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Impacts of Sustainable Design in Education Facilities

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INTRODUCTION

The change towards sustainable design continues to accelerate in this post-pandemic culture. Federal policy changes, education campaigns, and marketing have all been pointing to green design, and now more than ever, society realizes the importance of healthy buildings. Education facilities arguably play the most vital role in a sustainable future. By the time a child finishes high school, they will have spent an average of 15,600 hours inside a school building (Eitland, et al., 2017). Thus, it is imperative to understand how these sustainable environments impact student academic growth and development.

The link between school buildings and the health and safety of students is not a new development, as the National Research Council points out in their publication, *Green Schools: Attributes for Health and Learning* (2007):

> A report on the State of Maine's Schools in 1886 linked moisture, lighting, and ventilation of school buildings to health and learning: Nearly one-sixth of the population of our State spends about six hours daily during a large part of the year in our school rooms. This necessary confinement within the schoolroom walls, coming as it does during the growing period of the body, and while it is most susceptible to harmful influences, entails certain evils which have been too generally regarded as necessary accompaniments of school life. It is generally well known, however. . . that most of the diseases incident to school life are in quite a high degree preventable (p.15).

Nevertheless, over a century later, states are still struggling to provide healthy environments for students. Over 50 million children are regularly attending public schools within the United States. Previous estimates show that 46 percent of those public schools have environmental conditions that create poor Indoor Environmental Quality (IEQ) (Eitland, et al., 2017).

"All states require children to attend school. But no state ensures that those schools are environmentally safe and healthy" (Healthy Schools Network, 2016). The Environmental Protection Agency (EPA) and the Centers for Disease Control and Prevention (CDC) have created guidelines to assist states in establishing and implementing environmental health programs for K-12 schools (United States Environmental Protection Agency, 2021). Though, at this point, implementation and participation in these programs are still voluntary. Considerable research exists that correlates building health with student health. The challenge, however, is that many factors affect overall student performance, including socioeconomic status, time of day, amount of sleep, and other environmental influences. Most of which are outside the control of educators. Still, with the understanding that students will spend most

of their developmental years within the boundaries of educational infrastructure, it is imperative that those buildings provide the safest and healthiest learning environments possible. With this awareness, decision-makers need to have the information necessary to apply funding to the most impactful areas appropriately.

Significance

The purpose of this study is to explore the relationship between sustainable interior environments and students' overall health and academic success. First, we will examine existing statistical data regarding students' health and its impact on academic performance to establish a reference point for comparison. Second, we will explore the areas of sustainable design as follows: acoustics, indoor air quality (including ventilation, moisture management, and thermal health), lighting, space planning, and aesthetics. Then, through researched-based evidence, relate those effects on students' academic growth. The information gathered in this study should enable designers, educators, and public officials to identify which areas of sustainable design have the most impact and how they can apply those principles to improve overall student development.

LITERATURE REVIEW

In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 2021). This definition places educational facilities at the nexus of sustainable design. How we raise and educate our most vulnerable citizens will define the future of our society. It is imperative that the buildings in which these students spend most of their developmental years provide them with safe and healthy environments.

School buildings and their effects on occupant health have been researched and studied for hundreds of years. "Reports dating back to the 1800s have documented the link between school conditions to childhood illness (National Research Council, 2007) . The first major report in modern history detailing the characteristics that can contribute to student health and performance was published in 2007 by the National Research Council. Their breakthrough report *Green Schools: Attributes for Health and Learning* launched the groundwork for evidence-based research, demonstrating that the school building is foundational in student health and development and that we can no longer afford to neglect the condition of these buildings (Eitland, et al., 2017). Since then, numerous studies have been conducted on the sustainability of educational infrastructure and its impact on student health and performance.

This literature is categorized into four major topic areas relating to Indoor Environmental Quality (IEQ): (1) acoustics, (2) indoor air quality (IAQ), including ventilation, moisture management, and thermal health, (3) lighting, and (4) space planning and aesthetics.

Definitions and Organizations

According to the Center for Disease Control (CDC, 2013): IEQ "refers to the quality of a building's environment in relation to the health and wellbeing of those who occupy space within it. IEQ is determined by many factors, including lighting, air quality, and damp conditions."

