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The Influence of Indoor Environmental Quality in Schools

A Systematic Literature Review

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Abstract: The impact of IEQ (daylight, temperature, acoustics and indoor air quality) in school settings is a subject of concern for many scholars and parents and teachers. This review has appraised the breadth of studies that have examined the influence of IEQ on learning performance and health in schools. Using the replicable search processes of a systematic literature adopted from medical research practice, one hundred and fifty relevant articles were retrieved from four search databases (Science direct, Scopus, PubMed and Google Scholar). Analysis of these articles has revealed that the impact on students' health and comfort of each individual IEQ variable is significant. This, in some studies has been shown to influence learning performance. However, while these variables are interlinked in building design they are not studied together in health and learning performance studies. An evidence-based method is proposed for investigating what relative contributory effect these four variables have on learning performance. As these IEQ variables individually have a very significant effect on student performance, this study has the potential to guide important changes in the design and refurbishment of new and existing school buildings. If successful, it could support educational quality and effectiveness of teaching and learning.

Keywords: Daylighting; temperature; acoustics; indoor air quality

1. Introduction

Indoor Environmental Quality (IEQ) as a phrase is typically used to refer to the quality of the conditions inside a building's environment in relation to the comfort, health and wellbeing of its occupants. There are many variables that influence the quality of the indoor environment including: external conditions (air pollution, external temperature), building (construction materials, furniture), building services (HVAC systems) and people and activities (HVAC use, cleaning), etc., (Almeida, de Freitas, & Delgado, 2015). But studies have shown that among these variables, daylight, temperature, acoustics and Indoor air quality (IAQ) are perceived as the four major variables that define the quality of the environment inside a space (Akpan-idiok & Ackley, 2017; Wall, 2016; Dorizas, Assimakopoulos, & Santamouris, 2015; Barrett & Zhang, 2009). This is because, they are associated with the visual, thermal comfort and energy-efficiency design of a building (De Dear et al., 2015).

These variables are of primary importance in schools because they help to enhance IEQ and reduces building energy consumption. They also impact on students' health, comfort, and performance (De Dear et al., 2015). A child spends an average of 1,480 hours in a school building yearly. When this figure is multiplied by eight years (from kindergarten to 12th grade) they spend an average of 11,840 hours of their lives in a school building (Cheryan, Ziegler, Plaut, & Meltzoff, 2014) – which is about 25% of their waking lives. Considering the number of hours spent in the classroom, the impact of IEQ in school settings remains a subject of concern for many scholars and parents and teachers. Many of these studies show that IEQ in classrooms' can facilitate or hinder learning performance. Inadequate IEQ in these studies is related to worse test scores. The results are robust even when statistically controlling for other variables such as; the socioeconomic status of students, absenteeism, grade level, teacher bias, etc. (Heschong Mahone Group, 1999; Tanner 2008). A daylight study by Heschong Mahone Group, (1999) showed that, even with the analysis of the teacher characteristic, student absenteeism data, and grade level variables, the daylight variable stayed highly significant as a factor that impacts learning performance. In their teacher survey analysis, thermal and visual comfort, acoustic and adequate ventilation were all frequently listed as top priorities.

In section two, the methodology and data extraction process of the systematic literature review is described. Section three identifies models that describe the inter-relationship between learning performance and health and discusses the themes arising out of the review. Section four summarises the trends observed.

2. Methodology

Three hundred and eighteen potentially relevant scholarly articles were retrieved from computerised searches using four search databases (Science direct, Scopus, PubMed and Google Scholar). The articles were catalogued in a data base that stored at a minimum the titles, abstracts and keywords. A second refinement was performed using titles and abstracts to exclude papers that lacked measurable associations between IEQ and learning performance and health in a school. Duplicate articles and other works that did not have information's related to the study's inclusion criteria were disregarded. The articles were either included or excluded based on their relevance to indoor environmental quality and their influences on school building occupants. Thus, 150 of the 318 articles were selected and analysed.

