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Indoor Air Quality at School: Ventilation Rates and It Impacts Towards Children- A review

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***Abstract*-The reviews on the subject of school environments emphasized that indoor air quality (IAQ) is often inadequate in classrooms causing increased risk for asthma and other health-related symptoms in preschool environment. It is most pronounced in developed countries. The paper summarizes and explores the peer-reviewed literature on IAQ in schools environment and to explicit the importance of IAQ in school's environment by reviewing the previous studies on exposure of pupils towards poor IAQ in the classrooms. The existing reviewed data emphasizes on impact of Ventilation Rates and CO2, on children's health and performance while performing assessment on existing standards (ASHRAE, NIOSH, ACGIH and OSHA). The study found that, most of the children are exposed to the inadequate environment during their time in the classroom which is not complying with the established standard. Expectantly, this paper is comprehensive to determine the sufficient information and as a reference for further data collection to assess the IAQ in Malaysian's schools.**

Keywords- Indoor Air Quality, CO_2, Ventilation Rates, Schools, Review, Children

I. INTRODUCTION

Indoor air quality in schools can have a substantial impact on children's health, as an important environment where children may be exposed to pollutants and allergens [39]. School provides a major indoor environment for children away or apart from their home as they may spend 10 hours per day at school, and at least 10 hours per year [39] depending on the time that they arrive at the school and the time they leave the school. It is special concerns since the pupils are susceptible to poor IAQ. Indoor air pollutant might increase the chance of both long and short term health problems among pupils and staff, reduce the productivity of teachers and degrade the pupil's learning environment and comfort [32]. A significant influence from indoor environmental quality can effect and give the influence on student attendance and performance. Studies have shown that poor indoor air quality resulted more illness, absenteeism and asthma attacks. Studies done in United States [15] indicated that good air quality in schools have enhanced the attendance intensity and reduced the health problems among pupils. While, research on five classrooms in Hong Kong has indicated inadequate ventilation maximum CO2 level reach 5900 µl/l during class [16]. [38], in their study at the school buildings in Korean found that most of the classrooms stated poor IAQ and significantly higher than the Korean Indoor Air Standard. Both research stated that the indoor air quality and ventilation in school buildings may affect the health of the children and indirectly affect learning performance. Surprisingly, given the magnitude of the school population, information on indoor air quality in Malaysian's schools is very limited.

II. OBJECTIVES

This study embarks on the following objectives

A. Assemble, evaluate, and summarize existing measurement data on ventilation and Carbon Dioxide (CO2) concentrations in schools
B. Identify the most commonly reported building-related health symptoms involving schools

III. LITERATURE REVIEW

A Indoor Air Quality

Many factors affect indoor air pollution levels such as maintenance activities, the presence of contaminant sources (e.g. building materials, furnishings and equipment), the levels of contamination outdoors, the season, indoor humidity and temperature, and ventilation rates [14]. Concentrations of specific contaminants in indoor air can often be considerably higher than concentration levels outdoors [21]. Indoor contaminants include formaldehyde, volatile organic compounds (VOCs), particles, pesticides, radon, fungi, bacteria, and nitrogen oxides. In addition to indoor air contaminants, occupants can experience similar discomfort and health symptoms similar to those attributed to indoor contaminants due to indoor environmental factors .

Often, the presence of both indoor contaminants and other indoor environmental factors makes it difficult to identify direct causes of occupant discomfort and health symptoms. [22].