Indoor Air Quality (IAQ) measures air quality within the built environment, predominantly concerning the health and comfort of building occupants (EPA, 2021).

The American National Standards Institute (ANSI) is a private non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States. The organization also coordinates U.S. standards with international standards so that American products can be used worldwide (ANSI, 2021).

The Center for Disease Control and Prevention (CDC) is the national public health agency of the United States. It is a United States federal agency under the Department of Health and Human Services.

The Environmental Protection Agency (EPA) is an independent executive agency of the United States federal government tasked with environmental protection matters.

The U.S. Green Building Council (USGBC) is a non-profit organization that promotes sustainability in building design, construction, and operation.

Leadership in Energy and Environmental Design (LEED) is a green building certification program developed by the USGBC. It includes rating systems for designing, constructing, operating, and maintaining green buildings, homes, and neighborhoods.

Acoustics

In the classroom setting, most of the learning environment is based upon the talking and listening model, especially in younger age categories. "Students learn by listening to the teacher and each other" (National Research Council, 2007). Maintaining appropriate noise levels and listening conditions is vital to student performance (Eitland, et al., 2017).

Student Health and Performance

There are several factors that contribute to noise levels within a classroom setting: heating, ventilation, air conditioning (HVAC) systems, outdoor noise, noise from adjacent spaces, and reflected speech sounds (National Research Council, 2007). The effects of noise on student health involve auditory and emotional consequences (Eitland, et al., 2017; National Research Council, 2007). A report by Earthman and Lemasters (1997, as cited by Ketchum, 2015) evaluated 53 studies related to school facilities, student achievement, and behavior. The results found a link between acoustics and learning. It also concluded that high levels of excessive noise caused stress in students, and 70% of teachers reported that those high volumes affected their ability to teach (p.25).

Barrett et al. and Brill et al. point out that external background noise such as traffic, airplanes, other children playing nearby, and reverberation are the leading causes of distraction and have detrimental effects on comprehension and academic performance (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019; Brill, Smith, & Wang,

2020). HVAC systems are a common source of background noise within the classroom environment. Brill et al. noted that 91% of classrooms studied did not meet the current ANSI standards for noise levels (Brill, Smith, & Wang, 2020). In addition to hindering learning, the physical effects of noise exposure can include higher blood pressure and increased adrenaline (Eitland, et al., 2017). Students are aware of the impact poor acoustic quality can have on their learning. A combined total of 53% of students surveyed by Pulay reported that "low noise levels influenced their academic success above the rest of the classroom architectural interior design elements listed" (Pulay, 2010).

Sustainable Improvements

"The best way to ensure quiet background noise levels from building mechanical systems is to design for them and not rely on post-design solutions…" (Brill, Smith, & Wang, 2020). The ANSI and the Acoustical Society of America published the first classroom acoustic standard in the United States in 2002. The ANSI S12.60 recommends that the sound level in an unoccupied classroom should not exceed 35 dB(A) (Brill, Smith, & Wang, 2020). Classroom design should include considerations for materials and finishes that enhance the overall acoustic quality within the space as well as separation from other areas and appropriately designed HVAC systems (National Research Council, 2007). The newest edition of the LEED program developed by USGBC, LEED (v4), requires that unoccupied background noise level meets the ANSI S12.60 standard in order to receive certification. However, schools are not required to obtain LEED certification.

Indoor Air Quality

Indoor air quality encompasses the exchange of outdoor and indoor air (ventilation) and the pollutants within them, as well as moisture and humidity, thermal comfort, and sensory loads (odors or "freshness") (National Research Council, 2007).

Ventilation

Indoor air quality and its effects on occupant health have been studied for hundreds of years. Edwards documents that in the early twentieth century, the open-air school movement was started to benefit students in urban areas with higher levels of ventilation. The evidence gathered from observing these schools indicates that increased ventilation positively affects students' general health and academic performance (Edwards, n.d.). "Ventilation rate is the flow of outside air into a building per unit of time" (Eitland, et al., 2017). Currently, there are standards set by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) to control ventilation rates within the classroom in order to keep carbon dioxide (CO_2) levels low. When CO_2 levels increase beyond the recommended level of 1000 parts per million (ppm), so do the chances of increased concentrations of various irritants (Eitland, et al., 2017). The National Research Council (2007) lists irritants such as pollutants and allergens in indoor air: mold, dust, pet dander, bacterial and fungal products, volatile organic compounds (VOC), and particulate matter. All of which are associated with asthma and other respiratory symptoms

(Eitland, et al., 2017; Healthy Schools Network, 2016; National Research Council, 2007).