3. Discussion

3.1. The Influence of IEQ on Students Learning Performance in Schools

Daylight

Within the specific focus on IEQ and students' learning performance, only three articles showed a statistically significant association between daylighting and improved learning performance. Nicklas & Bailey (1997) compared the test scores of students in daylit schools to those in non-daylit schools. Their findings reveal that students in the daylit schools out- performed the students who were attending non-daylit schools by 5 to 14 %. Similarly, a study carried out by the Heschong Mahone Group (1999) provided proof of an association between high quality daylight in classrooms and improved students' performance. Their findings showed that students in classrooms with the most daylight had 7% to 18% higher test scores than those in classrooms with the least. They also found that, when compared to classrooms with the least amount of daylighting, the classrooms with a higher amount of daylighting had a 26% faster learning performance rate in reading tests and 20% in mathematics tests all through the studied school year. In addition, they reported that the influences of daylight in schools could directly help the students by improving their mood or help to indirectly improve the teacher's mood. When teachers were interviewed, their perception that windows and daylight improved the learning mood of their students by keeping them calm and improving their attention spans agreed with the positive effects of daylight on students learning performance. Furthermore, in New Zealand, a study by Jackson (2006) explored the possibility of generalizing the findings of the Heschong Mahone Group (1999) study by replicating their methodology in the New Zealand context. Their study found a correlation between daylight and improvement in students' test score and established that the HMG process could be replicable in another environment. However, their study suggested that direct sunlight penetration into classrooms may cause glare, which leads to negative student performance.

Though there is a significant association between good quality daylight and positive student performance, there is a question about what causes the improvement in students' performance in daylight classrooms. Recent studies (Bellia et al. 2015; Heschong Mahone Group 1999) have suggested that the positive effect of daylight on students learning is because of its effects on melatonin suppression in the body. When classrooms are adequately daylit, melatonin production becomes supressed, leading to an increase in alertness and concentration that will enhance learning performance. This assertion is affirmed by Bellia et al., (2015) whose study suggested that in the presence of daylight during typical clear and overcast winter days in Italy melatonin was suppressed.

The common conclusion of these three daylight studies is that, they support the argument that there is a predictable and well-founded influence of daylighting on students' learning performance. The study by the Heschong Mahone Group (1999) remains one of the most conclusive studies relating daylight and improvement in students' performance to date because; they use a large pre-existing data set to show the effects of the physical environment on students' performance by showing the association between building design and the social aspects of the school environment. Though the study by Jackson, (2006) agrees with this, they argue that, "There can be no assurance that daylight will always be successful in maximising human performance". However, their study findings could not be generalised to the entire New Zealand context because, their data set was insufficient to meet the target 95% confidence level which was required to make these generalizations.

Temperature

Fifteen articles showed a statistical significant association between temperature and improved learning performance. These evidences are found in a study carried out by Wargocki & Wyon (2007). They mentioned in their study that a research carried out by Wyon et al. (1979) showed the magnitude of the negative effect of temperature on students' performance. Their research strategically exposed 10-year-old children to three different classroom temperatures of 20°C, 27°C, and 30°C for two hours and another set of 11- to 12-year-old children were similarly exposed to a temperature of 20°C in two classes and 30°C in another two classes in the morning and in the afternoon. The children performed maths and reading tasks to assess their speed of work and the number of errors made. The performances of the children were significantly lower at a higher temperature of 27°C and 30°C as compared to those in the lower temperature of 20°C. The reading speed of the children reduced and a lower rate of working in the numerical tasks were identified in the classes with higher temperatures. The negative effects of raising classroom temperatures were more significant in the afternoon than in the morning, which is thought to be due to fatigue.