Generally, HVAC systems and water damage to the building envelope are the most common sources of building-related IAQ problems [22]. Other causes of IAQ problems can be attributed to various phases of the building process including poor site selection, choice of materials, roof design, poor construction quality, improper installation or any number or combination of other factors [14]. Poor ventilation was another common issue that affected school occupants. Low ventilation rates generally increase the risk

for health symptoms. There is also a consistent relationship between health symptoms and ventilation rates or CO2 concentrations. [25] found that some increases in ventilation rates up to 20 LS-1 per person decreased prevalence of SBS symptoms or improved perception of IAQ. [36] found that air-conditioned buildings may increase risk of SBS systems compared to those that are naturally ventilated

TABLE I: SUMMARY OF INDOOR AIR QUALITY REPORT

REPORT	SAMPLE	AREA OF FOCUS	RESULT/RECOMMENDATION
[7]	Scientific literature published in journals and conference proceedings as of 1999	School Building related health symptoms	• Classrooms are not adequately ventilated. • Consistent relationship between ventilation rates or CO2 concentrations and health symptoms. • Exposure to VOCs, molds, microbial VOCs and allergens measured in floor dust are related to asthma, SBS and other respiratory symptoms
[18]	Scientific literature through 2003	School environments effect on academic performance .	• Studies link indoor dampness and microbiological pollutants to asthma exacerbation and respiratory infection, which are associated with reductions in performance and attendance. • Evidence links low ventilation rates to reduced performance.
[25]	Reviewed 21 studies with 30,000 subjects.	CO2, ventilation rate and human health responses	• Ventilation rates below 10 LS-1 per person associated with significant worsening of one or more health or perceived air quality outcomes. • 1/3 of carbon dioxide studies indicate decrease risk of SBS symptoms with decreasing CO2 levels below 800 ppm.
[36]	peer-reviewed papers by EUROVEN scientific committee	Ventilation, CO2 and health symptoms of occupants	• Ventilation associated with comfort (perceived air quality), health and productivity. • Air-conditioned buildings may increase risk of SBS systems compared to those naturally ventilated. • Improper maintenance, design and functioning of air conditioning systems contribute to perceived prevalence of SBS symptoms

B. Ventilation Rates

Ventilation surrogates the IAQ level, minimizing the concentration of harmful pollutant. The higher ventilation rates are associated with improved of health. It has rarely been measured in schools, although inadequate ventilation is often suspected to be an important condition leading to reported health symptoms. [2] recommends a minimum ventilation rate of 8 L/s-person (15 cfm/person) for classrooms. Given typical occupant density of 33 per 90m2 (1000 ft2) and a ceiling height of 3m (10 ft), the current ASHRAE standard would require an air exchange rate of about 3 air changes per hour (ACH) for a classroom.

[34] reported ventilation measurements made in 6 non-complaint schools in the U.S. Northwest - 2 in Portland, and 4 in Spokane, WA. Schools ranged from 3-25 years in age, 1-3 stories; all had mechanical ventilation systems of some type. Ventilation rates, calculated on a whole building volume basis, ranged from 4.5 L/s-person to 31 L/s-person. The whole or average building rate, however, includes unoccupied areas such as hallways and gymnasiums, and, as the authors point out, this average rate overestimates the local ventilation rate of occupied classrooms. For example, in one of the elementary schools, the whole building ventilation rate was 4.5 L/s-person while the ventilation rate in an occupied classroom was only 1.6 L/s-person.

[35] also reported ventilation rates measured in 2 schools in Sante Fe, which were being mitigated for high radon concentrations. Twelve pre- and post-radon mitigation ventilation rates were below 3 ACH with one exception. [9] in his research of eight primary schools in United Kingdom revealed that pupils work and performance increased 7% in addition due to the intervention the fresh air supply from 0.3-0.5 to 16L/s per person. This is supported by [18], where the poor ventilation rates for the adult population could be expected that not only the comfort and health, but also the learning performance of school children are affected by the poor environmental conditions in classrooms. By improving classroom conditions can substantially improve the performance of school works by children [37].

C. CO2 Concentrations

Carbon dioxide concentrations are often used as a surrogate of the rate of outside supply air per occupant. Indoor CO2 concentrations above about 1000 ppm are generally regarded as indicative of ventilation rates that are unacceptable with respect to body odors. Concentrations of CO2 below 1000 ppm do not always guarantee that the ventilation rate is adequate for removal of air pollutants from other indoor sources [25], [1].