According to the CDC, childhood asthma is the leading cause of absenteeism (2015, as cited in Foundations for Student Success, 2017), with 13.8 million missed school days each year (p.6). As stated by the EPA, inadequate ventilation is one of the most often cited reasons for sick building syndrome. Sick Building Syndrome (SBS) "is a term used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building" (United States Environmental Protection Agency, 2021). Symptoms often include headache, fatigue, shortness of breath, sinus congestion, cough, and sneezing, as well as eye, nose, and throat irritation (Ketchum, 2015; Healthy Schools Network, 2016; Eitland, et al., 2017).

Through their research, Barrett et al., Lopez-Chao et al., Toyinbo et al. identified that low ventilation rates are directly correlated to low mathematical test scores (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019; López-Chao, Lorenzo, Saorín, De La Torre-Cantero, & Melián-Díaz, 2020; Toyinbo, et al., 2016). Proper ventilation also maintains quality sensory loads (smells) and supports protection against infectious disease (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019; Edwards, n.d.; Eitland, et al., 2017; Healthy Schools Network, 2016; National Research Council, 2007)

Moisture Management

"Entrance of water into damaged, poorly designed, and improperly maintained buildings has been identified as the main source of building-related illness from mold exposure in a review of over 120,000 indoor air quality documents published between 1994 and 2001 "(OSHA, 2006, as cited in Eitland et al., 2017). The National Research Council (2007) concluded that seventy-five percent of all building envelope problems are caused by excess moisture (Ch. 3). Eitland et al. documented the link between the presence of mold and an increase in respiratory symptoms.

In addition to mold, damp conditions increase the presence of pests such as cockroaches and mice (Eitland, et al., 2017; Healthy Schools Network, 2016; National Research Council, 2007; United States Environmental Protection Agency, 2021). Eitland et al. introduced the evidence that cockroach allergies exacerbate asthma symptoms, particularly in inner-city students (Foundations for Student Success, 2017).

Thermal Health

In relation to thermal health, often referred to as thermal comfort, Eitland et al. and the National Research Council identified that though thermal health can be highly subjective, there are several conditions that the built environment has on thermal health, such as air temperature, ventilation speed, and humidity. ASHRAE has set standards related to thermal health; however, both authors also noted that most studies on thermal comfort are conducted with adults in commercial office spaces. Studies have acknowledged that children are at a higher risk of being affected by heat stress and younger age categories tend to be more comfortable in cooler environments than adults. They identified that current ratings related to office

buildings do not account for the higher occupant density of educational facilities or the students' activity level (Eitland, et al., 2017; National Research Council, 2007).

Researchers have determined that the effects of thermal health on students' productivity and academic performance are significant (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019; Eitland, et al., 2017; Healthy Schools Network, 2016; National Research Council, 2007; Choi, Guerin, & Kim, 2013). Park (2016, as cited by Eitland et al.), documented a study involving 75,000 high school students and found that "for every increase of 1° F, test scores fell by 0.2%; for the average student, the likelihood of failing an exam taken on a 90° F Day versus a 75° F Day would be 12.3% higher" (Foundations for Student Success, 2017, p. 21)

Lighting

Researchers agree that quality lighting plays a dynamic role in the health and performance of students within school environments (Choi, Guerin, & Kim, 2013; Edwards, n.d.; Eitland, et al., 2017; Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019; Ketchum, 2015; López-Chao, Lorenzo, Saorín, De La Torre-Cantero, & Melián-Díaz, 2020; Moyano, Fernández, & González, 2020). Light affects both the visual and the circadian systems, and both must be taken into consideration when evaluating interior lighting systems (National Research Council, 2007).

Learning environments require various lighting types, such as dimming during media presentations or bright light for reading and projects. If the lighting system is inadequate, it can have noticeable physical and psychological effects on occupants (Ketchum, 2015). Sustainable lighting designs include both daylighting and artificial light.