Wargocki & Wyon, (2007) carried out two intervention experiments to investigate the influences of high indoor temperatures on students' performance in Danish classrooms. In the first case, the classroom temperature was gradually cooled from 25°C to 20°C. 10–12- year old children were given reading and mathematics task to assess their speed and accuracy of task performance. As temperatures decreased from 25°C to 20°C, the children's average speed of task performance increased by approximately 2% per 18°C temperature decrease. However, there was no measurable effect of the changes in temperature on the number of normalized errors. This finding argues for an infinitesimally small change when temperature decreases by 5°C. An investigation into the comfort of secondary school buildings in Cyprus compared perceived learning performance in air conditioned and fan-assisted naturally ventilated environments. The study findings reveal that students with uncomfortable thermal sensation reported worse perceived learning performance in fan-assisted naturally ventilated environments than those in air conditioned environments (Katafygiotou & Serghides 2014).

Many Scholars have studied the temperature range associated with better learning, they suggest that the optimal temperature range for learning appears to be between 22°C and 25°C (De Dear et al., 2015; Katafygiotou & Serghides, 2014). This assertion is line with the findings of Allen & Fischer, (1978) who investigated the influences of temperature on students' learning. Their study showed that, when the male undergraduates learned a test of word associations in a 22°C classroom, they performed best. They significantly performed worse when the temperatures became more extreme in either direction.

These studies agree that an increase in temperature above 25°C negatively affects students' learning and task performance while lower temperatures enhanced learning. However, the studies did not show if very low temperatures could also impact learning performance. In addition, most of the studies on the impact of thermal comfort on students' learning performance were intervention studies conducted in controlled spaces. New findings may be revealed if the effect of very low temperatures on learning performance is conducted. Also, a comparison of students' learning performance in naturally ventilated classrooms during the summer when temperatures are high and during the winter when temperatures are lower without HVAC systems will be interesting to explore.

Indoor Air Quality (IAQ)

On the association between indoor air quality and learning performance, fifteen articles showed a statistical significant association. For example, in Denmark, the second intervention experiment carried out by Wargocki & Wyon, (2007) showed an improvement in student performance when classroom ventilation rates were increased. It was found that, an increase in the outdoor air supply rate from 5.2 to 9.6 L/s per person significantly improved students' test performance. This suggests that air temperature, humidity and air flow are important components that determine IAQ in a building. Air temperature is affected by relative humidity and indoor air, outdoor humidity and surface temperatures influences the accumulation of moisture within a building envelope. Walinder et al. (1997) compared a naturally ventilated primary school with a mechanically ventilated school in Sweden. They found a high level of indoor air pollutants (respirable dust, bacteria, mould and VOCs) which was due to inadequate outdoor air supply and were 2 - 8 times higher in the naturally ventilated school. This, they say may cause a swelling of the nasal mucosa in the upper airways. This shows that there is a need for adequate flow of outdoor air in naturally ventilated classrooms, because inadequate outdoor air supply could lead to a contamination of the air within the space which may lead to health issues that will adversely affect learning performance. In England, an intervention experiment was conducted by Bakó-Biró et al. (2012) to investigate the effects of classroom ventilation on pupil's performance and learning. The results reveal that compared with the low ventilation conditions, the higher ventilation rates had a more precise and faster response for word recognition (15%), picture memory (8%), colour recognition (2.7%) and choice reaction (2.2%). This study agrees with the assertion that increased ventilation rates could improve learning performance. This will be best achieved in naturally ventilated classrooms when there is adequate flow of outdoor air supply.

In as much as air movement, relative humidity and air temperature determine the condition of indoor air, good air quality can be examined by the number of contaminants which could lead to health problems. Contaminates are mostly categorised as; inorganic compounds (carbon monoxide, sulphur dioxide, oxides of nitrogen, carbon dioxide, sand, etc.,), organic compounds (urea formaldehyde foam insulation, etc.,), particulate matter (sprays, mist and dust, etc.,), and biological contaminants (house dust mites, pollens, microbes such as fungal spores, viruses, bacteria and algae, etc.,) (Mclntosh, 2011). Particulate matter can cause respiratory difficulties, coughing, sneezing, dry eyes, throat, nose and skin irritation, and contact lens problems. Carrer et al., (1990) states that there is often higher concentration of particulate matter in classrooms than in offices because, children have higher indoor physical activities and they easily carry the particles on their shoes. Biological contaminants can actively grow in classrooms with poor IAQ (Armstrong, and Liaw, 2003). Where there is high humidity, water or dampness, fungi are most likely to grow. When these contaminants become airborne, the cause infections, respiratory diseases, allergy and asthma attacks (Mclntosh, 2011). Mclntosh, 2011 reveal that 83% of classrooms in their study had bacterial counts similar to those found in water treatment plants or higher. Where there is high humidity, bacteria, fungi and colonies of dust mites do grow rapidly.