It is difficult to adequately characterize indoor CO2 concentrations since they are a function of occupancy and ventilation rate, both varying as a function of time. Grab samples or other short-term measurements may be inadequate to provide information on the long-term ventilation conditions in schools. The most common

building factors associated with indoor environmental complaints are related to the Heating Ventilation and Air Conditioning (HVAC) systems. The recommended ventilation rate for a classroom is 15 cfm/person with a specified maximum occupancy of 50 persons per 1000 ft2 for schools [23]. [2]provides outdoor air requirements for classrooms of 15 cubic feet per minute (CFM) per person.

According to [5], the ventilation rate for schools with desiccant cooling systems (humidity control) averaged 15 cfm/person, whereas conventional HVAC system schools 20 averaged only 5 cfm/person. This study cited inadequate HVAC maintenance and poor design as causes for poor indoor air quality from HVAC systems. Students occupying rooms with old air handling unit filters reported more symptoms from the eyes, nose and throat than students with newer filters [29]. HVAC systems can cause indoor air quality problems and/or distribute contaminants throughout a building. Table 3.2 and figure 3.1 present findings from literature relative to measurements of CO2, ventilation and other measures of the indoor conditions in classrooms and schools. Specifically, the findings determined whether ASHRAE recommended concentration of 1,000 ppm CO2 and ventilation rate of 15-cfm/person were met. Results from Table II, only two studies met the ventilation guidelines, and 14 of the 16 studies failed to meet the ventilation guidelines. The data indicates that, most often, mechanically ventilated and unoccupied rooms meet standards for CO2, whereas naturally ventilated and occupied rooms did not. When new schools were compared to old schools, measurements were relatively equal.

TABLE II: MEASURING CO2(PPM) AND VENTILATION (CFM/PERSON)

STUDY	SAMPLE	CO2 ventilation guidelines met	CO2 (ppm) or ventilation (cfm/person)
[17]	3 schools 9 classrooms	Yes	• 638.27-698.60ppm, 555.50-647.60ppm, 545.60-675.0ppm
[3]	39 schools	No	• 1080 ppm
[5]	10 schools	Yes - desiccant No - HVAC sys.	• Desiccant (15 cfm) • HVAC system < 5 cfm/person
[6]	24 schools	No	• 4000ppm
[8]	10 schools 2 districts	No	• 1461 ppm • 79% exceeded standard
[11]	7 classrooms	No	• 1017-1735 ppm
[9]	3 schools 7 classrooms	No	• 1,387, 644, and 1,455 ppm
[12]	9 schools 64 classrooms	No	• 533-1552 ppm
[13]	7 Schools	No	• 1316 ppm
[16]	5 schools 5 classrooms	No	• > 1000 ppm
[19]	12 schools 12 Classrooms	No	• 1,150 ppm • Range 760 – 1620 : 84% did not meet standard
[20]	2 schools 5 classrooms	Yes	• Old school :509 ppm • New school: 512 ppm
[22]	67 schools 384 classrooms	No	• 1,070 ppm portable classrooms (1,064 ppm) • traditional classrooms (1074 ppm
[27]	22 schools 436 classrooms	No	• 45% of classrooms > 1,000 ppm
[28]	1 test chamber 1 classroom	No	• without ventilation (1790 - 2190 ppm) • with ventilation (1032 - 1536 ppm)
[33]	104 Childcare Center	Yes-Natural Ventilation No-Air-Condition	• Natural Ventilation (463-509 ppm) • With air-condition (Mean 1184ppm : range 995-1337 ppm)