Daylighting

Several studies have been conducted on the benefits of daylighting in classrooms, and the evidence concludes that the use of daylighting in educational environments improves academic performance by 21% (Choi, Guerin, & Kim, 2013; Moyano, Fernández, & González, 2020; Pulay, 2010; Eitland, et al., 2017; Edwards, n.d.). Along with academic performance, daylighting and views within the classroom aid in proper circadian rhythms. Studies have determined that balanced circadian cycles are necessary for proper sleep and influence basic cognitive processes, including attention, working memory, and executive function (Eitland, et al., 2017; Moyano, Fernández, & González, 2020; National Research Council, 2007).

As Barrett et al., Eitland et at., and Moyano et al. point out; traditional daylighting analysis methods may be inadequate in determining the best options for meeting occupants' needs within educational facilities since they currently do not account for the biological impact of lighting (Eitland, et al., 2017; Moyano, Fernández, & González, 2020; Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019). Moyano et al. further suggested that Climate-based Daylight Modeling (CBDM) would be an improved way of designing daylighting systems to meet the needs of adolescents' circadian cycles.

CBDM integrates light variations with natural seasonal changes within the local climate and time of day (Moyano, Fernández, & González, 2020). Dynamic lighting design must be used to avoid common issues that can arise from an improper

daylighting application, including glare and overheating (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019; Ketchum, 2015; National Research Council, 2007; Pulay, 2010).

Artificial Light

The use of artificial light also plays a significant role in the health and performance of students. Poor lighting can lead to decreased visual comfort and eye fatigue (Moyano, Fernández, & González, 2020; Ketchum, 2015). Color temperature and lamp types are other factors that can impact the quality of the interior environment and occupants' level of alertness. Eitland et al. documented the results from a nine-month study involving 110 primary (grade 3) and secondary (grade 10) students. The study concluded that using a warm 3500K light setting was significantly associated with reduced restless behavior. It also noted that users under artificial daylight (6500K) reported significantly higher alertness and performance levels (Eitland, et al., 2017).

Since artificial lighting represents the most significant portion of schools' electricity use, it is often the first area of sustainable improvement. However, researchers agree that to have the most significant impact on student's health and academic performance, a holistic approach to lighting design should focus on energy conservation and occupants' visual and biological needs.

Space Planning and Aesthetics

Barrett et al. introduced three categories related to school design elements: naturalness, individualization, and stimulation (Clever classrooms: Summary report of the HEAD project, 2015).

Naturalness

Naturalness encompasses the aforementioned elements of IEQ (light, sound, and temperature), but they also include views and links to nature as a component of successful sustainable designs. (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019). Eitland et al. and Determan et al. note that biophilic design can aid students in their recovery from stress and offer respite from mental fatigue.

Studies have also shown that students in classrooms with nature views performed significantly higher on tests of attentional functioning than students in classrooms with no windows or with views of other building facades (Eitland, et al., 2017; Determan, et al., 2019).

Individualization

Individualization refers to the elements of ownership, flexibility, and connection. For example, classroom layouts that allow for customization for each activity and student's needs with the aim of creating a student-centered environment (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019).

Flexibility. Following this line, Choi et al. found that "furniture plays a strategic role in addressing different learning styles and pedagogical delivery methods" (Choi, Guerin, & Kim, 2013). They also emphasized that human factors should be used to assess the learning experience and how the design of the classroom is meeting those needs. "Ergonomics cannot be understated when one considers the

amount of time that is spent in seated positions throughout the day" (Choi, Guerin, & Kim, 2013).

Ownership. Ownership offers distinct design characteristics that give students emotional stimulation and pride in their facility. The HEAD Project (2015) indicated that research regarding physiology and psychology highlights that "personalization of space is an important factor in the formation of an individual's identity and sense of self-worth." The authors noted that when students' projects and achievements are displayed, it promotes greater participation and involvement in the learning process (Clever classrooms: Summary report of the HEAD project, p. 30).

Connection. Connection incorporates wayfinding and corridor layouts that provide opportunities for collaboration between classes and additional areas for learning (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019).

Stimulation

Stimulation represents color and visual complexity (Barrett, Zhang, Davies, & Barrett, 2015). Grube investigated the effects of white-valued walls in classrooms and stated that "white used on classroom walls gives the appearance of being sterile and depressing." She also observed that the use of colored walls reduces eyestrain and can alter a personal perception of temperature (Grube, n.d.). Taheri also found that the use of color can significantly impact the happiness of occupants within the built environment and concluded that good design could reduce anxiety, lower blood pressure, and reduce pain. (Studying the Effect of Classroom Interior Design on the Happiness and Mental, 2019).