High CO2 levels which exceed 800 ppm are associated with lack of fresh air in a building and levels around 500-600 ppm have been suggested to be acceptable for school children (Daisey et al. 2003; Kruisselbrink et al. 2016). In Greece, a study by Dorizas et al., (2015) found that a 17% increase in the indoor CO2 concentrations leads to a reduction in students' performance by 16%. They identified a negative correlation trend between students achieved scores and the CO_2 concentrations and a positive correlation trend between their marks and the ventilation rates. The reported studies on the association between IAQ and learning performance have shown that poor air quality has a significant effect on students' performance in schools, but the detailed nature of its influences is not straightforward because; the nature of task carried out, the duration of exposure, the socio-cultural background of the students and the means of adaption available could all have different levels of contribution in determining the overall effect on performance. Furthermore, it establishes that, issues of IAQ in classrooms also poses a health risk and appears as the major IEQ variable that leads to health problems.

Acoustics

Seven articles in this review showed a statistical significant association between acoustics and learning performance. Poor acoustic properties of school buildings which allows the transfer of external noise into classroom spaces are more likely to result in lower student performance (Cheryan et al., 2014). Shield & Dockrell (2003) agrees with this view by stating that there is increasing evidence that poor acoustic properties in the classroom can create a negative learning environment for many students. For instance, Evans, G. W., & Maxwell (1997) compared reading test scores of students in two schools with different demographic factors. While one the schools was in a quiet neighbourhood the other was in a flight path of a major airport. The study found a significantly worse performance of students in the flight path school than those in the quiet neighbourhood school. In Sweden, pre-recorded noises of aircraft, road traffic, train, or verbal were compared with that of quiet conditions in an experimental demonstration consisting of 12- to 14-year-old students. The test of reading comprehension showed that students performed significantly worse when exposed to aircraft or road traffic noise than in the quiet conditions. There was no interference of the reading comprehension by noise from trains (Dockrell & Shield 2006; Hygge 2003). Noise levels in schools and classroom are of great concern to teachers. A study by Lackney (1999) found that teachers believe that noise impairs learning performance and noise causes more discomfort and decreases teacher's efficiency than for students. Poor acoustic properties have the potentials of affecting the quality of teaching, learning and ultimately performance. Teachers appear to be more concern about high noise levels, because it affects teaching communication, leads to discomfort and negatively affects learning performance. Unfortunately, the number of studies showing acoustic problems in schools is limited, thereby giving concerns for more research to identify the possible common sources of noise within the school environment which can affect learning.

3.2. The Influence of IEQ on Health in Schools

Daylight

The evidence associating daylight with health is found in a study carried out by Küller & Lindsten (1992) who assessed the effects of light on sick leave and the production of stress hormones. They identified an existence of a systematic seasonal variation with more stress hormones in summer than in winter. They suggest that basic hormone pattern may be distorted by working in classrooms with poor day-lighting. This could likely influence the annual body growth and sick leave of children and impact their ability to concentrate or co-operate. Lighting is a very vital element for cavity prevention in children. There is a strong relationship between the amounts of light a child is receiving to the level of dental decay. Hathaway et al, (1992) study into the effects of various lighting systems on elementary school's students' dental health reveal that, over a 2-year period, students who received ultraviolet light supplements had fewer dental caries, better attendance, greater gains in height and weight, and better academic performance than did students who did not receive the supplements.