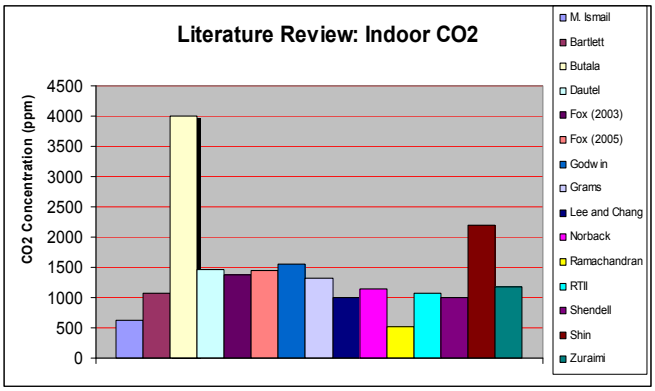

Figure I: Literature Summary On Measuring CO2 (ppm)

High levels of CO2 can result from inadequate ventilation systems, inadequate air exchanges from the opening and closing of windows and doors, and overcrowded classrooms. Occupied and air conditioned rooms measured higher levels of CO2 than rooms cooled with ceiling fans. Rooms with desiccant active control systems met standards for ventilation, while rooms with conventional HVAC systems did not [5]. Other study findings indicate that low ventilation rates were associated with worsening health or perceived air quality outcomes. Also, the literature associates increases in CO2 with decreased attendance [27].

[30,31] reported average and ranges of indoor CO2 concentrations for 96 classrooms in 38 Swedish schools randomly selected from a population of 130 schools; 61% of

them had mechanical supply and exhaust air systems while the remainder had natural ventilation. Concentrations averaged 990 ppm CO2 for the 38 schools, but were above 1000 ppm for 41% of the measurements (maximum = 2800 ppm).

In general, CO2 measurements in schools suggest a significant proportion of classrooms probably do not meet the ASHRAE Standard 62-2007 for minimum ventilation rate, at least part of the time. The particular concern is the potential for increased risks of contracting certain communicable respiratory illnesses, such as influenza and common colds in classrooms with low ventilation rates [17].

IV. DISCUSSIONS OF FINDINGS

The present paper supports on previous studies of IAQ for schools in various countries. Anxiously, majority of schools are exposed to the inadequate IAQ due to insufficient ventilation and maintenance activities, temperature, and ventilation rates. These conditions will lead to the SBS symptom and affecting the children performance as they are sensitive to any changes surrounding them. The peered researches indicate that 14 of 16 studies failed to meet the CO2 ventilation guidelines. Yet, it is difficult to endure the characteristic indoor CO2 as it often used as a surrogate of the rate of outside supply air per occupant and a function of occupancy and ventilation rate. The CO2 in selected researches shows quite low, where it will not affecting much the IAQ of the classroom, whereas most of the sources attribute from the outdoor contaminants such as the automobiles exhaust

V. RESEARCH NEEDS/CONCLUSIONS

This review shows that the state of knowledge regarding IAQ in schools is limited. With the possible exception of the early NIOSH investigations not reported in the peer-reviewed literature, there has been no consistent approach to evaluations of IAQ and health outcomes in schools. Many of the existing studies lack the rigor and quality necessary to adequately address the problem. In addition, although there is some effort to identify the IAQ problems in schools, there are no programs currently in place to improve the indoor environmental quality in schools

More studies are needed in which relations between symptoms and measured exposures to multiple specific contamination to be investigated. Furthermore, quantitative information is needed on exposure-health response relationships for specific pollutants suspected to cause health symptoms, in order to provide a sound basis for setting standards for refurbished pre-school and for insuring cost-effective mitigation measures. Finally, although there is evidence that many schools are not adequately ventilated, the extent of the problem is not known. Careful and thorough measurements of ventilation rates and/or CO2 levels in a representative sample of schools would provide much needed information on the fraction of schools with this problem. In closing, although more studies are needed to determine the extent of IAQ problems in schools, evidence shows that ventilation rates in new and existing schools often do not meet the minimum ASHRAE guidelines, and this may be related to significant increases in symptoms among children and teachers in schools. It is clear that programs should be put in place to ensure that all pre-schools provide necessary ventilation. Expectantly, this paper is comprehensive to determine the sufficient information and as a reference for further data collection to assess the IAQ in Malaysian's schools.

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