Additional Design Elements

Safety and security are vital elements in educational facility design and impact occupants' health and welfare within schools (Eitland, et al., 2017). However, they constitute an in-depth analysis of elements beyond the scope of sustainability and therefore not further discussed in this study.

Conclusion

These authors concur that students' multidimensional experience within classroom spaces will significantly impact their academic growth. Furthermore, research has proven that proper attention to these design elements will improve students' health and the welfare of other occupants within educational facilities. However, as the Healthy Schools Network has pointed out, legislation regarding the maintenance and inspections of educational facilities needs to change to ensure these buildings provide safe places for students to learn and grow (Healthy Schools Network, 2016, p. 56).

While the literature supports the importance of sustainable design in educational environments, it neglects to categorize the most critical areas. Additionally, further research and considerations need to be taken in light of the COVID-19 pandemic. The aim of this study will be to determine which design elements should be at the forefront of educational infrastructure upgrades and how schools can improve their environments in a post-pandemic society.

FINDINGS

Students spend the majority of their developmental years within the walls of educational facilities. With the increasing awareness of the vital role that sustainable design plays in the health and welfare of the population and its ability to reduce the human impact on the environment, schools should be at the forefront of innovation regarding its application and implementation. This study outlines the primary elements of sustainable design and investigates their impact on students' academic growth and development. These findings will enable educators and decision-makers to identify which areas of sustainability provide the most significant benefits to the students they serve.

A thorough review of the research indicates that IAQ plays the most significant role in students' academic growth. Children, especially in younger age categories, breathe in larger quantities of air relative to their body size (Eitland, et al., 2017) and are more susceptible to the pollutants and irritants contained in improperly ventilated air (Ketchum, 2015; Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019; Healthy Schools Network, 2016). Multiple studies have concluded that poor IAQ accounts for lower test scores from students, particularly in the area of mathematics (López-Chao, Lorenzo, Saorín, De La Torre-Cantero, & Melián-Díaz, 2020). Poor IAQ can also exacerbate asthma symptoms in occupants (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019; Choi, Guerin, & Kim, 2013; Eitland, et al., 2017; National Research Council, 2007). According to the CDC, asthma is the leading cause of absenteeism in students in America (CDC, 2013; Barrett, Treves, Shmis, Ambasz, & Ustinova, 2019).

Proper ventilation and filtration are also necessary to limit the spread of infectious diseases (National Research Council, 2007). Emerging research shows that "classrooms with more outdoor air dilution relative to the number of occupants will be more effective at interdicting transmission. Therefore, schools with proper ventilation can reduce the social distancing spaces to three feet instead of the standard six feet regarding preventing the spread of COVID-19" (Lynch, Favata, & Gochfeld, 2021).

CONCLUSIONS

The EPA has implemented a set of standards regarding IEQ and school health that outlines specific steps educational institutions can take to improve their IAQ and the wellness of students within their facilities. These guidelines include five key components: (1) Practice Effective Cleaning and Maintenance, (2) Prevent Mold and Moisture, (3) Reduce Chemical and Environmental Contaminant Hazards, (4) Ensure Good Ventilation, (5) Prevent Pests and Reduce Pesticide Exposure (United States Environmental Protection Agency, 2021). However, these are only guidelines and not mandatory for schools to implement. According to the National Data Summary provided by the Healthy Schools Network in their Report Towards Healthy Schools: Reducing Risks to Children, as of 2016, only twenty-three states have adopted an IAQ policy (p. 7). This report alone shows that over fifty percent of America's schools could be placing their occupants at risk.

Extensive evidence demonstrates how the school building affects student health and success. Acoustics, indoor air quality (including ventilation, moisture management, and thermal health), lighting, space planning, and aesthetics are vital

elements for successful sustainable design. Each factor impacts occupants in multifaceted ways, both in the short term and throughout their academic careers (Eitland, et al., 2017).

While indoor air quality is not the only sustainable design element that affects students, evidence suggests that it has the most significant impact on students' overall health and academic growth.

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