Daylighting is widely believed to promote health, because it is known to increase the production of vitamin D as its deficiency is caused by lack of adequate exposure to daylight (Nathaniel 2008). Exposure to high illumination levels is said to be key to help in the regulation of the body's circadian rhythms and it has been associated and recognized as a treatment for seasonal affective disorder (Zeitzer et al. 2000). Poor lighting makes reading visually stressful for students and could cause eye strain. Adequate daylight is good for school children, because it helps them to sleep at night. When people receive enough daylight within the day, their nocturnal melatonin production occurs sooner and they can enter into sleep more easily at night (Nathaniel, 2008). Light suppresses the brain hormone production of melatonin and increases alertness. Melatonin is primarily secreted at night and influences the body immunological functions including the production of estrogen by triggering a host of biochemical activities (Heschong Mahone Group, 1999; Zeitzer et al., 2000).

Furthermore, scientific evidences suggest that children spending much time outdoors is crucial in reducing myopia progression and a healthy development of their eye (Cohn, 1886; Kathryn, Ian, Wayne, George, Paul, & Seang-Mei, 2008; Morgan, iG; Xiang, F; Rose, KA; Chen, Q; He, 2012; Wu, Tsai, Wu, Yang & Kuo, 2013). This assertion is still being debated and explored. These researchers strongly suggest that the amount of light a child get as they grow determines whether they will develop myopia. Currently, there is no evidence that daylight in classrooms prevents myopia (Hobday, 2015), but there are limited studies that have shown that daylight in classrooms reduces the progression of myopia in children. In Taiwan, Wu, Tsai, Wu, Yang, & Kuo, (2013) conducted an intervention study on 571 students to examine the relationship between schools, age, gender, baseline refraction, and myopia prevalence. While some schools had children going outdoors for break, the other schools were a controlled group. After a year, new cases of myopia were significantly lower in the group of schools where the children were let to go outdoors during breaks than in the control group (8.41% vs. 17.65%P_0.001). They conclude that; "clinical trials support outdoor time as an effective intervention in reducing the progression of myopia". Similarly, in China, Morgan, Xiang, Rose, Chen, He, (2012) conducted a study in Guangzhou and found that, there was an association with a reduction in myopia onset by the participation of students in an additional outdoor class after school each day. In Sydney and Singapore respectively, a study was conducted to compare the myopic prevalence and risk factors in 6 and 7-year-old children of Chinese ethnicity. 124 primary school children participated in the study in Sydney while 628 participated from Singapore. The researchers found that the prevalence of myopia was significantly lower in Sydney (3.3%) than in Singapore (29.1%). They concluded that the lower prevalence of myopia in the children in Sydney was associated with increased hours of outdoor activities. They suggest that; "though they do not know exactly what activity protects from myopia, but they do know from their findings that the total time spent outdoors was protective" (Kathryn, Ian, Wayne, George, Paul, & Seang-Mei, 2008)

The strongest assertion of these studies is that time spent outdoors is crucial in reducing the progression of myopia, because daylight stimulates the release of the retinal transmitter dopamine (an organic chemical that plays an important role in the brain and body), which is known to inhibit axial growth of the eye. Children who are exposed to lower levels of light appear to be at a greater risk of myopia progression. However, these studies did not show what could be the causal biological mechanism through which outdoor activity influences the progression of myopia in children. They did not also state the amount of light needed, its intensity, the range of illuminance values, and spectral composition that affects refractive development. Myopia appears to be caused by several other factors which there may be other potential contributors to its onset and progression, but the reviewed studies argue that daylight plays an important role in reducing the progression of myopia in children in schools. This further supports the argument that daylight is an important IEQ variable that could enhance student's health and wellbeing in schools thereby enhancing learning performance.

