor air quality is linked with the prevalence of respiratory or allergic diseases among students in a school setting.	Questionnaire	1,019 students across 51 elementary schools in Coimbra, Portugal	Mean CO2 concentrations was above the maximum reference value for Portugal standards and caused lack of concentration. The most prevalent respiratory symptoms and illnesses include asthma, rales, rhinitis, sneezing, and wheezing.

| Kielb et al. | 2015 | To examine classroom characteristics in association with poor indoor air quality and the health symptoms related to the buildings condition. | Cross-sectional study | NYS teachers in NYS schools (excludes NYC) | A strong relationship found with high levels of indoor air quality-related classroom characteristics. More than one symptom was linked to dust (RR = 3.67), dust reservoirs (RR = 2.13), mold (RR = 1.71), and moldy odors (RR = 1.65). |
| Rawi et al. | 2015 | To assess indoor air quality and its correlation with respiratory health. | Cross-sectional comparative study | 111 Malay children in 4 preschools in Selangor | CO_2 distribution in the classrooms was not normal. The mean CO_2 and VOCs were higher in the comparative areas than in the studied areas. Mean CO, PM2.5, PM10, and RH were higher in the studied area than the comparative area. |

5.Discussion

Higher levels of indoor pollutants and inadequate fresh indoor air is associated with ventilation problems (Kielb et al., 2015). Climatic conditions, total classroom volume, and number of occupants is linked to high occupancy and inadequate ventilation (Ferreira & Cardoso, 2014). Poor ventilation and the accumulation of moisture leads to the accumulation of byproducts of combustion (CO and NO_2) especially when burning stoves, fuel space heaters, and gas cooking stoves are used for heating purposes (Babayiğiť et al., 2014). Formaldehyde, a known irritant, is linked to significantly more severe asthma-related symptoms, headache, and nausea in addition to irritation of the eyes, mouth, nose, and throat. Schools in areas with heavy traffic (< 100 m away) are exposed to significantly higher levels of automobile emissions, which is common since schools are built on moderately undesirable land and often located near highways (Babayiğiť et al., 2014).

Increased humidity was also associated with an occupants' behavior inclusive of shutting off unit ventilators to eliminate noise, opening doors or windows, and student activities that require entering and exiting the building. Since approximately half of buildings less than 10 years old (48.9%) demonstrated visible signs of water damage, water damage was identified as a prevalent issue in new school buildings(Angelon-Gaetz et al., 2015). Indoor dampness and increased RH levels >50% is an indicator of increased airborne fungus, concentrations of formaldehyde, dust mites, mold spores, and respiratory symptoms (Angelon-Gaetz et al., 2015). Moreover, low RH is also detrimental and linked to adverse health outcomes by

increasing a hosts' susceptibility to viral infections (Angelon-Gaetz et al., 2015; Rawi et al., 2015). Insufficient humidity in a classroom enhances the development of static build-up as children and teachers begin to experience dryness of the skin (Rawi et al., 2015). Annual classroom maintenance of the HVAC system was associated with increased odds of RH (> 60%) within the classroom when compared to classrooms that received HVAC maintenance on a quarterly basis due to the fact that quarterly HVAC maintenance prevents the accumulation of humidity by quickly identifying and repairing ventilation issues (Angelon-Gaetz et al., 2015).

6. Conclusion

The increased concentrations of several air pollutants, primarily CO_2, is indicative of the need for interventions to reduce air pollutants thus improving ventilation (Ferreira & Cardoso, 2014). The prevalence of classroom characteristics and building-related health symptoms in association with increased exposure to poor indoor air quality can be used to advocate for environmental health programmes that address indoor air quality issues (Kielb et al., 2015; Rawi et al., 2015). In designing healthy schools, key recommendations are proposed inclusive of quarterly HVAC maintenance, the ability to select a heating and cooling mechanism with options for humidity control to ensure humidity set points are adjusted to 50% RH and maintained at this level (Angelon-Gaetz et al., 2015). To safeguard a sustainable indoor environment in school buildings, the construction materials inclusive of adhesives, carpets, cleaning products, composite wood products, and paints should be safe (Babayiğiť et al., 2014). Schools should therefore continuously evaluate and monitor indoor air quality at periodic levels to ensure adequate levels are maintained to prevent and control the development and exacerbation of symptoms of respiratory illnesses.

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