Temperature and Acoustics

Only two articles showed a statistical significant association between temperature and health, of the two only one of the article showed this association in a school setting. This was the study by Puteh et al. (2014) who conducted a survey to identify and investigate students' perceptions towards classroom thermal comfort and the schools' surrounding in Malaysia. The study findings reveal that, due to contaminated air (poor IAQ) caused by heat, watery eyes, redness and blurring of the eyes were the most frequent health problems identified by the students. Only one article showed a statistical significant association between acoustics and health. In Egypt, teachers were assessed for vocal levels and effects of experienced noise in classrooms and throat symptoms as well as their effects on working and social activities. It was found that, 48% reported moderate or severe dysphonia (speaking difficulty) within the last 6 months. Frequent feelings of being in noise were reported by all the teachers and 82% of them felt it mostly during the working day, which made them to raise their voice (Abo-Hasseba et al. 2016). This suggests that poor thermal performance and acoustics could cause health problems in schools.

Indoor Air Quality (IAQ)

The eight articles showing a statistical significant association between IAQ and health associated the prevalence of allergic and respiratory diseases among school children with poor IAQ in classrooms (Cartieaux et al. 2011; Dorizas et al. 2015; Ferreira & Cardoso 2014; Salthammer et al. 2016; Fisk et al. 2013).Ferreira & Cardoso (2014) found that CO_2 concentration which went as high as 1,942 ppm were above the maximum reference value, especially during the fall and winter seasons thereby causing health risk for children in schools. Wheezing, sneezing, rales, rhinitis, asthma, irritation of mucous membranes, cough, headache, and poor concentration were the associated health symptoms identified. In another study, Cartieaux et al., (2011) observed that respiratory diseases such as asthma and allergies caused by several pollutants in the classroom were predominantly prevalent. Smedje & Norbäck (2001) found a positive association between mould and airborne bacteria and asthma in school children. These evidences support the argument that there is a relationship between the concentrations of pollutants in classrooms and the onset of health problems in school children. The experimental investigation of Dorizas et al., (2015) reveal that, the predominantly observed health symptoms affecting students in their studied schools were fatigue, allergies, and nose irritation, this significantly correlated to the levels of indoor particulate matter and CO_2 concentrations. Mendell et al. (2013) investigated the association of classroom ventilation with reduced illness absence. They found a statistically significant 1.6% reduction in illness, absence per each additional litre per second per person (l/s per person) of ventilation provided. This they mention is a much smaller change in illness, absence per unit of ventilation rate and that the evidences associating inadequate classroom ventilation rates with increased illness absence are limited. They suggest that increasing ventilation rates above the recommended minimum levels even up to 15 l/s-person or higher may further substantially decrease absence due to illness. Ventilation experiments that are measurable are normally designed with mechanical systems in place. Findings reveal that classrooms CO_2 levels can be significantly reduced by installing a CO_2 controlled mechanical ventilation system. It can be challenging to execute this design in classrooms, especially when the majority of classrooms is naturally ventilated and measurable rates of ventilation are not easily guaranteed with openable windows.

4. Conclusion

Generally, the studies have shown that they are many factors that influence the performance and health of students in school buildings. They include items such as control of confounding and demographic variables, survey instruments used to assess building conditions, and the way in which academic performance is reported. Though the studies have shown the influences of IEQ on students learning performance and health, none of the articles have shown a statistical significant relationship combining these four independent variables (Daylighting, thermal comfort, and acoustic and indoor air quality) as well as socio-economic considerations on the student's health and performance.

However, in building design, IEQ variables are interlinked, but this review of 150 health and learning performance studies shows that they are not studied together in these studies. This gives concerns about "what is the relative contributory effect of the four IEQ variables on learning performance"? This is a research gap that needs further investigation. If researchers, architects and planners are too strongly affirm to policy makers that, the combined effects of IEQ should be top priorities when considering changes to classroom environments, they may want to know the relative importance of each of the four leading IEQ variables as well as their contributory effect. Hence, this paper recommends that, researchers should explore the use of an evidence-based method to investigate what relative contributory effect these four IEQ variables have on learning performance. As these IEQ variables individually have a very significant effect on student performance and health.

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